



Participant Workbook



KTA-Tator, Inc.
Basic Coatings Inspection Training Curriculum
Version V: January 2020

BASIC COATINGS INSPECTION

Participant Workbook

KTA-Tator, Inc.

Basic Coatings Inspection Training

Curriculum

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Managing Editor: William D. Corbett

Technical Editors: William D. Corbett, Robert Leggat, Peter Blattner

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KTA-Tator, Inc.

115 Technology Drive

Pittsburgh, Pennsylvania 15275

412-788-1300

www.kta.com

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Version V

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Introduction to KTA's Basic Coatings Inspection

Modern industrial coatings are used for two key functions: aesthetics (or the beautification of the structure) and the protection of the substrate from corrosion. Aesthetics are important, but the primary role of an industrial coating is the protection of the substrate. Today's high-performance coatings are expected to perform both functions in a variety of service environments on many different substrates. Coating inspectors may encounter protective coatings on concrete, wood, cast iron, plastic, plasterboard, and a variety of metals, but the most common substrate protected by high performance coatings is hot rolled carbon steel. Therefore, the focus of this course is coating systems on steel.

The role of carbon steel in the design and construction of any modern city is critical. Carbon steel, literally, holds up the office towers, bridges, hospitals, stadiums, schools, storage tanks, reservoirs, even the locks and dams that control the traffic and flow of our rivers. While there are a variety of threats to structures built using steel, one of the most

persistent is the natural process of corrosion. The process of turning iron ore into carbon steel employs high temperatures and an enormous amount of energy, but the reversal of this process (corrosion) is spontaneous and requires little more than an electrolyte (water), and an anode, cathode, and electronic pathway. In other words, while the creation of carbon steel demands great energy and heat, the corrosion of steel merely requires exposure to a damp environment and oxygen.



While there are other products and processes that can be used to slow down the process of corrosion on steel substrates, the use of industrial protective coatings has had a long, successful history performing this service.



Industrial coatings can protect steel by isolating the substrate from a service environment (barrier protection), by adding rust inhibitors to the coating (inhibitive protection), or by incorporating metal, e.g., zinc, into the coating that will sacrifice itself or corrode first to protect the surface of the steel (sacrificial or

galvanic protection). Each type of protection will be examined in detail in Module One.

Protective, high performance coatings are big business, and many new products enter the market place every year. Better corrosion protection is a key driving force behind the development of many of the new products, but formulations change for other reasons, also: to produce faster curing times, to increase abrasion resistance, to gain equivalent



performance using fewer coats, and to stand up longer in severe service environments. Formulations also change to comply with environmental regulations, for example, the demand for a decrease in the amount of volatile



organic compounds (VOCs) allowed in a product has led to an increase in the use of water-based products. In the United States, Southern California has some of the strictest regulations regarding VOC, but coating manufacturers are aware that the trend toward lowering VOC content in coating products will continue.

Industrial coatings have a long history in the battle against corrosion, yet that history is still developing. No coating can be expected to provide corrosion protection forever. Even the service life (life expectancy) of the most successful coating system* has a beginning, middle, and end. For a coating system that has been designed and tested for a specific service environment, the expected service life may be from fifteen to twenty years (provided it is adequately maintained). If that system is applied and begins to fail during the first or second year, the result is called “premature failure.”



There are many reasons why a coating can fail, including faulty product, or a poorly-prepared specification (e.g., a specifier recommended a coating system that was not designed to protect the steel from the intended service environment).

Even when the best possible coating system for the substrate and the service environment has been specified, other components of a coating project can cause that coating to fail. In fact, inadequate surface preparation and poor application practices account for the majority of all coating failures

A successful coating project is dependent on many elements coming together at the same time, for example:

- a good specification and an appropriate coating system for the service environment,
- the correct atmospheric conditions for the work to proceed,
- well maintained, appropriate surface preparation and application equipment,
- skilled laborers,
- a carefully designed and implemented quality control and quality assurance program,
- well-trained, ethical coatings inspectors.

While there are other courses to assist coating specifiers, the next 3 1/2 days of training will help those with a role in the process of getting the surface prepared properly and the coating from the can to the surface *according to the specification*. “Basic Coatings Inspection” is basic training for any person who becomes involved in an industrial coating project: whether that project is the coating of a bridge, a stadium, a tank, a ship, or dam gates.

Learning Outcomes

Successful completion of this course will enable participants to:

1. Explain the relationship between coatings and corrosion control
2. Identify the elements of a corrosion cell
3. Describe the corrosion of metals
4. Explain sacrificial protection
5. List the differences and similarities between QA and QC roles
6. Discuss the general content of an inspection plan
7. Discuss key aspects of limiting project conflicts
8. Define the two-fold purpose of surface preparation
9. Describe pre-surface preparation inspections commonly invoked
10. List the inspection check points related to surface preparation that may be invoked by the governing specification
11. Measure and record surface profile
12. Evaluate surface cleanliness using the SSPC Visual Guides
13. Measure and record ambient conditions and surface temperature
14. Navigate a coating manufacturer’s product data sheet (PDS)
15. Calculate target wet film thickness (with and without thinner)
16. Describe proper mixing and thinning procedures
17. Describe differences between various methods of coating application
18. Measure dry film thickness according to SSPC-PA2
19. Detect pinholes and holidays in applied coatings
20. Measure coating hardness
21. Calculate coating coverage rates and material quantities
22. Explain five common methods of coating cure:
23. Navigate a coating specification
24. Develop an inspection plan
25. Perform surface preparation and coating inspection on a simulated project
26. Compare inspection results to specification requirements

Participation Guidelines

Participants are urged to actively engage in the training by asking questions, offering relevant observations, and learning as much as possible about and from other members of their work teams. The KTA instructor team encourages you to ask for clarification when needed. If you feel an instructor is covering significant material too quickly, ask them to slow the pace or repeat an important point. You will find that, whenever possible, KTA instructors are willing to help you during breaks and over lunch, even at the end of a training day. We encourage participants to make themselves at home, because at KTA we realize that establishing a safe, comfortable environment enhances learning. You will have an opportunity to evaluate each of the sessions during the course.

Use of Participant Workbooks

All workbooks are yours to keep and therefore to write in. The basic text, “Basic Coatings Inspection,” is written in narrative form. The agenda follows this text from beginning to end. The Instrument Use Supplement will be used to guide you through the correct use of coatings inspection instruments. You can use the highlighters we provide to highlight significant information. If you get lost at any point, simply ask the instructor to refer to the workbook and the page number that matches the information being covered. You will also be given an agenda, which will provide you with a day by day outline of sessions, including the names of your instructors, the approximate timeframe for each module and workshop, and the time allotted for breaks and lunch.

Dress for Hands-On Activity

Casual dress is encouraged, since you will be using painting equipment and working with coatings inspection instruments. Safety glasses, coveralls, and gloves will be provided during the appropriate workshops. Instructors will be leading you through each of the hands-on activities and they will instruct you on the required safety measures for each activity.



An Orientation to the Coatings Industry and Key Organizations

As part of this introduction, we will review a few of the key organizations that develop standards for the coatings industry, as well as explain common acronyms and terms used during the course:

Common Industry Organizations

- AISC American Institute of Steel Construction
- ASTM American Society for Testing Materials
- NACE National Association of Corrosion Engineers
- SSPC Society for Protective Coatings

Common Industry Acronyms

- CFM _____
- DFT _____
- SDS _____
- PDS _____
- PSI _____
- QA _____
- QC _____
- VOC _____
- WFT _____

Other common terms:

- Micrometer (Micron) _____
- Mil _____
- Mill Scale _____
- Hold point _____

Course Syllabus

The following section includes a short syllabus of the six modules, a description of the hands-on workshops, and an explanation of the team competition (review game) and the final examinations.

Module One: Protecting Metals from Corrosion: The Role of High-Performance Coatings

Corrosion is a process where metals give up energy and return to their natural state. Some metals have a stronger propensity to corrode than others. Only four elements need to be present for corrosion to occur: an anode, a cathode, a metallic pathway, and an Electrolyte (oxygen is assumed). While the corrosion of steel cannot be completely halted, it can be slowed. The most widely used method to prevent/slow corrosion today, particularly on carbon steel, is the application of high-performance coatings. Module One explains how today's high-performance coatings use barrier protection, sacrificial or cathodic protection, and inhibitive protection to protect steel structures from corrosion.

Approximate time: 1 hour.

Module Two: Quality Assurance (QA) vs. Quality Control (QC)

All too often, the lines between the QC and the QA on a coatings project get blurred. When that happens, the scope of work and responsibility for that work can also become blurred. This module is designed to clarify the common roles and responsibilities of both the contractor's QC and the Owner's QA personnel. Of course, this is textbook: the way it would work in a perfect world, but it is helpful to know how things "could/should" work before getting caught up in the day to day rush of a real-world coatings project. Module Two compares the roles of the QA and QC personnel on a typical coatings project. Module Two also explores the critical differences in the two roles, including issues of authority, reporting, testing, and documentation (which again, depend on the scope of work and the specification). Another issue explored by this module is the management of specification deviations and nonconformances.

Approximate time: 1.5 hours.

Module Three: Surface Preparation, Industry Standards and Inspection

Preparing the surface according to the specification can be the most labor intensive and costly phase of a coating's operation, and it is always critical to the project's success. Surface preparation is the foundation for the coating system and thus has a major focus in this training program, which covers in detail common standards used throughout the industry. The initial phase of pre-surface preparation and the inspection check points are covered first, detailing the problems of weld spatter, edges, and repair areas. Surface preparation, which follows, covers the many methods used to clean and roughen surfaces, with a special emphasis on dry abrasive blast cleaning. The National Association for Corrosion Engineers (NACE

International) and SSPC: The Society for Protective Coatings have developed consensus standards to govern surface cleanliness requirements. These standards will be explored, including descriptions of what must be removed from the surface and what may remain on the surface for each standard. In addition to the surface preparation standards, the training focuses on means and methods, including: blast cleaning equipment, a variety of abrasives, wet and dry abrasive blast cleaning, centrifugal blast cleaning, vacuum blast cleaning, hand and power tools, and water jetting. The final focal points for Module Three are the common inspection checkpoints for surface preparation and the methods used to verify conformance to the specification.

Approximate time: 4.5 hours.

Module Three Workshop: Surface Preparation Inspection Instrument Use

The Module Three Inspection Instrument use workshop is comprised of six work stations: three for measurement of surface profile; two for use of SSPC visual guides; and one for surface chloride contamination detection. You will work in teams and move from station to station to use the equipment and record the results of your inspections.

Time: 2.5 hours.

Module Four: Coating Mixing, Thinning, and Application

This module will overview the various methods used to apply coatings, including conventional (air) spray, airless spray, HVLP, air-assisted airless spray, plural component spray, electrostatic spray, and brush & roller. The advantages and limitations of each method, along with proper technique will be emphasized. Module Four will continue with the inspection of mixing, thinning, and coating application processes, including measuring ambient conditions, witnessing and documenting mixing and thinning procedures, wet and dry film measurements, use of the Tooke Gage (destructive testing) to determine the thickness of individual layers in a coating system, pinhole/holiday detection, adhesion and coating curing tests.

Time: 4 hours.

Module Four Hands-On Workshops: Coating Application and Inspection Instrument Use

The training group will apply coatings using conventional and airless spray equipment and measure the WFT. Subsequently the training group will participate in a second instrument use workshop using the inspection equipment to measure and record ambient conditions and surface temperature, calculate target WFT, measure dry film thickness, conduct pinhole/holiday detection, and use the Tooke Gage to determine the thickness of individual coating layers, and measure coating hardness.

Time: 2 hours.

Module Five: Industrial Coatings and Coating Systems

Module Five introduces the basic components of an industrial coating: non-volatiles and volatiles. Subsequently, VOC (volatile organic compound) regulations will be explored in the context of what a QC or QA inspector should know about monitoring and reporting the addition of thinner to coating products and the actual quantity of VOC emitted into the atmosphere during application. In Module Five, participants will also learn how coatings cure and how to calculate coating coverage.

Time: 1 hour

Module Five Workshop: Calculating Coating Material Quantities

Participants will work individually to calculate primer & topcoat material quantities and corresponding reducer quantities.

Time: 0.5 hour

Module Six: Simulated Coatings Inspection Project

Module Six will provide an opportunity for the trainees to follow a simulated coatings inspection project from beginning to end. Prior to beginning the inspection, the entire class will meet with the “Project Manager” who will assume the role of the Owner’s Engineer for the bridge. This meeting is a substitution for a pre-job conference. During this exercise the participants will assume the role of the contractor’s QC. Participants will be provided a copy of a simple specification for review, then have the opportunity to ask the project manager for clarification and prepare a simple inspection plan. The training group will break into small teams and perform inspections at seven different stations. *Each participant is responsible for keeping their own records (in this case, the worksheets). Approximate time: 5 hours.*

Review Game

Teams of participants compete for \$5.00 gift cards answering a series of 50 multiple choice questions (20 seconds/question) using flash cards. While designed to be both fun and competitive, it serves as a review of key information conveyed during the class and helps prepare participants for the written examination on Day 4.

Final Testing

Two tests are administered to all participants: a written, multiple choice, objective test, and a timed, practical test on the use of basic coatings inspection instruments.

You must pass both tests with a 70% or better to receive a Certificate of Completion and continuing education units (CEUs). If you receive a score below 70% on either test, but you have attended all instructor led course hours, you will

receive a Certificate of Attendance. Certificates will be mailed within one week after tests are graded. Copies of each certificate and the record of earned CEUs will be kept on file at KTA for 7 years.

Retesting

Arrangements can be made to retake either the written or the practical test within one year after you have taken the course. There is a fee to retake the exam(s) unless retesting is conducted in conjunction with a training course. Contact the KTA Training Administrator to discuss these arrangements.

Protecting Metals from Corrosion: The Role of High-Performance Coatings

Module 1

Learning Outcomes:

- Explain the relationship between coatings and corrosion control
- Identify the elements of a corrosion cell
- Describe the corrosion of metals
- Explain sacrificial protection

*How this information affects YOU:
Understanding the role of coatings in the prevention of corrosion sets the stage for comprehending the importance of proper surface preparation and coating installation, as well as the importance of verifying quality.*

Corrosion Defined

NACE International defines corrosion as the deterioration of a substance (usually a metal) or its properties because of a reaction with its environment. Corrosion is a natural process, the propensity or tendency of materials to “give up” energy and return to their natural state. While it takes tremendous amounts of energy to convert materials found in nature into usable materials for construction, like carbon steel, it will release that energy and convert back to their original state unless the process is stopped or slowed down.



The Role of Protective Coatings in Preventing/Slowing Corrosion

The most widely used method to prevent corrosion today, particularly on carbon steel, is the application of high performance, protective coatings. High performance coatings protect thousands of structures, including: off-shore drilling rigs, ships, storage tanks, sewage systems, power plants, shipping containers, pipelines, railway cars, refineries, and commercial buildings.



Industrial protective coatings have been around since the 1930s, but the industry was given a boost during World War II. The need to keep ships out to sea longer and in dry dock less, led first to the development of the epoxy resin, and next to the polyamide epoxy, which had better adhesion, some flexibility, and an increased resistance to water. As the demand for the materials of war increased, the demand for improvements to industrial coatings grew with it. Better adhesion, faster cures, and better resistance to abrasion were some of the driving forces, but the need to keep materials from corroding remained the primary motivation for improvements to coatings.

The Fundamentals of Corrosion

This discussion about corrosion fundamentals will focus on metals. Corrosion of metals is a natural process involving a chemical reaction – actually an electrochemical reaction, meaning that electric current is produced during the process. Corrosion will occur when four required elements are all present. If any one of the elements is missing, the corrosion process will not proceed. The required elements, which compose a “corrosion cell,” are:

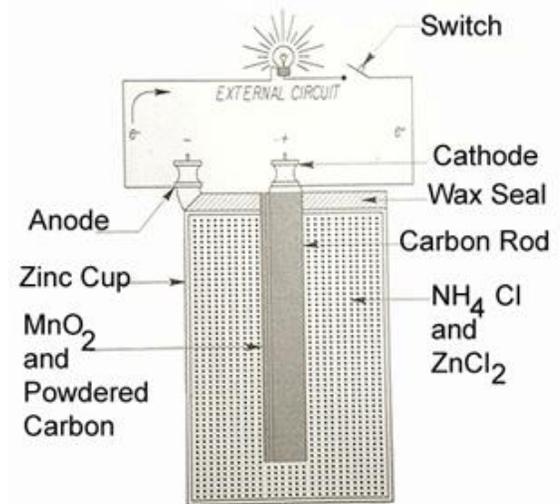


1. Anode
2. Cathode
3. Metallic pathway (connecting the anode and cathode)
4. Electrolyte

The surface of carbon steel already contains three of the four elements: the anode, cathode, and metallic pathway; only the electrolyte is missing. An electrolyte is a liquid that contains ions or “charged particles.” Most salts (e.g., sodium or calcium chloride) form ions when dissolved in water. Once the electrolyte is present, the process of corrosion will proceed.

To analyze how the four elements of a corrosion cell work together to produce the process of corrosion, we can use the example of a common household battery.

A corrosion cell is essentially a natural battery. The anode and its counterpart, the cathode, represent negative and positive terminals of the “battery.” During the chemical reaction process, electrons flow from the anode to the cathode via the metallic pathway or connection creating current flow. The electrolyte carries ions from the cathode to the anode to complete the electrical circuit. The anode (negative terminal) decays during this process while the cathode (positive terminal) remains intact or “protected.” The only difference between a corrosion cell and a manufactured battery is that the reaction process is designed to produce an electrical current for a productive use in the manufactured battery. A natural corrosion cell, however, is generally destructive since the reaction process depletes or decays the anode. When the anode is depleted in a manufactured battery, the reaction will stop, and the battery will “die” since it can’t produce more energy. When a corrosion cell is formed on a metal surface, some areas of the metal act as the anode and other adjacent areas the cathode. The corrosion reaction will not stop so easily since the anode may have a near endless supply as corrosion (and the anode) spreads across the surface of the steel.

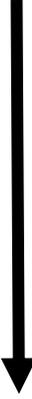


DRY CELL BATTERY - EXAMPLE OF GALVANIC (ELECTROCHEMICAL) CORROSION

Energy Required to Convert Ores into Metals

Most metals are not found in their pure state in nature, but rather as ores where they are combined with oxygen and other elements. The relative reactivity of metals is directly proportional to the amount of energy required for their conversion from ore. The chart below indicates how much energy is required to convert common metals to their pure form. Note that there are some metals that do exist in their pure form in nature such as gold, silver and copper; these metals are at the stable end of the chart.

Common Metals

Potassium	<i>Most Energy to Convert (Less Stable)</i>  <i>Least Energy to Convert (More Stable)</i>
Magnesium	
Beryllium	
Aluminum	
Zinc	
Chromium	
Iron (steel)	
Nickel	
Tin	
Copper	
Silver	
Platinum	
Gold	

Dissimilar Metals

A corrosion cell can also be formed when two dissimilar metals are in contact with one another. When two dissimilar metals are connected, the metal that is higher in the chart – i.e., requires more energy to convert to a pure metal – is the one that becomes the anode and corrodes, while the other metal acts as the cathode. The physical connection between the metals serves as a metallic pathway and water or moisture typically serves as the electrolyte needed to complete the cell. The metal that acts as the anode will decay while the other “cathodic” metal remains intact. The anodic metal thereby provides “cathodic protection” to the other metal.

Corrosion of Pure Metals

As was described in the definition of corrosion, the formation of a pure metal is not a natural state for most metals. Therefore, a metal in its pure form will begin to corrode and revert to its natural state when all of the elements of a corrosion cell are present. Exposure to air and water are usually enough to get the process started and the metal surface begins to corrode or oxidize (oxidation is another term that is sometimes used along with corrosion and simply refers to reaction with oxygen).

The corrosion of some metals does not necessarily create a problem. For example, aluminum will quickly oxidize (corrode) forming a layer of aluminum oxide on the metal surface. But the aluminum oxide layer essentially seals the metal surface and becomes protective because it stays tightly adhered and is not porous. Copper is another example of a metal that forms a protective oxide layer – in this case the characteristic green color that forms as copper weathers.

For many metals, however, corrosion is a problem because the oxidation of the metal surface does not stop after an initial layer is formed. In the case of iron (and steel), a porous layer of iron oxide is formed which is loosely held to the surface. The porosity allows corrosion to continue into the iron.



Copper Oxidation

What is Steel?

When considering the corrosion of common carbon steel, we can look at iron since it is the primary component of the steel that corrodes. Steel is primarily composed of iron at concentrations from 95 to 99 percent by weight. The difference between ordinary steel and pure iron is the addition of carbon (typically up to 2 percent) and other elements. The carbon increases strength and adds other desirable properties to the metal. A variety of steel alloys can be produced by adding elements such as

copper, chromium, nickel, or phosphorus (and others). Some of these additions can produce a significant reduction in the corrosion rate for particular steel alloys. One such alloy is known as “weathering steel.”

Mill Scale

Mill scale is an oxide layer of scale formed on structural steel when it is hot rolled – which represents the majority of steel. Mill scale is a problem for a number of reasons:

- Mill scale is cathodic to steel, meaning that under corrosive conditions, the steel becomes the anode and preferentially corrodes. In this case the mill scale is essentially a dissimilar metal.
- Mill scale may not be tightly adhered creating an adhesion issue when coating is applied.
- The mill scale layer (even if intact) is relatively smooth and coatings that require a surface profile will not adequately adhere (e.g. zinc primers)

Due to these problems, mill scale should be removed from steel if high performance coating systems are intended for application. Appropriate surface tolerant coatings can be successfully applied when only intact mill scale remains on the surface.

Weathering Steel

Weathering steels, a type of high-strength, low-alloy steels (or CORTEN, a US Steel trademark), provide greater resistance to atmospheric corrosion than conventional carbon steels. In the corrosion of weathering steel, the iron oxide layer becomes protective, similar to other metals like aluminum or copper. The oxide layer of weathering steel forms differently than for ordinary steel and its appearance changes from the typical red-orange color of rust to a dark purple as the weathering process proceeds. Weathering steel is designed to remain uncoated but can be coated for additional protection. Weathering steel is not recommended for certain environments including severe industrial exposures, locations subjected to salt-water spray, or continuous submergence in water.

How Coatings Protect the Substrate from Corrosion

Corrosion of metals really cannot be completely stopped. Slowing down the process as much as possible is the only option to preserve the metal and this is where protective coatings play a crucial role. Coatings are considered to function as a protective layer in three different ways: by providing barrier, sacrificial or inhibitive protection.

Barrier Protection

Barrier protection is the simplest way a coating functions as a protective layer and refers to the physical barrier that is formed on the substrate surface by any coating. This physical barrier prevents air and water, which are necessary for corrosion, from reaching the substrate. All coatings provide barrier protection, although some coatings have characteristics that enhance the barrier function of the coating. For example, coatings that contain micaceous iron oxide (MIO) or aluminum flakes in their formulation form plate-like layers in the coating film. Water or air cannot penetrate the “plates” and must take a longer path to eventually reach the substrate.

Sacrificial or Cathodic Protection

Coatings also may protect a substrate by providing sacrificial or cathodic protection. This occurs when the coating layer contains a metal that will act as the anode in the corrosion process, thereby protecting the metal substrate (or cathode). Sacrificial coatings are generally used as primers since the sacrificial metal must be in direct contact with the metal substrate. Zinc is the most common sacrificial



Metalizing

metal use to protect iron-based steel materials. The best example of this is with zinc-rich primers where zinc dust is added to the coating formulation in amounts up to 90% by weight. A zinc layer can also be formed on a steel substrate by metalizing or galvanizing – both of which essentially deposit a solid zinc layer on the substrate. Metalizing is accomplished by melting the zinc (and/or aluminum) and spraying it onto the substrate

surface using flame spray, electric arc or plasma arc processes. Metalizing can be performed in the shop or field at a project site. Galvanizing is completed by dipping steel parts in a molten zinc bath. The galvanizing process generally provides

superior protection to metallizing for comparable zinc thicknesses, with the obvious limitation that it can only be done in a factory or shop setting for new steel before erection.



Galvanizing

Inhibitive Protection

Some coatings also provide protection by containing inhibitive pigments that disrupt or prevent typical corrosion reactions from occurring. The mechanism by which inhibitors work is not always clear, but the common theory is that the inhibitive materials react or bind with water to prevent it from further penetrating the coating film or produce compounds that inhibit corrosion reactions. A good example of an inhibitor is lead, which is no longer widely used in coatings since it is a health and environmental hazard. Other inhibitive pigments may include borates, chromates (which may be restricted like lead), phosphates or molybdates.

Additional Cathodic Protection

As previously described, coatings provide cathodic protection when a component of the coating acts as a sacrificial metal to the substrate (e.g., zinc coatings on steel). But additional cathodic protection can be provided by passive or active means. Passive cathodic protection (as with coatings) can be accomplished by attaching a dissimilar metal directly to a metal substrate to act as a sacrificial anode. Of course, the other metal must be more reactive than the substrate to act as the anode and become sacrificial. To protect steel substrates or structures, zinc is often the other (dissimilar) metal used. A good example of passive cathodic protection is when small pieces of zinc are attached to the underwater hull of a ship. The zinc pieces (anodes) will corrode instead of the steel thereby protecting the ship's hull in the vicinity of the zinc attachment points – note that multiple zinc anodes are typically attached over the hull's surface. This protection is considered passive since corrosion (and cathodic protection) occurs spontaneously via the natural process.

For some structures, however, the potential for corrosion can be so great that passive cathodic protection may not provide adequate protection. Such environments might include offshore platforms or buried pipeline. In these cases, active cathodic protection can be provided by applying or “impressing” an electrical current to the structure (while also using a dissimilar metal to act as the anode). In

effect, the impressed current prevents the spontaneous reaction that would normally take place in a natural corrosion cell from occurring in the first place. An impressed current system requires an external power source and must be specifically designed for the structure and environment if it is to function properly. Maintenance and monitoring of the system is required.

Impressed Current System for Buried Pipelines

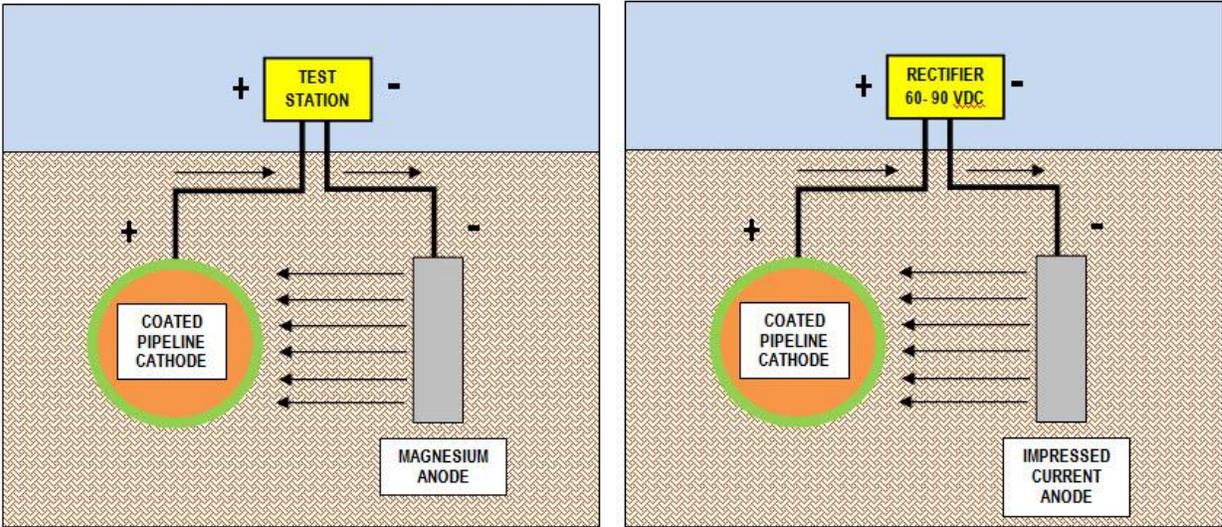
Buried pipelines are a good example of where impressed current systems are typically used. These pipelines often carry hazardous materials such as petroleum or natural gas products. The underground environment creates a potentially severe corrosion problem that warrants employing an impressed current system. These systems (and cathodic protection in general) must be used in conjunction with appropriate protective coatings.

NACE Standard Practice SP0169-2007, “Control of External Corrosion on Underground or Submerged Metallic Piping Systems” is a common industry reference standard that details the use of cathodic protection including impressed current systems. This referenced notes that the needs for corrosion protection should be based on corrosion surveys, operating records, visual observations, test results from similar systems and operating, safety and economic requirements. The design of a system must take into account all of the particular characteristics of the pipeline and surrounding environment. The corrosivity of the underground environment is generally based on soil resistivity, where a lower resistivity corresponds to a higher corrosion rate. An impressed current system must be designed by a qualified person, such as a registered professional engineer or recognized corrosion specialist.

Physically, an impressed current system consists of a rectifier and impressed current groundbed system. The rectifier supplies power to the system and transforms incoming high voltage AC current to the lower DC voltage that is required. The groundbed refers to anodes that are buried along the pipeline length. Anode spacing and depth varies by system design – typical spacing is 15 to 30 feet at a depth of 50 feet or less. Anode materials may consist of scrap iron, graphite, carbon, or more expensive magnesium-based materials. A cable connects the anodes to the positive terminal of the rectifier, while a second cable connects the pipeline to the negative terminal. This setup creates a corrosion cell where current

flows from the groundbed to the pipeline (the cathode), thereby protecting the structure.

After an impressed current system is installed, potential tests should be conducted to verify its operation. This is commonly referred to as a “pipe to soil” potential test which measures the potential based on a reference electrode (typically the copper sulfate half-cell). Measurements are made using a potentiometer or voltmeter attached to both the reference electrode (positive post of meter) and pipe (negative post). Potential readings of -0.85 volts or greater generally indicate that a structure (pipeline) is under cathodic protection. Readings below this value must be investigated to determine whether the system is adequately performing.



Module 1 Summary

One definition of corrosion is the deterioration or disintegration of man-made materials, for example: carbon steel, cast iron, aluminum or concrete. Corrosion is a natural process, the tendency of materials to “give-up” energy and return to their natural state. While it takes tremendous amounts of energy to convert materials found in nature into usable materials for construction, those same materials will readily release that energy and convert back to their original state unless the process is stopped or slowed down.

The corrosion of metals is a natural process, which involves an electrochemical reaction. Only four elements are needed for corrosion to occur: an anode, a cathode, a metallic pathway, and an electrolyte. These four elements in combination are referred to as a corrosion cell. The surface of carbon steel contains three out of the four elements; only the electrolyte is missing. Once the electrolyte (and any form of salt water is an electrolyte) connects with the surface of carbon steel, the process of corrosion will proceed.

When all four elements are present, corrosion occurs at the anode (the negative terminal), while the cathode (the positive terminal) remains intact or protected. This principle is used to create products that can protect the steel substrate (cathodic or sacrificial protection).

Most metals used in construction are not found in their pure state in nature. They exist first as ores where they are combined with oxygen and other elements. The more energy used to convert these metals to usable materials, the greater the tendency to give that “energy up” and return to a natural state (ore). Metals like carbon steel have a strong tendency to corrode and are “less stable” than metals like gold, platinum, and silver, which exist in their pure form in nature.

The addition of certain elements during the process of creating steel can produce steel alloys with a significantly lower corrosion rate. One such steel alloy is called weathering steel or CORTEN.

The most widely used method to prevent corrosion, particularly on carbon steel, is the application of high performance, protective coatings. Coatings protect metals from corrosion using three methods: barrier protection, sacrificial or cathodic protection, and inhibitive protection. All coatings provide some type of barrier protection, forming a physical barrier that prevents air and water from reaching the substrate. Sacrificial or cathodic protection is provided when a coating contains a metal which will become the anode in the corrosion process, thereby protecting the metal substrate (or cathode). Zinc is the most common sacrificial metal and is often added to primers, where the zinc can come into direct contact with the steel substrate. Pure zinc can also be melted and used to coat steel parts. The metallizing process melts zinc and uses flame spray, electric arc, or plasma arc to spray the zinc onto the substrate. Galvanizing is completed by dipping steel parts into a molten zinc bath.

An additional method to provide passive cathodic protection (which is also provided by sacrificial coatings) can be accomplished by attaching a dissimilar metal directly to a metal substrate to act as a sacrificial anode (usually pieces of zinc). The zinc will corrode instead of the steel.

For some structures, including offshore platforms and buried pipeline, passive cathodic protection may not provide adequate protection. By applying (impressing) an electric current to the structure, while using a dissimilar metal to act as the anode, the current prevents the spontaneous reaction (corrosion) from occurring in the first place.

Module 1 Quiz

Basic Coatings Inspection

1. When steel corrodes, it:
 - A. absorbs energy
 - B. gives up energy
 - C. returns to its natural state
 - D. B & C

2. Corrosion can only occur when the following elements are present:
 - A. an anode and cathode and a catalyst
 - B. a cathode, an anode, and a metallic pathway
 - C. an anode, cathode, metallic pathway and an electrolyte
 - D. a cathode, an anode, and an electrolyte

3. The most widely used method to prevent corrosion today, particularly on carbon steel, is:
 - A. galvanizing
 - B. the application of industrial protective coatings
 - C. sacrificial protection
 - D. passive cathodic protection

4. Corrosion occurs at the
 - A. anode
 - B. cathode
 - C. the connection between the anode and cathode
 - D. electrolyte

5. The anode, cathode, electrolyte and connection between the anode and cathode is known as:
 - A. galvanic corrosion
 - B. inhibition
 - C. a corrosion cell
 - D. galvanic protection

6. Assuming oxygen is present, the surface of carbon steel already contains three out of four elements needed to corrode; the missing element is:
- A. the anode
 - B. the cathode
 - C. the metallic pathway
 - D. the electrolyte
7. Which of the following metals is the most likely to corrode:
- A. Gold
 - B. Copper
 - C. Steel
 - D. Platinum
8. When some metals corrode, it is not a problem, because the corrosion forms a protective oxide layer. One of those metals is:
- A. Carbon steel
 - B. Iron
 - C. Copper
 - D. Gold
9. Sacrificial protection is accomplished by using:
- A. Zinc powder in a primer
 - B. Hot-dip galvanizing
 - C. Thermal Spray Coatings (Metallizing)
 - D. All of the above
10. When dissimilar metals are connected, the one that requires more energy to convert to a pure metal:
- A. Will become the anode and corrode first
 - B. Will become the cathode and remain intact
 - C. Won't change
 - D. Becomes the metallic pathway

11. Converting iron ore into carbon steel requires:
- A. High amounts of energy
 - B. Heat
 - C. The ore to give up energy
 - D. Answers A & B
12. The primary component of steel is:
- A. Carbon
 - B. Iron
 - C. Phosphorus
 - D. Chromium
13. A high strength, low alloy steel that provides greater resistance to atmospheric corrosion than conventional carbon steel is called:
- A. Weathering steel
 - B. Galvanic steel
 - C. Metallic steel
 - D. Sacrificial steel

The Role of a Coating Inspector

Module 2

Learning Outcomes:

- List the similarities and differences between Quality Assurance and Quality Control roles.
- Discuss the general content of an inspection plan
- Discuss key aspects of limiting project conflicts

How this information affects YOU:

Understanding the unique role of a coating inspector as a quality role can keep a project on course, mitigate conflict, and deliver a high-quality product. Knowing the differences between QA and QC roles helps you know your specific responsibilities on the job .

Introduction

It is common to encounter contract or specification requirements for quality control (QC) and/or quality assurance (QA) on coatings projects. Unfortunately, it is uncommon for specifications to define the specific and respective responsibilities of QC and QA personnel. All too often, the lines between QC and QA get blurred.

This module is designed to discuss the role of a coatings inspector, the concepts of QC and QA, clarify the differences and similarities in the roles and responsibilities and introduce tools to assist the coatings inspector in performing the duties.

Defining Quality, Quality Control and Quality Assurance

Quality is defined as the characteristics of a product or service that bear on its ability to satisfy stated or implied needs. Quality may be the degree to which a product or service is free of nonconformities and may be the extent of satisfying the specification requirements.

Quality Control (QC) is the contractor's responsibility and involves performing the necessary observations, tests and documentation to verify that the work performed meets or exceeds minimum (quality) standards established by the Owner through project specifications and/or industry standards. Quality control of industrial painting involves routine and systematic inspections and tests to verify that each phase of the work (or hold point) follows the quality standards established by the specification. Quality control is verification that the contractor's activities get the job done right.

Quality Assurance (QA) is generally performed by the Owner (e.g., facility project engineer) or a third party on behalf of the Owner. QA verifies that the quality of work performed by the contractor is what was reported by quality control. Quality assurance provides confidence that quality requirements are achieved. Quality assurance is an oversight function and is used to verify that the quality control is being performed and performed correctly and may include conducting periodic testing.

In simple terms, quality assurance by the Owner is meant to verify that the quality control implemented by the contractor meets the requirements of the specification.



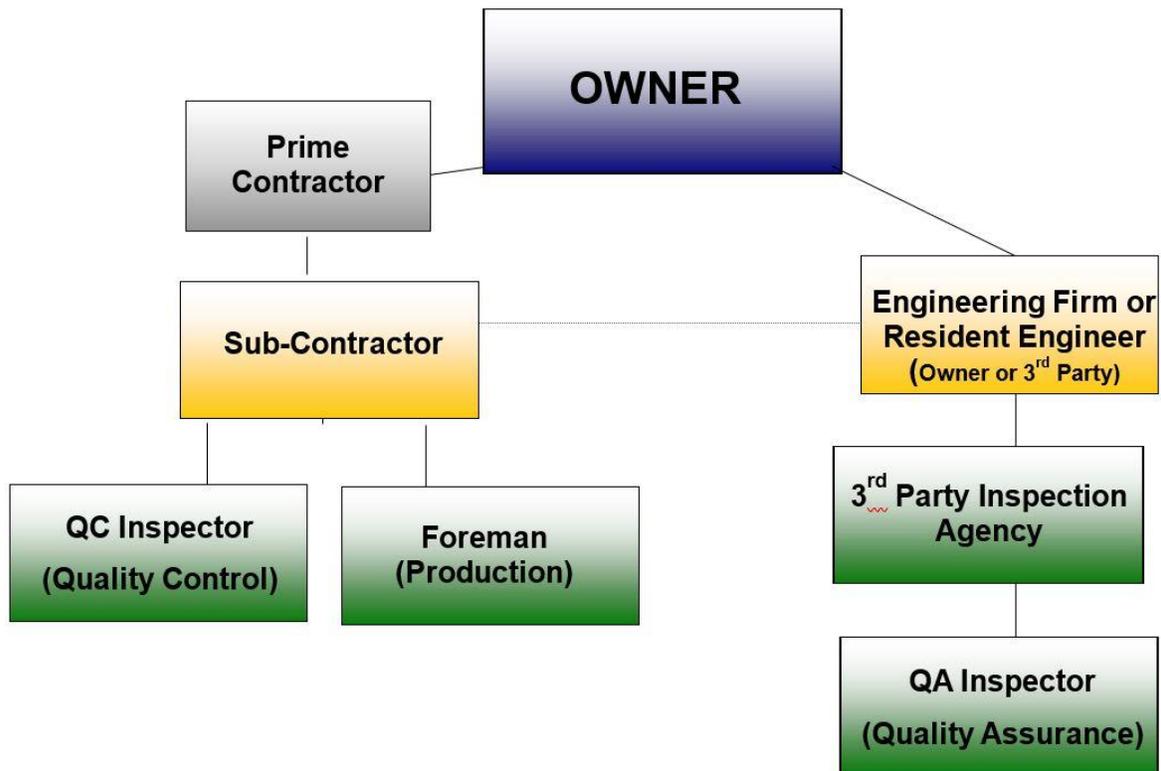
Testing at the job site

Contractual Relationships



The specific duties of the QC and the QA in the field and in shops will vary from project to project. The Owner's contract with contractors and third parties should define and establish the specific expectations, qualifications, and responsibilities for assigned QC and QA personnel.

Contractual relationship can vary from project to project and industry to industry. The diagram below generally illustrates coating project contractual relationships.



The Role of an Inspector

The role of an inspector is to Observe, Assess, Document, and Report, or OADR.

Observe... the work performed by the contractor

Assess... whether the work performed meets the requirements of the project specification

Document... the results of the inspection, independent of whether the work meets the specification

Report... on a predetermined frequency the progress and quality of workmanship relative to the specification requirements

There are a couple of roles that an inspector should never take, independent of their relationship to the parties on a project. These include the role of a “specification rewriter” and project manager.

Specification Rewriter: A coatings inspector must never revise the requirements of the painting specification. An analogy can be drawn between the role of a coating inspector and a police officer. The inspector enforces the contract specification without invoking personal bias or opinion on the content or adequacy of the specification, just like a police officer enforces laws without bias or interpretation. For example, when the posted speed limit on a highway is 55 MPH, the police officer enforces the maximum speed limit, despite personal opinion that 65 MPH is a more reasonable speed limit for the highway. The same holds true for a coating inspector. An inspector may believe that a “Near-white” level of surface cleanliness should have been specified (described later in this course), even though the project specification only requires a “Commercial” level of cleaning. Despite personal opinion and experience on other projects, the inspector can only enforce the minimum requirements of the project specification. Similarly, the inspector may feel that grinding of edges should have been specified, but if it was not, then the inspector cannot require the contractor to grind edges, as it was not a component to the contract.

Project Manager: Second, a coatings inspector should never “run a project” nor dictate the means and methods that the contractor will use to accomplish the scope of work in the specification. That is, how the contractor achieves the end result is up to them; the inspector simply verifies that the end result conforms to the requirements of a specification. For example, the inspector should not prescribe the nozzle type, air volume or pressure, nozzle distance, nozzle angle or dwell time to abrasive blast clean a surface. Nor should they prescribe the size of the abrasive to use (unless dictated by the project specification). Rather, the inspector simply verifies that the prepared surfaces meet the minimum cleanliness and the minimum and maximum surface roughness (surface profile) required by the specification. How the contractor gets to that point is up to them, provided they are performing the work safely without harm to workers, the environment, or the public.

Preparing for a Project

The responsibilities of the coating inspector begin long before surface preparation begins. Listed below are common responsibilities of a coating inspector. Responsibilities related to safety, environmental compliance, etc. are not listed, but may be included on certain projects. The responsibilities listed below are centered on surface preparation and coating application activities. Each of the responsibilities listed will be addressed in this course.

Preparation Prior to Surface Preparation

- Read and comprehend the project specification
- Read and comprehend the coating manufacturer's product data sheets (PDS) for each coating and coating component that will be used on a project
- Read and comprehend the coating manufacturer's Safety Data Sheets (for each coating component that will be used on a project)
- Attend and participate in the pre-job conference
- Prepare an inspection procedure or plan for the project
- Verify personal inspection equipment and personal protective equipment (PPE) conform to the specification and jobsite conditions
- Verify calibration of inspection equipment is current
- Verify the adequacy of the contractor's equipment for surface preparation and coating work
- Verify the adequacy of lighting for surface preparation, coating application and inspection activities
- Verify protective coverings are installed
- Verify the cleanliness of compressed air (if employed for surface cleaning, dust removal, or spray application)
- Verify removal of visible grease, oil and/or related contaminants (soluble salts)
- Verify the correct abrasive is on-site and stored properly
- Establish a project-specific cleanliness standard prior to production surface preparation
- Measure ambient conditions and surface temperature and verify conformance to the PDS and project specification (throughout all coating activities as specified)

Preparation Prior to Coating Application

- Verify surface cleanliness and measure surface roughness
- Verify correct coating materials and thinners are on-site and stored properly
- Verify coatings are mixed, thinned and applied properly
- Verify proper calculation of target wet film thickness

Responsibilities During and After Coating Application

- Verify the applicator's use of a wet film thickness gage
- Measure the dry film thickness of each coating layer
- Verify cleanliness between coats
- Verify conformance to minimum and maximum recoat intervals
- Examine the applied coating system for defects
- Examine the applied coating for continuity
- Carefully and thoroughly document the results of each of the inspections performed, including the inspection equipment employed
- Prepare a daily summary of the areas worked, the work performed and any non-conforming items

As illustrated by the list, the responsibilities of an inspector are many, and there is typically a limited window during which the inspector can perform these checkpoints without impeding production. This is why an inspector must be organized, be intimately familiar with the project specification and the coating materials, develop a thorough inspection plan, and perhaps most importantly, be proficient in the use of visual standards and inspection equipment. The inspector must possess good writing skills to document activities and the results of inspections. The inspector must possess good communication skills and display confidence when performing inspections and relaying results to the contractor, particularly when non-conforming items become evident.

Preparing a Project-Specific Inspection Plan

SSPC and other certifying agencies strongly advocate the development and use of an inspection plan as a planning tool. An inspection plan considers all phases of the work in sequence and the contractor's work plan and schedule. The coatings inspector obtains and reviews the project specification, product data sheets, referenced standards, test methods, and required inspection equipment.

The inspection plan would list each inspection check point, inspection method and the acceptance criteria. The following example illustrates a few inspection checkpoints prior to applying coatings:

Coatings Inspection Plan		
Inspection Check Point	Inspection Method	Acceptance Criteria
Surface Cleanliness	Visual using SSPC-VIS 1	SSPC-SP 10
Surface Profile	Replica Tape; SSPC-PA 17	1-3 mils
Ambient Temperature	Thermometer	50°F - 90°F

More detailed plans may include listing the frequency of inspection performance, the specification section where the requirement is listed, and/or comments. For example:

Inspection Check Point	Inspection Method	Acceptance Criteria	Frequency	Specification Reference	Comments
Surface Cleanliness	Visual using SSPC-VIS 1	SSPC-SP 10	Every time surface preparation is performed	3.3.2	None
Surface Profile	Replica Tape; SSPC-PA 17	1-3 mils	Every time surface preparation is performed	3.4.2	Requires angular profile
Ambient Temperature	Thermometer	50°F - 90°F	Prior to application and every 4 hours	3.1.2	Agreed - prior to start and post-lunch start-up

In most cases, whether you are acting as a QC or QA inspector, it will be critical for you to determine the specific responsibilities, tests, frequency and documentation you are responsible for completing. If you are working as or with a QC or QA representative, it is also important to clarify which inspections will be done by whom and how any discrepancies will be addressed. The best place to establish this division of duties is the pre-job conference.

Importance of Documentation

One of the most important responsibilities of a coatings inspector is to document the results of the inspections in a clear, concise, and timely manner. Oftentimes measurements and readings are recorded in an inspector logbook, then transferred onto inspection forms. Without timely, formal documentation, many of the key results may be lost or forgotten. It is acknowledged that few individuals enjoy paperwork. However, it is a necessary evil in today's litigious culture. Documentation of specific, key items as the work progresses may do nothing more than fill a file cabinet once the project is completed. However, in the event of a problem, it can provide key information for resolution of the problem. Documentation of the results of inspections can also be a key element in the event that the coating failure results in litigation against the coating contractor or the coating supplier. Just like homeowner's or car insurance, you may never use it, but when you need it, you're glad you have it.

There is no "standard inspection form" that every inspector uses. The design and content of the documentation forms can vary and may be customized to a project. It is important that the form ultimately used by the inspector address all the inspection checkpoints included in the project specification, and that the form allow ample space for commentary.

Specification Deviations and Non-conformities

Observations or tests that do not meet the specification are called deviations or non-conformances.

A deviation is a divergence from the approved specification that can be brought into conformance (typically on the same day or shift) and does not require evaluation and disposition by the Owner. An example of a deviation is a blast inspection revealing traces of mill scale, when a SSPC-SP 10 Near-white blast is specified. The contractor will continue to blast the surface until SSPC-SP 10 is achieved to correct the deviation. The contractor may choose the course of action to correct a deviation from the specification.

A non-conformance is a condition identified during inspection or testing deviating from the specifications. A nonconformance requires the Owner to provide an acceptable course of action (a disposition) to the nonconformance. An example of a non-conformance is the application of coatings when the ambient conditions are not acceptable or the application of coatings over a surface that didn't meet specified surface preparation requirements (such as applying a coating over small flakes of intact mill scale, when SSPC-SP 10 was specified). In these instances, the

area generally requires rework, repair or retesting by the contractor or the Owner agrees to accept the work “as-is.” Only the Owner may decide on the final disposition of a nonconformance.

QA: Managing Disputes

QA inspection personnel must remember their role is to observe, assess, document and report. Any deviation or nonconformance must be documented and reported if not adequately addressed within the specified reporting period. When a dispute arises, the QA inspector may offer helpful suggestions, but must be careful not to be perceived as directing any work or interpreting the specification. Any areas not meeting the specification must be communicated to the owner in some manner. Communicating this to contractor personnel or suggesting guidance from the Owner is a way to reinforce the QA inspector’s role is not negotiable.

QC: Managing Disputes

QC inspection personnel must remember their role (like QA inspectors) is to observe, assess, document and report. QC personnel should allow the foreman or other contractor production personnel to direct production activities. Any issues not meeting the specification must be communicated to project production personnel via the project supervisor/foreman. If the dispute cannot be resolved with production, the QC inspector should communicate with contractor management and reinforce deviations and non-conformances will be reported.

Establishing Communication Frequency and Content with the Owner

Communication frequency and content should be determined and established as soon as possible. Each project may have different requirements for communication, and each Owner representative may have different preferences. It is important to establish routine communication such as how often to call or provide reports (daily, weekly, when conditions change, etc....). The inspector should learn what would trigger immediate communication and what can be communicated more routinely. Owners do not like to be surprised by issues, especially issues that have lingered. If you are QA for the owner, issues may be resolved quickly by informing the contractor you will be seeking guidance from the Owner.

The Role of the Coatings Inspector in Failure Avoidance

The coatings inspector can play a key role in helping to prevent premature coating failure. The opportunity for failure is significantly reduced when a properly trained and equipped coatings inspector verifies each step in the surface preparation and coating/lining installation process meets the requirements of the project specification. The knowledgeable inspector identifies deficiencies as they occur. He works with the contractor to bring the deficient areas into conformance with the specification. He communicates deficiencies before additional work progresses. Areas where work should be verified as acceptable prior to work progressing are known as hold points. Hold point inspections should be performed as specified, and typically include acceptance of pre-cleaning, surface preparation, primer application, intermediate application, top coat application and the cure. A knowledgeable coatings inspector will also identify “problem areas” on a structure that are prone to coating failure despite the efforts put forth by the contractor. Alternative methods of corrosion protection can then be explored by the facility owner/specification writer (i.e., caulking of crevices) to help avoid premature breakdown of the coating.

The Role of the Coatings Inspector in a Failure Investigation

Despite efforts put forth by all parties on a coatings project (the owner/specifier, the contractor, the coating material supplier, and the inspector), coating failures occur. A coatings inspector can play a key role in helping to determine the cause of the failure, as well as what can be done to prevent the failure from reoccurring. The coatings inspector will not typically investigate the failure, but rather cooperate during the investigative process. The importance of thorough, complete inspection documentation cannot be emphasized enough. These inspection records will be scrutinized during the failure investigative process and may become a key component to the litigation process. Conversely, incomplete or inaccurate records can be a detriment to the investigative process and can reflect poorly on the coating inspector. For example, if the failure is related to incorrectly manufactured batches of coating and the inspector’s records do not indicate batch numbers, or do not reflect what batch was used on what portion(s) of the structure, the failure investigation may become increasingly difficult. Or simply recording ambient conditions “met” the specification requirements without recording the actual temperatures, conditions, date, and time will be essentially useless in the failure investigation. The failure investigator will often interview the coatings inspector and request copies of inspection records, photographs and other project documents to aid in the investigative process. The value of these documents is directly related to their completeness and accuracy. A coatings inspector must realize that inspection records, photographs, and written correspondence with the contractor, owner, and material supplier

are all “discoverable” items in the legal process. The inspector may be required to give a deposition, may need to testify, and may be subject to cross-examination in court if a coating failure is litigated. The quality of the inspection on the project, the completeness and accuracy of inspection records, is a direct reflection on the credibility of the coating inspector.

Industry Recognized Inspection Standards and Certification Programs

The coatings industry has a variety of industry groups that prepare inspection standards using a consensus process and certification programs to establish best practices and processes. Industry groups and their activities add the highest possible value for the coating customer. The content of standards, handbooks, guides, procedures, training and other documents produced by these groups make up a significant portion of this training and are an excellent resource to inspectors. These Industry Groups include:

SSPC: The Society for Protective Coatings

NACE International

ASTM International

NACE and SSPC provide training courses and certification programs addressing various aspects and types of coating activities and inspections. These programs and courses provide companies and inspectors with a pedigree. Certified coating inspectors and contractors are often sought by Owners to inspect coating projects. Specialized certifications are available to inspectors such as for bridge or concrete inspection (BCI or CCI). Certification may also be specific to coating contractors, blast & paint shops and inspection firms (SSPC-QP 1, QP 3, and QP 5), respectively.

Module 2 Workshop: New Scenarios

Review the scenarios, discuss with your team, and answer each of the assigned scenario questions. Have a spokesman prepared to discuss and defend your team's responses.

SCENARIO 1

You are performing part-time, third-party, Quality Assurance services for the Owner. The contractor blast cleaned and painted on Saturday, while you were not on-site. When you arrive Monday, the Owner hands you a piece of paper that says "Saturday, surface preparation ok. Ambients ok, 100 gallons primer applied, okay." He asks you to record this information on an inspection report dated Saturday and to sign it.

Question 1: Do you record the information?

Question 2: How might you record the information "ethically?" or otherwise address the situation?

SCENARIO 2

You have been the coating contractor's Quality Control inspector. The surfaces have been prepared and coated. All work has been completed according to the work instructions approved by your prime contractor. You are subsequently provided the Owner's specification. The surface preparation and coating thicknesses in the work instructions differ from the Owner's specification.

Question 1: What do you do?

Question 2: How might you prevent this issue from occurring in the future?

SCENARIO 3

You are the Owner's Quality Assurance inspector. The contractor's Quality Control inspector has accepted the blast cleanliness of a large outdoor structure's exterior. The preparation is acceptable except for numerous areas on the underside of pipes. There is not time to set up the equipment and re-blast the surfaces before an impending weather event will ruin two shifts of blasting cleaning. There is limited time available beyond the time needed to paint the structure and for the paint to sufficiently cure. The Owner is not available for guidance.

Question 1: What are the options?

Question 2: How might you prevent this issue from occurring in the future?

SCENARIO 4:

You are the Owner’s Quality Assurance inspector. The contractor is waiting for you to verify surface cleanliness, proper paint mixing, ambient conditions, surface temperature, and that the correct material is being used. You were delayed an hour past the agreed upon time and unavailable by mobile phone. When you arrive, the contractor is just finishing the application.

Question 1: Is the fact that the application was performed acceptable?

Question 2: What considerations to determine whether the application will perform?

Question 3: Does the Owner need to be notified? Why?

SCENARIO 5:

The coating specification requires a minimum and maximum surface profile depth and the application of three coats of paint. You inspect and are obtaining consistent measurements in excess of the maximum surface profile depth. You approach the contractor who responds, “I gave you the minimum and more is better anyway...” The previous project for another client allowed for surface profile depths greater than the maximum specified.

Question 1: Is the measured surface profile depth acceptable? _____

Question 2: Explain your response to question 1.

Question 3: If no, what can be done now?

Question 4: What may have prevented the issue?

Module 2 Quiz

Basic Coatings Inspection

1. Quality Control (QC) is the responsibility of the:
 - A. Owner
 - B. the contractor
 - C. the facility owner
 - D. the project engineer

2. Quality Assurance (QA) is:
 - A. an auditing function performed when a coating project is over
 - B. used to verify that quality control is being performed and performed properly
 - C. not necessary if there is a good QC program in place
 - D. typically, a review of documentation post-project

3. When QC or QA personnel discover work that is “out of specification,” if the problem is not fixed or corrected, the work is typically referred to as a:
 - A. coatings failure
 - B. hold point
 - C. nonconformance
 - D. ethical breach of contract

4. Which inspector activity can cause unnecessary conflict on a project?
 - A. documenting an unsatisfactory coat of paint
 - B. reporting a nonconformance to the Owner
 - C. having coating personnel mix paint when surface preparation inspection is complete
 - D. all of the above

5. Qualification Procedure 1 (QP1) of SSPC’s Painting Contractor Certification Program (PCCP) is an example of:
 - A. a specification
 - B. a coating application procedure
 - C. a trade association’s certification offering
 - D. answers B & C

6. An inspection plan helps the QC or QA inspectors:
 - A. identify and plan for hold point inspections
 - B. recognize the tests and equipment needed
 - C. itemize specification requirements and acceptance criteria
 - D. all of the above

7. Documenting activities on a coatings job that are not true:
 - A. will be considered a nonconformance
 - B. can be treated as fraud
 - C. a breach of the pre-job conference
 - D. can only be performed by the owner

8. Inspectors, depending on who hired them and why they were hired, can perform either quality control or quality assurance functions.
true____ false____

9. Which is not an element of an inspection plan?
 - A. instruments
 - B. inspector certification
 - C. inspection parameters
 - D. procedure or standards

10. What is foremost to limiting project conflicts
 - A. an effective pre-job meeting
 - B. minimizing hold points
 - C. picking and choosing your battles
 - D. all of the above

11. Which of the following statements is NOT true about quality control:
 - A. quality control is the Owner's responsibility
 - B. applies to all facets of the project
 - C. is systematic and routine inspection
 - D. responsibility of the contractor.

12. Clarification of issues involving the specification, product data sheets, and/or the roles and responsibilities of QC and QA personnel should be resolved (as much as possible):
 - A. during the bidding stage
 - B. at the pre-job conference
 - C. on the first day of the project
 - D. as problems occur throughout the project

13. A hold point is defined as:
 - A. specification requirement
 - B. a point after certain activities are completed where production is stopped and the work is inspected prior to the next painting process step
 - C. a stop payment condition
 - D. none of the above

14. The person who can direct the contractor's employees is:
 - A. the Owner
 - B. the Owner's QA Inspector
 - C. the Contractor's QC Inspector or Foreman
 - D. the Director

15. Quality is NOT defined as a characteristic of a product or service that:
 - A. satisfies a stated or implied need
 - B. produces safety concerns
 - C. adheres to the specification
 - D. is free of nonconformances

16. Which is incorrect?
 - A. Quality Assurance verifies Quality Control is adequate
 - B. Quality Control verifies coating materials and equipment are correct
 - C. Quality Assurance verifies the production schedule
 - D. Quality Control is responsible to update the Owner regarding issues

17. What is the purpose of an inspection plan:
 - A. to meet a specification requirement
 - B. organize inspection requirements.
 - C. to know which inspector is inspecting what
 - D. all of the above

18. How might an inspector quickly resolve a dispute?
 - A. suggest guidance from the Owner
 - B. affirm any unresolved deviation is documented
 - C. communicate that remaining issues will be reported to the Owner
 - D. All of the above

Surface Preparation: Industry

Standards and Inspection

Module

3

Learning Outcomes:

- Define the two-fold purpose of surface preparation.
- Describe pre-surface preparation inspections commonly invoked.
- List the inspection check points related to surface preparation that may be invoked by the governing specification.
- Measure and record surface profile.
- Evaluate whether surface cleanliness using the SSPC Visual Guides.

How this information affects YOU:

The quality of surface preparation is the key factor in determining the success of a protective coating system. As a coatings inspector, you will need to know what types of substrate defects can cause premature coating breakdown, the characteristics of various methods of surface preparation as well as the definitions of industry surface preparation standards. You will also need to know how to perform inspection of surface cleanliness, measure surface profile and you may need to extract and analyze soluble salt contamination.

Introduction

Preparing the surface for subsequent application of the coating system is the most critical (and typically the most expensive) step in an industrial coatings project. Whether the surface is plastic, glass, wood, concrete, aluminum, carbon steel or stainless steel, surface preparation (cleaning and roughening the surface) remains a key factor in determining the ultimate service life of the applied system. In general terms, the better the surface preparation, the longer the life of the coating system.

However, not all surfaces or service environments (the environment that the coating system must perform in; for example, immersion, atmospheric, chemical, etc.) and not all coating systems require the same degree of surface preparation. That is, a facility owner may be able to economize his maintenance painting program by specifying a lower degree of cleaning AND choosing a coating system that is



Abrasive blast cleaning

designed to perform over a lesser degree of surface preparation while still providing long-term protection in the service environment. For example, potable water storage tank owners often specify a higher degree of cleaning for the interior liner compared to the exterior surfaces, since the interior environment (immersion) is more severe. While a higher degree of cleaning on the exterior may lengthen the life of the coating system, the increased cost associated with the higher degree of cleaning may not justify a moderate increase in service life.

The Inspector's Role

The inspector's role related to surface preparation is multi-fold and may vary from project to project. For example, on most projects, the inspector is typically responsible for verifying the cleanliness of the abrasive media and compressed air (if abrasive blast cleaning is specified), verifying that grease, oil and other contaminants are adequately removed from the surfaces prior to surface preparation, and for verifying that the degree of surface cleanliness and roughness have been achieved prior to application of the primer. Other responsibilities may include verifying that structural deficiencies have been repaired and that the contractor's equipment is operating properly and productively, so that the project remains on or ahead of schedule. Each of these inspection checkpoints will be described in this module.

Purpose of Surface Preparation

The purpose of surface preparation is two-fold: to clean and to roughen the substrate according to the requirements of the specification. Sometimes the methods used to prepare surfaces for coating application achieve these criteria simultaneously (as with abrasive blast cleaning), while other times these steps must be performed separately (as with chemical stripping). In either case, the inspector must treat these as two distinct “acceptance criteria,” as the level of cleaning may be adequate, but the roughness may be insufficient or excessive. Alternatively, the surface roughness may be on target, but the level of cleaning may be inadequate.

Review of Industry Standards

ASTM International, NACE International and SSPC: The Society for Protective Coatings all have standards for measurement of surface roughness (profile) after abrasive blast cleaning. SSPC and NACE International have standards for surface cleanliness.

Industry Standards for Measuring Surface Profile Depth

The ASTM standard for measurement of surface profile (ASTM D4417, “Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel”) describes three methods of measurement, while NACE SP0287 describes only one method. These methods of measurement will be described later in the module. It is important to recognize that these standards simply describe *how* to procedurally conduct a test; they do not provide an acceptance criterion. Therefore, the specification writer must state the acceptable surface profile range.

SSPC-PA 17, “Procedure for Determining Conformance to Steel Profile/Roughness/Peak Count Requirements,” complements the existing ASTM standard for measuring surface profile and roughness; it does not replace the existing ASTM standard. Although the ASTM standard provides recommendations for the number of instrument readings to characterize the surface profile, it does not include the number of locations to measure or an acceptance criteria to determine whether the profile over the entire prepared surface is within the specified range. SSPC-PA 17 provides this information.

The use of SSPC-PA 17 to determine compliance with project specification requirements is discussed later in this training module.

In many cases, the coating manufacturer will recommend/specify the range of the surface profile depth for a given coating system on their product data sheet (PDS). If this information is not listed on the PDS, a technical representative of the coating manufacturer should be contacted. They should be informed of the target dry film thicknesses of the total system to be applied, not just the primer thickness, as the surface profile must be compatible with the entire coating system. It is advisable to receive written confirmation of their recommendation.

Industry Standards for Assessing Surface Cleanliness

The SSPC and NACE surface cleanliness standards prescribe a minimum acceptable level of cleaning, depending upon the specified degree of cleanliness required. The SSPC/NACE standards are known as “consensus documents” that are created by industry experts for inclusion in coating specifications. They are not law or regulations, but they become “contract law” once they are invoked in a specification for a coatings project. There are currently 21 surface cleanliness standards. NACE and SSPC have jointly published several of them. The written standards for surface cleanliness are contained in Volume 2 of the SSPC Steel Structures Painting Manual, “Systems and Specifications.” These standards define the minimum level of cleaning required, and many of them are accompanied by visual guides that an inspector can use to verify that the level of cleaning has been achieved. The surface cleanliness standards, their designations and definitions will be described later in this module, along with the proper use of the visual guides.

Pre-surface Preparation Inspection

Prior to beginning surface preparation operations, many specifications will require a “pre-surface preparation inspection” to verify that fabrication-related items (that may adversely affect coating system performance) are corrected, and that surface contamination (such as grease, oil, cutting compounds, lubricants and chemical contaminants) are sufficiently removed. With the exception of grease/oil removal from the surface, unless the governing specification addresses these items, the contractor should not be required or expected to perform corrective actions.

Weld Spatter

Weld spatter may be present on steel sections or pipe sections that were welded together using stick, flux core, gas metal arc (MIG) or gas tungsten arc (TIG) methods. Weld spatter is typically not present when submerged arc welding is performed. Welders are expected to remove weld spatter as it occurs.



Weld spatter

Spatters of weld rod material deposited on the steel surface can result in spot corrosion if it is not removed from the surface prior to coating application. Weld spatter is a protrusion from the surface. While coating may be deposited onto the spatter, surface tension that is created between the protrusion and the coating

causes the coating to draw thin on the spatter. In addition, the spatter may eventually dislodge from the steel, creating a void in the coating system and a pathway for corrosion of the underlying steel. For these reasons, many specifications will require the contractor to remove weld spatter (using chisels or grinding wheels) prior to surface preparation and coating system installation. If required by the specification, the inspector must visually inspect the weld areas for the presence of spatter and identify areas where weld spatter remains.

Preparation of Welds in Tanks and Vessels for Immersion Service

Appendix C of NACE Standard SP0178, “Standard Recommended Practice – Fabrication Details, Surface Finish Requirements, and Proper Design Considerations for Tanks and Vessels to be Lined for Immersion Service” contains written and graphical descriptions of five



Weld finish comparator

degrees of surface finishing of welds that can be specified prior to lining tanks or vessels for immersion service. The appendix is supplemented with a molded plastic weld replica comparator illustrating the weld condition prior to finishing and the various degrees of preparation for butt welds, fillet welded tee joints and lap welds. The degree of preparation (grinding) ranges from “minimal” (designation “E”) to smooth & blended (“D”), smooth and free of defects (“C”), smooth (“B”) and flush and smooth, free of all defects (“A”). Designations A & B are only applicable to butt welds. A coatings inspector may be responsible for verifying that the degree of weld grinding performed meets the requirements of the contract documents (specification) prior to surface preparation and lining installation.

Condition of Edges/Corners

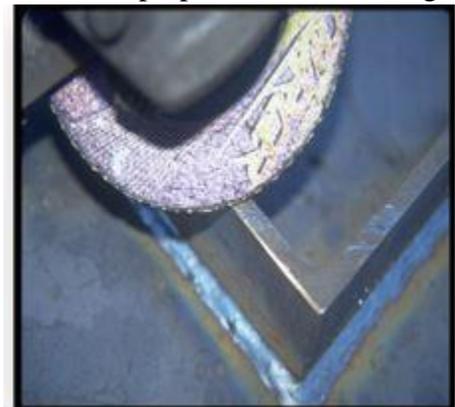


Grinding edges

“Sharp” edges and corners, such as those generated by torch cutting operations are difficult to coat, as the coating tends to pull away (draw thin) on the corners during application because of the surface tension that is created on the sharp edge. Some coatings have characteristically good “edge retention” properties, while others that shrink a lot during the drying and curing processes may have relatively poor edge retention properties. However, the inspector does not have to know how well or how poorly a coating will protect edges. The inspector is only responsible for verifying that edge preparation is performed and performed properly

(according to the specification requirement) prior to surface preparation and coating installation.

Specification requirements for edge/corner preparation vary widely. Common examples include: 1/16” radius or chamfer, 1/8” radius or chamfer, and even “break all edges,” while some specifications do not address edge preparation at all. There is no gage or instrument that is used to inspect the degree of edge preparation achieved. A tactile and/or visual assessment is typically all that is required, along with documentation that edge/corner preparation was satisfactory.



Edge preparation

Some project specifications will require the application of a “stripe coat” to edges and corners (as well as other “difficult to coat” areas) to help ensure that these surfaces are adequately protected, even if edge preparation is specified. Briefly, striping is a single or multi-layer application of coating to edges, corners, bolt/nut assemblies, rivets, weld seams, bolt holes and other surfaces that are traditionally hard to protect from corrosion. The stripe coat can be brush or spray applied, however spray application to edges and corners is often preferred, as brushing can pull wet coating off the edge, rather than deposit it onto the edge or corner. SSPC Guide No. 11, “Protecting Edges, Crevices, and Irregular Steel Surfaces by Stripe Coating” discusses the benefits of striping in more detail.



Striping or stripe coating

Laminations

Laminations occur during the rolling process in the steel mill. These laminations may be visible prior to blast cleaning or may be raised during abrasive blast cleaning operations in the shop, creating a sliver that projects from the surface. These steel defects should be removed by grinding; otherwise they may project above the coating film and subsequently corrode. The inspector should visually assess the prepared surfaces for slivers and laminations before and after abrasive blast cleaning. If discovered after blast cleaning, the affected area may have to be re-abrasive blast cleaned after grinding is completed.



Laminations/Sliver

Substrate Replacement

Older structures that have extensive corrosion may exhibit severe section loss, requiring replacement or patching of a portion of the structure. Examples include the “belly” of an elevated storage tank that has severe pitting (or even perforations), or structural steel beneath the roadway deck of a bridge structure that has been subjected to years of deicing materials. A structural engineer may ultimately determine that substrate replacement is required, which can involve removal of the affected areas by torch cutting and installation of



Section loss due to corrosion

replacement steel by welding, or simply welding a new section of steel over the deficient sections (patching). In any case, these operations must be performed prior to final surface preparation and coating system installation. If substrate replacement is required, the inspector must verify that all work is complete and is acceptable to the structural engineer prior to surface preparation operations. Subsequent rework of these areas after surface preparation will require rework by the painting contractor, which can adversely impact project cost and schedule.

Removal of Grease, Oil, Cutting Compounds and/or Lubricants

Grease, oil, cutting compounds or lubricants used in the fabrication process, or that have become deposited onto existing surfaces while in service can adversely affect the performance of the newly-installed coating system unless they are detected and adequately removed prior to surface preparation. In addition to potentially interfering with adhesion of the installed coating system and interfering with proper wetting of the substrate by the coating during application (causing a defect known as “fisheyes”), these contaminants can be driven into the surface during surface preparation and/or can contaminate the abrasive media or tool used for surface preparation (power tool cleaning and abrasive blast cleaning). This is particularly problematic when the abrasive will be recycled and reused. If the abrasive becomes contaminated and is reused, it too can deposit the contamination onto cleaned surfaces.

For these reasons, it is important that the surfaces be visually inspected for grease and oil contamination prior to surface preparation. If these contaminants are visually present, the contractor is responsible for properly removing them as most of the SSPC surface cleanliness standards invoke solvent cleaning (according to SSPC-SP1, discussed later in this module) if these types of contaminants are visibly evident. Organic contaminants like grease, oil, cutting compounds or lubricants can be removed using solvents like methyl ethyl ketone (MEK), xylene, or proprietary cleaners sold by coating manufacturers. Other cleaning methods include steam (with or without a cleaning compound or detergent) or pressure washing with a cleaning compound or detergent capable of dissolving the contamination.



Inspecting for grease and oil

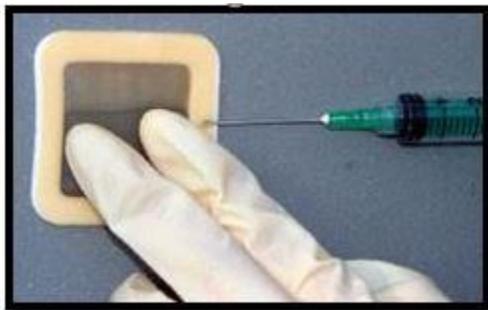
Inspection of these surfaces after cleaning is typically done visually or by wiping with a clean rag. Visual inspection can be enhanced through the use of a black light, which will cause many “hydrocarbon” oils to fluoresce. However, some synthetic oils will not fluoresce under black light exposure, which may result in a false negative for the presence of contamination.

To detect surface oils using a black light, shine a short or long wavelength black light onto the surface. In daylight or conditions of sun, a black sheet or drape may be required to shield the area from atmospheric light. Note that lint on the cloth or small cloth fibers on the steel surfaces may fluoresce but is not an indication of oil contamination. A bright yellow/green fluorescence of the surface indicates the presence of grease or oil contamination.

Another way to detect oil or grease on a surface is by performing a water break test. In this case, clean water is sprayed onto the surface using a spray atomizer. If the water forms “lenses” the surface is free of oil. However, if the water forms into droplets (forms a “water break”) within 25-30 seconds, it is likely that the surface contains grease, oil or another contaminant that is not soluble in water. ASTM F22, Standard Test Method for Hydrophobic Surface Films by the Water-Break Test may be referenced by the project specification.

Sampling, Detecting, and Removing Chemical Contamination

Chemical contaminants on a surface can include chloride, ferrous ions, sulfates and nitrates, among others. These chemicals are deposited onto surfaces while the structure is in service, or during transportation of new steel to the fabrication shop. These chemicals are soluble in water, so they can typically be removed from surfaces by pressure washing or water jetting using clean water or water with the addition of a proprietary salt removal-enhancing solution. The effectiveness of the washing step is dependent on the condition of the surface. That is, contamination is relatively easy to remove from smooth surfaces, but may be more challenging if the surfaces are pitted or are configured with difficult-access areas, as contamination will tend to concentrate in these areas. If the salts are not detected or are not adequately dissolved and rinsed from the surfaces, they can become trapped beneath a newly-installed coating system. If there is a sufficient quantity of water in the service environment, (e.g., immersion) the water-soluble contaminant trapped beneath the coating system



Soluble salt extraction using a latex cell

will draw the water through the coating film by a process known as “osmosis.” This drawing force can be quite powerful and will continue until the concentration of salt in water is the same on both sides of the coating film (the concentration reaches equilibrium). This process creates a build-up of water and pressure beneath the coating film, oftentimes enough to cause blistering of the coating (known as osmotic

blistering), underfilm corrosion and premature coating failure.

Additionally, if soluble salts on the surface are not sufficiently removed prior to abrasive blast cleaning, recycled abrasive media can become contaminated, which can lead to contamination of surfaces that were not originally contaminated.

It is for these reasons that many specifications are now requiring inspection of surfaces for chemical contaminants after surface preparation operations are complete, but before primer application. Because this type of contamination cannot be detected visually, the surface must be sampled and the “surface extraction” tested for the contaminant(s) of concern. The instrument use supplement provides step-by-step instructions for extracting a sample from a surface and analyzing the collected sample for ionic contamination. SSPC Guide 15, “Field Methods for Retrieval and Analysis of Soluble Salts on Steel and Other Nonporous Surfaces” describes common methods for sampling and analysis of soluble salt contamination, with the

intent of assisting the user in selection of an extraction and analysis procedure. Guide 15 is contained in Volume 2 of the SSPC Steel Structures Painting Manual, “Systems and Specifications.”

The most common methods of extracting soluble salts from surfaces include:

1. Surface swabbing
2. Latex patch/cell
3. Latex sleeve

The most common methods of analysis of the extracted soluble salts include:

1. Chloride ion test strips
2. Chloride ion detection tubes
3. Conductivity meter
4. Ferrous ion test strips
5. Nitrate ion test strips
7. Sulfate ion meter

Combination extraction and analysis methods include:

1. Soluble Salt Meters

Since there is no “industry standard” for tolerable levels of chemical contaminants, the project specification must indicate the maximum quantity of soluble salts that can remain on the surface and be safely coated over. For example, the specification of the coating of the interior of a water storage tank may specify a relatively low surface concentration of soluble salt, since the service environment is “immersion.”

Methods of Surface Preparation

Surface preparation methods employed by a painting contractor or facility owner can range from simple solvent cleaning to hand and power tool cleaning, dry and wet abrasive blast cleaning, chemical stripping, water jetting and other more non-traditional methods like sponge jetting and cryogenic blast cleaning using dry ice pellets. The degree of cleaning required by a given project specification is dependent on the service environment (the environment that the coating system must perform in), the coating system and the intended service life of the coating once installed.

Hand Tool Cleaning

Hand tool cleaning is typically performed with wire brushes, scrapers and other tools that do not depend on electric or pneumatic power to operate. These hand tools are only intended to remove loosely adhering corrosion products, old paint and flaking mill scale, and are not intended to produce an anchor pattern in the steel. Hand tools are frequently used to prepare surfaces for spot touch-up during maintenance painting activities.



Hand tool: wire brush

Power Tool Cleaning

Power tool cleaning is typically performed with grinders, pneumatic chisels, needle scalers, rotating impact tools and other tools that require an electric or pneumatic power source. Most of these tools can remove both loosely and tightly adhering corrosion products, paint and mill scale from the steel surfaces. Some of these tools can also produce an anchor pattern into the steel by “peening” the surface. Additionally, these tools can be purchased with vacuum ports and hoses for attachment to HEPA (High Efficiency Particulate Air) filtered vacuums so that the fine, airborne particles that are generated during surface preparation activities are collected at the point of generation.



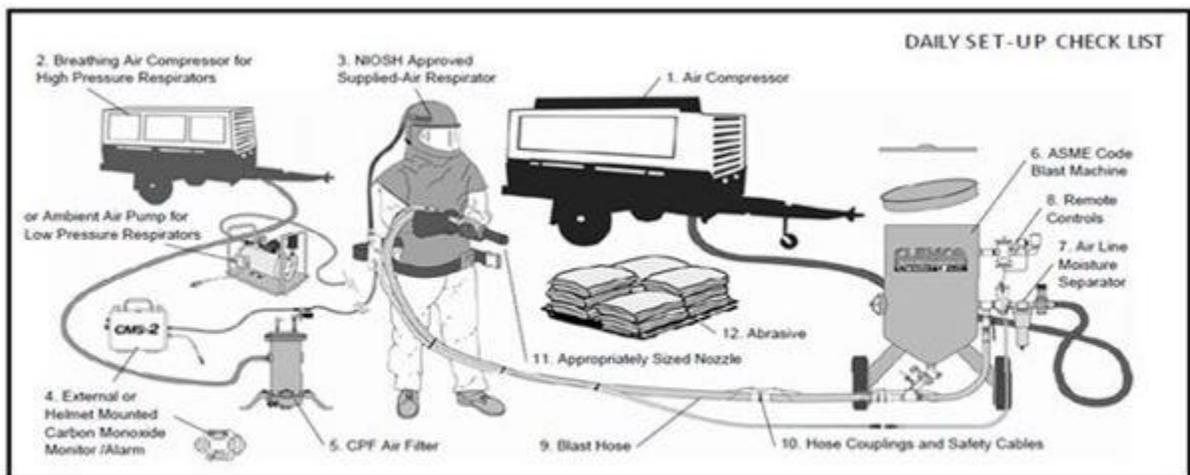
Power tools



Bristle blaster

Dry Abrasive Blast Cleaning

Blast cleaning using dry abrasive media is perhaps the most common method of preparing a surface for coating. Abrasive blast cleaning can be used to roughen an existing coating or hot dip galvanizing for subsequent overcoating or to completely remove the existing corrosion products, coating, and mill scale. Abrasive blast cleaning is the most productive of all surface preparation methods. Thousands of square feet of surface can be prepared for coating in a single work shift. The hardness and mass of the abrasive media combined with the velocity of the abrasive as it exits a nozzle at speeds exceeding 500 miles per hour (using air pressures up to 125 psi) generate high levels of energy. As the abrasive media impacts this surface with this energy, it can remove existing coating layers, corrosion and mill scale, while simultaneously increasing the surface area of the steel by generating a surface profile or anchor pattern. The level of cleanliness that is achieved is ultimately determined by the distance that the nozzle is held from the surface and the “dwell time” that the operator employs. The depth and shape of the surface profile is determined by the type and size of the abrasive media employed, as well as the hardness of the surface being prepared. Therefore, selecting the correct type and size of abrasive is critical. Selecting too small of an abrasive size will generate a surface profile that is too shallow and selecting too large of an abrasive will create a surface profile that is too deep. The abrasive type and size ultimately selected should be demonstrated prior to production to verify that the specified surface profile depth and shape can be achieved.



Clemco Industries dry abrasive blast cleaning set-up

A traditional dry abrasive blast cleaning set-up is illustrated in *Blast-Off 2*, published by Clemco Industries. This more traditional set-up consists of a source of compressed air (of sufficient capacity to provide an adequate volume of air to support the nozzle size, hose length, air pressure and number of operators), an ASME-coded abrasive hopper equipped with an air moisture and oil separator, a metering valve (located at the base of the hopper to meter abrasive from the hopper into the blast hose), a blast hose to carry the metered abrasive and compressed air to the nozzle (equipped with external hose couplings, safety wires and/or cables [whip checks]) and a blast nozzle. Safety is paramount to the blast cleaning process. The Occupational Safety and Health Administration (OSHA) has specific regulations governing abrasive blast cleaning that include hand, foot and skin protection from abrasive ricochet, respiratory protection (Type CE blast helmet under positive pressure, with tested and certified Grade D breathing air), and a pneumatic or electrically operated “deadman” that automatically stops the flow of air pressure and abrasive in the event that the operator loses control of the blast nozzle.

Projects employing “recycled” abrasives will typically use blast pots in conjunction with vacuum equipment for collecting spent abrasive and recycling equipment for separating the smaller particles and debris from the reusable abrasive.

Blast Nozzles

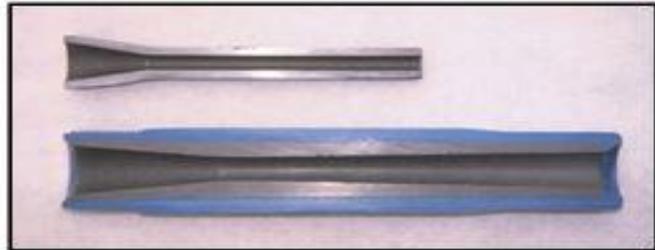
Blast nozzles range in both type and size (length and inside diameter). Some blast



nozzles are designed such that the abrasive exits through the side rather than the front, enabling the operator to clean even very tightly configured areas, like the backside of angles, etc. In general, there are two basic designs: straight-bore and venturi. Straight bore nozzles are generally less productive than the venturi design. The venturi

shape increases the velocity of the abrasive, so that as it exits the nozzle it is traveling at a higher speed. However, both nozzle designs can produce the desired degree of cleanliness and surface profile depth. Shorter venturi nozzles are generally less productive than longer venturi nozzles, as the abrasive speed does

not increase dramatically. However, a shorter blast nozzle may afford the operator better access to hard-to-reach or tightly configured areas. The lining of a blast nozzle can be manufactured from boron carbide, silicon carbide, tungsten carbide, even ceramic. While these lining materials are very resilient to wear, they are very brittle and can crack if the nozzle is handled improperly. All blast nozzles are sized in 1/16 inch, which represents the inside diameter of the nozzle. For example, a No. 7 blast nozzle has an inside orifice diameter of 7/16" when it is new. As abrasive passes through the nozzle, the lining will wear,



Straight bore and venturi nozzle cross sections

enlarging the orifice and opening the venturi, making it less productive over time. Nozzle wear can be monitored using a Pressure Orifice Gage (POG) Briefly, the conical-shaped gage is first marked using a black marker, then inserted into the threaded end of the blast nozzle as far as it will go, twisted and withdrawn. The nozzle opening will etch the black marking, which coincides with a demarcation on the gage face (increments of 1/16"). Blast nozzles should be replaced when the opening increases by two sizes (e.g., a No. 6 blast nozzle measures 8/16" on the nozzle orifice gage).



Pressure orifice gage

Abrasives

There are a variety of abrasives that can be used in the blast cleaning process. They fall into two broad categories: expendable and recyclable. Expendable abrasives are used once then discarded, since the "breakdown rate" is relatively high. Conversely, the breakdown rate of recyclable abrasives is relatively low, allowing them to be used multiple times, before they are discarded. For example, a recyclable steel grit abrasive can be reused over 100 times with minimal breakdown. However, even the recyclable abrasive supply is routinely augmented with fresh media to maintain the abrasive quantity required for operation of the system (the smaller particles are typically drawn off by the ventilation system) and to maintain the specified surface profile depth.

Expendable Abrasives

Expendable abrasives fall into two general categories: Mineral and Slag. Mineral abrasives are naturally occurring and include silica sand, garnet, and staurolite sand (StarBlast®). Note that garnet can be reused a couple of times, provided nozzle pressures are maintained below optimum (i.e., 75-80 psi). Slag abrasives are byproducts of other industries that are processed into abrasives. These include copper, coal and nickel slag. Ground-up corncobs, walnut shells and peach pits are can be used as polishing abrasives. However, these “agricultural” abrasives are not considered aggressive enough to remove industrial protective coatings and are not hard enough to generate a surface profile into steel. SSPC Abrasive Specification No. 1 (AB1), “Mineral and Slag Abrasives” defines the requirements for selecting and evaluating mineral and slag abrasives used for blast cleaning.

SSPC AB1 categorizes expendable abrasives by “Type, Class and Grade,” depending on the general type, the crystalline silica content and surface profile that the abrasive will yield. The two Types, three Classes and five Grades are listed below:

Type I: Natural Mineral Abrasives

Type II: Slag Abrasives

Class A: <1% Crystalline Silica

Class B: <5% Crystalline Silica

Class C: Unrestricted Crystalline Silica

Grade 1: Surface Profile yield of 0.5-1.0 mil

Grade 2: Surface Profile yield of 1.0-2.5 mils

Grade 3: Surface Profile yield of 2.0-3.5 mils

Grade 4: Surface Profile yield of 3.0-5.0 mils

Grade 5: Surface Profile yield of 4.0-6.0 mils

SSPC-AB 1 contains a list of tests that the abrasive manufacturer must conduct and report on prior to publishing that the abrasive meets the standard. Some of these tests can be performed by the inspector in the field (on a lot basis), while some can only be performed in a testing facility. If the project specification requires the abrasive to meet SSPC-AB 1, then the inspector should require a copy of the test report from the abrasive supplier. Field testing (oil content and water-soluble contaminants) is required to verify conformance to AB 1. Following is a list of tests required to qualify a media under SSPC-AB 1.

Specific Gravity
Weight change on ignition
Moisture content
Crystalline Silica content
Particle size distribution (sieve analysis)

Hardness
Water soluble contaminants
Oil content
Surface profile yield

Abrasive cleanliness requirements listed in SSPC-AB 1 are indirect (automatic) requirements of the SSPC abrasive blast cleaning standards when an expendable abrasive is used. This is explained in greater detail later.

Recyclable Abrasives

Recyclable abrasives generally include steel grit, steel shot and aluminum oxide. Steel grit and aluminum oxide (as well as all the expendable media listed above) are considered “angular,” which means they contain sharp points that produce sharp peaks and valleys in the surface. This increases the surface area of the steel, due to the density of the peak pattern (peaks are close together and there are many of them). Conversely, steel shot is considered a round or spherical abrasive that produces a rounded profile or a “peened” surface texture.



KTA-TATOR, INC.

Steel shot



KTA-TATOR, INC.

Steel grit

This results in a comparatively lower peak density pattern, because the peaks are round, further apart and there are less of them. Some coating systems (like thermal spray coatings) rely heavily on a mechanical bond to the surface, they cannot tolerate a peened surface texture, and can disbond independent of the surface profile depth. However, most liquid-applied

coatings adhere sufficiently to both angular and rounded surface profile patterns. SSPC Abrasive Specification No. 3 (AB 3), “Newly Manufactured or Re-Manufactured Steel Abrasives” defines the requirements for steel abrasives used for

blast cleaning, and SSPC Abrasive Specification No. 2 (AB 2), “Cleanliness of Recycled Ferrous Metallic Abrasives” defines the cleanliness requirements for recycled blast cleaning abrasive.

The abrasive cleanliness requirements (oil content and water-soluble contaminants) referenced in both abrasive specifications are indirect requirements of the SSPC abrasive blast cleaning standards (described later).

Similar to SSPC-AB 1, SSPC-AB 3 (Ferrous Metallic Abrasive) contains a list of tests that the abrasive manufacturer must conduct and report on prior to promoting that the abrasive meets the standard. If the project specification requires the abrasive to meet SSPC-AB 3, then the inspector should require a copy of the test report from the abrasive supplier. Field testing (oil content and water-soluble contaminants) is required to verify conformance to AB 3. Following is a list of tests required to qualify a media under SSPC-AB 3.

Class (Class 1 is steel abrasive and Class 3 is iron abrasive)

Abrasive size

Specific Gravity

Chemical composition

Hardness

Durability

Oil Content

Conductivity

SSPC-AB 2 (Cleanliness of Recycled Ferrous Metallic Abrasive) is different than either of the two abrasive specifications described previously. While SSPC- AB 2 governs steel and other “recyclable” abrasives, it specifies the cleanliness of used or recycled abrasive (not new abrasive). Therefore, the abrasive manufacturer does not test the abrasive nor prepare a test report for conformance to AB 2. Rather, the abrasive is tested in the field and/or in a laboratory. A list of the tests required by SSPC AB 2 is shown below.

Lead content (laboratory only, when intending to use the same abrasive on future projects)

Water soluble contaminants

Oil content

SSPC-AB 4 (Recycled Encapsulated Abrasive Media) describes performance requirements for recyclable encapsulated abrasive media consisting of steel grit or

aluminum oxide in a compressible open-cell matrix (i.e., “sponge”). It requires specialized equipment and is used when dust control is a priority.

Abrasive Size



Angular abrasive measuring sieves

Round abrasives (like steel shot) are sized based on the diameter of the shot. For example, an S330 shot is 0.33mm in diameter and an S230 shot is 0.23mm in diameter; therefore, the larger the shot number, the larger the abrasive size. Angular abrasives are sized differently than shot. These abrasives are sized according to sieve number. Each sieve contains a fine mesh screen containing square openings. The sieves are identified according to the number of openings in the mesh, per linear inch of screen. For example, a Tyler No. 20 sieve has 20 openings per linear inch of screen, while a No. 60 sieve has 60 openings per linear inch of screen. Naturally, these openings must be considerably smaller to fit three times the number of openings into the same area. Therefore, with angular abrasives the larger the number is, the smaller the abrasive size. For example, a No. 12 abrasive is larger than a No. 40. Sometimes abrasives are “pre-blended” by the manufacturer into two sizes. For example, garnet 3060 is a blend of particle size 30 and particle size 60 in a single bag or lot. The larger-sized particles fracture the rust and old coating and generate the surface profile depth, while the smaller particles “scour” the surface to the desired level of cleaning.

Abrasive Cleanliness

The contractor is required to monitor the abrasive supply for contamination by oil and water-soluble contaminants.

To perform a test for oil, per ASTM D7393, “Standard Practice for Indicating Oil in Abrasives,” place approximately one-inch of abrasive into a clear container, then put about one-inch of tap water into the same container. The water should be between 68° and 95°F. Cover and shake the abrasive/water sample vigorously for one minute, then remove the cover and allow the abrasive to settle for 5 minutes. Observe the surface of the water for an oil film or sheen. Discard the abrasive and document the result (pass/fail). If the abrasive is contaminated with oil, it cannot be used.

ASTM D4940, “Standard Test Method for Conductimetric Analysis of Water-Soluble Ionic Contamination of Blasting Abrasives” describes a procedure for

testing an abrasive for water-soluble contaminants. If the project specification references SSPC-AB 1, AB 2, AB 3 or AB 4 the tolerable threshold of conductivity is 1,000 microsiemen/cm. Note that the conductivity of the water used for the extraction should be tested for conductivity and this value (the “blank”) subtracted from the test value. The step-by step procedure for performing this test is described in the Coating Inspection Instrument Use Supplement.

Blast Cleaning Productivity

There are many factors that can impact the productivity of abrasive blast cleaning operations. First, the compressor must be adequately sized to provide the volume of air (measured in cubic feet per minute or CFM) necessary to maintain the desired nozzle pressure. Optimum blast nozzle pressure is 90-100 psi but can be increased to 120-125 psi if a



Hypodermic needle pressure gage

recyclable abrasive like steel grit is being used. According to Clemco, a 10-psi reduction in blast nozzle pressure equates to a 15% reduction in productivity, so maintaining nozzle pressure is critical to maintaining blast cleaning productivity. Blast nozzle pressure can be measured using a hypodermic needle pressure gage. The needle of the gage is inserted into the blast hose at a 45° angle (in the direction of air and abrasive flow) as close as feasible to the blast nozzle. The deadman valve (automatic system shutdown safety lever) is closed so that both abrasive and air begin to flow. The operational pressure is read from the gage dial. If multiple operators will be using the same source of compressed air, it is important that all deadman controls be closed simultaneously to obtain a representative pressure reading. Blast pressure can be increased by reducing the size of the blast nozzle or increasing the capacity of the compressed air source. *Blast-Off 2* by Clemco contains two charts shown on page 3-21) on the size of the compressor required to maintain pressure for a given nozzle size.

Compressed Air and Abrasive Consumption

Nozzle Orifice	Pressure at the Nozzle (psi)								Air (In cfm) Abrasive & HP requirements
	50	60	70	80	90	100	125	140	
No. 2 (1/8")	11	13	15	17	18.5	20	25	28	Air (cfm)
	.67	.77	.88	1.01	1.12	1.23	1.52	1.70	Abrasive (cu.ft./hr & Lbs/hr)
	67	77	88	101	112	123	152	170	Compressor hp
No. 3 (3/16")	26	30	38	41	45	55	62	62	Air (cfm)
	1.5	1.71	1.96	2.16	2.38	2.64	3.19	3.57	Abrasive (cu.ft./hr & Lbs/hr)
	150	171	196	216	238	264	319	357	Compressor hp
No. 4 (1/4")	6	7	8	9	10	10	12	13	Air (cfm)
	47	54	61	68	74	81	98	110	Abrasive (cu.ft./hr & Lbs/hr)
	2.68	3.12	3.54	4.08	4.48	4.94	6.08	6.81	Compressor hp
No. 5 (5/16")	268	312	354	408	448	494	608	681	Air (cfm)
	11	12	14	16	17	18	22	25	Abrasive (cu.ft./hr & Lbs/hr)
	77	89	101	113	126	137	168	188	Compressor hp
No. 6 (3/8")	4.68	5.34	6.04	6.72	7.40	8.12	9.82	11.0	Air (cfm)
	468	534	604	672	740	812	982	1100	Abrasive (cu.ft./hr & Lbs/hr)
	18	20	23	26	28	31	37	41	Compressor hp
No. 7 (7/16")	108	126	143	161	173	196	237	265	Air (cfm)
	6.68	7.64	8.64	9.60	10.52	11.52	13.93	15.6	Abrasive (cu.ft./hr & Lbs/hr)
	668	764	864	960	1052	1152	1393	1560	Compressor hp
No. 8 (1/2")	24	28	32	36	39	44	52	58	Air (cfm)
	147	170	194	217	240	254	314	352	Abrasive (cu.ft./hr & Lbs/hr)
	8.96	10.32	11.76	13.12	14.48	15.84	19.31	21.63	Compressor hp
No. 8 (1/2")	896	1032	1176	1312	1448	1584	1931	2163	Air (cfm)
	33	38	44	49	54	57	69	77	Abrasive (cu.ft./hr & Lbs/hr)
	195	224	252	280	309	338	409	458	Compressor hp
No. 8 (1/2")	11.60	13.36	15.12	16.80	18.56	20.24	24.59	27.54	Air (cfm)
	1160	1336	1512	1680	1856	2024	2459	2754	Abrasive (cu.ft./hr & Lbs/hr)
	44	50	56	63	69	75	90	101	Compressor hp

*Consumption rates are based on abrasives that weigh 100 pounds per cubic foot.

System Air Volume 1 Requirements at 100 PSI for a Complete Blast

Nozzle	Size of Orifice	Volume of Air	Plus Helmet	Plus 50% (reserve)	Minimum Air Required
No. 4	1/4"	81	20	50	151 cfm
	6.5mm	2.3	0.5	1.4	4.2 m ³ /min
No. 5	5/16"	137	20	79	236 cfm
	8.0mm	3.9	0.5	2.2	6.6m ³ /min
No.6	3/8"	196	20	108	324 cfm
	9.5mm	5.5	0.5	3.0	9.0 m ³ /min
No. 7	7/16"	254	20	137	411 cfm
	11.0mm	7.2	0.5	3.9	11.6 m ³ /min
No. 8	1/2"	338	20	179	537 cfm
	12.5mm	9.6	0.5	5.0	16.1 m ³ /min

Blast cleaning productivity is also affected by:

- The condition of the surface (number and relative brittleness of coating layers, presence of stratified or pack rust versus surface rusting, etc.),
- The abrasive type and size selected,
- The distance from the nozzle to the surface,
- The angle at which the operator holds the nozzle to the surface, and
- The flow of the abrasive from the hopper into the blast hose (through the metering valve).

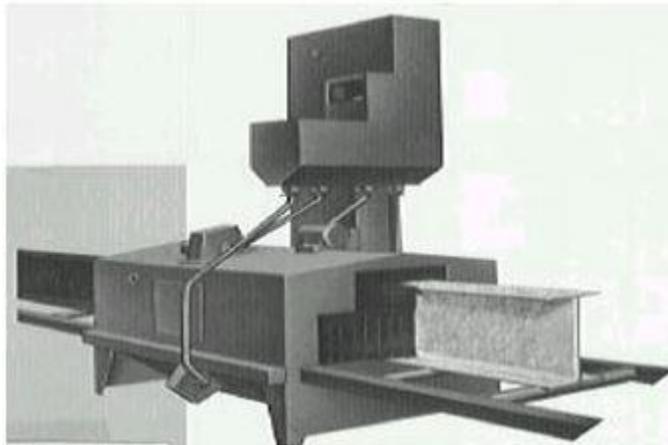
In general, brittle coatings are easier to remove than softer coatings or coatings with elasticity, as the abrasive tends to bounce off, rather than fracture soft/elastomeric coatings. Harder abrasives tend to remove coatings faster than softer ones, and smaller abrasives are generally more productive than larger abrasives, as smaller abrasives produce a higher number of impacts per area and in turn clean faster. However, the abrasive must have adequate mass to remove the existing coating system and produce the required profile depth, which is primarily dictated by the size of the abrasive.

Nozzle distance will vary and is dependent upon the difficulty in coating/rust removal. In general, the blast nozzle distance is maintained between 12 and 18 inches from the surface (closer for tenacious coatings and further away if coatings are easily removed). Distances greater than 24" are generally not recommended. The angle that the blast nozzle is held to the surface will also vary and is operator dependent. In general, mill scale and rust are best removed when the nozzle is maintained at an 80-90° angle, while old coatings are removed more easily if the nozzle is held 45-60° to the surface. Finally, the flow of abrasive from the hopper into the blast hose can impact productivity. If the metering valve is set too lean, there will be an insufficient quantity of abrasive exiting the nozzle, reducing productivity. Conversely, if the valve is set too rich, the blast hose and nozzle will become flooded with abrasive, also decreasing productivity. The metering valve should be set by the operator to achieve the optimum abrasive flow.

Centrifugal Blast Cleaning

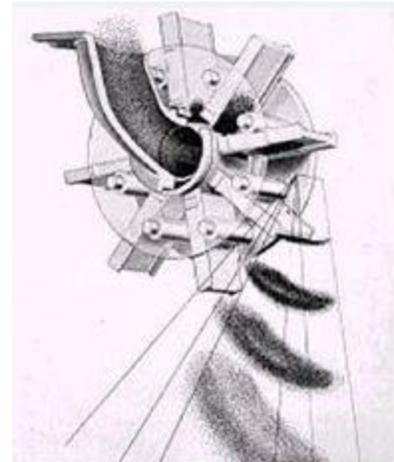
Centrifugal or automated abrasive blast cleaning can be performed using portable or stationary equipment. Portable centrifugal blast machines can be used to prepare floors in warehouse facilities, tank bottoms, ship decks and other large, flat surfaces. They can also be mounted to vertical surfaces like the interior/exterior of storage tanks. Stationary equipment is typically located in steel fabrication shops that perform blast cleaning and coating work. These machines throw or hurl abrasive at the surfaces to be prepared using high-speed centrifugal wheels.

The abrasive is automatically loaded onto the wheel vanes through a center hub. Stationary machines are multi-wheel, while portable machines generally only have a single wheel. Recyclable steel abrasives (grit, shot, or an operating mix of the two) are typically used. The abrasive and debris are collected, separated and the abrasive is reloaded and reused. Abrasive breakdown can be monitored by conducting routine



Centrifugal blast cleaning equipment

typically monitor the abrasive supply in the machine for contamination by oil and water-soluble contaminants using the test procedures described earlier.



Centrifugal blast cleaning

sieve analyses, or by monitoring the resulting surface profile. If the profile is decreasing, the system will require the addition of fresh abrasive. For specifications requiring an operating mix of steel grit and steel shot, the inspector must monitor the type, size and amount of abrasive added to replenish the supply. In addition, the operator and inspector will

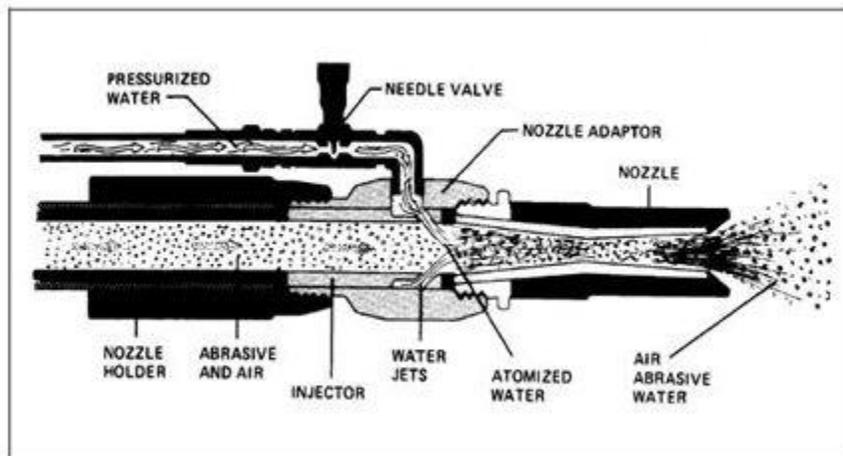
Vacuum Blast Cleaning



Vacuum blast cleaning is similar to dry abrasive blast cleaning, except that the blast nozzle is equipped with a Neoprene rubber & bristle brush shroud (collar) that is held tightly against the surface rather than 12-24 inches away. In this manner, the abrasive impacts the surface and is immediately vacuumed off, together with the materials removed from the surface. The debris is separated from the abrasive and the abrasive is reused. Vacuum abrasive blast cleaning is used when a high degree of cleanliness and a surface roughness are required, but airborne abrasive and dust cannot be tolerated. Surface irregularities can cause the vacuum shroud to lose contact with the surface and result in releases to the environment. Also, vacuum blast cleaning is slow, so it is often limited to preparing small areas.

Wet Abrasive Blast Cleaning

Wet abrasive blast cleaning may be used when airborne dust control is required by the specification or by local air quality regulations. Some facility owners specify the use of wet abrasive blast cleaning to reduce the complexity of the containment and ventilation system required on a given project. In addition, wet abrasive blast



Wet abrasive blast nozzle

cleaning is an engineering control that can reduce airborne worker exposures to toxic metals during the coating removal processes.

Three variations of this surface preparation method exist: water jetting with abrasive induction, abrasive blasting with water induction and the use of a water collar. All three methods employ a mineral or slag type abrasive media. The latter two methods (abrasive blasting with

water induction and the use of a water collar) rely on the abrasive to clean and prepare the surface. The water is used to suppress the dust and to remove some chemical contamination from the surfaces, if present. The former method (water jetting with abrasive induction) uses high pressure water as the removal media, while the abrasive inducted into the water stream etches the surfaces and accelerates the removal process. Naturally, the water used in this method will also suppress any airborne dust that is generated.

Any surface preparation method that incorporates water is going to cause carbon steel surfaces to flash rust. Therefore, the specifier may require the use of a rust inhibitor (that is compatible with the coating system to be applied to the prepared surfaces), or simply accept the flash rusting that occurs and select a coating system that is tolerant in the given environment. The SSPC visual guide (discussed later in this module) for wet abrasive blast cleaning illustrates three levels of flash rusting (light, medium and heavy), so that the degree of tolerable surface rust can be evaluated by the inspector.

In addition to flash rusting, wet abrasive tends to attach itself to the prepared surfaces, which requires the operator to thoroughly rinse the surfaces with clean (rust-inhibited) water to ensure that abrasive debris is not coated over.

Water Jetting

Surface preparation by water jetting under various water pressures can remove even tightly-adhering coating systems from the underlying surfaces but cannot etch an anchor pattern or profile into the surface. Water jetting can however restore an existing surface profile. SSPC categorizes water jetting into four levels, including:

LPWC: Low Pressure Water Cleaning (up to 5,000 psi)

HPWC: High Pressure Water Cleaning (up to 5,000-10,000 psi)

HPWJ: High Pressure Water Jetting (up to 10,000-30,000 psi)

UHPWJ: Ultra-High-Pressure Water Jetting (>30,000 psi)

Low pressure water cleaning (LPWC) or “pressure washing” is often specified for overcoating projects, where the existing coating is salvageable and is incorporated into the maintenance coating system for the structure. LPWC can be very effective in removing dirt, chalking, bird droppings and other contaminants from the surfaces, although mechanical agitation of the surface during LPWC is often required to ensure adequate removal. The remaining three levels of water jetting are used primarily to remove coatings. Waste generation is minimized, in that the water is

captured, filtered and reused. The debris that is created is limited to the materials removed from the surface. This is particularly advantageous when the coating to be removed contains toxic metals, as the cost of handling, transporting and disposing of hazardous waste can be relatively high.

Similar to wet abrasive blast cleaning, the water employed by these methods is going to cause carbon steel surfaces to flash rust. Therefore, the specifier may require the use of a rust inhibitor (that is compatible with the coating system to be applied to the prepared surfaces), or simply accept the flash rusting that occurs and select a coating system that is tolerant in the given environment. The SSPC visual guide (discussed later in this module) for water jetting illustrates 3 levels of flash rusting (light, medium and heavy), so that the degree of tolerable surface rust can be evaluated by the inspector.

Like most coating removal operations, water jetting has inherent worker hazards. Personal protective equipment, including (but not limited to) special foot, leg, arm, hand and torso guards are often required when water jetting operations are employed, since using water under these high pressures is essentially a lance and can cut or even dismember an operator or adjacent worker.



Water cleaning/jetting

Chemical Stripping

Removal of coatings using chemical strippers has been widely used outside of the industrial coating arena. Methylene chloride-based paint strippers were used for removing coatings in the residential, commercial and light industrial markets for years, and the commercial aircraft industry used these strippers to remove coatings from the exterior of the fuselage. However, when chlorinated solvents became



recognized as carcinogens (cancer-causing agents), their use as paint strippers declined. Other paint strippers came onto the market, and were formulated to

work on a variety of surfaces, including wood, steel, etc. These paint strippers were caustic-based (pH 14), and attacked the resin component of coatings, destroying their backbone and causing the coating system to debond from the underlying substrate. Caustic-based paint removers are the consistency of a heavy paste that is sprayed or troweled onto the surface. After a few hours of “dwell time,” the stripper is removed from the surfaces using scrapers, air or water pressure or even blasting with ice crystals. Multiple applications can be required, depending on the coating system and thickness. Neutralization of the surface after the stripper has been removed is required for proper coating performance.

Environmentally and user-friendly chemical strippers are available that have a neutral pH and little odor. They are slower to work on thicker films and may require several applications to remove multiple layers.

Chemical strippers do not generate a surface profile and will not remove rust or mill scale. Therefore, mechanical methods of surface preparation may be required after the coating has been removed or a coating system that is tolerant of intact mill scale and rust must be selected, provided it will perform adequately in the service environment.

The use of chemical strippers is described in SSPC Technical Update (TU) 6, “Chemical Stripping of Organic Coatings from Steel Structures.”

Surface Cleanliness Standards

SSPC and NACE International have written and published industry consensus standards for surface cleanliness. These cleanliness standards are contained in Volume 2 of the SSPC Steel Structures Painting Manual, “Systems and Specifications.” In many cases, SSPC and NACE International have published these standards jointly, but they reference different identification numbers. For example, SSPC designates SP10 as a “Near-white Metal Blast,” which is NACE No. 2. There are currently 21 SSPC surface cleanliness standards that a specifier can choose from for inclusion into a project specification. NACE is jointly referenced in 11 of the 21 standards. As stated earlier in this module, these surface cleanliness standards are not regulations or laws, but they become contract law once they are written into a specification, which is a contract document.

This next section will briefly define each of the current surface cleanliness standards. As an inspector, you are responsible for reading and comprehending the contents of the entire standard (or standards) referenced in a project specification before surface preparation work begins. Visual guides to aid the inspector in evaluating the degree of cleanliness achieved by the contractor are available through SSPC for abrasive blast cleaning, hand- and power-tool cleaning, water jetting and wet abrasive blast cleaning. These will be described later in the module. In the event of a dispute, it is the written standards and not the visual guides that are the governing document. Inspection is always performed using the unaided eye or corrected vision. Magnification is not permitted by any of the SSPC surface cleanliness standards.

SSPC surface cleanliness standards are numbered sequentially in the order that they are published. For example, SSPC-SP1 was one of the first surface cleanliness standards published by SSPC, while SSPC-SP16 is the most recent (“SP” indicates “**S**urface **P**reparation”). Therefore, the inspector cannot assume that SP1 represents the lowest degree of cleaning and SP16 represents the highest, or vice-versa. Initially, the NACE designations were sequenced in this manner (NACE No. 1 was the highest degree of cleaning, while NACE No. 4 was the lowest). However, once these were published jointly the NACE sequence became obsolete. Note that SSPC-SP 4, SSPC-SP 9 and SSPC-SP 12 are discontinued standards and that three of the cleanliness standards (SP 11, SP 15 and SP 16) invoke a minimum surface profile (roughness).

SSPC-SP1, Solvent Cleaning

SSPC-SP1, “Solvent Cleaning” requires the removal of all visible grease, oil, lubricants, cutting compounds and other visible contaminants from the surface. “Visible” means detectable with normal or corrected normal vision without the use of additional test equipment. SP1 is a prerequisite to all SSPC surface cleanliness standards (except SP13/NACE No. 6, Surface Preparation of Concrete), as mechanical methods of cleaning cannot remove this type of surface contaminant. Therefore, the inspector should recognize that solvent cleaning to remove surface contamination is a requirement of the contract, even if the project specification is not explicit, as long as the specification references an SSPC or NACE surface cleanliness standard.

SSPC-SP2, Hand Tool Cleaning

SSPC-SP2, “Hand Tool Cleaning” requires the removal of all loosely adhering rust, mill scale and paint. The remaining materials are considered tightly-adhering if they cannot be lifted using the blade of a dull putty knife (definition of dull putty knife extracted from SSPC Glossary shown below). The project specification may require the edges of intact paint to be feathered to facilitate a smooth transition and to prevent lifting of the edge by the application of subsequent coating layers. There is no surface profile requirement for hand tool cleaning.

DULL PUTTY KNIFE (for use as an inspection tool):

A commercially manufactured straight flexible metal blade with these characteristics: width – approximately [~]40 to 75 mm (1-1/2 to 3 in); length – ~ 75 to 125 mm (3 to 5 in); thickness – ~ 760 to 1270 μm (30 to 50 mils); flexibility - able to be bent by hand around an 28- to 33-cm (11- to 13-inch) diameter mandrel (or pipe or bucket) and return to its original shape without permanent deformation.

Discussion: The putty knife is acceptable for use if the thickness at end of the blade is not less than 635 μm (25 mils) or 75% of its original thickness, whichever is greater. Some commercially manufactured straight flexible metal blades are between 508 and 762 μm (20 and 30 mils) in thickness. New blade thicknesses between 508 and 762 μm (20 and 30 mils) are permitted provided the coating being tested is 508 μm (20 mils) or less in thickness, and the thickness of the blade is not worn to less than 508 μm (20 mils). The putty knife shall not be used if the edge is nicked or gouged, or if dry paint or other material is present along the edge that would prevent the blade from making intimate contact with the surface.

Source: SSPC Glossary

SSPC-SP

SSPC-SP3, Power Tool Cleaning

SSPC has published three power tool cleaning standards. They vary in the level of surface cleanliness required and surface roughness requirements.

SSPC-SP3, “Power Tool Cleaning” is similar to SSPC-SP2, “Hand Tool Cleaning” in that the standard requires the removal of all loosely adhering rust, mill scale and paint. The remaining materials are considered tightly-adhering if they cannot be lifted using the blade of a dull putty knife. The project specification may require that the edges of intact paint to be feathered to facilitate a smooth transition, and to prevent lifting of the edge by the application of subsequent coating layers. There is no surface profile requirement for power tool cleaning.

SSPC-SP11, Power Tool Cleaning to Bare Metal

SSPC-SP11, Power Tool Cleaning to Bare Metal” requires the removal of all loosely and all tightly adhering mill scale, rust and paint to expose the bare metal surface. The standard also requires that a minimum 1 mil anchor pattern or profile be etched into the bare steel surface to enhance the mechanical bond of the newly-applied coating system to the prepared surfaces. If the existing surfaces are pitted, trace quantities of paint, rust and mill scale can remain in the bottom of the pits.

SSPC-SP15, Commercial Grade Power Tool Cleaning

Similar to SSPC-SP11, SSPC-SP15, “Commercial Grade Power Tool Cleaning requires the removal of all loosely and all tightly adhering mill scale, rust and paint from the surface. Staining from rust, paint and mill scale is permitted, provided it does not exceed 33% (one-third) of each 9 square inches of prepared surface. If the existing surfaces are pitted, trace quantities of paint, rust and mill scale can remain in the bottom of the pits. SP15 also requires that a minimum 1 mil anchor pattern or profile be etched into the surface to enhance the mechanical bond of the newly applied coating system to the prepared surfaces.

Abrasive Blast Cleaning Standards

SSPC has published six abrasive blast cleaning standards. They vary in the level of surface cleanliness required. There is no specific surface profile range established for any of the abrasive blast cleaning standards. Therefore, the project specification must stipulate the required depth of the surface profile.

SSPC-SP7/NACE No. 4, Brush-off Blast Cleaning

SSPC-SP7/NACE No. 4, “Brush-off Blast Cleaning” requires the removal of all loosely adhering rust, mill scale and paint by “lightly sweeping” the surface with the abrasive media. The remaining materials are considered tightly-adhering if they cannot be lifted using the blade of a dull putty knife. The project specification may require that the edges of intact paint to be feathered to facilitate a smooth transition, and to prevent lifting of the edge by the application of subsequent coating layers. While there is no surface profile requirement for brush-off blast cleaning, some surface roughening will be created by the abrasive impacting the surface. Brush-off blast cleaning may fracture but not necessarily loosen aged, brittle coatings. Subsequent application of coating layers to this “damaged” surface may result in disbonding of the coating film from the substrate. Use of SSPC-SP7 to roughen existing surfaces must be done with great care and may not be the optimal choice if the existing coating is old or has become embrittled.

SSPC-SP14/NACE No. 8, Industrial Blast Cleaning

SSPC-SP14/NACE No. 8, “Industrial Blast Cleaning” requires the removal of all loosely adhering rust, mill scale and paint from the surface. Up to 10% of each 9 square inches of prepared surface can contain islands of intact mill scale, rust or paint. The remaining materials are considered intact if they cannot be lifted using the blade of a dull putty knife. The amount of permissible staining is unlimited. The project specification may require that the edges of intact paint to be feathered to facilitate a smooth transition, and to prevent lifting of the edge by the application of subsequent coating layers.

SSPC-SP6/NACE No. 3, Commercial Blast Cleaning

SSPC-SP6/NACE No. 3, “Commercial Blast Cleaning” requires the removal of all loosely and all tightly adhering mill scale, rust and paint from the surface. Staining from rust, paint and mill scale is permitted, provided it does not exceed 33% (one-third) of each 9 square inches of prepared surface. The difference between a “stain”

from rust, paint or mill scale can be hard to differentiate from actual rust paint or mill scale left behind. While guides are available, they too are visual and can be difficult to use to determine the presence of actual materials left on the surface versus staining. Some specifications reference the use of a small knife blade that is used to lightly scratch the surface. If the surface is lightly scratched and a powder or flakes are created, then the surface does not meet the SP6/NACE No. 3 definition. If, on the other hand, the light scraping does not produce a powder or small flakes, then the surface is considered stained and is acceptable, provided the staining does not exceed 33% of each 9 square inches of prepared surface area.

SSPC-SP10/NACE No. 2, Near-White Blast Cleaning

SSPC-SP10/NACE No. 2, “Near-White Blast Cleaning” requires the removal of all loosely and all tightly adhering mill scale, rust and paint from the surface. Staining from rust, paint and mill scale is permitted, provided it does not exceed 5% of each 9 square inches of prepared surface. The difference between a “stain” from rust, paint or mill scale can be hard to differentiate from actual rust paint or mill scale left behind. While guides are available, they too are visual and can be difficult to use to determine the presence of actual materials left on the surface versus staining. Some specifications reference the use of a small knife blade that is used to lightly scratch the surface. If the surface is lightly scratched and a powder or flakes is created, then the surface does not meet the SP10/NACE No. 2 definition. If on the other hand the light scraping does not produce a powder or small flakes, then the surface is considered stained and is acceptable, provided the staining does not exceed 5% of each 9 square inches of prepared surface area.

SSPC-SP5/NACE No. 1, White Metal Blast Cleaning

SSPC-SP5/NACE No. 1, “White Metal Blast Cleaning” requires the removal of all loosely and all tightly adhering mill scale, rust and paint from the surface. Staining from rust, paint or mill scale is not permitted by the SSPC-SP5/NACE No. 1 surface cleanliness standard.

SSPC-SP 16, Brush-off Blast Cleaning of Coated and Uncoated Galvanized Steel, Stainless Steels, and Non-Ferrous Metals

SSPC-SP 16, Brush-off Blast Cleaning of Coated and Uncoated Galvanized Steel, Stainless Steels, and Non-Ferrous Metals covers the requirements for brush-off blast cleaning of uncoated or coated metal surfaces other than carbon steel using abrasive. According to the Standard, brush-off blast cleaned non-ferrous metal surfaces, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, metal

oxides (corrosion products), and other foreign matter. Intact, tightly adherent coating (that cannot be lifted with the blade of a dull putty knife) is permitted to remain. Bare metal substrates shall have a minimum surface profile of 0.75 mil. Intact coatings that are present shall be roughened and cleaned as specified in the procurement documents. If the surface profile is not specified in the procurement documents, the abrasive selected shall roughen the cleaned surface to the degree required by the product data sheet for the coating to be applied.

The SSPC-SP 16 Standard also addresses removal of wet storage staining from galvanized surfaces prior to brush blast cleaning and describes a procedure for testing for the presence of passivating treatments (chromate) that prevents wet storage staining but may inhibit the adhesion of liquid applied coating.

SSPC-SP 17, Thorough Abrasive Blast Cleaning of Non-Ferrous Metals

SSPC-SP 17 defines the “Thorough Abrasive Blast Cleaning” level of surface cleanliness achieved using abrasive blast cleaning on uncoated or coated non-ferrous or stainless-steel surfaces. It also includes requirements for materials and procedures used to achieve and verify the cleanliness level. SP 17 is for the preparation of non-ferrous metals for coating application and should not be used for carbon steel substrates.

Substrates that may be prepared by this method include but are not limited to copper and copper alloys, aluminum and aluminum alloys, and stainless steel.

Because of the possible variations in the appearance of substrates covered by the standard, the contractor is required to prepare a sample area to serve as a Job Reference Standard (JRS) for the degree of surface preparation.

A thorough abrasive blast cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dust, dirt, oxides (corrosion products, coating, and other foreign matter. Random color variations shall be limited to no more than 5% of each unit area of surface (approximately [9.0 in²], and may consist of light shadows, slight streaks, or minor discolorations.

The entire metal surface shall be subjected to the abrasive blast to achieve the specified degree of cleaning and to produce a dense and uniform surface profile (e.g., depth and texture) on the bare metal substrate. The peaks and valleys on the surface shall form a continuous pattern, leaving no smooth, unprofiled areas.

Water Jetting Standards

Surface preparation by water jetting is governed by four SSPC standards:

SSPC-SP WJ-1/NACE WJ-1:

Clean to Bare Substrate: Surfaces are free of all visible rust, dirt, previous coatings, mill scale, and foreign matter. Discoloration of the surface may be present.

SSPC-SP WJ-2/NACE WJ-2:

Very Thorough or Substantial Cleaning: Surfaces are free of all visible oil, grease, dirt, and rust except for randomly dispersed stains of rust, tightly adherent thin coatings, and other tightly adherent foreign matter. The staining or tightly adherent matter is limited to a maximum of 5% of the surface.

SSPC-SP WJ-3/NACE WJ-3:

Thorough Cleaning: Surfaces are free of all visible oil, grease, dirt, and rust except for randomly dispersed stains of rust, tightly adherent thin coatings, and other tightly adherent foreign matter. The staining or tightly adherent matter is limited to a maximum of 33% of the surface.

SSPC-SP WJ-4/NACE WJ-4:

Light Cleaning: Surfaces are free of all visible oil, grease, dirt, dust, loose mil scale, loose rust, and loose coating. Any residual material shall be tightly adherent.

The four degrees of flash rusting permitted after water jetting is completed include:

None (requires the use of a rust inhibitor)

L: Light Flash Rusting

M: Medium Flash Rusting

H: Heavy Flash Rusting

Wet Abrasive Blast Standards

SSPC has five wet abrasive blast cleaning standards, listed below. The definitions are identical to their dry abrasive blast cleaning standards counterparts; however, flash rusting must be considered (same as the water jetting standards above).

SSPC-SP 7 (WAB)/NACE WAB 4 (Brush-off Wet Abrasive Blast)

SSPC-SP 14 (WAB)/NACE WAB 8 (Industrial Wet Abrasive Blast)

SSPC-SP 6 (WAB)/NACE WAB 3 (Commercial Wet Abrasive Blast)

SSPC-SP 10 (WAB)/NACE WAB 2 (Near-white Metal Wet Abrasive Blast)

SSPC-SP 5 (WAB)/NACE WAB 1 (White Metal Wet Abrasive Blast)

Other SSPC Surface Cleanliness Standards

Two standards not otherwise categorized include SSPC-SP8, “Pickling” and SSPC-SP13/NACE No. 6, “Surface Preparation of Concrete.”

SSPC-SP8, Pickling

SSPC-SP8, “Pickling” is a pretreatment process for steel surfaces prior to hot-dip galvanizing. The pickling bath may contain sulfuric or hydrochloric acid and is designed to remove grease, oil, mill scale, rust and other debris from steel surfaces.

SSPC-SP13/NACE No. 6, Surface Preparation of Concrete

SSPC-SP13/NACE No. 6, “Preparation of Concrete” prescribes methods for preparing the surfaces of concrete for coatings and linings, including mechanical methods (power tools and abrasive blast cleaning), chemical methods (acid etching) and thermal methods (flame cleaning followed by blast cleaning). Information on the degree of roughness, moisture content and methods to test the adhesion of the applied coating system is also provided in the standard.

Inspection of Surface Preparation

As described earlier, surface preparation is often regarded as the most important factor in determining the success of a protective coating/lining system, so the inspection processes associated with surface preparation are also considered critical. Once the primer is applied to the prepared surfaces, it is nearly impossible to determine the level of surface cleanliness and surface profile depth that was

achieved. Therefore, the inspector must carefully observe the surfaces before the primer is applied.

There are seven “inspection checkpoints” that can be associated with surface preparation. Not all of these checkpoints are invoked by every project specification. For example, if the specification requires power tool cleaning (SSPC-SP3), then measurement of surface profile depth, an abrasive cleanliness check and a compressed air cleanliness check will not be necessary. The seven most common inspection checkpoints associated with surface preparation include:

1. Verifying grease and oil removal
2. Measurement of ambient conditions prior to final surface preparation
3. Conducting a compressed air cleanliness (blotter) test
4. Conducting an abrasive cleanliness test
5. Assessing surface cleanliness
6. Measuring surface profile depth
7. Verifying surfaces are ready for primer application

Verifying Grease and Oil Removal

Prior to initiating surface preparation, the inspector should verify that the surfaces are free from visible oil, grease, lubricants and cutting oils as described in SSPC-SP1, “Solvent Cleaning.” This can be accomplished visually (with or without the aid of black light detection), tactilely (by touch) or by using the water break test. Each of these was described earlier in this module. The inspector may choose to observe solvent cleaning procedures to help ensure that all contaminated surfaces are cleaned. The inspector should also document the type of degreasing media employed by the contractor and whether the surfaces are properly cleaned.

Measurement of Ambient Conditions Prior to Final Surface Preparation



Sling psychrometer

The measurement of air temperature, relative humidity, dew point temperature and surface temperature are usually associated with coating application. However, if the air temperature and relative humidity are such that moisture from the air condenses on the surface during or immediately following final

surface

preparation,

the surface may flash rust. Therefore, it is important to verify that the temperature of the surfaces is at least 5°F (3°C) higher than the temperature of the dew point, to preclude airborne moisture from condensing on the surfaces.

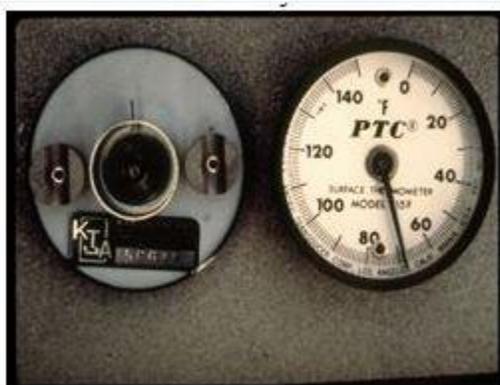
These values (surface temperature and dew point temperature) can be obtained using sling or battery-powered psychrometers in conjunction with US Weather Bureau Psychrometric Tables and surface temperature thermometers or can be obtained using direct read-out electronic psychrometers equipped with surface temperature probes. The step-by-step use of this



U.S. Weather Bureau psychrometric tables

instrumentation is detailed in

the instrument use supplement. It is important that the inspector not rely on prevailing weather conditions from a local news source or the internet as conditions at the project site can vary considerably. Ambient conditions should be measured and recorded prior to initiating final surface preparation and at 4-hour intervals thereafter, unless conditions appear to be declining. In this case, more frequent



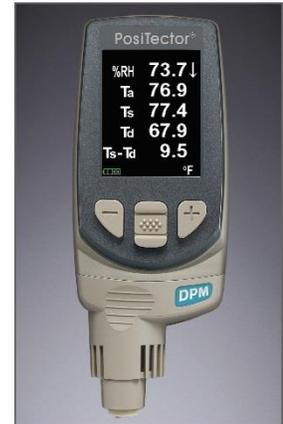
Surface temperature thermometer

checks may be required. If surface preparation work will be done inside a facility, tank or inside of a containment, then the prevailing ambient conditions *inside* of the areas (at the actual location of the work) should be assessed. The location, date, time

of day and the conditions of air temperature, relative humidity, dew point temperature and surface temperature should be recorded. However, since the only operation being monitored is surface preparation, the dew point – surface temperature relationship is the most critical. Typically, there is no specified range for air temperature and relative humidity during surface preparation operations.

Using Electronic Psychrometers to Assess Ambient Conditions and Surface Temperature

An alternative to sling and battery-powered psychrometers are the electronic (digital) psychrometers. There are several models on the market; however, some of these psychrometers are affected by wind current and are not recommended for outdoor use. It is important to inquire about outdoor use prior to purchasing one of these electronic psychrometers. Any of these psychrometers can be used for shop painting, provided the work is done in an enclosed facility.



Electronic psychrometer

Conducting a Compressed Air Cleanliness (blotter) Test

As described earlier, compressed air is used to propel abrasive through a blast hose and blast nozzle. The compressed air volume and pressure creates the energy needed



Compressed air cleanliness test

to clean and roughen the surface. However, if the air being generated by the compressor contains oil or water, then the abrasive and the surface can become contaminated. It is not unusual for compressed air to contain water and/or oil. As a result, the compressed air must be filtered and/or dried before it contacts the abrasive. Oil and water separators, desiccant air driers or air coolers are very effective at cleaning

and/or drying the compressed air provided they are both operational and properly maintained. From the perspective of the inspector, it is not enough to ensure operation and maintenance of this equipment. Rather the inspector must *verify* that the air is clean and dry. ASTM D4285, “Test Method for Indicating Oil or Water in Compressed Air” describes a standard practice for verifying the cleanliness of compressed air. Better known as a “blotter test,” a clean white absorbent cloth, white

blotter paper or plexiglass (known as “collectors”) is attached to a rigid frame and the compressed air is exhausted on to the collector (downstream of compressed air drying/filtration equipment) at a distance of approximately 24" for a minimum of one minute. After the test is complete, the collector is visually examined for oil or water. Any visible amount is cause for rejection. It is the responsibility of the contractor to maintain or replace equipment until a clean, dry air supply is achieved. The date, time of day and test result (pass/fail) is documented.

Abrasive Cleanliness

The SSPC surface preparation standards for abrasive blast cleaning (SSPC-SP 7, SP 14, SP 6, SP 10 and SP 5) have indirect or automatic requirements, including compressed air cleanliness, removal of grease and oil per SSPC-SP 1 and abrasive cleanliness. This means that even if the project specification or contract documents do not specifically call out these tests they must be performed.

Abrasive cleanliness entails two independent tests including oil content and conductivity. The procedure for determining oil content (ASTM D7393) was described earlier. Water-soluble contaminant testing is performed according to ASTM D4940, Standard Test Method for Conductimetric Analysis of Water-Soluble Ionic Contamination of Blasting Abrasives and is described below.

1. Verify the accuracy of the conductivity meter using a standard solution, then thoroughly rinse the electrode on the conductivity with distilled water. Remove any residual water and verify that the reading on the display is less than 5 μ S.
2. Measure 300 mL of distilled water. Collect 300 mL of abrasive and add it to the 300 mL of distilled water. Stir this mixture of abrasive and water for one minute using the glass stirring rod. Let the abrasive/water slurry stand for 8 minutes, then stir it again for one minute using the glass stirring rod.
3. Filter approximately 10 mL of the liquid from the abrasive extract and discard it. Filter the remaining liquid through the filter paper and collect it in a small container.
4. Pour a small amount of distilled water into a container and measure the conductivity of the source water. The value on the display is called the “conductivity of the blank.”

5. Immerse the electrode into the filtered liquid or extract from the abrasive. The value on the display is called the “conductivity of the abrasive extract.”
6. Calculate and record the conductivity of the abrasive extraction using the formula: $(A-B) = C$, where:

A = Conductivity of the Abrasive Extract

B = Conductivity of the lank (if any)

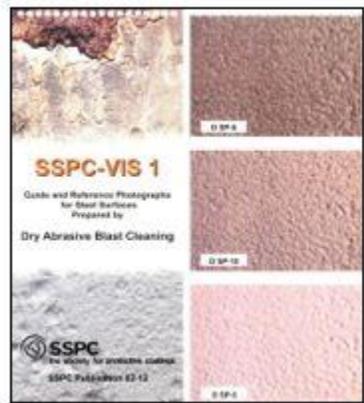
C = Actual Conductivity of the Abrasive Extract

According to the SSPC Abrasive Standards (SSPC-AB 1, AB 2, AB 3 and AB 4), the conductivity of the abrasive shall not exceed 1000 microSiemen per cm ($\mu\text{S}/\text{cm}$) or 1 milliSiemen/cm (mS/cm) when tested according to ASTM D4940.

Assessing Surface Cleanliness

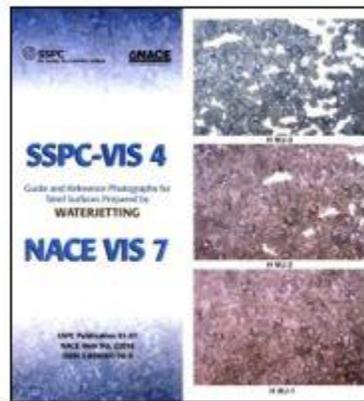
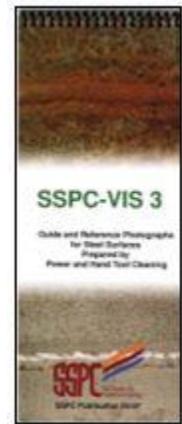
Determining visually whether the degree of cleanliness achieved by the contractor meets the minimum level required by the project specification is perhaps the most difficult inspection check point. To help reduce the variability associated with assessing surface cleanliness, SSPC has published a series of visual guides (VIS) or 3" x 3" color photographs that depict representations of the initial condition of the surface (prior to surface preparation or “before photos”) and the various levels of cleaning (“after photos”). The inspector selects the “before photo” category (e.g., 100% rusted), then locates the “after photo” in that category that depicts the level of cleaning required by the project specification. For example, if the “initial condition” of the surface is 100% rusted, then Rust Grade Category “C” is selected. If a “Near-White Blast” (SSPC-SP10) is specified, then the reference photo labeled “C SP10” is selected and used as a visual guide to determine whether the minimum specified level of cleaning has been achieved.

There are four visual guides available from SSPC. The visual guide selected is based on the method of surface preparation employed by the contractor. They include:



SSPC VIS 1,
“Guide and Reference Photographs for Steel Surfaces Prepared by Abrasive Blast Cleaning”

SSPC VIS 3,
“Guide and Reference Photographs for Steel Surfaces Prepared by Power- and Hand- Tool Cleaning”



SSPC VIS 4/NACE VIS 7,
“Guide and Reference Photographs for Steel Surfaces Prepared by Waterjetting”

SSPC VIS 5/NACE VIS 9, “Guide and Reference Photographs for Steel Surfaces Prepared by Wet Abrasive Blast Cleaning”



The step-by-step use of the SSPC visual guides is detailed in the instrument use supplement.

All surface cleanliness inspection is done with the unaided eye or corrected vision. Use of magnification is prohibited by the SSPC surface cleanliness standards.

Additionally, some abrasives will embed into steel surfaces. Embedded abrasive is tolerated by the SSPC surface cleanliness standards if they are not water- or solvent-soluble and are tightly adherent. If the embedded abrasive particles cannot be removed by blow down or vacuuming, then they are coated over.

If the level of cleaning performed by the contractor is unacceptable, then the deficient areas should be clearly marked and the surfaces re-prepared until the specified level of cleaning is achieved. The primer should not be applied until the surfaces are prepared and have been accepted by the inspector.

Establishing a Project-Specific Surface Cleanliness Standard/Test Section



The images depicted in the SSPC visual guides (both initial condition and post-surface preparation) are representative photographs and rarely match the actual conditions before and after surface preparation. Therefore, a specification may require the contractor to create a project-specific cleanliness standard

(test section, illustrated at left), which is generated by preparing a small, representative section of the structure to the desired level of cleaning. The visual guides can be used to help establish the degree of cleaning required by the specification. Once established, this area becomes the visual guide for that project. The agreed-upon condition can be preserved by taking digital images using appropriate lighting. Note that if the existing condition of the structure varies, then more than one test section may need to be generated. Even if the project specification does not require a test section, the inspector may request that the contractor to prepare one (or more), so that all parties are on the same page regarding the level of cleanliness required.

Measuring Surface Profile Depth

Surface profile is defined as the maximum peak-to-valley depth that is generated by abrasive impacting the surface at high speed and by the impact created using certain power tools. By imparting a profile, the surface area is increased, enhancing the adhesion of the coating system to the surface. While an insufficient surface profile depth may result in poor coating system adhesion, excessive surface profile may cause pinpoint rusting and will require significantly more coating to fill all of the “valleys” of the surface profile and provide the specified thickness of coating above the “peaks” of the surface profile. Therefore, compliance with the minimum and maximum specified surface profile depth is critical to the long-term performance of a coating system.

Factors affecting the depth of the surface profile were described earlier and included (for abrasive blast cleaning) the type, hardness and size of the abrasive media employed, as well as the hardness of the surface being prepared. Lesser factors include the distance from the blast nozzle to the surface and the angle at which the operator holds the nozzle to the surface. For power tool cleaning, the type of tool and the configuration of the “impactors” will oftentimes dictate the depth of the surface profile. Adjusting to changes in profile depth requirements in specifications is best achieved by selecting a different size abrasive. For projects requiring a relatively shallow surface profile depth, a smaller abrasive should be selected; for projects requiring a relatively deep surface profile, a larger abrasive should be selected, but may be blended with a smaller abrasive to increase productivity.

There are two industry-recognized standards for measuring surface profile, including ASTM D4417, “Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel” and NACE SP0287, “Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape.” These methods describe how to obtain measurements of surface profile depth, but do not provide an acceptance criterion (e.g., “the surface profile shall be 2-3.5 mils...”). Therefore, the project specification must indicate the desired surface profile depth.

ASTM D4417 describes three methods for field measurement of surface profile depth (Methods A, B, and C), while NACE SP0287 describes only one method (the same as Method C in ASTM D4417).



Keane-Tator surface profile comparator

Method A is a visual comparator method (Keane-Tator Surface Profile Comparator) and incorporates a 5-power illuminated magnifier and 3 comparator discs (one for surfaces blast cleaned using silica sand abrasive, one for surfaces blast cleaned using grit/slag abrasives and one disc for surfaces blast cleaned using steel shot abrasive). Each disc

contains five segments and a hole in the middle; and each segment depicts a different surface profile depth (in mils). The segments are stenciled with a code that indicates the type of abrasive represented, the surface profile depth (mils) and the year that the master disc was made (each disc is an electroformed copy of the master disc for reproducibility). A disc is selected that matches the type of abrasive employed and placed onto the prepared surfaces. By viewing the selected disc through the 5-power illuminated magnifier, the segment that closely matches the surface roughness can be selected and recorded. If the surface profile falls between two segments, a surface profile range is recorded (e.g., 1.5-2 mils).

Method B is a digital depth micrometer that measures profile depth using a 60° conical-shaped point that projects into the valleys of the surface profile while the base of the instrument sets on the peaks of the surface profile. The depth of the valleys, in relation to the tops of the peaks is read from the display. The micrometer must be verified for a “zero reading” on smooth plate glass prior to and after each period of use.



micrometer

Method C describes the use of replica tape manufactured by Testex® that is used in conjunction with a spring-loaded micrometer or Replica Tape Reader (RTR) to quantify surface profile depth. The Testex tape consists of a layer of compressible foam attached to a 2-mil polyester film (Mylar®). The amount of compressible foam mounted to the Mylar varies, depending on the range selected.

There are currently four ranges of replica tape to choose from, including:

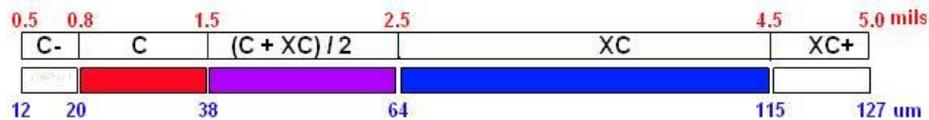
1. Coarse Minus (0.5-0.8 mil)
2. Coarse (0.8-2.5 mils)
3. X-Coarse (1.5-4.5 mils)
4. X-Coarse Plus (4.0-5.0 mils)



Replica tape and micrometer

The tape selected for measurement is based on the specified surface profile depth. For example, if the specified surface profile is 0.8-2.5 mils, then the **Coarse** tape is selected. If the specified surface profile is 1.5-4.5 mils, then the **X-Coarse** tape is selected. If the specified surface profile is 4-5 mils, then the **X-Coarse Plus** tape is selected. Independent of which tape grade is used, the thickness of the Mylar film is always 2 mils and does not vary.

If a measurement made with either Coarse or X-Coarse grade tape is between 1.5 and 2.5 mils inclusive, a second reading is taken in the same spot with the other grade. If both readings are in the range of 1.5-2.5 mils inclusive, the two measurements are averaged and recorded as the surface profile. If either reading is outside of 1.5 – 2.5 mil range, record that reading. This is illustrated in the diagram below.



Testex tape and burnishing tool

To obtain a surface profile measurement using the Testex replica tape, the paper backing is removed, and the tape is attached to the prepared surface. A burnishing tool is used with medium pressure to rub on the Mylar surface, effectively pushing the compressible

foam into the surface profile and picking up a mirror image. Once the burnishing is complete, the tape is removed from the surface and inserted between the top and bottom anvils of the spring micrometer. The surface profile (in mils) is read directly from the micrometer dial, less 2 mils for the



non-compressible Mylar thickness. Alternatively, a Replica Tape Reader (RTR) can be used. The RTR automatically deducts 2-mils for the Mylar. The replica tape can be attached to the inspector's documentation

and identified according to the area tested and the actual surface profile.



Replica Tape Reader

Frequency of Surface Profile Measurements

The number of locations for surface profile measurements may be stipulated by the project specification or SSPC-PA 17 may be invoked. If not, the inspector will need to use some judgment. The number of measurements per “location” is dependent on the method of measurement according to ASTM D4417. Method A requires a “sufficient” number of readings; Method B requires 10 measurements per location (record the maximum of the ten readings, discounting any outlier readings; or if all parties agree that average of ten readings can be reported) and Method C requires two (2) readings per location. The size of each location is not defined by ASTM.

SSPC PA-17

Because various methods of surface preparation may be used on a substrate during a given work shift, and each method will generate profile in a different way, SSPC-PA 17 requires that the profile created by each piece of equipment during a single work shift (12 hours or less) be verified in a minimum of three locations, regardless of the size of the area prepared.

The standard requires averaging individual instrument readings within each of three randomly selected 6x6-inch locations on the prepared surface to generate a “location average.” The highest and lowest location averages, and the average of the three location averages are reported. Each location average must fall within the specified profile range.

Using PA 17 to Determine Compliance with Specified Profile

Step 1: Identify the method used to take readings from the surface. This could be any of the three methods in ASTM D 4417. Method C (replica tape) will be used for this example.

Step 2: Identify the pieces of equipment used to prepare the surface during a work shift. If nozzles from Blast Pot A and Blast Pot B were used to prepare the surface, verification of the profile in areas prepared by Blast Pot A, Blast Pot B must be performed.

Step 3: Select a minimum of three 6x6-inch locations (L1, L2 and L3) on an area prepared by Blast Pot 1 during the work shift.

Step 4: Within each location, obtain 2 surface profile measurements in accordance with ASTM D 4417 Method C.

Step 5: Add the values obtained from the 2 measurements and divide the result by 2 to generate the “location average” for L1. The “location average” for L1 must be within the specified profile range.

Step 6: Perform Steps 3 through 5 in locations L2 and L3 within the area prepared by Blast Pot 1.

If the L2 and L3 location averages are also within the specified profile range, the area prepared by Blast Pot 1 is compliant.

Step 7: Report the highest and lowest location average, as well as the “measurement” (the average of L1, L2 and L3 values) for the area prepared by Blast Pot 1.

Step 8: Perform Steps 3 through 6 in the area prepared by Blast Pot 2.

Steps 1 through 8 are performed at a minimum of once per work shift. This frequency is intended to minimize work stoppages while periodically verifying conformity with project requirements during the course of production.

Identifying Non-Conforming Areas

If any “location average” is outside the specified profile range, select four additional locations equidistant from each other and approximately 5 feet away from the non-compliant location, and obtain “location averages” for each of the four locations. Each of these four location averages must comply with the specified profile range, or the process of selecting additional locations at five-foot distances from the non-compliant location must be repeated. If there is no room to take a measurement in a given direction, no measurement is required. Demarcate and report any non-compliant locations.

Inspection of Surfaces for Primer Application

After the specified level of surface cleanliness has been achieved and the surface profile depth has been measured and recorded, the inspector should verify that the prepared surfaces are ready for application of the coating. This includes dust removal, a final chemical contamination test (if required) and verification that the time interval from surface preparation to primer application will not be exceeded.

Dust/Debris Removal

Dust and debris remaining on the surface must be removed by brushing, compressed air blow down (or double blow down), or by vacuuming the surfaces. If compressed air blow down option is selected, then the compressed air must be verified for cleanliness by employing the blotter test (ASTM D4285) described earlier in this module. Compressed air blow down must be carefully inspected, as dust tends to cling to surfaces by static electricity. While a “white glove” test is not necessary nor recommended, if gloved fingers are traced across the surfaces and tracks are visually evident on the surface, then excessive dust remains and can interfere with coating adhesion and/or cause application defects. Alternatively, ISO 8502: Preparation of Steel Substrates Before Application of Paints and Related Products – Tests for the Assessment of Surface Cleanliness, Part 3: Assessment of Dust on Steel Surfaces Prepared for Painting (pressure-sensitive tape method) can be used to rate surface dust if the method is specified.

To perform this test, a special type of clear, pressure sensitive adhesive tape (25 mm wide with an adhesion peel strength of at least 90 N per meter width), a 10X illuminated magnifier and a white board (e.g., bright white cardboard or paper) must be acquired. Note: A spring-tensioned roller to attach the tape to the surface is not required by the standard unless the testing procedure or results are being disputed.

Use of the roller can be replaced by thumb pressure applied to the tape, as described below.

Step 1: Discard three full turns of tape from the roll.

Step 2: Remove a test piece of tape approximately 8-inches long, being certain to only touch the two ends (1-inch at each end).

Step 3: Attach (press) approximately 6-inches of the tape (excluding the two – 1-inch ends) to the surface.

Step 4: Press the tape to the surface by placing your thumb at one end of the tape, then move your thumb along the tape length (at a constant speed and pressure) three times in each direction (each stroke should take between 5 and 6 seconds to complete). Leave the two 1-inch ends of the tape up off of the surface (only the middle 6-inches of the tape should be attached). Note that thumb pressure must be replaced by a spring-tensioned roller in the case of disputes regarding procedure or test results.

Step 5: Remove (peel) the tape from the surface at a 180° angle (to the surface) at a peel rate of 300 +/- 30 mm/minute.

Step 6: Attach the peeled tape to a white backing.

Step 7: Rate the quantity of dust attached to the tape using Figure 1 (Dust Quantity Ratings). If required by the project specification, rate the dust size attached to the tape using Table 1 (Dust Size Classes). These pictorial references are provided in the standard.

Step 8: The standard requires one test for every 19 square meters (200 square feet) of prepared surface that is ready to be primed. Unless the project specification indicates otherwise, a dust quantity rating of 1 and a dust size rating of 3 or less is considered an acceptable surface for coating.

Final Chemical Contamination Test

If required by the specification, a final test to determine whether surface chemical contamination (e.g., chloride, ferrous ions, sulfates and/or nitrates) is performed to assess acceptability. If the levels are too high, then additional surface preparation may be required prior to application of the primer.

Verifying Surface Preparation-to-Primer Application Window

Many project specifications require that the prepared surfaces be “primed-in” within four hours, or within the same shift. If the specification contains this requirement, then the inspector should verify that this “window” is met. If surface rusting becomes evident, the surfaces must be re-prepared to achieve the minimum specified level of cleanliness, even if the “window” has not yet been exceeded.

Module 3 Summary

While every phase of a coatings operation can contribute to the success or failure of a coating system, surface preparation is critical. Preparing the surface can also be the most costly phase of a coatings operation.

Surface preparation has a two-fold purpose: cleaning and roughening the surface to successfully accept the coating. The inspector's role in verifying cleanliness depends on the specification. The specification may require the inspector to verify that grease, oil, and other contaminants have been adequately removed from the surface. This initial phase is referred to as *pre-surface preparation* and takes place before the actual surface preparation begins. During pre-surface preparation, an inspector's responsibilities may include verifying that structural deficiencies have been repaired, that weld spatter has been removed, and that edges and corners have been properly prepared. This initial phase may also require testing for chemical contamination of the surface.

If abrasive blast cleaning is invoked by specification, an inspector will be required to verify the cleanliness of the abrasive blast media and the compressed air used in the blast lines. Dry abrasive blast cleaning can both clean a surface and roughen it at the same time; however, it is possible to achieve the correct level of cleanliness while not achieving the specified roughness. The reverse is also true. Therefore, the inspector must treat and verify cleaning and roughening as separate criteria.

The inspector's role in achieving the specified roughness (also referred to as the surface profile or anchor pattern) may require verifying profile depth and uniformity over the project surface.

There are many methods that may be employed to prepare a substrate for the application of a coating system. Those methods include solvent cleaning, hand and power tool cleaning, dry and wet abrasive blast cleaning, chemical stripping, and water jetting. Dry abrasive blast cleaning is the most common method of surface preparation and can be used to roughen an existing coating system (to prepare for overcoating) or to remove the existing coating system completely. Of course, abrasive blast cleaning can also be used to prepare new surfaces for the application of a coating system.

Dry abrasive blast cleaning is highly productive. While the level of cleanliness achieved depends on the distance that the nozzle is held from the surface and the “dwell time” the operator employs, the depth and shape of the surface profile are determined by the type and size of the abrasive. Dry abrasive blast cleaning requires an abrasive media. These abrasives fall into two categories: recyclable and expendable. Recyclable abrasives include steel grit, steel shot, and aluminum oxide. They can be used multiple times (steel grit, for example, can be used over 100 times with minimal breakdown). Expendable abrasives breakdown and are used once, then discarded.

Centrifugal blast cleaning is an automated, very productive form of blast cleaning, which is typically employed in fabrication shops. Centrifugal blast cleaning is ideal for large flat surfaces, and there are portable versions of this equipment that can prepare horizontal surfaces like tank bottoms, ship decks or can be used to clean vertical surfaces, like the interior and exterior of storage tanks.

Vacuum blast cleaning is a much slower form of dry abrasive blast cleaning and is used when a high degree of cleanliness and surface roughness are required, but airborne abrasive and dust cannot be tolerated. Wet abrasive blast cleaning is another form of blast cleaning that can be used when airborne dust control is required by the specification. This process can also reduce hazards when airborne toxic metals are generated during the coating removal process.

Water jetting is another method of surface preparation. The variety of available water pressures can remove even tightly adhering coating systems. But while water jetting can restore an existing profile or anchor pattern, it cannot create a new one.

One problem with both wet abrasive blast cleaning and water jetting is that any system that incorporates water will cause carbon steel to flash rust. Specifiers may require the use of a rust inhibitor or accept the flash rusting and select a coating system that is tolerant of flash rusting on the substrate.

SSPC: The Society for Protective Coatings and the NACE International have developed consensus standards for surface cleanliness. Currently, there are 21 surface cleanliness standards. More than one cleanliness standard may be invoked for a coating project and it is imperative that the coatings inspector understands both the intent, as well as the details, of each specification invoked. SSPC-SP1 or “Solvent Cleaning” is a prerequisite and requires the removal of all visible grease, oil, lubricants, cutting compounds and other visible contaminants from the surface.

While each cleanliness standard has been assigned a code by NACE, SSPC, or both, each standard also has a descriptive title, such as “Brush-off Blast,” “Commercial Blast,” “Near-White Blast,” or “White Metal Blast.” The standards define the minimum level of cleanliness required, including the amount of mill scale, rust, or paint (or staining from these materials) that may or may not be allowed to remain on the surface. While experienced inspectors are very familiar with all of the standards, it is always advisable to review the standard(s) invoked in a specification in case there have been changes or updates.

There are seven “inspection check points” that may be invoked to verify the specified surface preparation. These common checkpoints include:

1. Verifying grease and oil removal,
2. Measurement of ambient conditions prior to final surface preparation,
3. Conducting a compressed air cleanliness (blotter) test,
4. Conducting an abrasive cleanliness test,
5. Assessing surface cleanliness,
6. Measuring surface profile depth,
7. Verifying surfaces are ready for primer application.

The final responsibilities of an inspector during the surface preparation phase of a coatings project are to verify that the prepared surfaces are free of dust and debris. Depending on the specification, there may also be a final test to determine whether soluble salts are at tolerable levels. And since many projects require that the prepared surfaces be primed within four hours or within the same shift, it is up to the inspector to verify that this timeframe has been met. (Even when the timeframe has been met, if surface rusting occurs prior to application of the coating, the surfaces must be re-prepared to achieve the specified level of cleanliness.)

Module 3 Workshop:

Using Instruments and Visual Guides for Inspection of Surface Preparation

Station 1: Abrasive Cleanliness

Attribute	Satisfactory (✓)	Unsatisfactory (✓)
Oil		
Conductivity		

Station 2: Testex Replica Tape (surface profile depth)

Measure and record the surface profile on Test Surfaces A and B.

Test Surface	Surface Profile (mils)	Place Tape Here
A		

Test Surface	Surface Profile (mils)	Place Tape Here
B		

Station 3: SSPC-VIS 1, “Guide and Reference Photographs for Steel Surfaces Prepared by Abrasive Blast Cleaning”

Part A

Record the initial rust grade, the SSPC surface cleanliness code and the reference photograph designation from the visual standard for each of the 5 scenarios in the table below:

Scenario 1: The surface contains both mill scale and rust, and a Brush-off Blast is specified.

Scenario 2: The surface is completely rusted, and the specification requires a Commercial Blast.

Scenario 3: The surface contains a weathered coating system over mill scale, and moderate pitting is present. The specification requires a White Metal Blast.

Scenario 4: The surface contains a weathered coating system over mill scale, and extensive pinpoint rusting is present. The specification requires an Industrial Blast.

Scenario 5: The surface is rusted and pitted, and the specification requires a White Metal Blast.

Station 3 Data Table			
Scenario	Initial Condition	Surface Cleanliness Code	Visual Guide Photo
1			
2			
3			
4			
5			

Part B

The backside of panel 3B represents the initial condition of the steel; the front side has been abrasive blast cleaned. The specification requires SSPC-SP6, Commercial Blast.

What is the initial condition? A, B, C, or D _____

Does the blast cleaned surface conform to the minimum cleanliness requirements of SSPC-SP6?

Yes or No _____

Station 4: SSPC-VIS 3 “Guide and Reference Photographs Steel Surfaces Prepared by Power- and Hand-Tool Cleaning”

Record the initial condition, the SSPC surface cleanliness code, the power tool code and the reference photograph designation from the visual standard for each of the 5 scenarios in the table below:

Scenario 1: The surface contains a zinc-rich primer. Power Tool Cleaning to Bare Metal is specified.

Scenario 2: The surface contains a weathered paint system applied over mill scale. The specification requires Power Tool Cleaning. The contractor is using a power wire brush.

Scenario 3: The surface is rusted and pitted. The specification requires Hand Tool Cleaning.

Scenario 4: The surface contains a light-colored coating applied to an abrasive blast cleaned surface. The specification requires Commercial Grade Power Tool Cleaning.

Scenario 5: The surface contains both mill scale and rust. The specification requires Power Tool Cleaning. The contractor is using a sanding disc.

Station 4 Data Table				
Scenario	Initial Condition	Surface Cleanliness Code	Power Tool Code	Visual Guide Photo
1			NA	
2				
3			NA	
4			NA	
5				

Part B

The backside of panel 4B represents the initial condition of the steel; the front side has been power-tool cleaned. The specification requires SSPC-SP15, Commercial Grade Power Tool Cleaning.

What is the initial condition? A, B, C, or D _____

Does the prepared surface conform to the minimum cleanliness requirements of SSPC-SP15?

Yes or No _____

Station 5 - Latex Patch Sampling and Chloride Ion Test Strip (Quantab®) Detection

Using the Bresle Patch and Quantab Indicator Strips, collect a sample from the surface and test the sample for chloride.

Entry	Result
PPM (from Quantab conversion chart)	_____ PPM
Quantity of Water Used in Syringe	2 mL
PPM x Quantity of Water Used	_____ micrograms of chloride
Area Tested	12.25 cm ²
Micrograms of Chloride ÷ Area Tested	_____ micrograms/cm ² chloride

Station 6 – Depth Micrometer (ASTM D4417, Method B surface profile)

Verify the zero-set and measure surface profile of the blast cleaned steel surface by obtaining 10 measurements in a 6" x 6" area. Report the average and maximum values.

Reading 1	Reading 2	Reading 3	Reading 4	Reading 5	Average & Maximum
Reading 6	Reading 7	Reading 8	Reading 9	Reading 10	

Module 3 Quiz

Basic Coatings Inspection

1. The range of surface profile depth is established by:
 - A. NACE SP02-87
 - B. The specification
 - C. ASTM D4417
 - D. SSPC-PA 17

2. There are a variety of surface cleanliness standards: several of them have been published by the joint efforts of:
 - A. SSPC and ASTM
 - B. ASTM and NACE
 - C. SSPC and NACE
 - D. None of the above

3. Regarding pre-surface preparation issues such as verifying that fabrication defects are corrected, the contractor should not be required or expected to perform corrective action unless the governing specification requires it.
 - A. True
 - B. False

4. Weld spatter on the surface of the substrate can cause:
 - A. The coating to draw thin along the spatter
 - B. Voids, if the spatter eventually disbonds
 - C. The weld to fail
 - D. Answers A & B

5. Sharp edges present special challenges to the coating applicator, because the:
 - A. Coating tends to pull away or draw thin on sharp edges
 - B. Because the only way to apply coating to these edges is with a brush
 - C. Because these edges are difficult to reach
 - D. Because the applicator is at risk when coating these areas

6. Stripe coating is:
 - A. Part of the cross hatch technique
 - B. A method used to give extra coating protection to sharp edges and other difficult to coat areas
 - C. A narrow row of parallel stripes on a steel substrate
 - D. A special type of coating

7. Grease and oil left on the surface of a substrate can:
 - A. Interfere with the adhesion of the applied coating
 - B. Can be driven into the substrate by the abrasive
 - C. Can cause a defect in the coating known as “fisheyes”
 - D. All of the above

8. If salts are trapped under an applied coating, they can:
 - A. Create a build-up of water pressure under the coating film
 - B. Cause osmotic blistering
 - C. Cause under film corrosion
 - D. All of the above

9. When the service environment is “immersion,” the specifier should allow:
 - A. A moderate concentration of soluble salts to remain on the substrate’s surface
 - B. A relatively high concentration of soluble salts to remain on the substrate’s surface
 - C. A relatively low concentration of soluble salts to remain on the substrate’s surface
 - D. Zero soluble salts to remain on the substrate’s surface

10. The most common and most productive method used to clean steel substrates is:
- A. Vacuum blast cleaning
 - B. Dry abrasive blast cleaning
 - C. Wet abrasive blast cleaning
 - D. Chemical stripping
11. The depth of an anchor pattern or surface profile is primarily dictated by the:
- A. Shape of the abrasive
 - B. The hardness of the abrasive
 - C. The size of the abrasive
 - D. The blast pressure
12. In general, which type of coatings is easier to remove by abrasive blast cleaning?
- A. Soft coatings
 - B. Elastomeric coatings
 - C. Brittle coatings
 - D. Black coatings
13. Clemco, Inc. claims that a 10 psi reduction in blast nozzle pressure equates to a:
- A. 15% reduction in productivity
 - B. 30% reduction in productivity
 - C. 15% increase in productivity
 - D. No noticeable reduction in productivity
14. Chemical strippers:
- A. Can generate a surface profile
 - B. Can remove rust and mill scale
 - C. Cannot generate a surface profile or remove rust or mill scale
 - D. Are dangerous and no longer used

15. If a specification requires a “Brush-off Blast” or a “Commercial Blast” or a “Near White Blast” it is automatically implied that the following standard is invoked:
- A. SSPC-SP11, “Power Tool Cleaning to Bare Metal”
 - B. SSPC-SP14, “Industrial Blast Cleaning”
 - C. SSPC-SP1, “Solvent Cleaning”
 - D. SSPC-SP10, “Near White Blast Cleaning”
16. SSPC-SP11, “Power Tool Cleaning to Bare Metal”
- A. Has no surface profile requirement
 - B. Requires a minimum 1 mil profile be etched into the bare steel
 - C. Requires only the removal of all loosely adhering mill scale, rust, and paint
 - D. Allows up to 10% intact mill scale, paint or rust to remain
17. A “White Metal Blast” or SSPC-SP5, allows _____ to remain on the surface.
- A. No rust, no mill scale, no old paint and 5% stains
 - B. No rust, no mill scale, no old paint, and no stains
 - C. No rust, no mill scale, no old paint, and 33% stains
 - D. No rust, no mill scale, no old paint, and unlimited stains
18. Prior to final surface preparation, the most important relationship to assess while recording ambient conditions is:
- A. The relationship between the air temperature and the surface temperature
 - B. The relationship between the surface temperature and the dew point temperature
 - C. The relationship between the relative humidity and the air temperature
 - D. The relationship between the relative humidity and the dew point temperature
19. If the compressed air used during abrasive blast cleaning contains oil or water, it can:
- A. Decrease the psi
 - B. Contaminate the surface
 - C. Increase the velocity of the flowing abrasive
 - D. Reduce the velocity of the flowing abrasive

20. The photographic guides developed by SSPC to aid in the visual assessment of surface cleanliness were designed to be used:
- A. With the aid of a laboratory microscope
 - B. With the aid of hand-held magnification
 - C. With the unaided eye or with corrected vision
 - D. In place of the written standards
21. Surface profile or the anchor pattern:
- A. Increases the surface of the steel
 - B. Promotes the adhesion of the coating
 - C. Is the maximum peak-to-valley depth generated by abrasive blast cleaning or power tools.
 - D. All of the above
22. An excessive profile depth may:
- A. Cause pinpoint rusting
 - B. Require less paint than a shallower profile
 - C. Result in poor coating adhesion
 - D. Pitting
23. If Testex X-Coarse replica tape is used to measure the surface profile and the measurement is between 1.5 and 2.5 mils, what must be done?
- A. Take a second reading in another area with the X-Coarse replica tape
 - B. Take a second reading in the same area with the Coarse replica tape
 - C. Take a second reading in the same area with the X-Coarse replica tape
 - D. Record the measurement and proceed to the next area

24. According to SSPC-PA 17, how many locations (minimum) are assessed for surface profile?

- A. 1 – 6” x 6” location per work shift
- B. 6 – 6” x 6” locations per work shift
- C. 5 locations in each 100 square foot
- D. 3 – 6” x 6” locations per work shift, per surface preparation apparatus

25. Which of the following surface profile measurement frequencies is false?

- A. Replica Tape: 2 readings per area
- B. Visual Comparator: 5 readings per area
- C. Depth Micrometer: 10 readings per area
- D. All three choices are false

Coating Mixing, Thinning and Application: Equipment Overview and Inspection

Module 4

Techniques

Learning Outcomes:

- Measure and record ambient conditions and surface temperature
- Navigate a coating manufacturer's product data sheet (PDS)
- Calculate target wet film thickness (with & without thinner)
- Describe proper mixing and thinning procedures
- Describe differences between various methods of coating application
- Measure dry film thickness according to SSPC-PA2
- Detect pinholes and holidays in applied coatings
- Measure coating hardness

How this information affects YOU:

Next to surface preparation, proper coating mixing, thinning and application is the most critical step in corrosion protection. It starts with comprehending the manufacturer's instructions. Once you understand how the coating materials to be mixed, thinned and applied (and under what conditions) the rest is up to the skills of the applicators. In order to make sure they did their job, you need to measure and record the dry film thickness and you may need to check the applied coating for cure, continuity, hardness and adhesion. Understanding how to perform these tests and what the information means in terms of coating performance is critical for quality assurance/quality control inspection personnel.

Introduction

Transferring the coating material from the container to the surface may seem like a routine task and would hardly warrant training and inspection. Yet, next to surface preparation, it is one of most important steps to ensuring corrosion

protection of structural steel. As discussed in Module 1, coatings protect the substrate by barrier, inhibitive and/or galvanic means. If the coating material is not properly mixed, thinned and applied, then any protection afforded by the coating may be minimized or eliminated. This is why it is important to read and comprehend the project specification and the manufacturer's written instructions for product use, then verify that the proper mixing and application procedures are employed. This module describes the proper methods of coating mixing, thinning and application, and discusses the associated inspection procedures. It also provides an overview of common application methods.

The Inspector's Role

The inspector's role related to coating mixing, thinning and application is multi-fold, and will vary from project to project (and from product to product). For example, on many projects, the inspector is typically responsible for measuring and recording ambient conditions and surface temperature, and for witnessing coating mixing, thinning and application procedures employed by the contractor's personnel. The inspector may also be responsible for calculating the target wet film thickness and for measuring the dry film thickness. Additionally, verification of the cleanliness between coats and compliance with recoat intervals are also typically monitored by the inspector. The inspector may also be responsible for performing pinhole or holiday detection, assessing the degree of coating cure, or for measuring the adhesion of the applied coating system. Finally, if it is necessary to measure the thickness of individual layers after the whole system is installed, the inspector will need to know how to use a Tooke Gage. Each of these inspection checkpoints is described in this module.

Review of SSPC Standards for Coating Application

SSPC: The Society for Protective Coatings has two primary standards for coatings application. The general content of SSPC-PA 1 is provided below. SSPC-PA 2, "Procedure for Determining Conformance to Dry Coating Thickness Requirements" is described later in this module.

SSPC Paint Application Specification No. 1 (PA 1): Shop, Field and Maintenance Painting of Steel

SSPC PA 1 is the first **P**aint **A**pplication specification released by SSPC. It is a common reference in project specifications for painting of steel surfaces and contains much of the same information as will be covered by this module. The standard contains 15 sections:

1. Scope
2. Contents
3. Referenced Standards
4. Definitions
5. Requirements for Handling and Storage of Coating
6. Requirements to Address Before Coating Application
7. General Requirements for Application of Coatings
8. Requirements for Brush, Roll, and Spray Application
9. Requirements for Shop Coating
10. Requirements for Field Coating
11. Repair of Existing Damaged Coatings
12. Curing and Handling of Applied Coatings
13. Inspection Requirements
14. Disclaimer
15. Notes

Coating Manufacturer's Product Data Sheets

A coating manufacturer's product data sheet (PDS) is essentially an "instruction manual" for the coating. A PDS contains information for the specifier that includes the product brand name and number, the generic type of coating (epoxy, polyurethane, etc.), and when and where the coating can and cannot be used, as well as compatible coatings. A product data sheet will contain technical information such as the weight and volume solids content of the coating, the theoretical coverage or spreading rate of the coating (the number of square feet that one gallon of the coating will cover), the recommended level(s) of surface preparation and the recommended dry film thickness, the Volatile Organic Compound (VOC) content of the coating as it is manufactured and the adjusted VOC content based on the type and amount of thinner added to the coating. Sometimes a PDS is used to communicate "performance data" to the specifier, such as adhesion characteristics, accelerated weathering/corrosion resistance, hardness, abrasion resistance, etc.

The PDS contains valuable information for the applicator as well, including the recommended method(s) of application (brush, roller, air/airless spray, etc.), and equipment recommendations for each application method listed. Additionally, the PDS contains mixing and thinning instructions, and if the coating contains multiple components, the number of components to be blended together, and the pot life of the coating (how long the coating can be used once the components are blended). Some multiple component coatings require an induction or “sweat-in,” which allows the individual components to co-react after mixing, but before application. If required, the time period and material temperature will be listed under the mixing instructions on the PDS (e.g., allow the mixed coating material to induct for 30 minutes at 77°F). Note that the induction time (when required) is part of the pot life of the coating. That is, if a coating has a pot life of 4 hours and a 30-minute induction, the “usable pot life” is only 3 ½ hours. The pot life is also dependent on the material temperature. A pot life of 4 hours at 77°F may only be 3 hours at 90°F, but may be 5 hours at 60°F.

Drying and curing times are also listed on the PDS. These times are dependent on the air and surface temperatures, even the relative humidity (the amount of moisture present in the air). Drying times are often listed based on “dry-to-handle,” “dry-to-recoat” and “full cure.” The maximum recoat time may also be listed. Some coating manufacturers will even recommend the method(s) used to verify cure of the coating. Finally, the PDS provides information on clean-up of equipment, approximate shipping weights and the various sized units that the coating is available in (e.g., 3.5-gallon kits, 1-gallon kits, 5-gallon kits, etc.). The shelf life is also indicated. The shelf life is the time that the coating can be used, from the date of manufacture. For example, the shelf life of a coating may be listed as 24 months, provided it is unopened and is stored at the proper conditions of temperature and humidity. Coatings should not be used beyond the shelf life, even if they “appear” to be in good condition.

ASTM F 718 “Standard Specification for Shipbuilders and Marine Paints and Coatings Product/Procedure Data Sheet” provides a format and lists the information that should be included on a PDS. However, there are no requirements for the type of information listed. While there is certainly commonality to the type of information that is conveyed, a coating manufacturer can list any information they desire and place it anywhere on the PDS. Some manufacturers provide the information on two pages, while others use a six or an eight-page format. Some manufacturers publish a “Technical Bulletin” *and* a set of Application Instructions, rather than combining the information into one

document. The information conveyed on a PDS is critical to the success of a coating installation. The specifier, inspector and the contractor should be familiar with the information listed on the PDS, for each product to be applied. The most current version of the PDS for each coating to be applied should be readily available on the project site and should be supplied to the inspector(s) by the contractor. Many coating manufacturers provide access to their product information as PDF files, which can be accessed from the Internet by logging onto their website. In this manner, the most current information is obtained with little effort or delay.

Product data sheets contain recommendations. For example, the manufacturer may recommend preparing the surface to achieve a “Commercial Blast” (SSPC-SP6/NACE No. 3) with a 1.5-2 mil surface profile, while the project specification may require a “Near-White Metal Blast” (SSPC-SP10/NACE No. 2) and a 2-3 mil surface profile. Similarly, the manufacturer may recommend one coat at 5-7 mils, while the specification may require two coats at 4-8 mils each. *In all cases, the specification is the governing document.* However, if there are discrepancies between the



manufacturer’s recommendations and the specification, they should be brought to the attention of the facility/structure owner to ensure that the variance was not an oversight. For example, if the product data sheet states, “Do not exceed 7 mils dry film thickness” and the specification requires 8 mils dry film thickness, the contractor or the inspector should “red flag” the discrepancy and advise the owner.

Some owners will elect to invoke information on the product data sheets into the specification. In these cases, the product data sheets become the governing document. Others may state that the document that is more restrictive (specification or PDS) shall govern.

Calculating Wet Film Thickness

Prior to mixing, thinning and applying the coating, the contractor should determine the target wet film thickness to apply. Some coating manufacturers list the wet film thickness or “WFT” on the product data sheet (many do not). Even if

the target WFT is listed on the PDS, the contractor must ensure that the recommended dry film thickness or “DFT” is the same as the specified DFT for the product. Further, if the coating will be reduced (thinned), the target WFT must be adjusted based on the amount of thinner added, so the manufacturer’s target WFT will no longer be representative. The contractor and/or the applicator should be knowledgeable in how to calculate a target wet film thickness. In most cases, the inspector is concerned with the dry film thickness and not the wet film thickness. But the contractor must ensure that the proper wet film thickness is applied, in order to comply with the dry film thickness requirements of the specification. If the coating is applied too thin or too thick, then rework is often required.

The percentage of solids by volume of a coating is a key component in the calculation of the wet film thickness. Unfortunately, the published value may be “theoretical” and based on the formulation or may not account for complete coating film shrinkage. Therefore, the contractor may choose to apply a test area of the coating (thinned if appropriate), measure the wet film thickness, then after the coating dries on the test area, measure the dry film thickness. This will provide the applicators with a “practical” wet film target. If the resulting dry film thickness meets the requirements of the specification, the actual volume solids content of the coating material becomes a moot point. Conversely, if the resulting dry film thickness is too low or too high, the actual percentage of volume solids can be calculated provided the wet film and dry film thickness is known. Then the revised target wet film thickness can be calculated. This is illustrated below. Concurrently, the applied coating film can be evaluated for flow characteristics, resistance to sag, etc.

<p>Target DFT (from the specification): 5 mils Calculated Target WFT (based on 50% solids by volume): 10 mils Actual WFT (measured): 10 mils Actual DFT (measured): Only 4 mils</p> <p>(Actual DFT / Actual WFT) x 100 = Adjusted Percent Volume Solids Content</p> <p>(4 / 10) x 100 = .40 or 40%</p> <p>Revised Target WFT = 5 mils DFT / 0.40 = 12.5 mils WFT</p>
--

Calculating the Target Wet Film Thickness

Three values are needed to calculate wet film thickness:

Value No. 1: The target dry film thickness (DFT)

Value No. 2: The solids by volume content of the coating material

Value No. 3: The amount of thinner that will be added to the coating

Step 1: Determine Value No. 1 – The Target Dry Film Thickness

The target dry film thickness (DFT) is indicated in the project coating specification. It is typically expressed in mils (0.001”) or microns (μm). There are 25.4 μm in 1 mil. If the project specification does not provide the target DFT, then the recommended DFT from the coating manufacturer’s application instructions should be used. If the project specification or the manufacturer’s instructions provide a range for the DFT rather than a target, then use the range.

Example: “The primer coat shall be applied to a dry film thickness (DFT) 2-4 mils.” Use 2-4 mils DFT

Step 2: Determine Value No. 2 – The Solids by Volume Content of the Coating Material

The solids-by-volume content is indicated on the coating manufacturer’s product data sheet and is expressed as a percent (%). This value represents the non-volatile or non-evaporative content of a coating (e.g., the resin, pigment and any additives). Often there is a solids-by-weight value on the product data sheet as well. Do not use this value.

Example: Solids by Volume: 75%

Step 3: Determine Value No. 3 – The Amount of Thinner that will be added to the Coating

If the project specification and the coating manufacturer permit thinner to be added to the coating, the amount of thinner that will be added must be taken into consideration when calculating a target wet film thickness. This is because the

thinner is part of the wet film that is applied to the surface but is not part of the dry film that remains on the surface (the thinner will evaporate into the air).

Coating manufacturers typically convey the amount of thinner to add based on a percentage of the total volume of coating mixed for application (e.g., 15%), or based on a certain volume (1 pint per gallon). Ultimately, a “percent thinner” value is needed for the calculation. If the coating manufacturer provides the percentage of thinner to add, then no further work is required. If the coating manufacturer indicates thinner addition by volume, then the percentage must be calculated using some very basic units of measurement.

- a) There are 4 quarts in 1 US gallon. A quart is 25% (1/4) of 1 US gallon
- b) There are 8 pints in 1 US gallon. A pint is 12.5% (1/8) of 1 US gallon

Example: The coating was thinned 1 pint per gallon, or 12.5%

Step 4: Select a Formula

There are two formulas. Select one of the two formulas when calculating a wet film thickness. The formula you should select is based on whether the coating was thinned prior to use. Here are the two formulas. Formula A is one step, while Formula B requires two steps.

Formula A (NO thinner addition):

$$\text{DFT} \div \% \text{ solids by volume} = \text{WFT}$$

Formula B (WITH thinner addition)

$$\text{Step 1: } \% \text{ solids by volume} \div (100\% + \% \text{ thinner added}) = \\ \text{adjusted volume solids content}$$

$$\text{Step 2: } \text{DFT} \div \text{adjusted volume solids content} = \text{WFT}$$

Step 5: Enter the Values into the Formula Selected in Step 4

Enter the values into the appropriate formula to arrive at the wet film thickness range. Remember, ALL percentage values must be converted to decimal format, simply by moving the decimal point two places to the left. For example, 75% is 0.75. Alternatively, the “%” key on the calculator may be used.

Example 1 – DFT range of 2-4 mils with no thinner added:

$$2 \text{ mils DFT} \div 0.75 = 2.7 \text{ mils WFT}$$

$$4 \text{ mils DFT} \div 0.75 = 5.3 \text{ mils WFT}$$

Therefore, the applicator should strive to apply a range of 2.5-5.5 mils WFT

Example 2 – DFT range of 2-4 mils with 12.5% thinner added:

$$(75 \div 112.5) = 0.67 \text{ adjusted volume solids content}$$

$$2 \text{ mils DFT} \div 0.67 = 3.0 \text{ mils WFT}$$

$$4 \text{ mils DFT} \div 0.67 = 6.0 \text{ mils WFT}$$

Therefore, the applicator should strive to apply a range of 3-6 mils WFT. Even with the addition of 12.5% thinner, the coating should “shrink” to 2-4 mils DFT.

Material Receipt Inspection and Storage Conditions

ABC Contractor prepared the steel to the specified degree of surface cleanliness (SSPC-SP10/NACE No. 2, Near-White Metal Blast), then the blast operators performed a blow down of the steel to remove the dust. The contractor’s QC personnel and the QA inspector verified that the degree of cleaning was adequate and measured the surface profile, which was also within the specified range. During this inspection, the applicator pulled the zinc-rich primer from the storage area, only to discover that one of the components (the activator) was never received. A call to the coating manufacturer’s representative confirmed the backorder. Even though the activator was now available, it would not be delivered to the project site for two days. The contractor had to re-blast the steel to remove the flash rusting that occurred while he was waiting on the missing activator to arrive.

Lesson Learned: Inventory the coating materials upon receipt.



A material receipt inspection is performed to verify what was ordered for the project was shipped to the project site and was received in good condition. The contractor should verify the name of the manufacturer; the product name, number and color; the shelf life of the coating components (discussed earlier in this module); and the type and quantity of thinner received. In addition, the contractor should record the batch or lot number associated with each component (and thinner), in case a formulation problem with the batch is discovered later on. Many industrial coatings are multiple component, which means they are composed of two or even three components. All components must be blended into one container prior to application. Otherwise they will not cure properly, nor provide protection of the underlying coating and/or substrate.

The contractor should also verify that the coatings are properly stored on the project site prior to use. The manufacturer's product data sheets will contain storage conditions of temperature and humidity. Some specifications will require the contractor to monitor the actual temperature and humidity in the storage facility using a recording hygrometer or data logger. Waterborne coatings must be protected from freezing during storage. Excessive heat or high humidity can be equally as damaging to a coating during storage.

Contractors or steel fabrication shops may elect to use chart recorders to document the temperature and relative humidity over a 24-hour or 7-day period, inside paint storage areas. Limitations to this type of equipment include battery life and someone must be responsible for changing the chart daily or weekly. Also, the charts must be stored in the project file.

Small data loggers are an alternative to chart recorders. These devices are self-contained, portable recorders equipped with internal temperature and humidity sensors, memory and extended battery life (multi-year). The data loggers are placed in the storage area and time-based temperature/humidity readings are acquired automatically (up to several times in one minute). The data collected by the devices can be monitored remotely using a Tablet or cell phone.



Data logging device for monitoring paint storage conditions

Coating Mixing Procedures

One of the most important steps in the successful installation of a protective coating system is the proper mixing or blending of the coating materials, prior to application. The procedures for blending single component materials is straightforward and needs little instruction other than ensuring the material is homogeneous by mixing all settled pigment and solids materials into the liquid. The mixing procedures for multiple component materials is more complex. This section provides a step-by-step guide to the proper mixing procedures of multi-component coating materials.

Coating Mixing Step 1: Agitating the Individual Components



Before combining the individual components of the coating (if multi-component), the individual liquid components must be thoroughly mixed. Power agitation using a mechanical mixing blade such as a “Jiffy Mixer” mounted into a pneumatically-operated drill or stirrer is often required. Hand stirring using wooden paddles may be acceptable for house paints but is inadequate for mixing industrial coatings and is often prohibited by the specification. Non-liquid components like zinc powder do not require pre-mixing.

Coating Mixing Step 2: Blending the Components and Mixing the Blended Product



Most coating manufacturers and/or the project specifications prohibit the blending of partial kits for good reason. First, many coating components may be ratioed by weight, not by volume. In order to mix partial kits, the contractor would need to accurately weigh out a portion of each component prior to blending. In addition, there may be a critical minimum volume of material that must be blended so that the chemical reaction between the components occurs. This information is typically not published but is no less critical.

Many coatings are available in both larger and smaller kits. The contractor may choose to have a few smaller kits on hand.

Unless permitted by the specification and the coating manufacturer (and the ratio of components is published), the contractor should always mix complete kits. The coating manufacturer pre-measures each component to ensure the proper ratio is achieved when complete kits are used. Even if partial kit mixing is permitted and the ratio is known, the contractor must have graduated containers for blending by volume or weighing devices for blending by weight before partial mixing should even be attempted.

Once the components are combined into one container, they must be thoroughly blended by power agitation using mixing blades described earlier. Alternatively, the materials can be blended by “boxing,” which is done by emptying ½ of the material into a clean container, then alternating dumping the material back and forth, from container to container until the material is blended. This procedure is typically prohibited when mixing inorganic zinc-rich primers, moisture cured urethanes or other coating materials that react with moisture. Once the coating material is blended, the pot life begins.

Mixing Zinc-Rich Primers

Zinc-rich primers are commonly used for corrosion protection and require special mixing procedures.

Some zinc-rich primers are single component and cure by a reaction with airborne moisture. In this case, the zinc powder is already blended with the liquid, so the single component material mixing



instructions described earlier can be employed for these types of products. In fact, over-mixing moisture-cured zinc-rich primers can entrain (bring in) moisture, which can cause the material to gel.

Multi-component zinc-rich primers can be either two- or three-component. In most cases, the zinc powder is one of the components that must be blended with the liquid component(s). In this case, the liquid components are thoroughly agitated, then the zinc powder is slowly and evenly dispersed into the liquid component(s) while the liquid is under power-driven agitation. Once the zinc powder is blended in, the coating should be power agitated for several minutes to help ensure thorough wetting of the dry zinc particles. Finally, the blended coating should be strained through a fine mesh cloth sieve or screen to remove any particles that may clog the spray gun tip or become lodged in the applied coating film.

Note: Any coating can be strained after mixing. Some specifications require straining of the coating material after mixing and before application.

Coating Mixing Step 3: Measure the Coating Temperature



After the components are blended and strained (if required), the temperature of the coating should be measured. A long-stem, stainless steel liquid thermometer can be used. This stem thermometer is equipped with a can clip, so that that thermometer can be attached to the perimeter lip of the can. The thermometer should be allowed to stabilize for three minutes before it is read, removed and cleaned. This temperature ultimately determines the length of the

induction time and/or the pot life (both terms were described earlier) of the coating. In general, the warmer the coating, the shorter the induction time and/or the pot life, since heat increases the rate of reaction.

Coating Mixing Step 4: Consider Whether Pot Agitation During Application is Required

Because zinc is a heavy, dense pigment it may tend to settle out of the blended material during application. In this case, the original mix ratio of the product becomes distorted, and the protection afforded by the primer is lying on the

bottom of the pot or can. Most coating manufacturers and project specifications will require automated, constant agitation of the mixed material during application to prevent settling-out of the zinc. Many spray systems are equipped with motor-driven agitating blades. Note however that many single-component moisture-cured zinc-rich primers contain anti-settling agents and do not require pot agitation during spray-out. In fact, agitation can draw airborne moisture into the coating, causing it to gel. Therefore, pot agitation is not recommended for these products, even though they contain zinc powder. The PDS will often provide guidance as to whether pot agitation during application is required.

Coating Thinning Procedures

Similar to mixing, the thinning of a coating material is perceived to be rather straightforward. However, the type and amount of thinner added to the coating impacts the volatile organic compound (VOC) content, the target wet film thickness of the coating, and over thinning or under thinning a coating can adversely affect the application and the performance characteristics. Therefore, thinning of a coating is an important area to discuss and is equally important to verify that it is done properly.

Coating Thinning Step 1: Determine if Thinning is Permitted

Fairly restrictive air quality regulations have caused manufacturers to reformulate coating materials with less solvent (higher solids content) and even different solvents. To this end, field addition of thinner for the purposes of reducing the viscosity of the coating material may be restricted or even prohibited. If thinning is allowed, there is oftentimes a maximum amount that can be added to maintain the volatile organic compound threshold established by Federal and/or local air quality regulations. Therefore, prior to adding thinner, the contractor must determine whether thinning is permitted. Some manufacturers prohibit thinner addition and claim that the coatings can be applied as supplied. Conversely, while the coating manufacturer may allow the coating to be thinned, the specification may prohibit the use of thinner.

Coating Thinning Step 2: Determine the Type and the Amount of Thinner to Add

Once it is determined that thinner addition is permitted, the next step is to determine the type and amount of thinner to add. This information can be gleaned

from the manufacturer's product data sheet. The type of thinner to add may be dependent on the air temperature during application. Manufacturers may have a slow-evaporating thinner for warmer temperatures and a faster one for colder temperatures. Only the manufacturer's recommended thinner should be used. Use of thinners other than those recommended can void the warranty on the coating and can result in reduced coating system performance. Thinners should be clean, new, and in their original containers. Contaminated, recycled, or used thinner should never be used for thinning coatings.



The amount of thinner to add is also based on the application temperatures, the method of application and the local air quality regulations. Most coating manufacturers will indicate the VOC content of the coating material as formulated, and the adjusted VOC content based on the type and amount of thinner added. Any *regulated* thinner that is added to the coating in the field will increase the VOC content. Conversely, the use of a *non-regulated* solvent (e.g., water) will not increase the VOC content of the coating. But there is still a maximum amount that can be added to maintain sag resistance and performance of the coating while in service.

The permissible amount of thinner that can be added is listed on the product data sheets in various ways, including:

“Thin up to 1 pint per gallon”

“Thin up to 10%”

Both statements are phrased as the maximum amount of thinner that can be added. It may not be necessary to add the maximum amount. For example, 4 ounces (1/2 pint) may be adequate for proper atomization and flow-out of the coating.

Converting Percentage to Volume

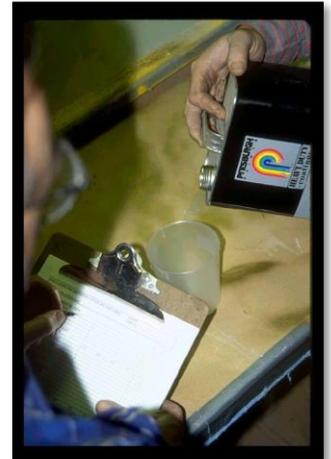
In the example provided above, if the manufacturer recommends thinning up to 1 pint per gallon (and it is determined that 1 pint per gallon is necessary), then measuring and adding 1 pint of thinner for each gallon mixed is straightforward. That is, if 10 gallons of coating is mixed, 10 pints of the recommended thinner are permitted. Since there are 2 pints in a quart and 8 pints in a gallon, a total of 1 ¼ gallon of thinner (5 quarts) is allowed.

However, if the manufacturer recommends thinning by a percentage of the total volume of coating material mixed, the contractor may need to convert from the percentage to a volume. Here's an example:

The coating can be thinned up to 20%. It is determined that 15% thinner is required, based on the coating and air temperatures. A total of 9 gallons of coating has been mixed.

1. 9 gallons x 15% (9 x 0.15) = 1.35 gallons of thinner
2. 1.35 gallons x 8 pints per gallon = 10.8 pints
3. By adding 1 gallon + 1 quart + 1 pint of thinner (11 pints total), the coating will be adequately thinned without exceeding the manufacturer's recommended amount.
4. The total volume of coating is now 10.35 gallons

Consequences of Under or Over-Thinning Consequences of Adding Thinner to Extend the Pot Life



Some contractors may not measure the amount of thinner added to the coating, but simply dump in thinner until the material appears or “feels” right. There are several consequences associated with this practice, some of which affect both quality and productivity.

First, by adding an unknown quantity of thinner to the coating, the effect on the VOC content is unknown, which may result in a violation of a local air quality regulation or contract requirement. Not only is the VOC content unknown, but the target wet film thickness cannot be accurately calculated, since the amount of thinner added cannot be included in the formula. This can result in insufficient or excessive coating thickness and potential rework. The addition of thinner does not increase the spreading rate of the coating, since the thinner is a component of the wet film, but not the dry film layer. While the volume of material being applied to the surface increases, the resulting dry film thickness and coverage rate will not.

The addition of excessive amounts of thinner may cause the coating to sag on vertical surfaces, and if the surface of the coating dries or “skins-over” before the solvents in the body of the coating have an opportunity to escape and evaporate, a porous film filled with solvent voids can result. Under-thinning a coating may cause poor film integrity, as the applied material may dry before it has an

opportunity to flow into a continuous film. This can result in exposure of the substrate or the underlying coating layers.

As a coating approaches the end of the pot life, the material often increases in viscosity. Some may believe that by adding thinner and reducing the viscosity of the coating, that they can extend the pot life of the coating. This is not the case. The pot life of a coating material is a defined time period that can only be extended by maintaining the material at a lower temperature. For example, if the pot life of a coating is 4 hours at 77°F, it may be possible to use the coating for up to 5 hours after it is mixed if the temperature of the material is maintained at 65°F. Therefore, the practice of adding thinner to reduce viscosity, so that the coating can be used beyond the pot life is poor painting practice and can result in premature failure of the applied film.

Coating Application Methods

Transferring the coating materials from the can to the surface can be accomplished in several ways. Factors that should be considered when deciding on an application method include the size and configuration of the surfaces to be coated, the type of coating, environmental regulations, the proximity to other operations, the specification and the coating manufacturer's recommendations.

The seven methods of coating application that we will describe in this Module include:

1. Brushes and rollers
2. Conventional (air) spray
3. High Volume Low Pressure (HVLP) spray
4. Airless spray
5. Air-assisted airless spray
6. Plural component spray
7. Electrostatic spray

Brushes and Rollers

The use of brushes on industrial painting projects is generally reserved for striping or “cutting in” of inside/outside corners, welds, around rivet heads and bolt/nut assemblies, etc. Striping is the application of a layer of coating to surfaces that are relatively difficult to achieve a normal film build on. Wet



striping can be done on any coating layer. After the “wet stripe” is given an opportunity to release most of the solvent (becomes tacky after several minutes), the full coat is applied. Conversely, dry striping is applied after the full coat of primer or intermediate coat, since the stripe coat in this case is allowed to *dry* for the full recoat interval (e.g., 12-16 hours), but not completely cure. Many specifications that address the application of lining systems (e.g., inside of water storage tanks) will require striping of the weld seams and other appurtenances prior to application of the full coat, since the service environment is “continuous immersion.” If striping is not specified, then it is up to the contractor as to whether he wants to apply a stripe coat.

Rollers can be used to coat large, flat surfaces, and provide the user with a high “transfer efficiency” (the percentage of coating that reaches the surface versus waste). Careful attention must be paid to acquiring the recommended roller nap depth. Too deep of roller nap can result in streaking and poor appearance. Additionally, roller nap can be pulled from the roller core and become embedded in the dry coating film. This can act like a small wick and draw moisture into the coating film. Also, the gloss level of the coating will be reduced as roller “stipple” is increased, and coating thickness is difficult to control. Some industrial coatings dry/cure too rapidly and are not recommended for roller application.



Conventional (air) Spray



Air Hose



Paint Hose

Conventional or “air-atomized” spray uses compressed air to transport the paint from a pressurized pot to the spray gun, to atomize the coating into a fine spray, then propel the atomized coating to the surface. The ratio of air to paint is quite high; therefore, compressed air cleanliness is critical and transfer efficiency is relatively low. The major reason conventional (air) spray may be used to apply industrial coatings is the ability to control both the amount of paint that exits the spray gun tip and the shape of the spray pattern.

Conventional spray equipment consists of a pressure pot equipped with two regulators. One pressure regulator is used to control the amount of pressure in the pot itself (forces the paint through a hose to the spray gun) and the other is used to control the volume of atomization air that is used to break up the stream of paint exiting the spray tip. Coating



Air Cap

manufacturers will provide recommended pot and atomization pressures, which oftentimes must be adjusted based on project conditions (amount of thinner addition, temperature, etc.). Two hoses traverse to the spray gun from the pot. One hose contains the paint and the other contains the atomization air. There are two controls on the spray gun. The lower control regulates the amount of paint that comes out of the spray tip. This control essentially adjusts how far the operator can pull back the spray gun trigger (and the needle from the tip opening), which regulates the amount of paint that exits the spray tip. The upper control regulates the shape of the fan pattern from a small circle for striping of corners, etc. to a larger oval for spraying flat surfaces. A conventional spray gun can be “half-triggered” (pull the trigger back part way), so that the atomization air (without paint) exits the spray nozzle. This compressed air can be used to perform a final blow-down of the surface immediately prior to coating application.



Trigger



Gun position

The distance that the conventional spray gun is held from the surface is 6-10 inches and varies depending on the type of coating and prevailing spraying conditions (i.e., air temperature, wind speed). Spray technique will be described later in this module.

High Volume Low Pressure (HVLP) Spray

Similar to conventional spray, high volume low pressure (HVLP) spray uses compressed air to transport the paint from a pressurized pot to the spray gun, to atomize the coating into a fine spray, then propel the atomized coating to the surface. In this case, the coating is atomized using a high volume of air under very low pressure (less than 10 psi, versus 50-75 psi for conventional spray). Like

conventional spray, compressed air cleanliness is critical. But unlike conventional spray, the transfer efficiency can be much higher. The major reasons HVLP spray is used to apply industrial coatings is the ability to control both the amount of paint that exits the spray gun tip, the shape of the spray pattern and most importantly reduced blow-back (paint rebound from the surface due to the high velocity of the paint as it exits the spray tip), which increases the transfer efficiency. When the transfer efficiency is increased, less coating is used, which translates into lower volatile organic compound (VOC) emissions.

The equipment itself consists of a pressure pot equipped with two regulators (similar to conventional spray). A third regulator is sometimes positioned near the spray gun, so that that atomization pressure can be finely regulated just before it enters the spray gun. Unfortunately, many coating manufacturers do not provide recommended pot and atomization pressures for HVLP on the PDS. However, the atomization air should never be set higher than 10 psi. Otherwise, the HVLP spray becomes traditional conventional spray, negating the transfer efficiencies.



HVLP tip/aircap

The biggest noticeable difference between conventional and HVLP spray gun lies in the design of the spray tip and air cap. Compared to conventional spray, the atomization air ports around the perimeter of the spray tip and in the air cap are much larger, enabling a higher *volume* of air to pass through them. Similar to conventional spray, an HVLP spray gun can be “half-triggered” (pull the trigger back part way), so that the atomization air (without paint) exits the spray nozzle. This compressed air can be

used to perform a final blow-down of the surface immediately prior to coating application. However, because of the low air pressure, the blow down may not be adequate for removal of heavy dust deposits. The distance that the HVLP spray gun is held from the surface is 6-10 inches.

Airless Spray

Airless spray is the most common method used for the application of industrial coatings. If the equipment is operating properly and the applicator employs good spray technique, the finish can approach that which is created by conventional or HVLP spray, but at much higher production levels. Because airless spray does not employ compressed air to atomize the coating, the transfer efficiency is relatively higher than conventional spray,



Airless spray paint hose

reducing airborne emissions. And because airless spray does not incorporate compressed air into the paint stream, the cleanliness of the compressed air is not critical.

Airless spray is analogous to a garden hose with a spray nozzle on the end. Both work by pressurizing a stream of fluid through a tiny orifice in the spray nozzle. This pressure is released on the opposite side of the spray nozzle as the fluid exits the nozzle. This causes the fluid to atomize, or to break-up into tiny-sized droplets. However, airless paint pressure is 10 to 75 times higher than residential water pressure.

A reciprocating pump is used to siphon paint from a non-pressurized container into the chamber, which puts the coating under the designated pressure. These pumps are ratioed. For every pound of pressure that is regulated into the spray pump, the pump generates a given paint pressure. For example, an airless spray pump that is ratioed at 60:1 will produce 60 psi of paint pressure for every pound of air that is regulated into the pump. Therefore, if the coating manufacturer recommends an airless spray pressure of 3,600 psi, then the pressure regulator should be set at 60 psi ($60 \times 60 = 3,600$). Pumps as high as 74:1 can be purchased for application of heavy materials that may not otherwise properly atomize.

The equipment itself consists of a paint pump that is operated using an air compressor (although electric pumps are available) equipped with a regulator. Coating manufacturers provide recommended airless spray pressures that are frequently adjusted based on project conditions (amount of thinner addition, paint temperature, etc.). A single hose containing the paint traverses from the pump to the spray gun. There are no controls on the spray gun. In fact, the only way to control the shape of the spray fan is to change the spray tip. Most tips are identified using a 3-digit number; the first number is doubled to obtain the width of the spray fan at 12 inches from the surface, and the remaining 2 digits indicate the orifice size of the spray tip. For example, the orifice of a 521 tip is 0.021 inches, and the fan width is 10 inches when the spray tip is maintained 12 inches from the surface. An airless spray gun cannot be “half-triggered” the way the conventional or HVLP guns can.



The operating pressures of airless spray gun are considered dangerously high, and paint can be injected beneath the operator’s skin if fingers are held too close to the spray tip and the trigger is pulled. Use of a special-color (typically

bright orange or yellow) guard attached to the tip and a trigger lock can help prevent these types of injuries.

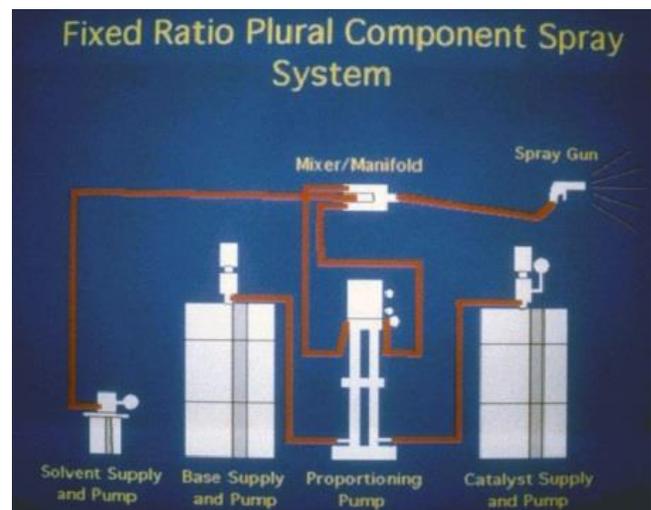
The recommended distance that the airless spray gun is held from the surface is 12-18 inches but varies depending on the type of coating and prevailing spraying conditions.

Air-Assisted Airless Spray

Air-assisted airless spray combines the productivity of airless spray with some of the control of conventional spray. An “air cap” attached to the exit port of the spray gun is used to help atomize the coating and to shape the spray fan. One control knob located on the back of the spray gun is used to adjust the pattern shape. Compressed air cleanliness is once again critical to coating quality. Air-assisted airless spray operates at slightly lower pressures than traditional airless spray.

Plural Component Spray

Plural component spray is used for coating materials with a relatively short pot life or coating materials that do not have viscosity-reducing solvents in them (e.g., 100% solids materials). Plural component spray does not require “pre-mixing” of the coating components. Rather, the individual components are pumped to a mixer/manifold at the correct ratio, then are mixed and traversed to the spray gun using a short material hose that can be flushed with solvent using a purge system. This is known as an internal mix process. There are also external mix plural component systems that send each component to the spray gun in separate material hoses. The components blend as they exit the spray tip. It is common for the material hoses to be heated for plural component spray, to reduce the viscosity of the components (for easier transport through the material hoses and improved atomization). The use of heat to reduce the viscosity of the components is analogous to the motor oil in your vehicle’s engine that reduces in viscosity as it increases in temperature.



Plural component spray is available in two basic designs: fixed ratio and variable ratio proportioning pumps. Fixed ratio pumps can only proportion the components in a set ratio (e.g., 1:1), while a variable ratio pump can proportion the materials according to the required ratio (e.g., 2:1, 4:1, 8:1, 16:1 and so on...). Plural component spray equipment can be complex and typically requires a technician to set-up the equipment and to monitor the mix ratio, so that the coating materials are not applied “off-ratio.” Most plural component “rigs” now contain an off-ratio alarm that alerts the applicator when the ratio of the components is incorrect. This prevents the applicator from applying under or over catalyzed coating to the surface. Some contractors have employed plural component spray systems even when using multi-component coatings that could be mixed prior to application and have a fairly lengthy pot life. In this case, plural component spray is being used to minimize waste and reduce material usage. That is, by keeping the components separated, the cans containing the individual components can be resealed and used another time, rather than having to discard unused material. Further, the coating will not need to be reduced, since heat can be used to reduce the viscosity of the components. Note that coatings requiring an induction time cannot be applied using plural component spray equipment.

Electrostatic Spray

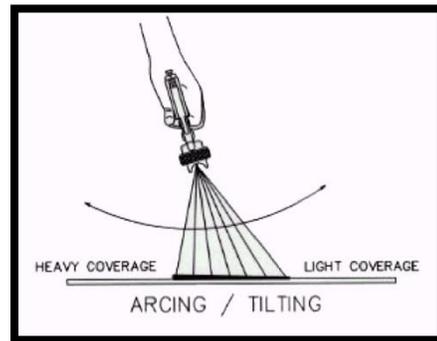
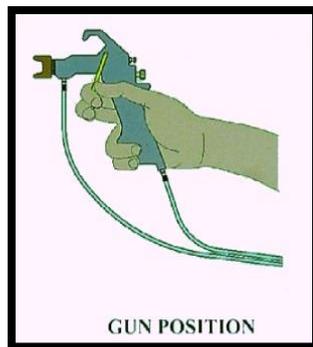
Electrostatic spray is rarely used to apply industrial coatings. However, it is worth mentioning because of its potentially high transfer efficiency rate, and the resulting reduction in material usage. In principal, the paint particles (frequently powder) are energized (+) as they exit the spray gun. The electrical charge is imparted by a small wire protruding from the spray nozzle. The surface to be coated is grounded (-). The particles are “attracted” to the component or part having the opposing electrical charge, significantly reducing overspray and material usage. The coating however must be able to accept an electrical charge, and the addition of a polar solvent to liquid coatings is sometimes required to inhibit the coating’s natural resistivity. Electrostatic spray can also result in a wrapping of the coating on the opposite side of the direction of spray, making it attractive for coating small metal components, etc. However, because of the inherent difficulty in achieving a uniform ground on large structures, electrostatic spray has not been widely used to coat industrial structures. Electrostatic spray equipment is typically set-up to spray as an airless operation, although air-assisted airless is available.

Spray Technique

Spray technique cannot typically be taught in a classroom, but rather by practice and experience with the spray equipment using different industrial coatings to various configurations. In fact, many automotive coating applicators struggle with industrial coatings application, as the techniques and equipment can vary considerably. It is not the intent to teach application techniques in this course, but rather to inform the inspector of the techniques that applicators should demonstrate.

Remain Perpendicular to the Surface; Maintain Proper Distance

It is important that the spray gun be positioned perpendicular to the surface to be coated, and that the applicator maintain this position throughout the application process (to the extent feasible) to build a consistent coating layer. If the applicator does not remain perpendicular to the surface, then light and heavy areas will likely result. The applicator must also maintain the proper distance from the surface, which varies depending on the application equipment (conventional, airless, etc.) Spray distances were discussed earlier in this Module.



Use Overlapping and Crosshatch Spray Techniques

The quantity of coating material exiting the spray gun tip varies, due to the atomization air that creates a fan-shaped spray pattern. That is, the amount of material in the center of the fan is greater than the amount of material at the ends of the fan pattern. This variation can only be corrected by the applicator. Once the applicator makes the first pass (e.g., left to right), the applicator should overlap the previous pass by approximately 50% when making the second pass (e.g., right to left), then overlapping that pass when making the third pass (left to right again) and so on. This overlapping technique is important. It helps to ensure an even film build and will improve the consistency of coating thickness.

The applicator can alternate between horizontal and vertical passes, overlapping each type of pass by 50% as described above to build an even more consistent film. This is called a crosshatch spray technique.

Inspection of Mixing, Thinning and Application of Coatings

Next to surface preparation, the inspection of mixing, thinning and coating application procedures can make or break a coatings project. Typically, a lot of time, money and effort are expended to properly prepare a surface for coating. These efforts and dollars can be wasted very quickly if a product is mis-mixed, an inappropriate type or amount of thinner is used, or poor application technique is employed. These mistakes can result in the need to remove newly applied coatings. Inspection of these procedures as they are occurring can help reduce the number of premature coating failures and the amount of rework.

The inspection of mixing, thinning and application includes the following checkpoints.

- Measuring ambient conditions and surface temperature
- Inspecting mixing procedures
- Inspecting thinning procedures
- Measuring wet and dry film thickness
- Assessing intercoat cleanliness
- Verifying recoat times and temperatures
- Detecting pinholes and holidays
- Assessing cure

Measuring Ambient Conditions and Surface Temperature

The measurement of air temperature, relative humidity, dew point temperature, and surface temperature is required before and during coating application activities. Air or surface temperatures above/below the manufacturer's specified range, as well as excessive or inadequate moisture levels in the air (relative humidity) can contribute to application challenges, inadequate curing and performance problems. In addition, a surface temperature at or below the dew point temperature can result in moisture condensation on the surface. Therefore, it is important to verify that the temperature of the surfaces to be coated is at least 5°F (3°C) higher than the temperature of the dew point (and rising), and to verify

that the air and surface temperatures, as well as the relative humidity, are all within the coating manufacturers specified range and/or as required by the project specification.



These values (air temperature, relative humidity, surface temperature and dew point temperature) can be obtained using sling or battery-powered psychrometers in conjunction with US Weather Bureau Psychrometric Tables and surface temperature thermometers; or can be obtained using direct read-out electronic psychrometers equipped with surface temperature probes. The step-by-step use of this instrumentation is described in the instrument use supplement. It is important that the inspector not rely on prevailing weather conditions from a local service (e.g., local weather station or weather.com) as conditions at the project site can vary considerably. Ambient conditions should be measured and recorded prior to mixing the coating materials and at 4-hour intervals thereafter, unless conditions appear to be declining. In this case, more frequent checks may be required. If coating work will be done inside a facility, tank, or containment, then the prevailing ambient conditions *inside* of these areas (at the actual location of the work) should be assessed. The location, date, time of day and the conditions of air temperature, relative humidity, dew point temperature, and surface temperature should be recorded. A wind meter can be used to monitor wind speed if required by the project specification.



Inspecting Mixing Procedures

Prior to mixing the coatings, the materials should be checked to verify that they are within the manufacturer's shelf life. Using coating materials beyond the shelf life or "expiration date" can result in mixing and application difficulties as well as poor coating performance, and it is likely that the material will not be warrantied.

The person mixing the coating materials should be knowledgeable in mixing procedures for various generic coating types and should both read and comprehend the coating manufacturer's written instructions for mixing. All liquid components should be thoroughly blended using a mechanical mixing blade (e.g.,

Jiffy mixer). If the coating to be applied is multi-component, the inspector must assess whether partial kit mixing is permitted. Most of the time, the mixing of partial kits is prohibited by the manufacturer and/or the project specification. If permitted, the mixer will need to determine whether the components should be blended by weight or by volume. If by weight, then a scale is required to weigh-out the individual components. If by volume, then graduated containers are required so that the individual components can be measured out. The mixing of partial kits should be discouraged, as ratio errors and approximate measurements can lead to under/over catalyzed coatings.

Mixing Zinc Primers

Zinc-rich primers containing a zinc powder component require special mixing procedures. After blending the liquid component(s), the zinc powder is slowly sifted into the liquid while under agitation. It is important not to reverse this procedure (empty the liquid into the zinc powder). After the zinc powder is thoroughly blended into the liquid components, the mix should be strained through a fine mesh screen to remove any un-wetted zinc particles that may clog the spray tip. Straining of other coatings (non-zinc-rich) is usually not necessary unless required by the project specification.

Measuring Coating Temperature

After all of the components are thoroughly blended, the temperature of the mixed coating can be measured using a paint thermometer, which contains an 8” long, stainless steel stem and a clip for attaching the thermometer to the side of the paint can. After a minimum of three minutes, the temperature of the coating can be read from the thermometer and recorded. The temperature of the coating material is important, since the induction time and the pot life are both based on the temperature of the coating, not the air or surface temperature.

Induction Period

Some coatings require an induction period. Also known as sweat-in, cook time, and digestion, this represents a specific period (after blending of the components but before application) that the coating must chemically react or “simmer.” Without this induction time, the coating may not cure properly, and the applicator may encounter application difficulties (e.g., sagging, etc.). Not all coatings and not all manufacturers require an induction time. It is based on the formulation of

the material. If required, the time period and material temperature will be indicated on the manufacturer's product data sheets, typically under the "mixing" instructions. Generally, the warmer the material, the shorter the induction time that is required. Conversely cooler materials will require a longer induction time. Induction time is part of the pot life. A coating with a four-hour pot life at 75°F and a 30-minute induction at the same temperature has a usable potlife of only 3 ½ hours.

Pot Life

The pot life of a multi-component material is the period (starting immediately after mixing the components together) that the coating is usable. The pot life varies depending on the manufacturer and the formulation of the coating and can range from a few minutes to 24 hours or more. Once the pot life has expired, any remaining coating should not be used.

Coating Agitation

Because of the density of the zinc particles, most multi-component zinc-rich primers require that the spray pot be constantly agitated to keep the zinc in liquid suspension. If agitation is disregarded, the zinc pigment will fall-out of the mixed product and collect on the bottom of the spray pot or container. The inspector should verify that pot agitation is employed when required by the manufacturer and/or the project specification. Single-component (moisture-cure urethane zinc primers) do not require pot agitation. In fact, agitation of the pot or container can entrain moisture from the air and cause the coating to gel.

Inspecting Thinning Procedures

Strict air quality regulations prevalent throughout the U.S. dictate that the type and amount of thinner added to the coating be monitored. If thinning is permitted by the coating manufacturer and by the project specification, then only the manufacturer's recommended type and amount of thinner can be used. Use of alternate thinners or over-thinning a coating can result in application difficulties, premature coating failure, and violation of local/Federal air quality regulations. If thinning is permitted (and is necessary), the inspector should verify the correct type of thinner is used and should verify that graduated containers are used to measure the quantity of thinner (e.g., one pint per gallon, 10% of the total volume

mixed, etc.). Thinner addition for the purpose of reducing the viscosity of the coating material to “extend” the pot life is not recommended and may adversely affect coating performance. The only way to extend the pot life is to reduce the material temperature to retard the rate of reaction. The type and amount of thinner added, including the batch number of the thinner should be documented.

Measuring Wet Film Thickness

Theoretically, an accurate measurement of the wet film thickness, together with the volume solids content of the coating will correspond to the targeted dry film thickness. Applicators should routinely verify that the targeted wet film thickness of the coating is being achieved during application, which is why a wet film thickness gage is regarded as much of an applicator’s tool as a paint brush or spray gun. The standard for measuring wet film thickness is ASTM D4414, “Practice for Measurement of Wet Film Thickness by Notch Gages.” Calculation of the target wet film thickness as well as the proper use of a wet film thickness notch gage are described in the instrument use supplement.



Measuring Dry Film Thickness

While the applicator is concerned with the wet film thickness of the applied coating, the inspection personnel are much more concerned with the dry film thickness. The measurement of wet film thickness is simply a means to an end on most metal surfaces, where measurement of the dry film is feasible. Currently there are four standards that address the nondestructive measurement of coating thickness: SSPC PA2, “Procedure for Determining Conformance to Dry Coating Thickness Requirements,” ASTM D7091, “Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals,” ASTM D 6132, “Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Applied Organic Coatings over Concrete Using an Ultrasonic Gage,” and SSPC PA9, “Measurement of Dry Coating Thickness on Cementitious Substrates.” The ASTM standards describe methods for verifying the accuracy of the measuring devices and for obtaining coating thickness measurements, while the SSPC standards provide requirements for the

frequency of measurements (number of measurements to obtain based on the size of the coated area) and places limits on the thickness readings obtained versus the specification requirements.

Coating thickness measurements should be obtained after the application of each coat in a multiple coat system, not just after the final coat. Nondestructive coating thickness gages cannot distinguish individual coating layers, but rather measure the total “gap” between the substrate and the gage probe.

The process of measuring coating thickness involves 5 or 6 very basic steps:

- Step 1: Gage Selection
- Step 2: Instrument Calibration
- Step 3: Verification of Gage Accuracy on Certified Coated Standards or Certified Shims
- Step 4: Base Metal Reading Acquisition or Gage Adjustment (using certified or measured shims)
- Step 5: Measurement of Coating Thickness
- Step 6: Correction for Base Metal Reading (if acquired).

Each of these steps will be described in this section.

Gage Types

SSPC-PA 2 and ASTM D7091 addresses two types of dry film thickness gages both are supplied by a variety of manufacturers. Magnetic pull-off gages are categorized as Type 1. These gages were designed in the 1950's and while their use has declined, they are still readily available and used. For these gages, a permanent magnet is brought into direct contact with the coated surface. The force necessary to pull the magnet from the surface is measured and converted to coating thickness, which is displayed on a scale on the gage. The operating principle is quite simple. Less force is required to remove the magnet from a thick coating, while more force is required to remove the magnet from a thinner one. The scale is not linear.

Electronic gages are categorized as Type 2. These gages use electronic circuitry to convert a reference signal into coating thickness. They are typically regarded to be faster, more accurate and easier to use, compared to Type 1 gages.

Gage Calibration, Accuracy Verification and Adjustment

To help assure the reliability of the coating thickness measurements, ASTM D 7091 describes three operational steps that must be performed prior to coating thickness measurement. These steps include (1) gage calibration, (2) verification of gage accuracy and (3) gage adjustment. These steps are incorporated by reference in SSPC-PA 2 and are completed before obtaining coating thickness measurements to determine conformance to a specified coating thickness range. The steps to verify the accuracy of the gage are based on the principle that you check the gage by measuring a known thickness before you use the same gage to measure an unknown thickness. Verification of gage accuracy is typically performed using certified coated thickness standards (for Type 1 or Type 2 gages) or certified shims on a smooth surface (Type 2 gages). Adjustment of Type 2 gages to compensate for substrate characteristics (described later) can be performed using certified shims. Measured shims (individually labeled with a stated thickness value) commonly supplied with Type 2 gages can also be used for gage adjustment.

Dry film thickness gages are *calibrated* by the equipment manufacturer, their authorized agent or an accredited calibration laboratory (under controlled conditions). A test certificate or other documentation showing traceability to a national metrology institution is required. While there is no standard time interval for re-calibration, an interval is usually established based upon experience and the work environment. A one-year calibration interval is a typical starting point suggested by gage manufacturers.

Verifying Gage Accuracy

To guard against measuring with an inaccurate gage, SSPC-PA 2 requires that gage accuracy be verified (at a minimum) at the beginning and end of each use (e.g. work shift) according to the procedures described in ASTM D 7091. If a large number of measurements are being obtained, the user may opt to verify gage accuracy during measurement acquisition (for example, hourly). If the gage is dropped or suspected of giving erroneous readings during use, its accuracy should be rechecked.

Verifying the Accuracy of Type 1 Gages

The accuracy of Type 1 (magnetic pull-off) gages is verified by placing the gage probe onto a certified coated thickness standard. A one-point or two-point

accuracy verification procedure can be performed; typically, the two-point verification provides greater accuracy. If a one-point verification procedure is adopted, the coated standard should be selected based on the intended range of use. For example, if the intended use is between 4 and 6 mils, then a 5-mil coated standard is appropriate. Using the same example, if a two-point verification procedure is adopted, then a 2 -mil and an 8-mil set of coated standards (slightly below and above the intended range of use) is appropriate.

The final step in the process is to obtain a set of base metal readings (BMRs) to compensate for substrate characteristics including (but not limited to) substrate metallurgy, geometry, thickness/thinness and roughness. These readings represent the effect of the substrate conditions on the coating thickness measurement device. SSPC-PA 2 states that a minimum of 10 (arbitrarily spaced) locations should be measured (one reading per location), then averaged. This average base metal reading is then deducted from subsequent coating thickness measurements to remove any effect of the base metal surface and its conditions.

Since Type 1 gages cannot be adjusted by the user, it was thought that a “correction value” could be applied to the coating thickness readings to compensate for the inaccuracy of the gage. For example, if a gage reads 5.7 mils on a 5-mil coated standard, a 0.7-mil “correction value” could be deducted from subsequent coating thickness measurements. However, since the scale on Type 1 gages is non-linear, one cannot assume a linear correction value across the full range of the gage. While the gage may be out of tolerance by 0.7 mil at 5 mils, it may be out of tolerance by a greater or lesser amount at a different thickness. Accordingly, SSPC-PA 2 states that this practice is not appropriate. However, Note 6 in the standard states, *“A correction curve can be prepared by plotting the actual gage readings against the stated values on the (coated) test blocks (standards). Subsequent coating thickness measurements can be “corrected” by plotting the measurements along the correction curve. The correction curve may or may not cover the full range of the gage but should cover the intended range of use. The Base Metal Readings (BMR) described in 6.1 may also need to be plotted on the correction curve.”* This requirement makes Type 1 gages more challenging to use. While some users may simply subtract a fixed amount (e.g., 0.5 mils) from any reading, such a practice is not in compliance with SSPC-PA 2.

Verifying the Accuracy of Type 2 Gages

The accuracy of Type 2 (electronic) gages can be verified by placing the gage probe onto a certified coated thickness standard (described for Type 1 gages) or certified shims. The certified shim should be placed onto a smooth, uncoated

metal surface to remove any effect of the surface roughness during this process. A one-point or two-point accuracy verification procedure can be performed (as described for Type 1 gages).

Adjusting Type 2 Gages

The final step in the process is to *adjust* the gage on the surface to which the coating will be applied. This is accomplished by placing a certified or measured shim (or shims) onto the prepared, uncoated metal surface and adjusting the gage (when feasible) to compensate for substrate characteristics including (but not limited to) substrate metallurgy, geometry, thickness/thinness and roughness. The gage reading is adjusted to match the thickness of the shim, which effectively removes any influence from the underlying surface.

This step sounds reasonably straightforward but poses several “hidden” challenges. First, once the surface is coated (e.g., with a primer), an uncoated surface may no longer be available for subsequent gage adjustments, so the user may want to have a similar surface prepared and reserved for future gage adjustments on a given project. Naturally this surface must be representative of the metallurgy, geometry, thickness/thinness and roughness of the actual surface, which can be challenging to acquire. Secondly, some Type 2 gages cannot be adjusted. In this case, the user will need to obtain base metal readings (BMR) from the prepared, uncoated substrate (described earlier for Type 1 gages). While many Type 2 (electronic) gages have a “zero-set” function, the gages should never be adjusted to zero unless the surface is smooth.

Measurements to Determine Conformance to a Specification

This section of SSPC-PA 2 is where many users get confused, which can result in either under or over-inspection. One of the most critical sections in the SSPC-PA 2 Standard is Section 8, which describes how many areas to check, the size of the areas, the number of measurements to obtain in each area and what steps to take if spot or area measurements do not conform to the specification.

SSPC-PA 2 contains three definitions that are critical to understanding this next area of discussion. They include:

Gage Reading: A single instrument reading.

Spot Measurement: The average of at least three gage readings made within a 4 cm (~1.5 inch) diameter circle. Acquisition of more than three gage readings within a spot is permitted. Any unusually high or low gage readings that are not

repeated consistently are discarded. The average of the acceptable gage readings is the spot measurement.

Area Measurement: The average of five spot measurements obtained over each 10 m² (~100 ft²) of coated surface, or portion thereof.

An area is defined as approximately 100 square feet. Within each area, five randomly spaced spots are selected. Each spot consists of a 1 ½ inch diameter circle. A minimum of three gage readings are obtained in each spot, culminating in a minimum of fifteen gage readings within an area. Unusually high or low gage readings that cannot be repeated consistently are discarded. The average of the three acceptable gage readings is the spot measurement.

The number of areas that must be measured for coating thickness varies, depending on the size of the coated area. There are three categories of coated area: less than 300 square feet; 300-1,000 square feet; and greater than 1,000 square feet. For areas containing less than 300 square feet of coated surface, every 100 square foot area must be measured for coating thickness. For areas of coating 300 to 1,000 square feet, three random areas are selected and measured. For areas of coating exceeding 1,000 square feet, three random areas are selected from the first 1,000 square feet, plus one additional area for each additional 1,000 square feet.

Because areas of coating often exceed 1,000 square feet, our example will be based on this third tier (> 1,000 square feet). Let's assume that the total coated area (perhaps the area coated during a work shift, although SSPC-PA 2 does not equate coated area with work shift) is 12,500 square feet. A total of 15 areas must be measured (3 in the first 1000 square feet and one additional area in each remaining 1000 square foot area or portion thereof; in this example 12). This culminates in a total of 75 spot measurements (15 x 5) and a minimum of 225 gage readings (15 x 5 x 3). If spot measurement variances result in area measurements that do not meet the specification, then additional spot measurements are acquired (radiating outward in eight directions from the non-conforming area) to determine the magnitude of the non-conforming thickness. This process is described later in this article.

Acceptability of Gage Readings, Spot Measurements and Area Measurements

While individual gage readings that are unusually high or low (and cannot be repeated consistently) can be discarded, there are limitations on the thickness

values representing the spot measurements (the average of three gage readings). A minimum and a maximum thickness are normally specified for each layer of coating. However, if a single thickness value is specified and the coating manufacturer does not provide a recommended range of thickness, then the minimum and maximum thickness for each coating layer is established by SSPC-PA 2 at +/- 20% of the stated value. For example, if the specification requires 3 mils dry film thickness and the coating manufacturer does not provide any additional information regarding a recommended thickness range, then by default the specified range is established as 2.4-3.6 mils. Therefore, it is important for the specifier to indicate an acceptable range for each coating layer, as the coating may not perform at the lower thickness. SSPC-PA 2 incorporates a Restriction Level Table, that enables the specifier to select from five different restriction levels related to spot and area measurements.

Coating Thickness Restriction Levels

Thickness	Gage Reading	Spot Measurement	Area Measurement
Level 1			
Minimum	Unrestricted	As specified	As specified
Maximum	Unrestricted	As specified	As specified
Level 2			
Minimum	Unrestricted	As specified	As specified
Maximum	Unrestricted	120% of maximum	As specified
Level 3 (Default)			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	120% of maximum	As specified
Level 4			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	150% of maximum	As specified
Level 5			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	Unrestricted	Unrestricted

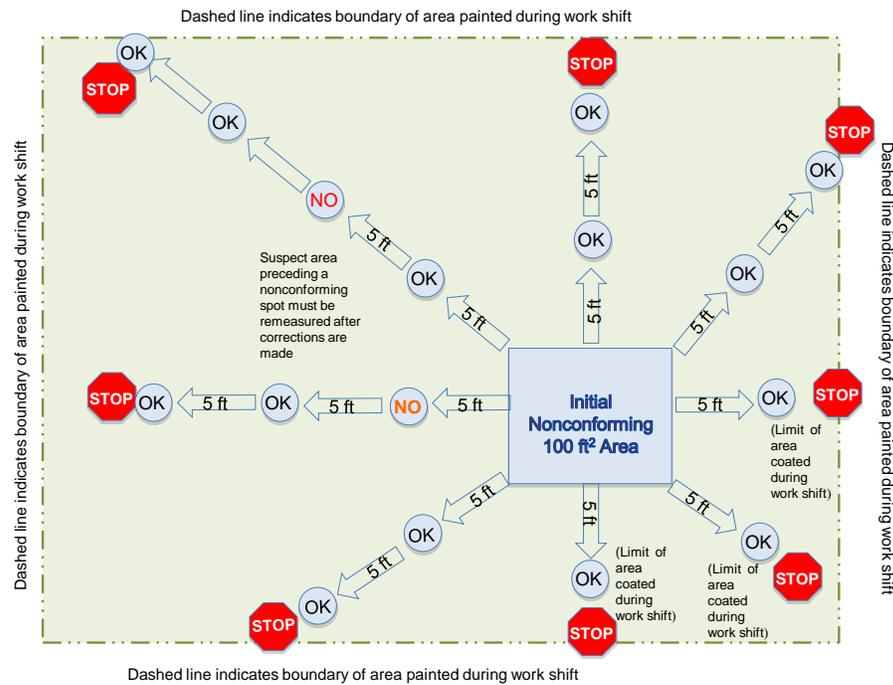
Level 1 is the most restrictive and does not allow for any deviation of spot or area measurements from the specified minimum and maximum thickness, while Level 5 is the least restrictive. Depending on the coating type and the prevailing service environment, the specifier can select the dry film thickness restriction level for a given project. The specifier may also invoke a maximum thickness threshold for Level 5 Spot or Area measurements for a generic product type and/or service

environment that will not tolerate an unlimited thickness. If no Restriction Level is specified, then Level 3 is the default.

For the purpose of final acceptance of the total dry film thickness, the cumulative thickness of all coating layers in each area must be no less than the cumulative minimum specified thickness and no greater than the cumulative maximum specified thickness.

Determining the Magnitude of Non-Conforming Thickness

If a non-conforming area is identified, spot measurements are made at 5-foot intervals in eight equally spaced directions radiating outward from the nonconforming area as shown in the figure below (courtesy of SSPC).



If there is no place to measure in a given direction, then no measurement in that direction is necessary. Spot measurements are obtained in each direction (up to the maximum surface area coated during the work shift) until two consecutive conforming spot measurements are acquired in that direction, or until no additional measurements can be made. Acceptable spot measurements are defined by the minimum and maximum values in the contract documents. That is, no allowance is made for variant spot measurements (e.g., +/- 20%), which is consistent with the practice followed when determining the area DFT.

On complex structures or in other cases where making spot measurements at 5-foot intervals is not practical, spot measurements are taken on repeating structural units or elements of structural units. This method is used when the largest dimension of the unit is less than 10 feet. Spot measurements are obtained on repeating structural units or elements of structural units until two consecutive units in each direction are conforming or until there are no more units to test.

Non-compliant areas are demarcated using removable chalk or another specified marking material and documented. All of the area within five feet of any non-compliant spot measurement is considered non-compliant. For a given measurement direction or unit measurement, any compliant area or unit preceding a non-compliant area or unit is designated as suspect, and as such is subject to re-inspection after corrective measures are performed.

Measuring the Thickness of Individual Layers

The thickness gages discussed to this point all measure the dry film thickness of a coating *non-destructively*. However, these coating thickness gages cannot distinguish the thickness of individual layers after all of the coats have been applied; they can only measure the “gap” between the gage probe and the metal substrate. This gap is represented by all layers applied to the substrate (e.g., primer, intermediate coat and topcoat), which is why it is so important to measure the thickness of each coat after it is applied, but before the next layer is applied. This way, there is some indication that each layer was applied to the correct thickness.

Occasionally, the inspector may need to measure the thickness of the individual layers (e.g., primer, intermediate coat and topcoat) after they have all been applied. using a device called a Tooke Gage.

Tooke Gage

The Tooke Gage (named after the inventor) conforms to ASTM D4138, “Test Method for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Cross-Sectioning Means.” It consists of a gage body and battery compartment, a 50x illuminated ocular with a reticule inside the lens, a focus adjustment for the ocular and three tungsten carbide precision cutting tips. The Tooke Gage is unaffected by the type of substrate, the effect of the



Tooke Gage

base metal, and its' roughness. The Tooke Gage is destructive, in that it makes an incision or groove (about the width of a line drawn with a pencil) through the coating film down to the substrate, and it cannot be used to measure coating thickness beyond 50 mils.

The Tooke Gage measures coating thickness using basic trigonometry. That is, by cutting a precision “V” groove into the coating system using one of the tungsten carbide cutting tips, a right triangle is created. The angles of the right triangle are known. By measuring the length of one leg of the triangle, the user can calculate the length of the other leg, which represents the coating thickness. If the coating layers are different or alternating in color, then each layer can be both seen, and the thickness measured through the Tooke Gage lens. There are 10 basic steps to follow when using the Tooke Gage:

Step	Operation
1	Determine the thickness range you will be measuring
2	Create a benchmark on the top of the coating
3	Select a cutting tip
4	Position the cutting tip
5	Cut a groove into the coating film using the cutting tip you selected in Step 3
6	Locate the groove through the illuminated, 50X ocular
7	Line-up the scale divisions on the reticule so that they are parallel with the groove length
8	Count and record the number of layers on the surface
9	Count and record the number of divisions on the scale that overlay each layer
10	Convert divisions to mils*

Note: Tooke Gages with a “Universal Ocular” (designated with the Model No. OG204-U) employ a different conversion table when converting ocular divisions to mils, microns or millimeters. Distribution of these models began in late 2010.

Model OG204-U: Each Division Equals:			
Unit	1X Tip	2X Tip	10X Tip
Mils	2	1	0.2
Micrometers	40	25	5
Millimeters	0.05	0.025	0.005

Assessing Intercoat Cleanliness

Airborne dirt and dust are common on industrial painting sites and may become deposited onto the coated surfaces. Dust is not a problem unless the surface is scheduled to be recoated. In this case, a visual or tactical (touch) examination of the surface is required to help prevent intercoat contamination and potential adhesion issues. Surface dust/debris can cause subsequent applied coatings to fisheye (inability to wet the surface) and, in sufficient quantities, can cause intercoat delamination.

Verifying Recoat Times/Temperatures

Coating materials typically have both a minimum and a maximum recoat time. This time period is often based on the prevailing air and surface temperature, as well as the relative humidity. The inspector must verify that the coating has been allowed to dry or cure the minimum amount of time, and ensure the next coat is applied before the maximum recoat time. Otherwise, pressure washing, and mechanical etching of the surface may be required to achieve mechanical bonding between the coating layers.

Detecting Pinholes and Holidays

Project specifications for coating the interior of storage tanks and vessels, railcars, or for the application of coatings and linings to liquid and gas pipelines frequently require a continuous, holiday and pinhole-free coating or lining system. Rather than relying on a visual inspection, holiday/pinhole detectors are used to determine the number and location of skips, misses, and pinholes, so that they can be repaired prior to placing the tank, vessel, railcar, or pipeline into service. If holiday testing is not performed, and there are undetected voids in the coating or lining system, then the contents of the tank, vessel, railcar, or pipeline may attack the exposed substrate and cause pitting corrosion, loss of section and eventual perforation of the substrate. In addition, the contents may become contaminated with corrosion products and coating/lining debris if deterioration occurs. Holiday testing is governed by two industry standards: ASTM D5162, “Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates” and NACE SP0188, “Standard Recommended Practice-Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates.”

What are Pinholes and Holidays?



*Inspecting the Coated Surface
for Holidays and Pinholes*

The terms “pinhole” and “holiday” are used interchangeably. However, they represent two different types of “breaches” in the coating/lining system. **Pinholes** are tiny voids in the coating or lining. These voids may enable the contents of the tank, vessel or pipeline 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 permit easy access to the unprotected substrate.

Pinholes are usually caused by poor wetting of the coating/lining on the surface during application, or out-gassing (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 or lined (e.g., 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, rough welds, bolts, nuts and threads, behind angles and clips, inside holes, between back-to-back angles, etc. Large, flat surfaces like the shell of a tank or vessel are easier to coat, and therefore usually contain fewer pinholes and holidays.

When is Holiday Detection Performed?

Pinhole or holiday detection is usually conducted after the final coat has been applied, but before it has achieved complete cure, in case repair of the coating film is required. Some project specifications require holiday testing before the application of the final coat. If this is done, intercoat cleanliness of the surfaces must be verified prior to application of the final coat, and a wetting agent should not be used with the holiday detector, as the coated surfaces can become contaminated and may result in intercoat adhesion problems.

Selecting a Holiday Detector

There are two different types of holiday detectors. Low voltage or “wetted sponge” holiday detectors are used on coatings/linings that are less than 20 mils thick. High voltage holiday detectors or “spark testers” are 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 could not (zinc is a conductive metal in the coating). Some high voltage detectors can be used on non-conductive coatings applied to concrete.

The step-by-step use of low voltage and high voltage holiday detectors is described in the instrument use supplement.

Calculating Test Voltages for High Voltage Holiday Detection



Unlike low voltage holiday detection that is typically performed with a detector set to 67.5 volts, high voltage holiday detection requires the inspector to calculate and set the voltage on the detector prior to performing holiday/pinhole detection. ASTM D5162 contains the formula for determining the correct voltage setting:

$$K * \sqrt{T_c}$$

T_c: Coating Thickness

K: Constant: 525 for coatings < 40 mils; 1250 for coatings > 40 mils

Example: Coating Thickness is 45 mils

Square Root of 45 is 6.7; 1250 * 6.7 = 8375 V, or 8.4 kV

Assessing Coating Cure

Prior to application of subsequent coats, or prior to placing the lining system into service, many specifications require that the coating/lining be assessed for proper cure. Coatings and linings cure in a variety of ways, including solvent evaporation (air dry), oxidation (reaction with oxygen), polymerization (chemical cross-linking) and moisture cure (reaction with moisture). If a coating or lining system is placed into service before it is fully cured, it may exhibit a reduced service life or may catastrophically fail.

ASTM has four test methods that can be employed to evaluate drying or curing of coatings. Each of these test methods is briefly described below. Prior to

conducting any of these tests, the inspector should carefully read the applicable ASTM test method and acquire the necessary equipment/supplies.

Coatings and linings can be evaluated for “drying” according to the procedures described in ASTM D1640, “Standard Test Methods for Drying, Curing, or Film Formation of Coatings.” The standard includes test procedures for evaluating set-to-touch, dust-free, tack-free, dry-to-touch, dry-hard, dry-through and dry-to-recoat.

ASTM D3363, “Test Method for Film Hardness by Pencil Test” can also be used to assess the drying characteristics of a coating, as indicated by its inherent hardness. Pencils containing various hardnesses of lead (shown below), from very soft (6B) to very hard (6H) are sharpened, then blunted (dressed) using a fine sandpaper. The pencil is held at a 45° angle to the coated surface and the edge of the blunted lead is pushed into the coated film, attempting to penetrate the coating. If the coating is penetrated, a softer lead is selected, and the coating film is re-tested. If the coating is not penetrated, a harder lead is selected, and the coating film is re-tested. The hardest pencil lead that cannot penetrate the coating is recorded as the “pencil hardness.”

ASTM D3363 Pencil Hardness Scale

6B	5B	4B	B	2B	B	HB	F	H	2H	3H	4H	5H	6H
<i>Soft</i>							<i>Medium</i>						<i>Hard</i>

ASTM D5402, “Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs” can be used to evaluate the cure of any coating which cures by polymerization (chemical cross-linking) or by moisture cure. Briefly, it involves saturating a cloth with solvent (i.e., methyl ethyl ketone) and conducting a series of “double rubs” (one forward and backstroke is one double rub) until a specific number of double rubs is achieved, or until the coating is dissolved by the solvent. ASTM D4752, “Test Method for Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc-Rich Primer by Solvent Rub” describes a similar procedure but is only intended for inorganic (ethyl silicate type) zinc-rich primers.

Durometer hardness (Shore D) is measured according to ASTM D2240. Durometers are frequently used to verify adequate cure of a pipe coating prior to backfilling.



Durometer



Durometer Probe

Measuring Adhesion

Some project specifications may require the inspector to measure the adhesion of the coating system after it has been applied and is cured. Or, the inspector may be required to measure the adhesion of a coating system that has been on a structure for several years, to determine its condition or whether it can be successfully overcoated. In either case, it is important to perform adhesion testing properly. Otherwise the inspector may obtain misleading results. The instrument use supplement describes the procedures for performing two different types of adhesion testing: shear or knife adhesion and tensile or pull-off adhesion. But before conducting an adhesion test, it is important for the inspector to understand what is being measured when the adhesion of a coating is evaluated.

When performing an adhesion test, the strength of a coating at several different “planes” is being measured. First, the adhesion of the coating system to the substrate is being assessed. Second, the adhesion of the coating layers to each other (provided there is more than one layer of coating on the surface) is being assessed. In both cases, the adhesive strength of a coating, or the bond of the layers to one another and to the substrate is being tested. Finally, when performing an adhesion test, the inner-strength of each coating layer is being tested. This is known as the cohesive strength of a coating, or the ability of each layer to hold itself together.

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, which is why there is no industry-wide standard that says that a certain type of coating must have a minimum adhesion or cohesion 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 technical data sheets. Sometimes this value is adopted into a project specification.

Types of Adhesion Testing

Prior to performing an adhesion test, a test method must be selected. The project specification should indicate the required method, as the various methods can generate very different results. There are four adhesion test methods. The chart below summarizes the methods that are commonly used to test the adhesion of industrial coatings.

ASTM Standard	ASTM Test Method
D3359	“Adhesion by Tape Test”
D6677	“Knife Adhesion”
D4541	“Pull-off Strength of Coatings Using Portable Adhesion Testers”
D7234	“Pull-off Strength of Coatings on Concrete Using Portable Adhesion Testers”

The first two methods listed (ASTM D3359 and D6677) do not require any special instrumentation and can be conducted rather quickly. The third and fourth methods (ASTM D4541 and D7234) require an instrument and the attachment of loading fixtures using an adhesive that may need to cure overnight, up to 24 hours.

The tests listed in the table above evaluate two different adhesion properties, and they use different testing mechanisms. The tape and knife adhesion tests (ASTM D3359 and D6677) are used to evaluate the “shear” or “peel” strength of coatings, while the pull-off test (ASTM D4541 and D7234) are used to evaluate a coating’s tensile strength, or its resistance to a perpendicular pull. Since the testing mechanisms are different (peel-back versus pull-off), the test results generated from each test should not be compared. Also, any type of adhesion test is “destructive;” that is, the coating in the test area will be damaged, and oftentimes it must be repaired. Therefore, adhesion testing should not be conducted unless required by the project specification. The specification should include repair procedures for the affected areas.

Module 4 Summary

Next to surface preparation, coating application is one of the most crucial steps in a successful coating operation. If the coating is not properly mixed, thinned and applied, the protection of that coating may be diminished. Therefore, the study and comprehension of both the specification and the manufacturer's recommendations (known as the Product Data Sheet or PDS) are necessary to verify that proper mixing, thinning, and application procedures are followed.

The inspector's role in a coating project varies according to the specification. While there are several checkpoints that could become an inspector's responsibility, the coating specification should spell them out. Common checkpoints *may* include:

1. Performing materials inspection
2. Witnessing and verifying (documenting) the coating mixing and thinning procedures
3. Measuring and documenting ambient conditions and surface temperature
4. Measuring wet film thickness
5. Measuring dry film thickness
6. Verifying re-coat times and intercoat cleanliness
7. Performing pinhole/holiday detection
8. Assessing cure

Coating manufacturer's technical bulletins or **product data sheets (also referred to as the PDS)** contain very useful information about the products being used on the project. While the PDS typically contains critical information about the use of the coating products, in cases where the PDS and the specification differ (say on the maximum humidity during application), *the specification is the governing document.*

Some coating manufacturers list **the target wet film thickness**, while others do not. But even when the targeted wet film thickness is listed on the PDS, this

thickness will change if thinner is added to the product. It is very important for contractors and inspectors to know how to calculate the correct target wet film thickness to arrive at the desired dry film thickness.

Verifying that what was ordered (coating components, thinners, etc.) has been shipped and received at the project site in good condition and in the correct amounts is called **a material receipt inspection**. The contractor should also verify that the coating products are properly stored on the project site prior to use.

Mixing or blending coating products is another essential step in a successful coatings project. Mixing or blending a single component coating is a straightforward process with the main concern being that all pigments and solid materials become suspended in the mix. While some single component coatings require thorough agitation, there are other single component products that do not. Over-mixing moisture-cured zinc rich primers, for example, can bring moisture into the product, which can cause the material to gel in the can. (Since mixing procedures may vary from product to product, always review the PDS prior to mixing.)

The mixing of multi-component products is more complex. Before combining individual components, they must be thoroughly mixed. Power agitation using a mechanical mixing blade is often required.

In the case of multi-component zinc-rich primers, the liquid components are blended, and then the zinc powder is slowly blended in while the entire mix is under mechanical agitation. A final step is the straining of the blend, to remove any zinc particles that did not thoroughly blend into the product and might clog the tip of the spray gun or become lodged in the applied coating film.

Most specifications, as well as coating manufacturers, prohibit the blending of partial kits. This is to prevent the combination of product components in the wrong ratio. Once the components are combined into one container, they must be thoroughly blended by mechanical agitation. Once the coating material is blended, the “pot life clock” begins.

Once the components are blended (and strained, if required), the temperature of the coating should be measured. Some products require an induction or “sweat-in” time, which is necessary to initiate the chemical reaction. Generally, the warmer the coating the shorter the pot life time, since heat increases the rate of the

chemical reaction. Induction time (which is part of the pot life time) is also based on the temperature of the coating material.

The next step in the mixing process is to determine whether the product will need constant, automated agitation during application.

Thinning a coating product impacts the VOC content and the targeted wet film thickness. Even when thinning is permitted, it must be done according to the specification and with the products and ratios recommended on the PDS. There are times when the manufacturer will permit thinning, but the specification will not.

Adding an unknown quantity of thinner to reduce viscosity or to extend the pot life is a poor painting practice that can result in a variety of consequences. This practice does not extend the pot life (it can only be extended by maintaining the product at lower temperatures). The addition of unknown quantities of thinner alters VOC content (but it is no longer measurable), and the target wet film thickness can no longer be calculated, which can result in excessive or insufficient coating thickness. Excessive thinning can cause the coating to sag on vertical surfaces. If the coating should dry or “skin-over” before the solvents have an opportunity to escape, a porous film filled with solvent voids can result.

The method of coating application depends on any number of factors: the size and configuration of the surfaces to be coated, the proximity to other structures, environmental regulations, and the specification and the coating manufacturer’s recommendations.

The use of **brushes** for industrial projects is typically limited to striping: the application of a layer of coating to surfaces where it is difficult to achieve a normal film build. Brushes are also used around rivet heads, welds, bolt and nut assemblies and to “cut-in” inside and outside corners. **Rollers** have a high coating transfer efficiency and can be used to coat large flat surfaces; however, roller nap can become embedded in the dry coating film and pull moisture into the coating, and film thickness is hard to control.

With **conventional (air) spray** the applicator can control both the amount of paint that exits the gun and the shape of the spray pattern. Another advantage is that the gun can be half triggered so that compressed air (without paint) can exit the gun and blow-down the surface to remove dust and debris.

High Volume Low Pressure (HVLP) Spray is similar to conventional spray but uses a much lower atomization pressure, yielding an improved transfer efficiency and lower VOC emissions. Like conventional spray, HVLP can also be half-triggered to blow-down the surface, but since the atomization pressure is low, the blow down may not be adequate to remove heavy deposits of dust.

Airless spray is the most common method used for the application of industrial coatings. It is a very productive method to apply industrial coatings, but it operates using dangerously high pressures. The tip guard and the trigger lock are important safety features. If the equipment is operating correctly, a skilled applicator can create a finish similar to finishes created by conventional spray, but at much higher production rates.

Air-assisted airless spray is an adaptation of airless spray. The addition of atomization air helps control the shape and quality of the spray pattern. The atomization air, as well as the operation of the equipment at lower pressures gives the applicator some of the control of conventional spray.

Plural component spray equipment mixes multi-component coating products either “inside” the spray equipment or as it exits the spray gun. The proportioning pumps come in two basic designs: fixed ratio and variable ratio. This is complex equipment that requires expert maintenance and skilled operators. Typically, plural component spray is used for coating materials with a short pot life and coatings that don’t contain viscosity-reducing solvents, i.e., 100% solids.

Good **spray technique** and the consistency of the coating thickness go hand in hand. Unfortunately, classroom teaching has its limitations as a job-training tool. Experience with the equipment and with a variety of industrial coatings has proven to be the “best teacher.” One technique that applicators must learn is to keep the spray gun perpendicular to the surface. The distance of the gun from the surface will vary according to the type of spray gun used, but the angle of the gun will remain the same. Overlapping technique is also important, because whenever a fan pattern is created, the paint will be thicker at the center of the fan. Only the operator using good technique can correct this characteristic of the spray fan.

Inspection of the mixing, thinning and coating application, whether by the contractor (QC), the owner (QA), or the owner’s representative (also QA), can make or break a coatings project.

Prior to the mix, it is important for the QC personnel to verify that all necessary materials/products/ and equipment necessary for the job are on hand, are within the manufacturer's shelf life (check the expiration dates) and are properly stored.

Prior to the mix and throughout the application process, the measurement of ambient conditions (relative humidity, dew point temperature, air temperature, wind conditions) and the surface temperature helps determine whether the application of the coating can move forward. Often, both the specification and the PDS will contain information on the conditions required to apply each specific coating product. (If the requirements differ on the PDS and the specification, the specification is the governing document.) If a coating must have moisture to cure, too little moisture in the air becomes a problem. Conversely, for some coatings, too much moisture in the air creates a problem. Warm versus cold air and surface temperature ranges are also important issues (check both the specification and the PDS). And wind conditions are important, especially in areas where strong winds are frequent.

Ambient conditions should be measured at regular intervals both before and throughout the application process, and *anytime* the weather conditions appear to be declining. Perhaps the single most important temperature relationship is between the dew point temperature and the surface temperature. To prevent applicators from coating a "damp surface," the surface temperature should be at least 5°F higher than the dew point temperature and rising.

Both the individual responsible for **mixing the coating** and the inspector(s) responsible for verifying the mix, should first read the coating manufacturer's written instructions for mixing. Required documentation of the mix may vary, but typically includes: specific name of the product, batch numbers, time of the mix, amount of each component blended, type of agitation used, and coating temperature once blended. Storage conditions should also be verified and documented. It should also be noted if full kits were mixed. If partial kits were permitted, the measured amounts of each component should be recorded. If a product requires an induction time, the amount of time allowed for the induction to take place should be recorded. Potlife should also be noted. Remember: potlife includes the induction time (when applicable), so the induction time must be subtracted from the potlife to assess the actual time the coating is usable.

When agitation of the coating mix is required according to the PDS (especially with coatings that require constant agitation) the equipment used should be documented. The type of agitation and when the agitation took place (at the

beginning of the mix only, intermittently, or continually throughout the mix) should also be verified and documented.

If thinning is permitted, the type and amount of thinner added should be monitored and documented. If a contractor uses an alternate thinner or exceeds the amount of thinning recommended in the specification or the PDS, the details of these actions also need to be recorded.

Calculating the target wet film thickness (WFT) is necessary to arrive at the correct dry film thickness. And since the PDS often fails to provide a targeted wet film thickness, it is important for both the contractor and the inspector(s) to know how to arrive at the WFT. While measuring and documenting the wet film thickness with a wet film gage is a relatively simple task, calculating the target wet film thickness is more complex.

There are four different standards that apply to the measurement of **dry film thickness (DFT)**. The specification should state which standard applies, but the dry film thickness of each layer in a multi-coat system should be assessed after the application and before the next layer is applied, regardless of the standard utilized. All coating thickness gages, whether Type 1 (magnetic pull-off) or Type 2 (electronic), must be verified for accuracy before use.

SSPC-PA 2, a commonly referenced standard has specific requirements for the number of readings that must be taken according to the amount of the coated area.

Once all the coatings of a multi-coat system have been applied, the only way to assess the thickness of each coat is by using a **Tooke Gage**. The Tooke Gage cuts a groove through the coating layers all the way down to the substrate using one of three precision cutting tips. An inspector can conduct an examination of the coating through the 50x ocular to determine the thickness of each layer. The Tooke Gage can be used to examine a multi-coat system up to 50 mils thick.

Since coating materials typically have both a minimum and maximum recoat time, the inspector must verify that the coating has been allowed to dry or cure the recommended minimum amount of time. The inspector must also verify that the next coat is applied before the maximum recoat time has expired.

Some coatings must perform in challenging service environments and must be continuous: for example, the linings applied to the interior of storage tanks, railcars, and coatings on the exterior of liquid and gas pipelines. Visual

inspection of these coatings would not be adequate, therefore holiday* and pinhole* detectors are used to determine the location of skips, misses, and pinholes. This testing is performed so the coating or lining can be repaired before it is put into service.

***Holidays** are skips or misses in the coating/lining.

***Pinholes** are tiny voids in the coating.

ASTM has several test methods for evaluating or **assessing coating “cure.”** One of these tests is ASTM D3363 “Test Method for Film Hardness by Pencil Test.” Different lead pencils with known “hardness” values are inserted into the coating at a 45° angle. The hardest pencil lead that *cannot* penetrate the coating is recorded as the “pencil hardness” of the coating.

Another test for cure is ASTM D5402, “Assessing the Solvent Resistance of Coatings Using Solvent Rubs.” This method can be used to evaluate any coating that cures by polymerization or reaction with moisture. The method involves a cloth saturated with solvent and a series of “double rubs” until a specific number of double rubs is achieved or until the coating is dissolved by the solvent. ASTM D4752 is also a solvent rub test but is specifically used to evaluate the cure of ethyl silicate-type inorganic zinc-rich primers.

Some specifications require assessing **the adhesion of the coating** system after it has been applied and has cured. Adhesion assessments reveal the adhesion of the coating to the substrate, the adhesion or the bond of one layer of the coating to another, and the inner-strength of the coating or the ability of a coating layer to hold together, also known as cohesive strength.

Different adhesion tests measure different coating adhesion mechanisms (peel back versus pull-off). “Adhesion by Tape Test” (ASTM D3359) and the “Knife Adhesion Test” (ASTM D6677) are used to evaluate the coating’s “shear” or “peel” strength. “Pull-off Strength of Coatings Using Portable Adhesion Testers” (ASTM D4541) and “Pull-off Strength of Coatings on Concrete using Portable Adhesion Testers (ASTM D7234) are used to evaluate the coatings resistance to a perpendicular (tensile) pull. All adhesion testing is destructive and should not be conducted unless required by the specification. The specification should include repair procedures for the affected areas.

MODULE 4 WORKSHOP:

Using Instruments and Standards for Inspection of Coating Application

Station 1: Sling Psychrometer, US Weather Bureau Psychrometric Tables and Surface Temperature

Condition	Reading			
Date				
Time of Day				
Dry Bulb Reading (air temperature or "t")				
Wet Bulb Reading (t')				
Depression of the Wet Bulb Thermometer (t-t')				
Relative Humidity				
Dew Point Temperature				
Surface Temperature				

Note: Use the shaded areas to record the dry and wet bulb readings as they stabilize (i.e., every 15-20 seconds). Base the depression (t-t'), relative humidity and dew point measurements on the stabilized readings in the unshaded blocks.

Station 2: Calculating Wet Film Thickness Targets

Formula A (NO thinner addition)

$$\text{DFT} \div \% \text{ solids by volume} = \text{WFT}$$

Formula B (WITH thinner addition)

$$\text{Step 1: } \% \text{ solids by volume} \div (100\% + \% \text{ thinner added}) = \text{adjusted volume solids content}$$

$$\text{Step 2: } \text{DFT} \div \text{adjusted volume solids content} = \text{WFT}$$

Scenario 1:

The specification requires a dry film thickness of 4 mils. The volume solids content is 87% and no field thinning is permitted. Use Formula A.

Value	Enter Data Here
Specified Dry Film Thickness	
Volume Solids Content of the Coating	
Calculated Wet Film Thickness	

Scenario 2:

The specification requires a dry film thickness of 7 mils. The volume solids content is 68% and no field thinning is permitted. Use Formula A.

Value	Enter Data Here
Specified Dry Film Thickness	
Volume Solids Content of the Coating	
Calculated Wet Film Thickness	

Scenario 3:

The specification requires a dry film thickness of 4 mils. The volume solids content is 87% and the coating will be thinned 10%. Use Formula B.

Value	Enter Data Here
Specified Dry Film Thickness	
Volume Solids Content of the Coating	
Amount of Thinner	
Adjusted Volume Solids Content of the Coating	
Calculated Wet Film Thickness	

Scenario 4:

The specification requires a dry film thickness of 7 mils. The volume solids content is 68% and the coating will be thinned 20%. Use Formula B.

Value	Enter Data Here
Specified Dry Film Thickness	
Volume Solids Content of the Coating	
Amount of Thinner	
Adjusted Volume Solids Content of the Coating	
Calculated Wet Film Thickness	

Station 3 – Use of Type 2 Electronic Coating Thickness Gage

Verify the accuracy of the Type 2 electronic coating thickness gage and measure and record the coating thickness from the test plate provided. First verify the accuracy of the gage using the coated test blocks, then adjust the gage as necessary (to compensate for substrate metallurgy, curvature, roughness, etc.) by placing measured shims on the prepared, uncoated portion of the test plate and adjusting the gage to closely match the thickness stated on the shim(s). You do not need to measure or deduct a BMR, since the gage has been adjusted over the prepared steel surface.

Procedure	Enter Data Here		
Verification of Accuracy (Enter Test Block Value)			
Adjustment (Enter Shim Value)			
Measured Coating Thickness			

Station 4 – Use of the Tooke Gage

Determine the number and thickness of each layer. Record the information below. The incision was made using a 2X cutting tip.

Layer ID	Color	Divisions	Division ÷ Cutting Tip	Mils

Station 5 – Low Voltage Holiday/Pinhole Detection

Assemble the low voltage pinhole detector and inspect the coated plate for pinholes.

Pinholes Present (circle one): YES NO

Station 6 – Durometer Hardness

Verify the accuracy of the Shore D Durometer and determine the average hardness value of the coating.

1	2	3	4	5	Average

Module 4 Quiz

1. The volume solids content of a product can be found in the:
 - A. the specification
 - B. the scope of work
 - C. the PDS (product data sheet)
 - D. the MSDS (material safety data sheet)

2. Prior to primer application, the inspector may be required to:
 - A. test for holidays and pinholes
 - B. verify the coating cure
 - C. document compliance with re-coat times
 - D. document thinning procedures

3. Over mixing of coatings that require moisture to cure can:
 - A. create a product that is too thin
 - B. alter the shelf life of the product
 - C. bring in moisture and cause the product to gel in the container
 - D. Help accelerate the cure of the applied coating film

4. Some multiple component coatings require an induction period, which is:
 - A. when the components of the coating chemically blend
 - B. part of the pot life, but not the “usable” pot life
 - C. subtracted from the pot life to determine the “usable pot life”
 - D. all of the above

5. Shelf life is the period of time:
 - A. that an opened product can be stored and used (from the date of manufacture)
 - B. that an unopened coating product can be stored and used (from the date of manufacture)
 - C. that a multiple component product can be mixed, then stored and used (from the date of manufacture)
 - D. that an opened and resealed product can be stored and used (from the date of manufacture)

6. The information provided by the manufacturer's PDS (product data sheet):
 - A. is carefully regulated by SSPC and NACE
 - B. requires a uniform format
 - C. lists any information a coating manufacturer decides to list in the format of their own choosing
 - D. Is dictated by ASTM

7. When there is conflicting information between the specification and the PDS (product data sheet), for example, a difference between the surface preparation required or the dry film thickness required:
 - A. the specification is the governing document
 - B. the PDS is the governing document
 - C. the contractor can choose to follow the specification or the PDS, as long as he/she documents the choice
 - D. the inspector can choose to follow the specification or the PDS, as long as he/she documents the choice

8. It is a "best practice" to inventory all coating products for a job:
 - A. prior to application
 - B. prior to abrasive blast cleaning
 - C. upon receipt
 - D. At the pre-job conference

9. A material receipt inspection involves:
 - A. opening the products to examine the condition
 - B. conducting tests to verify color and gloss
 - C. verifying that the products ordered for the job were the products received
 - D. Alphabetizing all products prior to storage

10. Most coating manufacturers and project specifications prohibit:
 - A. the blending of multi-component coatings by weight
 - B. the blending of partial kits
 - C. the blending of chemical components
 - D. the use of approved accelerators

11. The mixing of a multi-component zinc rich primer requires:
 - A. thorough agitation of the zinc powder
 - B. sifting of the dry zinc powder into the liquid slowly and evenly
 - C. adding the liquid slowly and evenly into the dry zinc powder
 - D. all of the above

12. An experienced contractor doesn't need to "measure" thinner; they can gage how much to add by the look and feel of the thinned product.
 - A. True
 - B. False

13. According to SSPC-PA 2, what is the minimum number of gage readings that are obtained in each spot?
 - A. Five
 - B. Fifteen
 - C. Ten
 - D. Three

14. According to SSPC-PA 2, what is the number of spot measurements that are obtained in each 100 square foot area?
 - A. Five
 - B. Fifteen
 - C. Ten
 - D. Three

15. SSPC-PA 2 has been invoked by the specification. The surface that was coated is 5,750 square feet. Based on that area, which of the following is correct?
 - A. Eight areas, six spot measurements per area and minimum of four gage readings per spot
 - B. Seven areas, five spot measurements per area and minimum of three gage readings per spot
 - C. Eight areas, five spot measurements per area and minimum of three gage readings per spot
 - D. Five areas, six spot measurements per area and minimum of four gage readings per spot

16. According to SSPC-PA 2 Restriction Level 3, what is the tolerance of the spot measurements?
- A. Unrestricted
 - B. 80% of the minimum thickness and 150% of the maximum thickness
 - C. No tolerance is allowed
 - D. 80% of the minimum thickness and 120% of the maximum thickness
17. Which of the following statements is true regarding low voltage (wet sponge) holiday detection?
- A. Performed on conductive coatings, greater than 20 mils thick, applied to a non-conductive substrate
 - B. Performed on non-conductive coatings, greater than 20 mils thick, applied to a non-conductive substrate
 - C. Performed on non-conductive coatings, less than 20 mils thick, applied to a conductive substrate
 - D. Performed on conductive coatings, less than 20 mils thick, applied to a conductive substrate
18. Calculate the correct voltage setting for a coating that was applied 60 mils thick.
19. Calculate the target wet film thickness using the following data:
DFT: 8 mils
Volume Solids: 59%
Target WFT: _____
20. Calculate the target wet film thickness using the following data:
DFT: 6 mils
Volume Solids: 82%
Thinner added: 12%
Target WFT: _____

Industrial Protective Coatings

Module 5

Learning Outcomes:

- Calculate coating coverage rates and material quantities
- Explain five methods of coating cure:
 1. Solvent Evaporation
 2. Coalescence
 3. Oxidation
 4. Polymerization
 5. Moisture Cure

How this information affects YOU:

Understanding how a coating cures is paramount to thorough inspection, especially as it relates to ambient conditions and surface temperature. For example, if a coating requires moisture to cure and the inspector is focused on verifying a minimum temperature (and not a minimum relative humidity) it may not cure adequately. In addition, verifying that proper amounts of coating have been ordered for a project includes an understanding of how material coverage rates are calculated and how losses due to surface profile (roughness) and application impact material requirements.

Introduction

This module includes an introduction to the primary ingredients in coatings, an explanation of five basic curing mechanisms, and methods used to calculate theoretical and practical coverage rates of coatings (for the purpose of estimating quantities of coating materials required for a project).

Industrial Protective Coatings Versus Paint

A house paint and an industrial protective coating can look very much the same from the outside of the paint can; therefore, it is what is inside the paint can that

makes the difference. When asked, “*What is the difference between house paint and an industrial coating?*” some will respond, “*About \$30.00 a gallon!*” While the per-gallon cost of an industrial protective coating is frequently higher than house paint, it is not the only difference. The main reason for the added cost is related to the ingredients that are used to formulate a coating, versus the ingredients used to formulate a house paint. Think about the performance requirements of house paint versus that of an industrial coating. A house paint is used primarily to improve aesthetics but must have color and gloss retention properties (exterior paints) and scrub resistance (interior paints). Conversely, an industrial protective coating may have to be resistant to immersion in water, chemical exposure, impact and abrasion, as well as be able to maintain color and gloss.

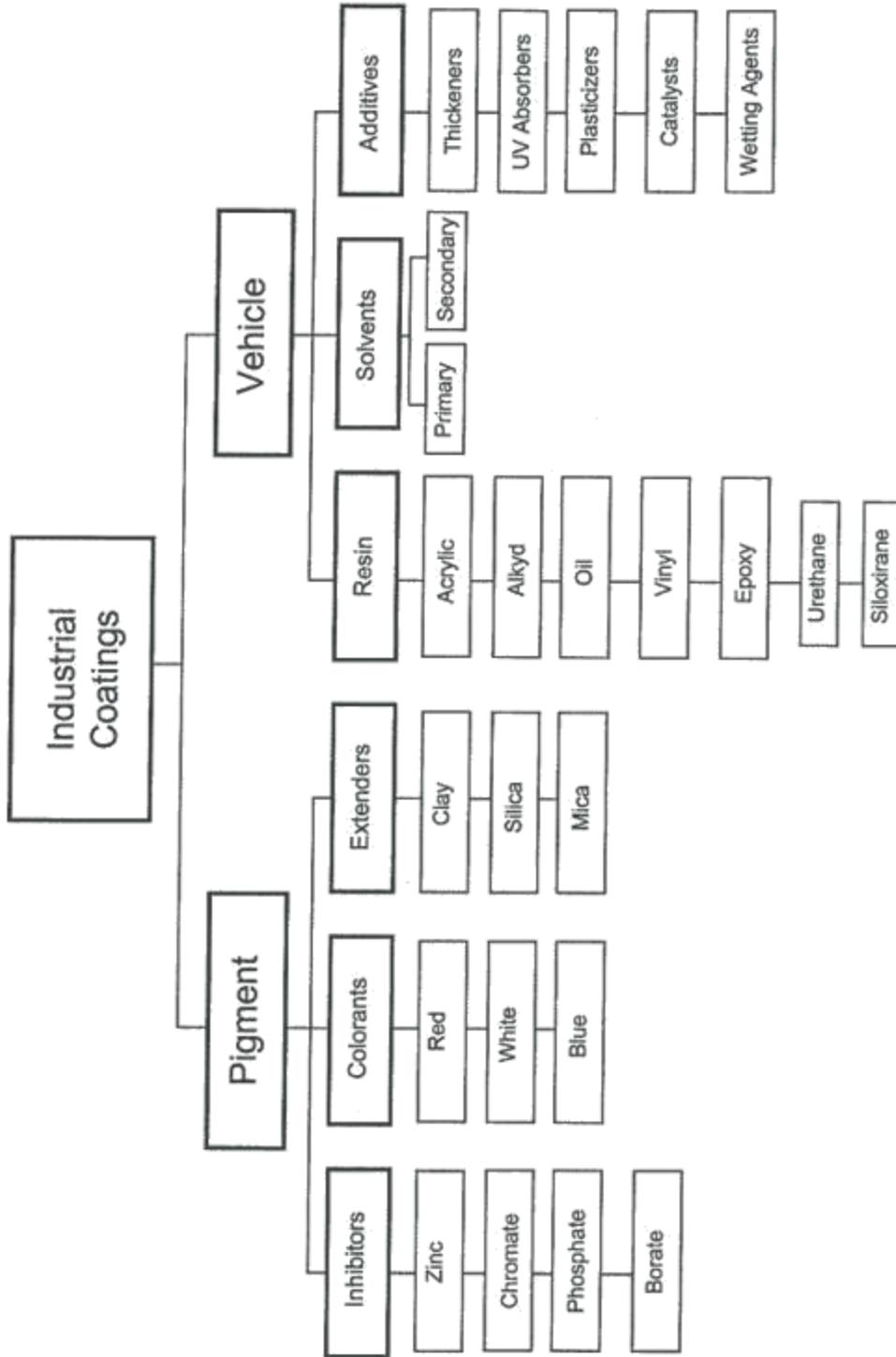
Industrial Coatings: Components

There are many ingredients or raw materials that are used to formulate an industrial coating. They can be categorized as non-volatile components and volatile components. Non-volatile components remain in the coating and on the surface once applied, while the volatile components evaporate from the coating into the air once the coating is applied to the surface. The non-volatile components typically include the resin or binder, the pigmentation and any additives that may be incorporated into the formulation. The volatile component is the solvent system used in the formulation that is a component to the wet film, but not the dry film of the coating.

The figure on the next page illustrates the basic components of an industrial protective coating. It divides a coating into two major components: pigmentation and vehicle. The pigmentation typically consists of corrosion inhibitors, colorants and extenders, although other raw materials may also be included. The vehicle “carries” the pigmentation to the surface and binds it into the coating film. The vehicle typically consists of the resin or binder, solvents and any additives that may be included in the formulation. The vehicle may also contain other raw materials to provide additional or different performance characteristics.

Resin (Binder)

The resin or binder is a non-volatile component. That is, it is both part of the wet film and the dry film. Oftentimes (but not always), a coating is identified generically by the type of resin used in the formulation. For example, a commonly



specified coating system for the interior of a potable water storage tank is a two or three-coat epoxy. In this case, “epoxy” is used to describe both the coating type and the raw material resin system used to formulate the coating. The resin system is the film-forming component of a coating. It cohesively bonds the pigmentation together and adhesively bonds the coating to the underlying substrate or coating layer. It is essentially the “glue” of the coating. In many cases, the resin type dictates the performance properties of a coating.

Pigmentation

The pigmentation is also a non-volatile component of the coating formulation. The pigment is essentially an insoluble raw material. That is, it does not dissolve in the resin and solvent, but rather is suspended in the vehicle. Many may think that the pigment merely gives the coating its color. While color is certainly a function of the pigment, it is only one of several potential functions. The pigment gives the coating its ability to “hide” the underlying surface. This is called hiding power. A coating formulated with pigmentation that demonstrates poor “hiding” may require the application of multiple coats to cover over the previous coating layer. For example, if a white coating is to be applied over a black coating, the coating must be formulated with good hiding pigments. Otherwise the black will show through, requiring multiple applications of the white overcoat. The level of pigmentation, as well as the shape and grind of the pigment also determines the gloss level of a coating. For example, a “flat” sheen is created by formulating the coating with more pigment than say a semi-gloss or gloss sheen, which is generated by using less pigment in the formulation.

The pigmentation in a coating may also provide corrosion protection. If used, the pigmentation must be formulated into the primer layer (the layer adjacent to the carbon steel substrate). Inhibitors like iron oxide, barium, phosphorous and others formulated into a primer “inhibit” the corrosion process. Zinc powder added to a primer in sufficient quantities galvanically protects the underlying carbon steel. Certain pigments even provide barrier protection. That is, their inherent shape and the way in which they orient themselves in the dry film create a barrier to moisture penetration through the coating. Examples include micaceous iron oxide and leafing aluminum pigments. These raw materials are “laminar,” which means they are plate-like, lay flat in the coating film and cause any moisture that penetrates the coating film to take a considerably longer pathway to the substrate. Finally, extenders such as silica, mica and clay may be incorporated into the formulation to improve film build, increase the solids content of the coating and/or provide added barrier protection.

Additives

Additives formulated into the coating also become part of the dry film. Various quantities of additives are used by the formulator to adjust the consistency, flow-out, surface wetting, color, ultraviolet (UV) light (or sunlight) resistance, flexibility, or to prevent settling in the can (suspending agents). For example, an alkyd coating that typically chalks and fades upon exposure to sunlight can be formulated with silicone (minimum 30%) to provide better color and gloss retention characteristics. In this case, the silicone is an additive. Polyurethane coatings are formulated with hindered amine light stabilizers (HALS) to help preserve gloss and color upon exposure to sunlight, and plasticizers formulated into a coating provide film flexibility. There are many additives that a formulator can employ. These are only examples.

Solvents

The solvent system in a coating is the volatile component. While the solvent system is part of the wet film during application, it is not intended to be part of the dry film once the coating dries or cures. The reason we refer to this component as a “solvent system” is that it is very common for a coating to be formulated with multiple solvent types (blends). Typically, a blend of solvents is used, and each type of solvent in the blend may perform a different function. The figure on page 5-4 segmented solvents into two basic categories: primary and secondary. As a general rule, primary solvents are formulated into the coating to reduce the viscosity of the resin, pigment and additives, so that the coating can be properly atomized through a spray gun or applied by brush and roller. Secondary solvents typically stay in the wet coating film longer than the primary solvents (they are slower evaporating solvents) and help the coating flow-out and knit together to form a uniform, continuous film. Solvents used to formulate a coating should not be confused with thinner that may be added to the coating by the applicator.

Many solvents systems in a coating (and thinners added to a coating by the applicator) are categorized as “volatile organic compounds” (VOC’s) by the Environmental Protection Agency (EPA). Therefore, the type and amount of solvent(s) used in an industrial coating may be regulated by the EPA, because as these solvents evaporate from the coating film into the air, they photochemically react with sunlight and become a precursor to ozone (a component of smog). Federal and state environmental agencies have developed regulations to control ozone-producing operations, as part of the Clean Air Act. The amount of VOC’s that can be legally emitted into the atmosphere varies considerably from location

to location. For example, densely populated areas like Southern California and Houston, Texas, have very strict VOC regulations, while less populated areas typically comply with the Federal limit, which represents a considerably higher threshold.

The VOC content of a coating is expressed in pounds per gallon or grams per liter, and is reported on the manufacturer's product data sheet (PDS). Many manufacturers also recalculate the VOC content of a coating after the addition of thinner. This information is also commonly referenced on the PDS. To convert from pounds/gallon to grams/liter, multiply pounds per gallon by 119.8. To convert from grams/liter to pounds/gallon, divide grams/liter by 119.8.

When painting a structure in the field, the VOC limit is typically dictated by the specification or the local air pollution agency for that project. Conversely, fixed facilities like painting shops are sometimes required to log the number of gallons of paint used over a specific period (say 90 days) and the VOC content of each type. In this manner, the total VOC emission can be calculated (e.g., 500 gallons of coating "X" with a VOC content of 2.8 pounds/gallon = 1400 pounds of solvent emission in 90 days). The local environmental agency regulates the maximum quantity of VOC's produced by the fixed facility.

Coating manufacturers can formulate coatings to comply with governing VOC regulations by using non-regulated solvents (like water and acetone), or by increasing the non-volatile content of the coating. Note that the addition of thinner in the field contributes to the VOC content of a coating. A coating that was formulated and selected based on the VOC content "as manufactured" may not be compliant once thinner is added. In some cases, field thinning is prohibited. If thinning is permitted, the amount of thinner added must be carefully measured to avoid exceeding the allowable VOC threshold.

Curing Mechanisms

The method in which a coating converts from a liquid to a solid is known as the curing mechanism. Many liquid-applied coatings "dry" by solvent evaporation, but cure by employing a separate reaction. Five basic curing mechanisms are discussed: solvent evaporation, coalescence, oxidation, polymerization and moisture cure. Other mechanisms include heat, infrared radiation, and ultraviolet (UV) light.

Solvent Evaporation

Coatings that “cure” by solvent evaporation only “dry.” That is, the resin, pigment and additives are suspended in a solvent system. When the solvent evaporates from the applied film into the air, the resin, pigment and additives remain on the surface. Because there is no subsequent curing reaction, the resin can be re-dissolved by the solvent system that evaporated from the coating film. That is why a coating that cures by solvent evaporation should not be overcoated with a coating containing strong solvents, since they will dissolve the underlying coating film. A vinyl coating is an example of a coating that cures by solvent evaporation. These are rarely used today due to their inherently high VOC content.

Coalescence

Waterborne acrylic coatings cure by solvent evaporation and form a coating film by a process known as coalescence. Water (the primary solvent in these coatings) first evaporates from the coating film. As the water evaporates, a special coalescing solvent (e.g., propylene glycol) aids in fusing the acrylic molecules together to form a solid film. The coalescing solvent then evaporates from the coating film. Without this coalescing solvent, the acrylic molecules will not impinge and fuse together, and can result in a poor performing coating film. Note that the coalescing process typically requires a minimum 50°F air temperature. Should the air temperature fall below 50°F before the coalescing process is complete, curing may stop and may not start again once the temperature recovers. This is a major concern with industrial waterborne acrylic coatings and should be carefully considered by the specifier.

Oxidation

Coatings that cure by oxidation react with oxygen (air) to form a film. This oxidation process never stops, as long as the coating is exposed to oxygen. For example, alkyd coatings (which typically contain unsaturated oils, pigments and driers) cure by oxidation. Many aged alkyd systems (those that have been in service for many years) become very brittle, as the resin continues to oxidize long after the coating is fully cured.

Polymerization

The prefix “poly” means many. Many monomers are used to create a polymer. These monomers are formulated into components and the components are

packaged by the coating manufacturer separately. It is only when these components are blended together (in the correct proportions) that a chemical reaction occurs, generating a very resilient, coating layer. The chemical reaction that occurs is known as polymerization. Coatings that cure by polymerization are multi-component (typically two or three containers). Prior to application, these components are blended together in the correct ratio (or complete kits are blended). Once blended, the chemical reaction begins. Coatings that cure by polymerization have a pot life. The blended components must be used before that pot life expires. The pot life will vary from a few minutes to several hours, depending on the formulation and temperature of the coating. Many coatings cure by polymerization; epoxy coatings and aliphatic acrylic or polyester polyurethane coatings are a few of the more common.

Moisture Cure

The reaction of a coating with moisture (in order to cure) is known as hydrolysis. Only a few industrial coatings “hydrolyze” in the curing process. These include moisture-cure urethanes and ethyl silicate-type inorganic zinc-rich primers. These coatings require a minimum amount of moisture to cure. In this process, moisture-cure urethanes release carbon dioxide (CO₂), and inorganic zinc-rich primers release ethyl alcohol. The result is a very resilient coating layer, similar to that achieved by polymerization.

Methods Used to Calculate Theoretical and Practical Coverage Rates for Estimating Coating Quantities

Receiving competitive bids for coating materials is dependent on the volume of coating required to coat the surface. The price per gallon for 250 gallons of coating will probably be less than the price per gallon for 50 gallons of the same coating (i.e., quantity discounts).

Coating manufacturers frequently provide a rate of coverage on their product data sheets. However, this rate is theoretical assumes no loss and is based on their recommended coating thickness, which may or may not be the same as that specified. The theoretical coverage rate (based on the specified coating thickness) can be calculated using the information below.

All coating manufacturers determine coverage rates based on a standard formula: **“One gallon of 100% volume solids paint will cover 1,604 square feet of smooth surface, when applied 1 mil thick.”** Based on the actual volume solids (from the product data sheet) and target coating thickness (from the specification), the theoretical coverage rate can be calculated.

For example, let’s assume that the specification requires the coating be applied 4-6 mils thick, and that the volume solids content of the coating is 65%. The theoretical coverage rate can be calculated as:

$$\frac{1604 \text{ square feet/gallon}}{6 \text{ mils}} = 267 \text{ square feet/gallon (at 100\% solids by volume)}$$

$$267 \text{ square feet/gallon} \times 0.65 \text{ volume solids} = 174 \text{ square feet per gallon}$$

Therefore, if the project encompassed 35,000 square feet of structural steel, a minimum of 202 gallons of paint will be required (35,000 square feet ÷ 174 square feet per gallon).

However, this assumes that every drop of paint that is mixed will be transferred to the surface. This is not possible, due to mixing and application losses. Quantifying these losses can be challenging and is dependent on the transfer efficiency of the application method, as well as other factors. And coating manufacturers typically will not provide any written guidance on their data sheets, other than a statement like, *“Allow for losses due to mixing and application.”*

In order to calculate a practical coverage rate, an estimation of the transfer efficiency must be made, and is based on the porosity or roughness of the substrate, the complexity of the structure being coated, the method of application, etc. For example, brush and roller application to large, flat surfaces will generate a very high transfer efficiency rating, while spray application to intricate parts will typically generate a lower transfer efficiency rating. It is up to the contractor or material estimator to generate a transfer efficiency rating based on the specifics of the project. For illustration purposes, we will assume a 20% loss, or an 80% “transfer efficiency.” The “practical” coverage rate is calculated by multiplying the theoretical coverage rate (above) by the transfer efficiency, as shown below:

$$174 \text{ square feet per gallon} \times 0.80 \text{ transfer efficiency} = 139 \text{ square feet per gallon}$$

$$35,000 \text{ square feet} \div 139 \text{ square feet per gallon} = 252 \text{ gallons}$$

Based on this *practical* coverage rate, the number of gallons of paint required to coat 35,000 square feet increases from 202 gallons to 252 gallons.

The final factor that impacts the amount of *primer* to order includes the depth of the surface profile, as well as the peak density. Generating a surface profile effectively increases the surface area. However, the coverage rate formula is based on application of the coating to a smooth surface. If the primer is applied to an abrasive blast cleaned surface with a nominal surface profile of 3 mils, the estimator may figure on losing as much as 20-25% of the primer in the anchor pattern, since dry film thickness is measured from the tops of the peaks.

The practical coverage rate of 139 square feet per gallon will not be accurate for the primer coat applied to an abrasive blast cleaned surface with a nominal 3 mil anchor pattern. The coverage rate for the primer must be adjusted as shown below (based on a projected 25% loss in the anchor pattern):

139 square feet per gallon x 0.75 = 105 square feet per gallon.

35,000 square feet ÷ 105 square feet per gallon = 334 gallons

A theoretical coverage rate of 174 square feet per gallon resulted in a 202-gallon material order. Estimated material losses and surface roughness resulted in a practical coverage rate of 105 square feet per gallon and a 334-gallon material order to coat the same 35,000 square feet (an additional 132 gallons of primer).

Note that when intermediate or finish coat materials are estimated, there is no need to account for the effect of surface profile, since these coating layers will be applied to a relatively smooth surface (the surface of the primer). However, material losses caused by mixing and application should still be considered.

Module 5 Summary

Module Five begins by describing the differences between ordinary household paints and industrial protective coatings. One notable difference is the increased cost of protective coatings, another is the reason behind the higher costs. The performance expectations of industrial coatings are much higher than those of house paints that are used primarily to improve aesthetics. Protective coatings, on the other hand, may have to withstand immersion in water, chemical exposure, impact and abrasion, as well as provide aesthetics.

There are many raw materials that are used to formulate an industrial coating that generally fall into two categories: volatiles and non-volatiles, or pigmentation and vehicle. Volatiles are part of the wet film but evaporate into the air once the coating is applied to the surface, while non-volatiles are part of the wet and dry film and remain on the surface once the coating is applied.

The vehicle “carries” the pigmentation to the surface and binds it into the coating film. The vehicle consists of the resin or binder, solvents, and any additives that may be included in the formulation. While part of the vehicle evaporates (the solvents) once the coating is applied, other components, like the resin, remain behind as part of the dry film. The resin system cohesively bonds the coating together and adhesively bonds the coating to the underlying substrate or coating layer. The type of resin is often used to generically identify the coating and frequently determines the performance properties of a coating.

Additives are also a part of the vehicle and are added to coating formulations to improve flow-out, surface wetting, and flexibility. Additives can also be used to adjust the consistency of a coating, to resist solar radiation (sunlight), and to prevent settling in the can.

The pigment gives the coating the ability to hide the underlying surface. Pigments also give coatings their color and the amount of pigment used determines, in part the gloss. Certain pigments provide corrosion protection. Pigments like iron oxide or barium can be formulated into a primer to inhibit the corrosion process, and zinc powder can be added to the primer in sufficient quantities to galvanically protect the underlying carbon steel. Other pigments like

micaceous iron oxide and leafing aluminum pigments provide barrier protection. These pigments are plate-like, and the way they orient themselves in the coating film forces any moisture that penetrates the coating film to take a longer path to reach the substrate.

Extenders are pigments like clay, silica, and mica that can be incorporated into the formulation to improve film build. Extenders also increase the solids content of a coating and provide added barrier protection.

The solvent system is the volatile component of a coating. While it is part of the wet film during application, it is not intended to be part of the dry film once the coating dries or cures. Typically, a blend of solvents is used in the formulation of a coating and each type of solvent in the blend may perform a different function. Generally, primary solvents reduce the viscosity of the resin, pigments and additives, so the coating can be atomized through a spray gun or applied by brush or roller. Frequently the primary solvents evaporate from the coating film first, while secondary or coalescing solvents typically remain in the wet film a little longer to help the coating flow-out and knit together to form a uniform, continuous film.

Many solvent systems (and thinners) are categorized as “volatile organic compounds” or VOC’s by the Environmental Protection Agency (EPA). The amount of VOC’s that are allowed to be emitted into the atmosphere varies across the US. In the field, the VOC limit is usually predetermined by the coating system specified. Fixed facilities like paint shops are sometimes required to log the number of gallons of paint used over a specific period, as well as the VOC content of each type.

Coating manufacturers can formulate coatings to comply with VOC regulations by using non-regulated solvents or by increasing the non-volatile content of the coating. Since adding thinner in the field will increase VOC levels, the type and amount of thinner added must be carefully monitored.

The method in which a coating converts from a liquid to a solid state is known as the curing mechanism. Five basic curing mechanisms include solvent evaporation, coalescence, oxidation, polymerization and moisture cure.

For solvent evaporation, the solvent in the coating evaporates into the air after application, while the resin, pigment, and any additives remain on the surface to form the dry film. There is no second step or subsequent curing reaction, so the resin can be re-dissolved by the same solvent system that was used in the blended

coating. Coatings that cure by solvent evaporation should not be overcoated with a coating that contains strong solvents.

Coalescence also involves evaporation of solvents from the coating film, but the primary solvents evaporate first and coalescing solvents (secondary solvents) remain in the film longer to help fuse the molecules together to form a solid film. After the film has been formed, the secondary solvents also evaporate. This type of cure typically requires a minimum air temperature of 50°F, and only applies to waterborne acrylic latex coatings.

Oxidation is a third method of coating cure. The resin reacts with oxygen (from the surrounding air) to form a film. The process of oxidation never really stops as long as the coating is exposed to oxygen. Alkyds, which cure by this method, can become very brittle after many years of service, since the resin continues to oxidize long after the coating is cured.

Polymerization is a more complex curing mechanism. Different components are carefully pre-measured by the manufacturer and packaged separately, so that when they are properly blended a chemical reaction occurs known as polymerization. The components must be blended in the correct ratios (complete kits) for the chemical reaction (or polymerization) to occur. Coatings that cure by this method are multi-component, and once they are blended together, the pot life begins. The pot life may vary from a few minutes to several hours. A few of the more common coatings that cure by polymerization are epoxies and polyurethanes.

Moisture cure is the final method of coating cure discussed in Module 5. The coating components react with moisture and require a minimum amount of humidity in the surrounding air to cure. Moisture-cure urethanes cure this way and release carbon dioxide (CO₂) during the process, while inorganic zinc-rich primers release ethyl alcohol during the hydration process.

Calculating coverage rates to determine the quantity of coating to order, or to verify has been mobilized to the project site may be required. The standard formula is used to generate a “theoretical” coverage rate. Estimates of losses due to mixing and application, as well as surface profile (primer only) are then used to generate a “practical” coverage rate. When calculating a practical coverage rate it is important to use the transfer rate and not the loss rate. For example, if the anticipated losses due to mixing and application are estimated to be 30%, the transfer efficiency that is used in the calculation is 70%.

Module 5 Workshop: Calculating Coating Coverage

Based on the following facts and assumptions, calculate the number of gallons of primer and topcoat required to coat 28,000 square feet of steel. Estimate the quantity of thinner for both the primer and topcoat as well.

You may use your calculator, but you must show how you arrived at each answer in the space provided.

Data	Primer	Topcoat
Target Dry Film Thickness	4 mils	2 mils
Solids by Volume	75 %	46 %
Mixing/Application Losses Estimate	20 %	20 %
Surface Profile Losses Estimate	15 %	None
Thinner Amount (maximum)	10 %	5 %

1. Quantity of Primer to Order: _____
2. Quantity of Topcoat to Order: _____
3. Quantity of Thinner to Order for Primer: _____
4. Quantity of Thinner to Order for Topcoat: _____

Work Space:

Module 5 Quiz

Basic Coatings Inspection

1. Match the name of the curing method with the mechanism by placing the letter of the curing method in the space next to the mechanism. There is one mechanism that will not have a match.

Curing Method

- A. Solvent Evaporation
- B. Coalescence
- C. Oxidation
- D. Polymerization
- E. Moisture

Mechanism

- ___ Chemical cross linking
- ___ Reaction with water
- ___ Fusing of latex particles
- ___ Reaction with oxygen
- ___ Release of vapors
- ___ Reaction with soluble salts

2. Match the name of the curing method with the coating type by placing the letter of the curing method in the space next to the type of coating. There is one coating that will not have a match.

Curing Method

- A. Solvent Evaporation
- B. Coalescence
- C. Oxidation
- D. Polymerization
- E. Moisture

Coating Type

- ___ Vinyl
- ___ Ethyl silicate inorganic zinc
- ___ Galvanizing
- ___ Acrylic latex
- ___ Alkyd
- ___ Epoxy

3. Calculate the amount of primer that should be ordered to coat 15,800 square feet based on the following information. Show the steps you used below.
Formula: One (1) US Gallon of 100% volume solids coating will coat 1,604 square feet of smooth surface when applied at 1 mil DFT.

Dry Film Thickness	6-9 mils
Volume Solids Content	78%
Mixing & Application Losses Anticipated	15%
Losses Due to Surface Roughness	25%

Primer Quantity: _____ gallons

A Simulated Coatings Inspection Project

Module 6

Learning Outcomes:

- Navigate a coating specification
- Develop an inspection plan
- Perform surface preparation and coating inspection on a simulated project
- Compare inspection results to specification requirements

Instructions

Module Six provides you with the opportunity to perform basic coatings inspection during the coatings operations on a simple grade separation (overpass) bridge structure.

You will be working for the industrial coating contractor as the Quality Control Specialist. As the QC inspector, you are responsible for routine testing and documentation of the surface preparation and coating processes from beginning to end.

Prior to beginning, you will meet with the Project Manager in a simulated pre-job conference. The Project Manager works for KTA and has been hired to represent the owner of the bridge (the Department of Transportation or DOT). Since this will be the same person who looks over your shoulder throughout the job, this is your opportunity to ask any questions about the specification or any other issues that may arise on this project. A copy of the specification and two pictures of the structure are provided.

After reviewing the specification with the Project Manager, you will prepare an inspection plan using the forms provided. Your plan will include a list of inspection checkpoints and corresponding acceptance criteria from the specification. The center column of the inspection plan will include HOW the inspection will be performed (visual, gage, etc.).

There are seven different workstations set up around the room; each station represents at least one quality control inspection check point. Be sure to read the information section at the beginning of each workstation.

For this exercise, it isn't possible to move each team through the inspection check points in the sequence they would be completed on a real project. Your team can rotate through the workstations in any order. Stay with your teammates. There may be one or more inspection check points at each workstation. The information and testing equipment you need to complete the inspection are located at each station. Although you will work in teams during this workshop, each person will be responsible for keeping his or her own records. Individual worksheets are provided for this purpose. We will review the results of your inspections at the end of the workshop

Project Specification for the Maintenance Painting of Bridge Structure

SECTION 45: PAINTING

45-1 General

45-1.01 Description

The work shall consist of maintenance painting the KTA Bridge (grade separation, overpass design) in conformance with the provisions of the various sections of these specifications. The structure consists of three spans. Each span contains two fascia girders and four stringers.

Painting shall conform to the provisions specified in these specifications and the special provisions, and as shown on the plans or directed by the Engineer.

45-2 Preparing and Painting Structural Steel

45-2.01 General

Cleaning and painting of structural steel shall conform to the provisions in Section 45-1, “General,” and this Section 45-2. All exposed surfaces of structural steel and other metals, except galvanized surfaces shall be cleaned and painted. The Contractor is responsible for controlling the quality of the work and shall provide a trained Quality Control Specialist for the project.

45-2.02 Surface Preparation

All surfaces of structural steel or other metals that are to be painted shall be prepared by solvent cleaning, then abrasive blast cleaning as described in sections 45-2.03 and 45-2.04. The Contractor shall notify the Engineer, in writing, at least one week in advance of the date cleaning operations are to begin.

45-2.03 Pre-surface Preparation

All dirt, grease, soluble salts or other foreign material that have accumulated on the existing painted or galvanized surfaces shall be removed by solvent cleaning in accordance with SSPC-SP1. Soluble salts, if present in excess of 7 micrograms per square centimeter ($\mu\text{g}/\text{cm}^2$) shall be removed by water washing using pressures not less than 4,000 psi. Verification of sufficient chloride remediation shall be performed according to SSPC Guide 15 using the Bresle Patch and Quantab Chloride Indicator methods. Solvent cleaning and pressure washing shall precede all

Note: This document is a mock specification and is not intended to represent a properly prepared specification. It is only to be used during Module 6 of the Coatings Inspection Training Course.

other phases of cleaning but shall not be performed more than 2 weeks prior to painting or other phases of cleaning.

45-2.04 Surface Preparation (Abrasive Blast Cleaning)

Abrasives used for blast cleaning shall be of an expendable type, capable of producing a sharp, angular surface roughness. The use of abrasives other than those specified in this Section 45-2.04 will not be permitted unless authorized in writing by the Engineer.

The cleanliness of the compressed air used for abrasive blast cleaning shall be verified for cleanliness in accordance with ASTM D4285.

Surfaces shall be prepared according to the requirements of SSPC Surface Preparation Specification No. 10/NACE No. 2, "Near-White Blast Cleaning." Blast cleaning shall leave all surfaces with a dense, uniform, angular anchor pattern that produces a minimum surface profile depth of 1.5 mils and a maximum depth of 3 mils as measured according to Methods B or C described in ASTM D 4417.

Blast cleaned surfaces shall be primed the same day blast cleaning is performed, unless otherwise authorized by the Engineer. If prepared surfaces rust or are contaminated with foreign material before primer application is completed, the surfaces shall be re-cleaned by the Contractor at the Contractor's expense.

Abrasive blast cleaned surfaces shall be free of visible dust prior to primer application. Dust removal may be performed by brushing, blow down or vacuuming. The cleanliness of the compressed air used for blow-down shall be verified for cleanliness in accordance with ASTM D4285.

Surface preparation shall be performed during daylight hours.

45-2.05 Coating Application

The paint system shall consist of an organic (epoxy) zinc-rich primer applied to a dry film thickness of 3-5 mils, a polyamide epoxy mid-coat applied to a dry film thickness of 5-7 mils, and an acrylic polyurethane finish coat applied to a dry film thickness of 2-3 mils. The finish coat color shall conform to Federal Standard 151B, Color 23456 (Royal Blue). The minimum total system thickness shall not be below 10 mils and shall not exceed 15 mils. Coating thickness requirements are from the tops of the peaks of the surface profile. The manufacturer, product name and number and batch or lot numbers for each component shall be recorded.

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The Contractor shall notify the Engineer, in writing, at least one week in advance of the date painting operations are to begin. All painting shall be performed during daylight hours.

45-2.06 Weather Conditions

Paint shall be applied only on thoroughly dry surfaces and during periods of favorable weather. Application will not be permitted when the atmospheric or surface temperature is at or below 40°F or above 100°F, or when the relative humidity exceeds 85% at the site of the work. Application of paint will not be permitted when the steel surface temperature is less than 5°F above the dew point, or when freshly painted surfaces may become damaged by rain, fog or condensation, or when it can be anticipated that the atmospheric temperature or relative humidity will not remain within the specified application conditions during the drying period. If fresh paint is damaged by the elements, it shall be replaced or repaired by the Contractor at the Contractor's expense.

Subject to approval by the Engineer in writing, the Contractor may provide suitable enclosures to permit painting during inclement weather. Provisions shall be made to control atmospheric conditions artificially inside the enclosures within limits suitable for painting throughout the painting operation and drying period. Lighting inside the enclosure shall be in accordance with the guidelines provided in SSPC Guide 12 (Illumination) for coating application and inspection activities. Full compensation for providing and maintaining the enclosures shall be considered as included in the prices paid for the various contract items of work requiring paint and no additional compensation will be allowed.

45-2.07 Mixing and Thinning Paint

Mechanical mixers shall be used to mix paint. Prior to application, the paint shall be mixed a sufficient length of time to thoroughly blend the pigment and vehicle together. The zinc-rich primer shall be strained immediately prior to pouring into the spray pot. An agitating spray pot shall be used during application of zinc-rich primer. The agitator or stirring rod shall reach to within 2" of the bottom of the spray pot and shall be in motion at all times during primer application. The motion shall be sufficient to keep the primer well mixed. Agitation of the spray pot during application of the mid-coat and finish coat is not required. Paints specified are formulated ready for application. Thinning is permitted (if required and approved by the engineer). The type and amount of thinner used shall be as required by the manufacturer.

45-2.08 Application

The primer shall be applied by spray. Unless otherwise specified, the mid-coat and finish coat may be applied by brush, spray, roller or any combination of these methods. Rollers, when used, shall be of a type that will not leave a stippled texture in the paint film. On surfaces that are

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inaccessible for painting by regular means, the paint shall be applied by sheepskin daubers, bottle brushes, or by any other means approved by the Engineer.

Each application of paint shall be thoroughly cured. Painting shall be done in a neat and workmanlike manner. Any holidays, thin areas or other deficiencies must be corrected before the succeeding application. Runs, drips and sags are not permitted in any coating layer. Runs, sags, thin and excessively thick areas in the paint film, holidays, or areas of non-uniform appearance shall be considered as evidence that the work is unsatisfactory, and the Contractor may be required to blast clean the areas and reapply the paint.

The dry film thickness of each coat shall be measured in conformance with the requirements of SSPC-PA2.

The surface of the preceding layers shall be free from moisture, dust, grease or any other deleterious material that may prevent the bond of the succeeding applications.

45-2.09 Protection Against Damage

The Contractor shall provide protective devices, such as tarps, screens or covers, as necessary to prevent damage to the work and to other property or persons from all cleaning and painting operations.

Upon completion of all painting operations and of any other work that would cause dust, grease or other foreign materials to be deposited upon the painted surfaces, the painted surfaces shall be thoroughly cleaned.

45-3 Stenciling

45-3 Special Stenciling

The date (month and year) of painting shall be stenciled at 2 locations on the outside of both fascia girders in block letters 2.5" high. The exact locations of the stencils will be determined by the Engineer. The paint used shall form a distinct contrast with the finish coat color.

45-4 Payment

45-4 Payment

Cleaning and painting structural steel will be paid for on a lump sum basis, unless otherwise specified in the special provisions. The lump sum payment shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals, and for doing all the work involved in cleaning and painting the structural steel as shown on the plans, and as specified in these specifications, and as directed by the Engineer.

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View of Overpass from Below the Deck



Highway View of Overpass

Module Six: Workstation #1 Worksheet

Ambient Conditions, Surface Temperature, and Cleanliness of Compressed Air

Information

A visual inspection of the surface during pre-surface inspection revealed no grease or oil on the surfaces in Span Two. The containment has been erected and blast cleaning is scheduled to begin today. Abrasive blast cleaning began at 8:00 am.

Workstation Equipment

- Sling psychrometer
- US Weather Bureau Psychrometric Tables
- Small bottle of water
- Surface temperature gage
- Digital Psychrometer
- Blotter A: the blotter used to test the compressed air cleanliness at 7:05 am
- Blotter B: the blotter used to test the compressed air cleanliness at 7:30 am

Document the following:

Location on the structure where the work and the quality control inspection will take place:

How frequently will you/should you measure ambient conditions and surface temperature?

When else will you/should you measure ambient conditions and surface temperature?

What time did you take the first set of ambient conditions?

Document your first set of ambient conditions in the table below:

Item	Readings from Analog Instruments	Readings from Digital Dew Point Meter (DPM)
Date		
Time		
Air Temperature		
Wet Bulb Temperature		NA
Depression of Wet Bulb Thermometer		NA
Relative Humidity		
Dew Point Temperature		
Surface Temperature		
△ Between Dew Point and Surface Temperature		

Document the compressed air cleanliness in the table below:

Blotter	Satisfactory	Unsatisfactory	Time Tested
Blotter A			
Blotter B			

Based on the ambient conditions and surface temperature, can work be initiated? _____

If the answer is no, what should you do?

If the results of the compressed air cleanliness check (Blotter A or Blotter B) were unsatisfactory, what action should be taken?

Module Six: Workstation #2 Worksheet

Assessing Surface Cleanliness: Soluble Salt Contamination

Information

You will be inspecting the blast cleaned steel in Span Two for chloride contamination. The panels provided at Workstation #2 represent the blast cleaned steel on Span Two.

Note: $\mu\text{g}/\text{cm}^2$ stands for “micrograms per square centimeter”

Workstation Equipment

- Bresle Patches™ (the sampling area of the latex cell is 12.25 cm²)
- Syringes
- Cups
- Quantab® Chloride Detection Strips
- Quantab® Conversion Chart (on bottle)
- Water: use 2 ml (2 cc) of water
- Metal panels

Document the results of the chloride contamination test in the table below and indicate whether the test result conforms to the specification requirements.

Entry	Result
PPM (from Quantab® conversion chart)	_____ PPM
Quantity of Water Used in Syringe	_____ mL
PPM X Quantity of Water Used	_____ micrograms of chloride
Area Tested	_____ cm ² of surface
Micrograms of chloride ÷ Area Tested	_____ micrograms/cm ² chloride

_____ **Meets the Specification**

_____ **Does Not Meet the Specification**

Module Six: Workstation #3 Worksheet

Surface Preparation: Cleanliness

Information

You will be conducting a visual inspection of surface cleanliness on a freshly blast cleaned steel panel. For this exercise, the panel represents 300 square feet in Span Two. A 1 square foot area has not been prepared; it represents the condition of the surface prior to blast cleaning. You will be using the “SSPC-VIS 1, Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning.”

Workstation Equipment

- One blast cleaned plate with an unprepared area.
- SSPC-VIS 1, Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning

Conduct a Visual Inspection and Document the Results

Condition of the area on the panel that was not prepared. _____

Are there remnants of old paint, mill scale or rust on the prepared portion of the panel? Describe:

Does the blast cleaned area meet the specification? _____

If the blast cleaned area does not meet the specification, document (describe in detail) the issues:

Module Six: Workstation #4 Worksheet

Surface Preparation: Surface Profile

Information

The contractor is using a Venturi blast nozzle. The specification requires an angular profile of 1.5-3.0 mils. All blast cleaning is being performed in Span Two. Complete the chart below. Use replica tape on Panel A and the depth micrometer on Panel B.

Workstation Equipment

- Panel A
- Panel B
- Replica tape, 2 grades (C, XC)
- Burnishing tool
- Micrometer
- Depth micrometer (SPG)
- Sample of coal slag
- Sample of steel shot
- Nozzle
- Nozzle Orifice gage
- Clemco Air Consumption Chart

Inquiry	Entry
Which grade replica tape did you use on Panel A?	
Surface Profile Measurement for Panel A	
Surface Profile Measurement for Panel B	
Does Panel A meet the specification?	
Does Panel B meet the specification?	
Two abrasive samples are provided. Which one meets the specification requirements?	
If either Panel A or B does not meet the specification, what action(s) is/are required? _____ _____	

Determine the orifice size of the blast nozzle provided. Based on the nozzle orifice size, use the chart provided to determine the minimum size compressor is required (in CFM) to maintain 100 psi blast nozzle air pressure.

Inquiry	Entry
Nozzle Orifice	
Minimum compressor Size (CFM)	

Module Six: Workstation #5 Worksheet

Mixing, Thinning, WFT's

Information

The contractor has mixed 10 gallons of a two-part epoxy and has thinned it 10%. The mix ended at 10:00 am. The mixed paint temperature is 73° F. The coating will be applied by airless spray, aided by brush, in Span One. Record the information requested in the chart below.

Workstation Equipment

- Product Data Sheets
- An empty can of thinner and a measuring cup
- Paint cans with batch numbers on the cans
- Can or receptacle in which paint will be mixed and thinned
- A mechanical stirrer
- A WFT Gage (pre-dipped in the wet film)
- Calculator

Coating Manufacturer	
Product No.	
Maximum Recommended % of Thinner	
Batch Number Part A	
Amount of Part A Added to the Mix	
Paint Temperature	
Induction Time	
Potlife	
Thinner No.	

Thinner Batch Number	
Amount of Thinner Added (in ounces)	
Adjusted Volume Solids Content Following Thinning	
WFT Range	
Reading from WFT Gage	

Module Six: Workstation # 6 Worksheet

Dry Film Thickness

Information

Obtain primer thickness on Panel A. Obtain the cumulative primer and intermediate coat thickness on Panel B-1. Measure the thickness of the intermediate coat (only) on Panel B-2. Note: All panels represent portions of Span One.

Workstation Equipment

- Electronic DFT Gage (SSPC-PA2, Type 2)
- Tooke Gage
- Coated Standards
- Measured Shims
- Panel A is coated with a zinc primer
- Panel B-1 and B-2 are both coated with a zinc primer and the epoxy mid-coat
- Panel C is an uncoated steel panel (representative of surface preparation)

Measure DFT's by following the specific instructions given for each panel. Document your results:

Panel A (coated with a zinc primer only). The test plate represents 100 square feet. Verify the accuracy of the gage, adjust the gage using a measured shim then take measurements per SSPC-PA 2 (record the spot measurements on page 6-18) and record the requested information in the table below for Panel A.

Panel B-1 (coated with a zinc primer and mid coat of epoxy). The test plate represents 100 square feet. Using a Type 2 Gage, measure and record spot readings on page 6-18. Complete the table below for column B-1.

Inquiry	Panel A	Panel B ¹
Accuracy Verification Standard		
Measured Shim Used		
No. of Spot Measurements		

Inquiry	Panel A	Panel B ¹
Range of Coating Thickness		
Average Coating Thickness		

Panel	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5
A					
B-1					

Panel B-2 (coated with a zinc primer and mid coat of epoxy). Using the Tooke Gage, measure and record the thickness of the epoxy mid-coat layer.

Layer	Thickness (mils)
Intermediate Coat	

Module Six: Workstation # 7 Worksheet

Visual Inspection of the Three Coat System

Information

The zinc primer, the epoxy mid coat, and the urethane finish coat have been applied to Span One. Your only equipment is an inspection mirror. Inspect the cross brace, document the results and determine whether the area conforms to the specification.

Workstation Equipment

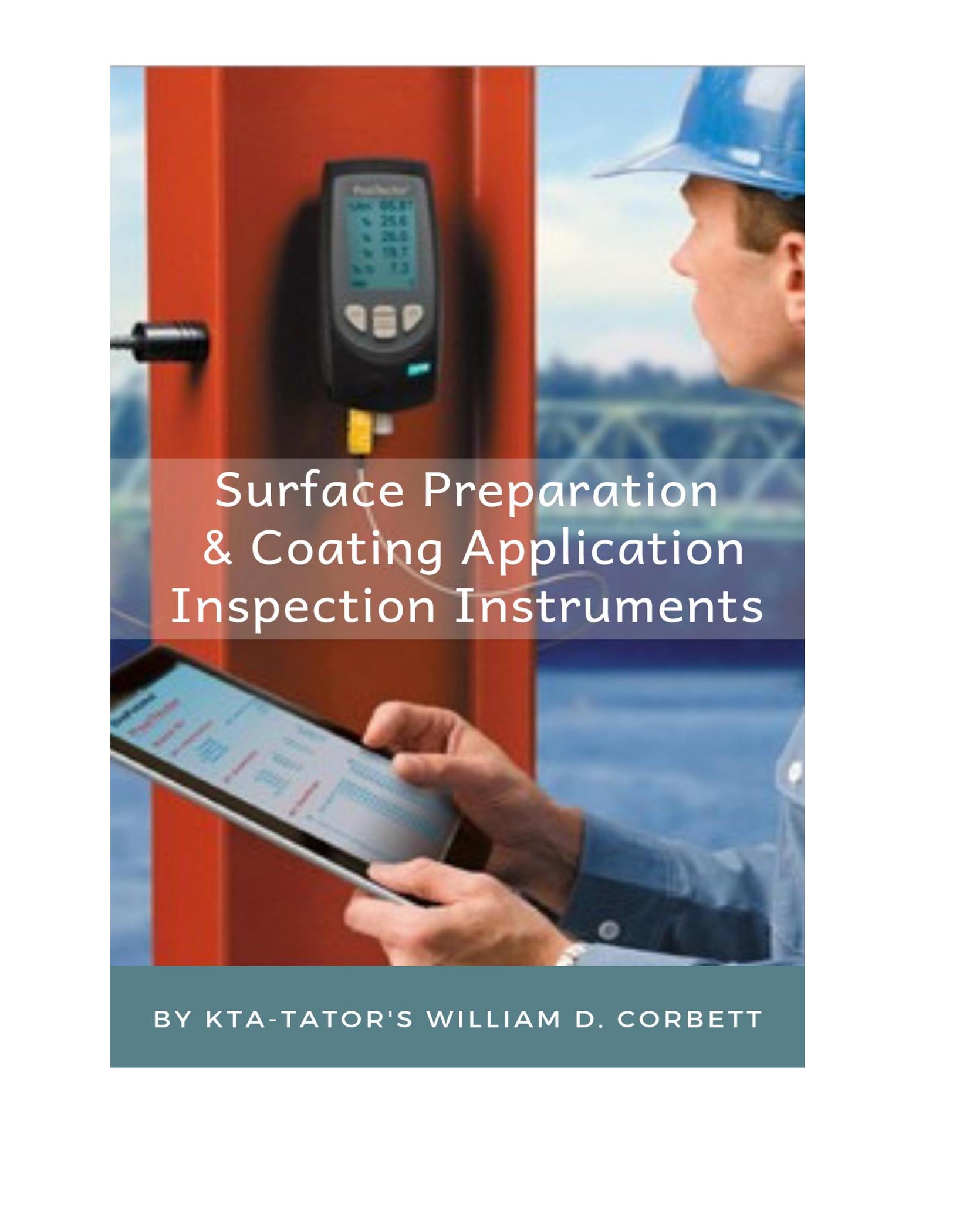
- Inspection mirror
- Mock section with bolts and angle

Document Your Visual Observations

_____ **Meets the specification**

_____ **Does not meet the specification***

*If checked, indicate corrective actions.



Surface Preparation & Coating Application Inspection Instruments

BY KTA-TATOR'S WILLIAM D. CORBETT

Surface Preparation and Coating Application Inspection Instruments

Preface

This Instrument Use Supplement provides information on the proper use of test instruments and kits for verifying the quality of surface preparation of new steel in the shop and previously coated structural steel prior to the application of protective coatings, as well as the quality of coating application both during and post-application.

Successful corrosion prevention using protective coating systems is based in part on the quality of the surface preparation and the 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 Supplement 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 and test kits, with references to industry standards throughout. Instrument use however is only part of the coating's inspection equation. It must be combined with thorough knowledge of the project specification and field practicality. Formal training in coatings inspection techniques remains a critical component. This publication is not intended to replace formal training, but rather to supplement the learning process before, during and after training.

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Chapter 1

Verifying the Quality of Surface Preparation



Introduction

Common quality control checkpoints associated with surface preparation include:

- Grease/Oil Removal (SSPC-SP 1)
- Abrasive Cleanliness
- Compressed Air Cleanliness (ASTM D4285)
- Surface Profile (ASTM D4417/NACE SP0287/SSPC-PA 17)
- Surface Cleanliness (SSPC/NACE/ISO)
- Surface Soluble Salt Detection

The focus of Chapter 1 is on the use of instruments, kits & visual guides associated with four of the six checkpoints listed above, including:

- Verifying Abrasive Cleanliness
- Measuring Surface Profile (ASTM D4417/NACE SP0287/SSPC-PA 17)
- Verifying Surface Cleanliness (SSPC/NACE/ISO)
- Detecting Surface Soluble Salt Concentrations

In addition, the importance and value of measuring peak density (in addition to the peak-to-valley depth) is discussed, and the instrumentation is described. Both traditional methods and novel techniques for verifying quality are explored.

Abrasive Cleanliness

Abrasive cleanliness is an indirect or automatic requirement of the SSPC/NACE surface cleanliness standards for abrasive blast cleaning. Further, the SSPC Abrasive Standards (AB 1, AB 2, AB 3, and AB 4) all require the abrasive (whether new or reused) to be clean. There are two parameters associated with abrasive cleanliness, including oil contamination and water-soluble contaminants resulting in elevated conductivity.



Figure 1-1

Verifying Abrasive Cleanliness - Oil. ASTM D7393, “Standard Practice for Indicating Oil in Abrasives” describes a method for determining whether an abrasive is contaminated with oil. To perform this test, place about 1” of abrasive into a clear glass or plastic container, then add clean tap water one inch above the abrasive level (Figure 1-1). The water should be between 68° and 95°F. Cover and shake the abrasive/water sample vigorously for one minute, then remove the cover and allow the abrasive to settle for up to 5 minutes. Observe the surface of the water for an oil film or sheen. Discard the abrasive and document the results.



Figure 2-1

Verifying Abrasive Cleanliness - Water Soluble

Contaminants. The second parameter for assuring an abrasive is clean is described in ASTM D4940, "Standard Test Method for Conductimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives." To perform this test, add 300mL of distilled water (available from most grocery stores) to 300 mL of abrasive. Stir the abrasive/water slurry for one minute, then allow the slurry to sit undisturbed for 8 minutes. Re-stir for an additional one minute (total extraction time of 10

minutes), then filter and discard 10 mL of the extract solution through laboratory-grade filter paper (e.g., Whatman). Filter the remaining extract and test the solution for conductivity using a temperature-compensating conductivity meter. Test the water used for the extraction for conductivity and subtract this value (known as the "blank") from the conductivity value obtained from the abrasive extract. A kit containing all the equipment and supplies for conducting 25 abrasive ionic contamination tests is shown in Figure 2-1. If the project specification references SSPC/NACE surface cleanliness standards for abrasive blast cleaning and/or the SSPC abrasive (AB) standards listed above, the maximum allowable threshold of water-soluble contaminants is 1,000 microsiemen (μS), which is 1 millisiemen (mS).

Annual calibration of the conductivity meter is critical to achieving confidence in the data that is generated on the abrasive, as is verification of accuracy of the meter prior to each use. Procedures for calibration and verification of accuracy are described below.

Calibration and Verification of Accuracy of the Conductivity Meter



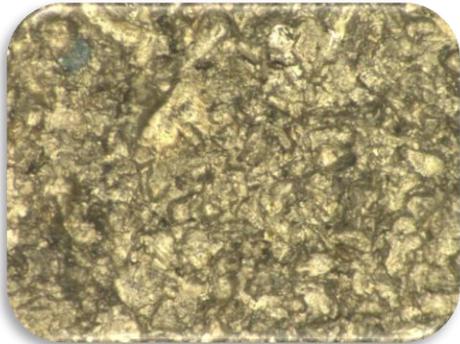
Figure 3-1

Calibration of the temperature-compensating conductivity meter (Figure 3-1) using standard solutions across the range of the meter for its intended use (in this case up to 1,000 μS) can be performed by an instrument supplier or an accredited calibration laboratory. Annual calibration is recommended. A Certificate of Calibration is typically provided listing the calibration checkpoints and tolerance relative to the standard solutions used, along with the manufacturer's stated accuracy of the meter. Readings that fall outside of the combined tolerance of the meter and standard solution(s) often indicate that the probe is defective and that the meter should be replaced.

Verification of accuracy should be performed by the inspector prior to each use (if multiple tests are performed daily, then once daily is adequate). A single standard solution (mid-range; e.g. 445 μS) is adequate. This standard solution is provided in the kit shown in

Figure 2-1. Place a small amount of the standard solution in the cap of the conductivity meter, then place the cap over the probes. The value displayed should match the standard solution value (+/- 5 μS , or 440-450 μS for the 445 solution). Readings that fall outside of the acceptable range often indicate that the probe is defective and that the meter should be replaced.

Measurement of Surface Profile



The surface profile, anchor pattern, or roughness is defined as the maximum average peak to valley depth (or valley to peak height) created during surface preparation. The terms are most commonly associated with abrasive blast cleaning and are the result of the impact of the abrasive onto the substrate. Some impact-type power tools can also produce a roughness in a steel surface. Surface profile is important because it increases the surface area to which the coatings can adhere, providing a mechanical anchor to enhance the adhesion of the coating. Generally, heavier coatings require a deeper surface profile than coatings of lesser thickness.

Surface profile determinations are commonly made in the field or shop using one of three instruments: a visual comparator, a depth micrometer, or replica tape. All three methods are described in ASTM D4417, "Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel." Recent advances in technology enable acquisition of peak density measurements directly from replica tape using a Replica Tape Reader. Traditional and novel methods of quantifying surface roughness characteristics are explored next.

Two of the more traditional methods for measuring surface profile depth include the use of a depth micrometer (Method B in ASTM D4417) and replica tape (Method C in ASTM D4417). Each is briefly described below.



Figure 4-1

A depth micrometer (Figure 4-1) consists of a 60° conical pin that projects from a flat base. First, zero the instrument on a float glass plate (included with the instrument) and verify accuracy using a specially-designed shim placed onto the glass plate (with a notch of a known depth, also included with the instrument) prior to each use. Next position the probe of the instrument on the blast cleaned substrate, resting the base on the tops of the "peaks" and push downward (slightly) so that the 60° conical pin projects into the valleys of the profile. The depth of the profile, relative to the height of the peaks is displayed by the gage. Obtain a minimum of 10 readings in each area, and report the maximum value after discarding any outliers, which are unusually high or low readings that cannot be



Figure 7-1

repeated. That is 12-14 readings may be required to obtain 10 representative readings. The average of the ten readings may also be reported. It is important to pick the instrument up and place it down for each reading, rather than drag it across the profile; otherwise, the point can become blunted, yielding erroneous readings. *Note: According to ASTM D4417, SSPC-SP 15 (Commercial Grade Power Tool Cleaning) and SSPC-SP 11 (Power Tool Cleaning to Bare Metal), Method B is the only suitable method for quantifying the surface profile depth generated by impact-type power tools.*



Figure 5-1

Newer models have a remote probe (Figure 5-1) for taking surface profile measurements in difficult access areas, like the underside of a pipe.

Calibration

Calibration of a depth micrometer can be performed by the instrument manufacturer, authorized service dealer or an accredited calibration laboratory. Annual calibration is recommended. A Certificate of Calibration is provided listing the manufacturer's stated accuracy, the readings from the instrument and the associated deviation (if any). The calibration often includes a visual inspection of the probe for wear. Probe tips are replaceable. Based on the degree of variation from the manufacturer's stated accuracy, the calibration provider may recommend repair or replacement of the instrument.

Probe tips are replaceable. Based on the degree of variation from the manufacturer's stated accuracy, the calibration provider may recommend repair or replacement of the instrument.



Figure 6-1

Replica tape is described in ASTM D4417, Method C and NACE SP02-87, Field Measurement of Surface Profile of Abrasive Blast-Cleaned Steel Surfaces Using a Replica Tape. The Testex Press-O-Film Replica Tape consists of compressible foam attached to a uniform, 2 mil film of Mylar® (a polyester film). The tape is available in three ranges: "Coarse" for profile measurements from 0.8 to 2.5 mils; "X-Coarse" for measurements from 1.5 to 4.5 mils; and "X-Coarse

Plus" for measurements from 4 to 5 mils. The X-Coarse Plus tape may be used to measure surface profile up to 6 mils or so, provided the tape is pre-measured to verify adequate compressible foam is available.

Remove the paper backing and attach the tape to the blast cleaned steel surface, foam side down. Using medium pressure, vigorously rub the Mylar with a burnishing tool (Figure 6-1). The peaks and valleys of the profile conform to the compressible foam and the peaks will ultimately touch, but not alter the thickness of the Mylar, as the Mylar is non-compressible. Remove the

tape from the surface once the white Mylar is uniformly gray and measure the compressed foam and Mylar using a light spring-loaded micrometer, which provides a reading from the upper or outermost surface of the Mylar to the high spots on the foam (corresponding with the valleys of the profile). Subtract 2 mils from the gage dial to determine the maximum surface profile depth (e.g., 3 mils in Figure 7-1). The gage dial may be preset to “8” (-2) to auto-correct for the Mylar thickness. Obtain a minimum of 2 readings per area. The replica tape will reportedly retain the impression indefinitely, provided it is stored in a cool area with no pressure applied. Conceivably, replicas of profile depths could be kept on file permanently for future reference.



Figure 8-1

A Testex linearizing micrometer specially designed to be used with Testex Press-o-Film Replica Tape effectively removes the need to preset the dial to 8 (-2) or deduct 2 mils from the gage reading, provided the gage indicator is set properly (as shown in Figure 8-1). Note however that the maximum surface profile depth that can be measured using this micrometer is 5 mils, so use of the X-Coarse Plus replica tape beyond 5 mils (as described above) is not feasible with the linearizing micrometer.



Figure 9-1

A Replica Tape Reader (RTR; Figure 9-1) can be used in lieu of the standard micrometer and the linearizing micrometer. Insert the burnished replica tape into the slot and press the gray button. The surface profile is displayed (in mils or microns). The Mylar thickness is automatically subtracted; therefore, no user correction is necessary. Additional information such as peak density¹ can be acquired from the same replica tape and Advanced Model Replica Tape Reader.

¹ Research indicates that increased peak density can improve coating system adhesion and provide greater resistance to corrosion undercutting when the coating is damaged in service

Optical Grade Replica Tape A special Optical Grade Replica Tape (when used in conjunction with an Advanced Model Replica Tape Reader) can provide 3-dimensional images of peak density, or Pd (Figures 10a-1 and 10b-1).

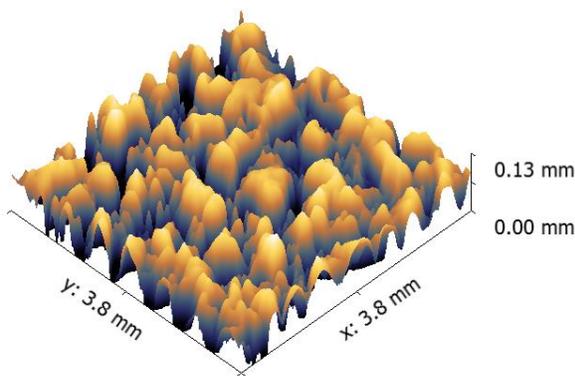


Figure 10a-1 (Pd of 5/mm²)

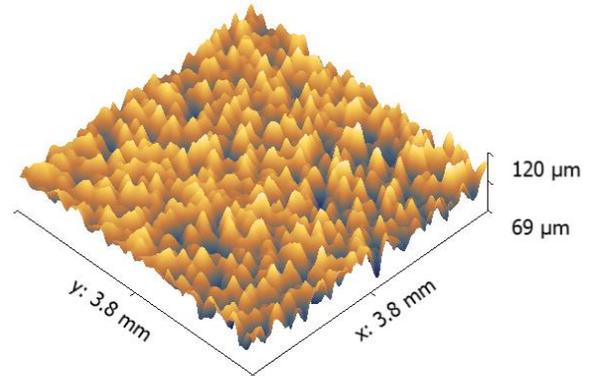


Figure 10b-1 (Pd of 16/mm²)

It is important to realize that there is little correlation among the methods described herein because each considers a different peak count or surface area for its measurement. Therefore, it is advisable that all parties agree upon the method that will be used to determine the surface profile and not deviate from it. Oftentimes project specifications will dictate the method of surface profile measurements.

Calibration

Calibration of the Testex micrometers and the Replica Tape Readers can be performed by the instrument manufacturer, authorized service dealer or an accredited calibration laboratory. Annual calibration is recommended. A Certificate of Calibration is provided listing the manufacturer's stated accuracy, the readings from the instrument and the associated deviation (if any). Based on the degree of variation from the manufacturer's stated accuracy, the calibration provider may recommend repair or replacement of the instrument. The Testex micrometers can be verified for accuracy in the shop or field using the same certified or measured shims that are used to verify the accuracy of electronic dry film thickness gages

Frequency of Measurement

While ASTM D4417 prescribes the number of readings to take per area, it does not prescribe the number of areas to measure. SSPC-PA 17, "Procedure for Determining Conformance to Steel Profile/Surface Roughness/Peak Count Requirements" fills this gap. It states, *"Unless otherwise specified, select a minimum of three 6 x 6-inch locations in which to take readings for each specific surface preparation apparatus used during each work shift or twelve-hour period, whichever is shorter. For the purpose of this standard, "apparatus" is defined as an individual blast pot (which may supply multiple nozzles), individual self-contained abrasive recycling/blast*

cleaning units (which may contain multiple pots), individual stationary or mobile centrifugal cleaning unit, or individual power tool.”

Assessment of Surface Cleanliness

All surfaces should be visually inspected after surface preparation to ensure compliance with the cleanliness requirements of the governing specification. The SSPC Surface Preparation Standards describe the appearance of various methods of surface preparation (e.g., hand and power tool cleaning, abrasive blast cleaning, etc.), including the type and percentage of residues or stains permitted to remain on the surface.

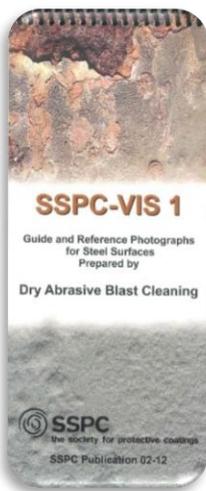


Figure 11-1

The written definitions for abrasive blast cleaned surfaces are supplemented by SSPC-VIS 1 Guide, which photographically depicts the surface appearance of various grades of blast cleaning over four initial mill scale and rust conditions of steel and three conditions of coated steel (Figure 11-1). The images in the Guide are visually compared with the prepared surface to determine the degree of cleanliness. SSPC has also produced a visual guide for hand- and power-tool cleaned surfaces (SSPC-VIS 3; shown in Figure 12-1). Other visual guides for surface cleanliness evaluation include the ISO Pictorial Standards (8502-1); however, these are only used when ISO surface cleanliness standards (e.g., Sa 1, Sa 2, Sa 2½ and Sa 3) are specified.

Using SSPC-VIS 1, Guide and Reference Photographs for Surfaces Prepared by Dry Abrasive Blast Cleaning

SSPC-VIS 1 is a collection of color reference photographs depicting various initial conditions and different levels of dry abrasive blast cleaning. To use the SSPC VIS 1 visual standard, follow these four basic steps:

Step 1: Determine the initial condition of the steel surfaces: Determine what the existing steel looks like *before* it is prepared by abrasive blast cleaning. To do this, locate the reference photographs in the visual guide illustrating the seven possible initial conditions of the steel. The SSPC-VIS 1 Guide illustrates seven *Initial Conditions*, including:

Condition A: Steel surface completely covered with adherent mill scale; little or no visible rust.

Condition B: Steel surface covered with both mill scale and rust.

Condition C: Steel surface completely covered with rust; little or no pitting visible.

Condition D: Steel surface completely covered with rust; pitting visible.

Condition G₁: Weathered coating system over mill scale with extensive pinpoint rusting

Condition G₂: Weathered coating system over mill scale with moderate pitting

Condition G₃: Weathered coating system over mill scale with severe pitting

Select one or more of the “before” reference photographs that best illustrates the condition of the steel (the steel may be represented by more than one condition).

Step 2: Determine the level of surface cleanliness the specification requires: After you select a reference photograph(s) that depicts the existing condition of the steel surfaces (the “before photograph”), reference the project specification to determine the degree of surface cleanliness required. The degree of surface cleanliness will typically appear in the project specification as one of five possible “levels,” including SSPC-SP7, *Brush-off Blast*; SSPC-SP14, *Industrial Blast*; SSPC-SP6, *Commercial Blast*; SSPC-SP10, *Near-White Metal Blast*; or SSPC-SP5, *White Metal Blast*. At this point, you should have both a code for the initial condition (A, B, C, D, G₁, G₂ or G₃) and a code for the surface cleanliness (SP7, SP14, SP6, SP10 or SP5).

Step 3: Locate the reference photograph in the visual standard.

The SSPC-VIS 1 visual guide illustrates various levels of surface cleanliness (after abrasive blast cleaning is completed) for each of the conditions in Step 1. We’ll call these “after photographs.” Table 1 provides the combinations of initial conditions (before photographs) and surface cleanliness levels (after photographs)

Table 1 - Combinations of Initial Conditions and Surface Cleanliness Levels in SSPC-VIS 1

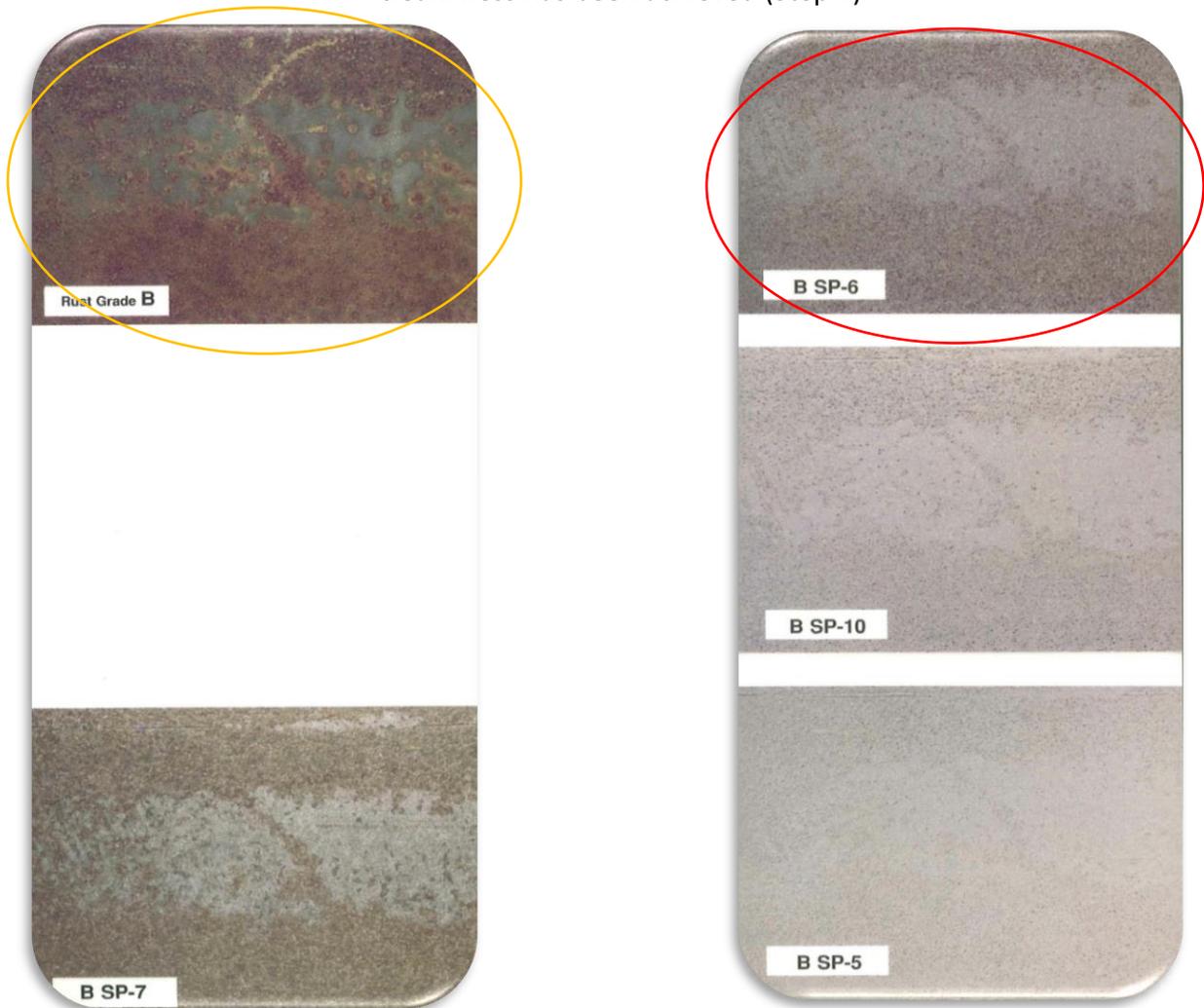
Rust Grade	Surface Cleanliness Levels Depicted in the Reference Color Photographs
A	<i>Near-White Metal Blast (SP10) and White Metal Blast (SP5)</i>
B	<i>Brush-off Blast (SP7); Commercial Blast (SP6); Near-White Metal Blast (SP10); and White Metal Blast (SP5)</i>
C	<i>Brush-off Blast (SP7); Commercial Blast (SP6); Near-White Metal Blast (SP10); and White Metal Blast (SP5)</i>
D	<i>Brush-off Blast (SP7); Commercial Blast (SP6); Near-White Metal Blast (SP10); and White Metal Blast (SP5)</i>
G ₁	<i>Brush-off Blast (SP7); Industrial Blast (SP14); Commercial Blast (SP6); Near-White Metal Blast (SP10); and White Metal Blast (SP5)</i>
G ₂	<i>Brush-off Blast (SP7); Industrial Blast (SP14); Commercial Blast (SP6); Near-White Metal Blast (SP10); and White Metal Blast (SP5)</i>
G ₃	<i>Brush-off Blast (SP7); Industrial Blast (SP14); Commercial Blast (SP6); Near-White Metal Blast (SP10); and White Metal Blast (SP5)</i>

Select the reference photograph in the visual guide by combining the code for the initial condition (from column 1 in Table 1) and the code for the specified surface cleanliness level (from column 2 of Table 1).

Step 4: Assess the prepared surfaces.

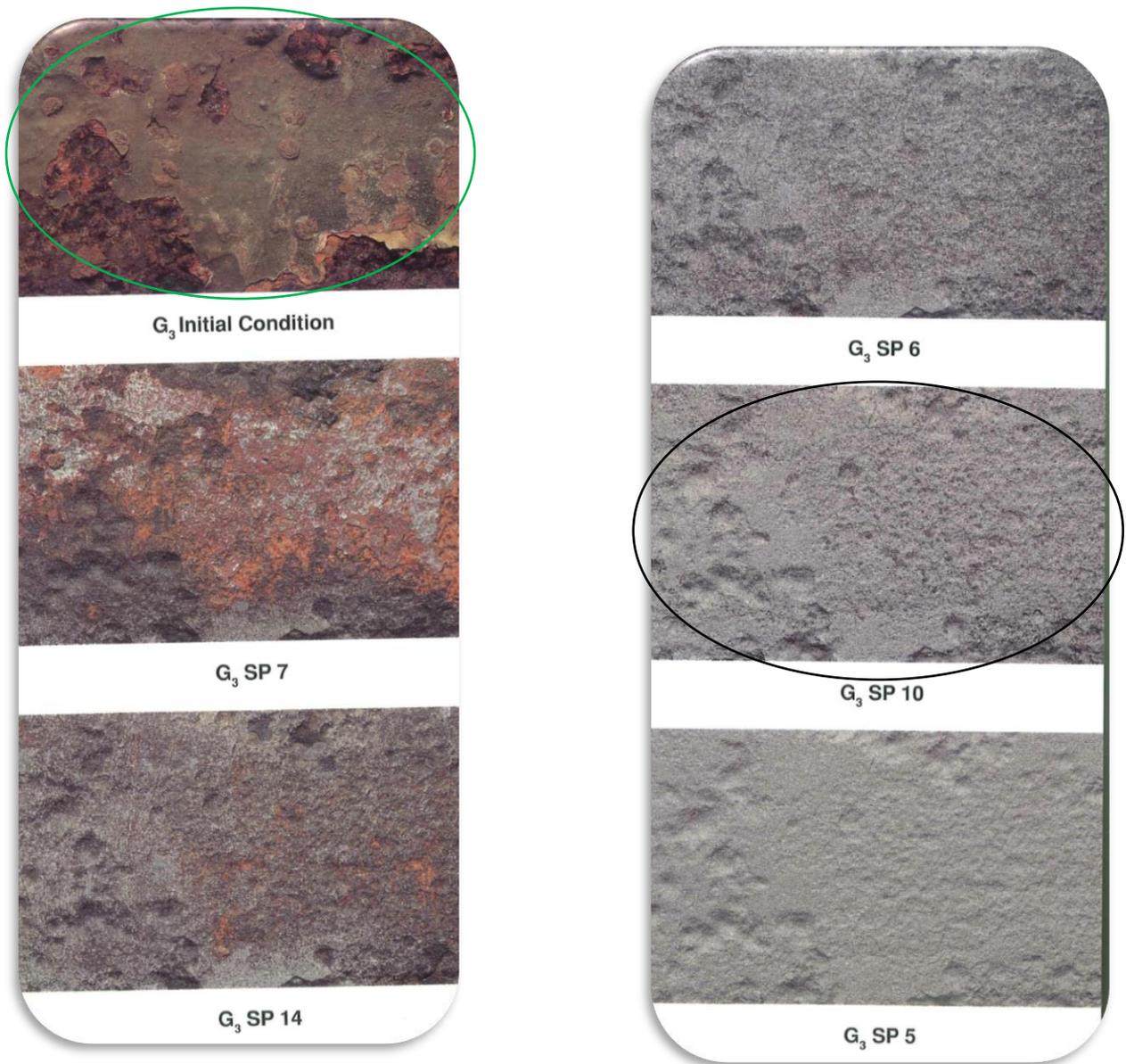
Use the reference photograph selected in Step 3 to determine whether the prepared surface(s) meet or exceed the specified level of surface cleanliness. Here are two examples:

Example 1: If the steel surface contains both mill scale and rust, select Condition B (image within yellow circle). Assuming the specification requires a Commercial Blast (SSPC-SP 6), select level SP6. Combine the two codes (B SP6). Locate the section of the SSPC-VIS 1 visual guide that contains the “before” photograph Rust Grade B and the “after” photographs of the four levels of surface cleanliness. Select the “after” photograph that contains the complete code (e.g. B SP6; red circle). Use this reference photograph to help assess whether the minimum surface cleanliness has been achieved (Step 4).



Example 1 Images

Example 2: If the steel contains a weathered coating system over mill scale with severe pitting, select Initial Condition G₃ (image within green circle). Assuming the specification requires a Near-white Blast (SSPC-SP 10), put the two codes together to arrive at the complete code (G₃ SP10), and locate the section of the SSPC- VIS 1 visual guide that contains the “before” photograph Rust Grade G3 and the “after” photographs of the five levels of surface cleanliness. Select the “after” photograph that contains the complete code (e.g. G3 SP10; image within black circle). Use this reference photograph to help assess whether the minimum surface cleanliness has been achieved (Step 4).



Example 2 Images

Using SSPC-VIS 3, Guide and Reference Photographs for Surfaces Prepared by Power and Hand Tool Cleaning

SSPC-VIS 3 is a collection of color reference photographs depicting seven initial conditions and three degrees of cleaning for each condition. To use the SSPC-VIS 3 visual guide follow these five steps.

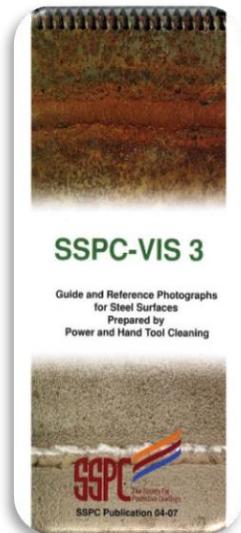


Figure 12-1

Step 1: Determine the initial condition of the steel surfaces: Determine what the existing steel looks like *before* it is prepared by hand- or power-tool cleaning. Locate the reference photographs in the visual guide illustrating the seven possible initial conditions of the steel. These “before photographs” depict the condition of the steel “before” it was hand- or power-tool cleaned. The SSPC-VIS 3 guide illustrates seven *Initial Conditions*, including:

- Condition A: Steel surface completely covered with adherent mill scale; little or no visible rust (Rust Grade A).
- Condition B: Steel surface covered with both mill scale and rust (Rust Grade B).
- Condition C: Steel surface completely covered with rust; little or no pitting visible (Rust Grade C).

Condition D: Steel surface completely covered with rust; pitting visible (Rust Grade D).

Condition E: Previously painted steel surface; mostly intact, light-colored paint applied to a blast cleaned surface.

Condition F: Previously painted steel surface; mostly intact, zinc-rich paint applied to a blast cleaned surface.

Condition G: Paint system applied to mill scale bearing steel; system thoroughly weathered, blistered, or stained.

Select one or more of the “before” reference photographs that best illustrates the condition of the steel (the steel may be represented by more than one condition).

Step 2: Determine the level of surface cleanliness the specification requires: After you select a reference photograph(s) that depicts the existing condition of the steel surfaces (the “before photograph”), reference the project specification to determine the degree of surface cleanliness required. The degree of surface cleanliness will appear in the project specification as one of four possible “levels,” including SSPC-SP2, *Hand Tool Cleaning*; SSPC-SP3, *Power Tool Cleaning*; SSPC-SP11, *Power Tool Cleaning to Bare Metal*; or SSPC-SP15, *Commercial Grade Power Tool Cleaning*.

Step 3: Locate the reference photograph in the visual guide: The SSPC-VIS 3 visual guide illustrates various levels of surface cleanliness (after hand or power tool cleaning is completed) for each of the conditions in Step 1. We’ll call these “after photographs.” Table 1 provides the combinations of initial conditions (before photographs) and surface cleanliness levels (after photographs).

Table 2 - Combinations of Initial Conditions and Surface Cleanliness Levels in SSPC-VIS 3

Rust Grade/ Initial Condition	Surface Cleanliness Levels Depicted in the Reference Color Photographs
A	<i>Hand Tool Cleaning (SP 2) and Power Tool Cleaning (SP 3)</i>
B	<i>Hand Tool Cleaning (SP 2) and Power Tool Cleaning (SP 3)</i>
C	<i>Hand Tool Cleaning (SP 2) and Power Tool Cleaning (SP 3)</i>
D	<i>Hand Tool Cleaning (SP 2) and Power Tool Cleaning (SP 3)</i>
E	<i>Hand Tool Cleaning (SP 2); Power Tool Cleaning (SP 3); Commercial grade Power Tool Cleaning (SP 15) and Power Tool Cleaning to Bare Metal (SP 11)</i>
F	<i>Hand Tool Cleaning (SP 2); Power Tool Cleaning (SP 3); Commercial grade Power Tool Cleaning (SP 15) and Power Tool Cleaning to Bare Metal (SP 11)</i>
G	<i>Hand Tool Cleaning (SP 2); Power Tool Cleaning (SP 3); Commercial grade Power Tool Cleaning (SP 15) and Power Tool Cleaning to Bare Metal (SP 11)</i>

Select the reference photograph in the visual guide by combining the code for the initial condition (from column 1 in Table 2) and the code for the specified surface cleanliness level (from column 2 of Table 2).

Step 4: Assess the prepared surfaces.

Use the reference photograph selected in Step 3 to determine whether the prepared surface(s) meet or exceed the specified level of surface cleanliness. Here are two examples:

Example 1:

The surface contains 100% rust with little or no visible pitting:

Select Condition C

The specification requires SSPC-SP 2 Hand Tool Cleaning:

Select Image C SP2

Example 2:

The surface contains a thoroughly weathered paint system:

Select Condition G

The specification requires SSPC-SP 15 Commercial

Grade Power Tool Cleaning:

Select Image G SP15

Agreement on the desired appearance of a cleaned surface using commercially available reference photographs is often difficult to achieve because of shadows and hues caused by the abrasive used, the pattern and degree of prior rusting and numerous other factors unique to each project. As a result, jobsite standards are often developed to reach agreement on the appearance prior to beginning production work. Sections of the structure (or test panels of a similar nature) are prepared and all parties involved ultimately select the panels or areas that are representative of the desired end-result.

Using ISO 8501-1, Preparation of Steel Substrates Before Application of Paints and Related Products – Visual Assessment of Surface Cleanliness – Part 1: Rust Grades and Preparation Grades of Uncoated Steel Substrates and of Steel Substrates After Overall Removal of Previous Coatings



Figure 13-1

The ISO 8501-1 Visual Guide (Figure 13-1) is similar in use to the SSPC VIS 1 and VIS 3 Guides previously described, however the images in the guide conform to the ISO surface cleanliness standards and not the SSPC surface cleanliness standards. Therefore, the images in the ISO 8501-1 guide should only be used when ISO surface cleanliness standards are specified.

Four initial conditions are shown:

Condition A: Steel surface completely covered with adherent mill scale; little or no visible rust.

Condition B: Steel surface covered with both mill scale and rust.

Condition C: Steel surface completely covered with rust; little or no pitting visible.

Condition D: Steel surface completely covered with rust; pitting visible.

Two levels of hand and power tool cleaning are shown for each condition:

St 2: Thorough Hand/Power Tool Cleaning

St 3: Very Thorough Hand/Power Tool Cleaning

Four levels of dry abrasive blast cleaning are shown for each condition:

Sa 1: Light Blast Cleaning

Sa 2: Thorough Blast Cleaning

Sa 2 ½ : Very Thorough Blast Cleaning

Sa 3: Blast Cleaning to Visually Clean Steel

Use the ISO 8501-1 guide to inspect prepared surfaces using these three steps:

Step 1: Select the image that closely represents the existing condition of the surfaces.

Step 2: Determine the specified degree of cleanliness for the project specification.

Step 3: Select the image in the ISO visual guide that references both the initial condition code and the surface cleanliness code. Here are two examples:

Example 1:

Surface contains 100% adherent mill scale

Select Condition A

Very thorough Blast Cleaning is specified (Sa 2 ½)

Select Image A Sa 3

Example 2:

Surface contains 100% rust

Select Condition C

Thorough Hand/Power Cleaning is specified (St 2)

Select Image C St 2

Assessing Surface Dust

After the specified level of surface cleanliness has been achieved and the surface profile depth has been measured and recorded, the prepared surfaces should be examined to assess whether they contain levels of dust that may interfere with coating adhesion.

Dust and debris remaining on the surface is frequently removed by brushing, compressed air blow down (or double blow down), or by vacuuming. If the compressed air is used, it must first be verified for cleanliness per ASTM D4285, "Standard Test Method for Indicating Oil or Water in Compressed Air." While a "white glove" test is not necessary nor recommended, if gloved fingers are traced across the surfaces and tracks are visually evident on the surface, then excessive dust remains and can interfere with primer adhesion and/or cause application defects. Alternatively, ISO 8502-3: Preparation of Steel Substrates Before Application of Paints and Related Products – Tests for the Assessment of Surface Cleanliness, Part 3: Assessment of Dust on Steel Surfaces Prepared for Painting (pressure-sensitive tape method) can be used to evaluate the presence of surface dust.

To perform this test, a special type of clear, pressure sensitive 1-inch wide adhesive tape, a special spring-tensioned roller, a 10X illuminated magnifier and a white backing (e.g., bright white cardboard or paper) are needed. The spring-tensioned roller is not required by the standard unless the testing procedure or results are being disputed. The roller can be replaced by thumb pressure applied to the tape, as described below.

- Step 1: Discard three full turns of tape from the roll.
- Step 2: Remove a test piece of tape approximately 8-inches long, being certain to only touch the two ends (1-inch at each end). Attach (press) approximately 6-inches of the tape (excluding the two – 1-inch ends) to the surface.
- Step 3: Press the tape to the surface by placing your thumb at one end of the tape, then move your thumb along the tape length (at a constant speed and pressure) three times in each direction (each stroke should take between 5 and 6 seconds to complete). Leave the two 1-inch ends of the tape up from the surface. Only the middle 6-inches of the tape should be attached.
- Step 4: Remove (peel) the tape from the surface at a 180° angle (to the surface). Attach the peeled tape to a white backing.
- Step 5: Rate the quantity of dust attached to the tape using the Dust Quantity Ratings figure provided in the standard (Figure 14-1) and compare the results to the specification requirements for the maximum dust rating. The standard requires one test for every 200 square feet of prepared surface that is ready to be primed.

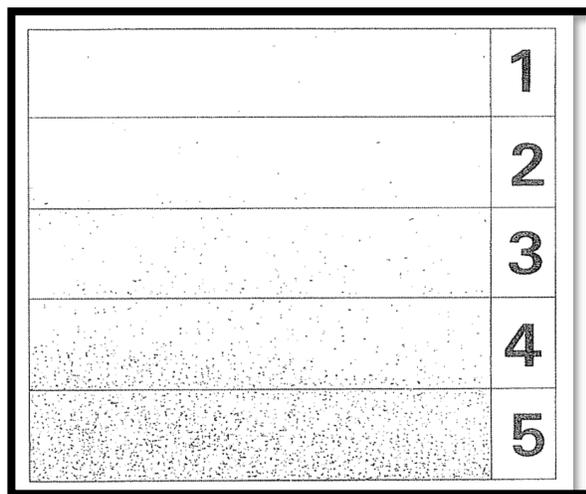


Figure 14-1

Surface Soluble Salt Detection

Chemical contaminants on a surface can include chloride, ferrous ions, sulfates, and nitrates, among others. These chemicals are deposited onto surfaces while the structure is in service, or during transportation of new pipe/steel to the fabrication shop. These chemicals are soluble in water, so they can typically be removed from surfaces by pressure washing. The effectiveness of the washing step is dependent on the condition of the surface. That is, contamination is relatively easy to remove from smooth surfaces, but may be more challenging if the surfaces are pitted or are configured with difficult-access areas, as contamination will tend to concentrate in these areas. If the salts are not detected or are not adequately dissolved and rinsed from the surfaces, they can become trapped beneath a newly-installed coating system. If there is a sufficient quantity of water in the environment, the water-soluble contaminant trapped beneath the coating system will draw the water through the coating film by a process known as “osmosis.” This drawing force will continue until the concentration of salt in water is the same on both sides of the coating film (the concentration reaches equilibrium). This process creates a build-up of water and pressure beneath the coating film, oftentimes enough to cause blistering of the coating (known as osmotic blistering), underfilm corrosion and premature coating failure.

Additionally, if soluble salts on the surface are not sufficiently removed prior to abrasive blast cleaning, recycled abrasive media can become contaminated.

It is for these reasons that many specifications are now requiring testing of surfaces for chemical contaminants after surface preparation is complete, but before application of the primer. Because this type of contamination cannot be detected visually, the surface must be sampled and the “surface extraction” tested for the contaminant(s) of concern. There are several methods to choose from. SSPC Guide 15, “Field Methods for Retrieval and Analysis of Soluble Salts on Steel and Other Nonporous Surfaces” describes common methods for sampling and analysis of soluble salt contamination, with the intent of assisting the user in selecting an extraction and analysis procedure.

This eBook highlights two procedures, including a non-ion-specific method (conductivity) and an ion-specific method for chloride, sulfate, and nitrate contamination. Specific step-by-step instructions are too lengthy to provide in this eBook, but the ISO standard and/or the manufacturer’s instructions are relatively easy to follow.

Non-ion specific Analysis (Latex Patch/Conductivity per ISO 8502-6/8502-9)

For this procedure, attach a latex patch (Bresle Patch, Figure 15-1; DeFelsko Patch or PosiPatch, Figure 16-1) to the prepared, uncoated surface using an adhesive or a magnet. Inject the prescribed amount of distilled water into the patch and agitate the water inside the patch (Figure 17a-1/17b-1). Once the extraction is complete, remove the solution from the patch and place it onto a conductivity bridge (Figure 18-1) or Soluble Salts Tester (Figure 19-1). Conductivity results are displayed in microsiemens/cm ($\mu\text{S}/\text{cm}$) or millisiemen (mS/cm); surface concentrations are displayed in $\mu\text{g}/\text{cm}^2$ or mg/m^2 . Either can be compared to the maximum allowable contamination referenced in the project specification.

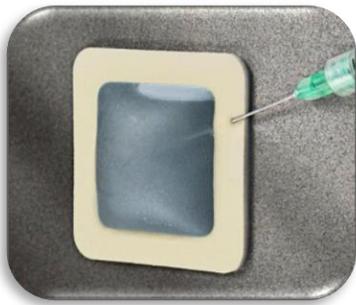


Figure 15-1



Figure 16-1



Figure 17a-1



Figure 17b-1



Figure 18-1



Figure 19-1

This test will not reveal the type of surface contamination; only that some type of water-soluble ionic contamination was extracted from the surface, causing an increase in the conductivity of the distilled water used for the extraction.

Ion-specific Analysis – Chloride-Sulfate-Nitrate (CSN) Test Kit

If ion-specific testing for chloride, sulfate and nitrate surface contamination is required, then a special kit is required to perform both the extraction and analysis. The CSN kit contains latex sleeves, pre-measured extraction liquid, chloride ion detection tubes (Kitagawa), nitrate test strips, and pre-measured chemicals and a meter for sulfate analysis.

A premeasured amount of extraction solution is emptied into the latex sleeve (Figure 20-1) and the sleeve is attached to the prepared, uncoated surface (Figure 21-1). An extraction is performed (Figure 22-1), the latex sleeve removed, and the solution analyzed for chloride (Figure 23-1), nitrate (Figure 24-1) and/or sulfate (Figure 25-1). Because the opening of the latex sleeve is 10 cm² and the premeasured amount of solution is 10 mL, these values cancel one another, so the reading from the tube, strip, and meter (in PPM) is the same as µg/cm².



Figure 20-1



Figure 11-1



Figure 22-1



Figure 23-1

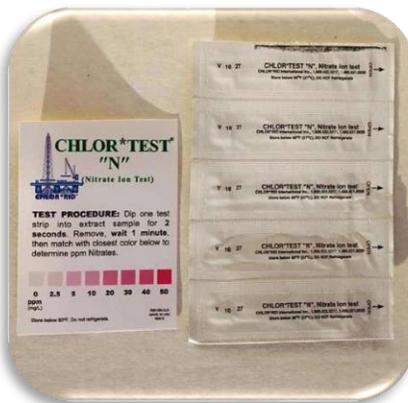


Figure 24-1



Figure 25-1

Conclusion

Surface preparation is considered the foundation for the coating system. In this case, installing a solid “foundation” includes verifying that the surface is prepared according to the project specification prior to application of the primer. This frequently involves quality control check points to verify conformance and to correct deviations before they become nonconformities. Common quality check points include those described in Chapter 1 of this Supplement - *Surface Preparation and Coating Application Inspection Instruments*.

Chapter 2

Verifying the Quality of the Application of Protective Coatings



Introduction

Common quality control checkpoints associated with coating application include:

- Measuring Prevailing Ambient Conditions & Surface Temperature
- Measuring the Coating Temperature
- Calculating and Measuring the Wet Film Thickness
- Measuring Dry Film Thickness

Measuring Ambient Conditions & Surface Temperature

The measurement of air temperature, relative humidity, dew point temperature, and surface temperature is oftentimes required before and during coating application activities (*Figure 1-2, right*). Air or surface temperatures above/below the manufacturer's specified range, as well as excessive or inadequate moisture levels in the air (humidity) can contribute to application challenges, inadequate curing, and performance problems. In addition, a surface temperature at or below the dew point temperature can result in moisture condensation on the surface.



Figure 1-2

Therefore, it is important to verify that the temperature of the surfaces to be coated is at least 5°F (3°C) higher than the temperature of the dew point, and to verify that the air and surface temperatures, as well as the relative humidity, are all within the coating manufacturers' specified range or as required by the project specification. These values (air temperature, relative humidity, surface temperature and dew point temperature) can be obtained using sling (*Figure 2-2*) or



Figure 2-2



Figure 3-2

battery-powered psychrometers (*Figure 3-2*) in conjunction with US Weather Bureau Psychrometric Tables (*Figure 4-2*) and surface temperature thermometers (*Figure 5-2*) or can be obtained using electronic psychrometers equipped with surface temperature probes (*Figures 6-2 and 7-2*). Each of these procedures is described herein.

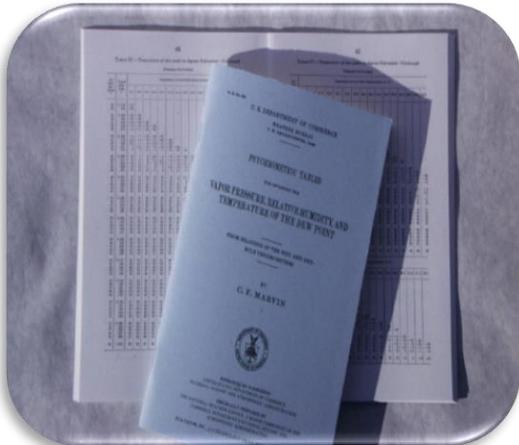


Figure 4-2



Figure 5-2



Figure 6-2



Figure 7-2

Ambient conditions should be measured and recorded prior to mixing the coating materials and at 4-hour intervals thereafter, unless conditions appear to be declining. In this case, more frequent checks may be required. The prevailing ambient conditions at the actual location of the work should be assessed. The location, date, time of day and the conditions of air temperature, relative humidity, dew point temperature, and surface temperature should be recorded.

Traditional and least expensive methods of measuring the prevailing ambient conditions include the use of whirling psychrometers in accordance with ASTM E337, *Standard Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)*, psychrometric charts, and dial-type surface temperature thermometers.

The whirling or battery-powered psychrometer is used to measure the air temperature and to assess the latent heat loss caused by water evaporation from a wetted sock on the end of a bulb thermometer. The psychrometric tables are used to look-up the relative humidity and dew point temperature (based upon temperature readings from the psychrometer and the barometric pressure).

Obtaining Temperature Readings from the Psychrometer



Figure 8-2

Sling and the battery-powered psychrometers are each equipped with two bulb thermometers. The two thermometers are identical, except that one has a wick or sock covering the end of the bulb. This thermometer is called the wet bulb. The thermometer without the wick

is called the dry bulb thermometer (Figure 8-2 above). Follow Steps 1 through 3 below to obtain the dry bulb and wet bulb temperatures.

Step 1 - Verify that the wick surrounding the wet bulb thermometer is relatively clean.



Figure 9-2

Step 2 - Saturate the wick with distilled water or fill the water reservoir at the end of the sling psychrometer (*Figure 9-2*).



Figure 10-2

Step 3 –

For the sling psychrometer, whirl the instrument (*Figure 10-2*) through the air (away from your body) for approximately 15 or 20 seconds, then obtain a reading from only the wet bulb thermometer. *Without* re-wetting the wick, whirl the instrument for another 10 or 15 seconds and obtain another temperature reading from the wet bulb thermometer. Repeat this process until the two consecutive temperature readings are within 0.5°F of one another. This is considered a stable wet bulb temperature. Then read and record the dry bulb (air) temperature.

If you are using a battery-powered psychrometer, a fan draws the air across the thermometers, rather than whirling them through the air. Allow the fan to operate for approximately 2 minutes, then record the wet bulb temperature after it stabilizes, as well as the stable dry bulb (air) temperature.

Determining the Dew Point Temperature and Relative Humidity

The next step is to determine the relative humidity and the dew point temperature. The relative humidity is the amount of moisture in the air, relative to total saturation at the given temperature. This is expressed as a percentage (e.g., the relative humidity is 56%). The dew point is the temperature that moisture in the air will condense on a surface. The surface temperature needs to remain warmer than the dew point temperature for coating work to begin or continue to be assured that moisture is not present. If the temperature of the surface is at or below the dew point, condensation will form, and it may not even be visible.

Measuring Wet Film Thickness

Once the target WFT is calculated, the thickness of the wet coating film can be monitored as it is applied using a wet film thickness gage. These are known as notch-type gages and conform to ASTM D4414, *Standard Practice for Measurement of Wet Film Thickness by Notch Gages*.

All notch-type gages contain four or eight faces with a series of steps, with notches between the steps. Each step is numbered. The number corresponds to the wet film thickness in mils (0.001”) or micrometers (µm). There are 25.4 µm in 1 mil.

The traditional aluminum (*Figure 18-2*) and hardened steel (*Figure 19-2*) wet film thickness gages have four (4) measuring faces. Each face contains a different wet film thickness range. The chart below provides the measuring ranges for each of the four faces, for both the aluminum and hardened steel type gages.



Figure 18-2



Figure 19-2

WFT Gage Type	WFT Range on each Face			
	Face 1	Face 2	Face 3	Face 4
Hardened Steel (low)	½ - 2 mils	2 ½ - 4 mils	5 - 8 mils	10 - 20 mils
Hardened Steel (medium)	4 - 10 mils	12 - 24 mils	28 - 40 mils	45 - 60 mils
Hardened Steel (high)	10 - 40 mils	50 - 80 mils	100 - 160 mils	200 - 500 mils
Aluminum (Side 1-mils)	1 - 6 mils	7 - 12 mils	14 - 30 mils	35 - 80 mils
Aluminum (Side 2-µm)	25-150 µm	175-300 µm	350-750 µm	875-2000 µm

The US Weather Bureau Psychrometric Tables contain charts that are used in conjunction with dry bulb temperature and the depression of the wet bulb thermometer from the dry bulb (air) temperature to determine the relative humidity and dew point temperature.

One set of charts is used for calculating relative humidity and another set is used for calculating dew point. The names of the charts are at the top of each page. First, locate the charts of interest (e.g., dew point temperature), and select the ones that correspond to 30-inches barometric pressure. If the exact barometric pressure where the project is located is known (e.g., 29 inches), use those charts instead.

Locate the dew point chart at the appropriate barometric pressure (say 30 inches) and find the dry bulb temperature (air temperature) reading in the far left-hand column, entitled "air temperature t ". Subtract the wet bulb reading from the dry bulb reading. The difference is the "depression of the wet bulb thermometer" ($t-t'$). Locate the depression of the wet bulb thermometer across the top row of the table. Intersect the depression of the wet bulb thermometer (along the top row) with the air temperature (down the left column). The intersection of the two values represents the dew point temperature in °F (*Figure 11-2, next page*). Repeat this same process using the relative humidity charts at the appropriate barometric pressure (*Figure 12-2 on two pages from now*).

TABLE I.—Temperature of dew point in degrees Fahrenheit—Continued
[Pressure=30.0 inches]

Air temperature <i>t</i>	Vapor pressure <i>e</i>	Depression of wet-bulb thermometer (<i>t-t'</i>)														
		8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
25	0.130	-51														
26	.136	-32														
27	.143	-23	-45													
28	.150	-17	-29													
29	.157	-12	-20	-39												
30	0.164	-7	-14	-25	-57											
31	.172	-4	-10	-18	-31											
32	.180	-1	-6	-12	-21	-42										
33	.187	+2	-2	-7	-14	-26										
34	.195	5	+1	-3	-9	-17	-32									
35	0.203	7	4	±0	-5	-11	-20	-41								
36	.211	10	7	+3	-1	-6	-14	-25	-58							
37	.219	12	9	6	+2	-3	-8	-16	-29							
38	.228	14	11	8	5	+1	-4	-10	-19	-36						
39	.237	16	13	11	8	4	±0	-5	-12	-22	-47					
40	0.247	18	15	13	10	7	+3	-1	-6	-14	-26					
41	.256	19	17	15	12	10	6	+2	-2	-8	-16	-30				
42	.266	21	19	17	14	12	9	6	+2	-3	-9	-18	-36			
43	.277	22	20	19	16	14	11	9	5	+1	-4	-11	-21	-45		
44	.287	24	22	20	18	16	13	11	8	4	±0	-5	-12	-24	-60	
45	0.298	25	23	22	20	18	15	13	10	7	+4	-1	-6	-14	-27	-30
46	.310	27	25	23	21	20	17	15	13	10	7	+3	-2	-7	-16	-17
47	.322	28	26	25	23	21	19	17	15	12	9	6	+2	-3	-9	-10
48	.334	29	28	26	25	23	21	19	17	14	12	9	5	+1	-4	-5
49	.347	30	29	28	26	24	23	21	19	16	14	11	8	5	±0	-5
50	0.360	32	30	29	27	26	24	22	21	18	16	13	11	8	+4	±0
51	.373	33	32	30	29	27	26	24	22	20	18	16	13	10	7	+3
52	.387	34	33	32	30	29	27	26	24	22	20	18	16	13	10	7
53	.402	36	34	33	32	30	29	27	26	24	22	20	18	15	13	10
54	.417	37	36	34	33	32	30	29	27	25	24	22	20	18	15	12
55	0.432	38	37	36	34	33	32	30	29	27	25	24	22	20	17	15
56	.448	40	39	37	36	34	33	32	30	29	27	25	24	22	19	17
57	.465	41	40	39	37	36	34	33	32	30	29	27	25	24	21	19
58	.482	42	41	40	39	37	36	35	33	32	30	29	27	25	23	21
59	.499	44	43	41	40	39	37	36	35	33	32	30	29	27	25	23
60	0.517	45	44	43	41	40	39	38	36	35	33	32	30	29	27	25
61	.536	46	45	44	43	42	40	39	38	36	35	33	32	30	29	27
62	.555	47	46	45	44	43	42	40	39	38	36	35	33	32	30	29
63	.575	49	48	47	45	44	43	42	41	39	38	36	35	34	32	30
64	.595	50	49	48	47	46	44	43	42	41	39	38	37	35	34	32
65	0.616	51	50	49	48	47	46	45	43	42	41	40	38	37	35	34
66	.638	52	51	50	49	48	47	46	45	44	42	41	40	38	37	35
67	.661	53	53	52	50	49	48	47	46	45	44	43	41	40	38	37
68	.684	55	54	53	52	51	50	49	48	46	45	44	43	42	40	39
69	.707	56	55	54	53	52	51	50	49	48	46	45	44	43	42	40
70	0.732	57	56	55	54	53	52	51	50	49	48	47	46	44	43	42
71	.757	58	57	56	55	54	53	52	51	50	49	48	47	46	45	43
72	.783	59	58	58	57	56	55	54	53	52	51	50	48	47	46	45
73	.810	60	60	59	58	57	56	55	54	53	52	51	50	49	48	46
74	.838	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
75	0.866	63	62	61	60	59	58	57	56	55	55	54	52	51	50	49
76	.896	64	63	62	61	60	60	59	58	57	56	55	54	53	52	51
77	.926	65	64	63	62	62	61	60	59	58	57	56	55	54	53	52
78	.957	66	65	64	64	63	62	61	60	59	58	57	56	55	54	53
79	0.989	67	66	66	65	64	63	62	61	60	59	58	57	56	55	54
80	1.022	68	68	67	66	65	64	63	63	62	61	60	59	58	57	56

Figure 11-2

TABLE VI.—Relative humidity, percent—Fahrenheit temperatures—Continued

[Pressure=30.0 inches]

Air temperature <i>t</i>	Depression of wet-bulb thermometer (<i>t-t'</i>)																					
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	
20	92	85	77	70	62	55	48	40	33	26	19	12	5									
21	92	85	78	71	63	56	49	42	35	28	21	15	8	1								
22	93	86	78	71	65	58	51	44	37	31	24	17	11	4								
23	93	86	79	72	66	59	52	46	39	33	26	20	14	7	1							
24	93	87	80	73	67	60	54	47	41	35	29	22	16	10	4							
25	94	87	81	74	68	62	55	49	43	37	31	25	19	13	7	1						
26	94	87	81	75	69	63	57	51	45	39	33	27	21	16	10	4						
27	94	88	82	76	70	64	58	52	47	41	35	29	24	18	13	7	2					
28	94	88	82	76	71	65	59	54	48	43	37	32	26	21	15	10	5					
29	94	88	83	77	72	66	60	55	50	44	39	34	28	23	18	13	8	3				
30	94	89	83	78	73	67	62	56	51	46	41	36	31	26	21	16	11	6	1			
31	94	89	84	78	73	68	63	58	52	47	42	37	33	28	23	18	13	8	4			
32	95	89	84	79	74	69	64	59	54	49	44	39	35	30	25	20	16	11	7	2		
33	95	90	85	80	75	70	65	60	56	51	46	41	37	32	27	23	18	14	9	5	0	
34	95	90	86	81	76	71	66	62	57	52	48	43	38	34	29	25	21	16	12	8	3	
35	95	91	86	81	77	72	67	63	58	54	49	45	40	36	32	27	23	19	14	10	6	
36	95	91	86	82	77	73	68	64	60	55	51	46	42	38	34	29	25	21	17	13	9	
37	95	91	87	83	78	74	69	65	61	57	53	48	44	40	36	31	27	23	19	15	11	
38	96	91	87	83	79	75	70	66	62	58	54	50	46	42	37	33	29	25	21	17	14	
39	96	92	87	83	79	75	71	67	63	59	55	51	47	43	39	35	31	27	24	20	16	
40	96	92	87	83	79	75	71	68	64	60	56	52	48	45	41	37	33	29	26	22	18	
41	96	92	88	84	80	76	72	69	65	61	57	54	50	46	42	39	35	31	28	24	20	
42	96	92	88	85	81	77	73	69	65	62	58	55	51	47	44	40	36	33	30	26	23	
43	96	92	88	85	81	77	73	70	66	63	59	55	52	48	45	42	38	35	31	28	25	
44	96	93	89	85	81	78	74	71	67	63	60	56	53	49	46	43	39	36	33	30	26	
45	96	93	89	86	82	78	74	71	67	64	61	57	54	51	47	44	41	38	34	31	28	
46	96	93	89	86	82	79	75	72	68	65	61	58	55	52	48	45	42	39	35	32	29	
47	96	93	89	86	82	79	75	72	69	66	62	59	56	53	49	46	43	40	37	34	31	
48	96	93	90	86	83	79	76	73	69	66	63	60	57	54	50	47	44	41	38	35	32	
49	96	93	90	86	83	80	76	73	70	67	64	61	57	54	51	48	45	42	39	36	34	
50	96	93	90	87	83	80	77	74	71	67	64	61	58	55	52	49	46	43	41	38	35	
51	97	94	90	87	84	81	78	75	71	68	65	62	59	56	53	50	47	45	42	39	36	
52	97	94	90	87	84	81	78	75	72	69	66	63	60	57	54	51	49	46	43	40	37	
53	97	94	90	87	84	81	78	75	72	69	66	63	61	58	55	52	50	47	44	41	39	
54	97	94	91	88	85	82	79	76	73	70	67	64	61	59	56	53	50	48	45	42	40	
55	97	94	91	88	85	82	79	76	73	70	68	65	62	59	57	54	51	49	46	43	41	
56	97	94	91	88	85	82	79	76	73	71	68	65	63	60	57	55	52	50	47	44	42	
57	97	94	91	88	85	82	80	77	74	71	69	66	63	61	58	55	53	50	48	45	43	
58	97	94	91	88	85	83	80	77	74	72	69	66	64	61	59	56	54	51	49	46	44	
59	97	94	91	89	86	83	80	78	75	72	70	67	65	62	59	57	55	52	49	47	45	
60	97	94	91	89	86	83	81	78	75	73	70	68	65	63	60	58	55	53	50	48	46	
61	97	94	92	89	86	84	81	78	76	73	71	68	65	63	61	58	56	54	51	49	47	
62	97	94	92	89	86	84	81	79	76	74	71	69	66	64	61	59	57	54	52	50	47	
63	97	95	92	89	87	84	82	79	77	74	71	69	67	64	62	60	57	55	53	50	48	
64	97	95	92	90	87	84	82	79	77	74	72	70	67	65	63	60	58	56	53	51	49	
65	97	95	92	90	87	85	82	80	77	75	72	70	68	66	63	61	59	56	54	52	50	
66	97	95	92	90	87	85	82	80	78	75	73	71	68	66	64	61	59	57	55	53	51	
67	97	95	92	90	87	85	83	80	78	75	73	71	69	66	64	62	60	58	56	53	51	
68	97	95	92	90	88	85	83	80	78	76	74	71	69	67	65	62	60	58	56	54	52	
69	97	95	93	90	88	85	83	81	79	76	74	72	70	67	65	63	61	59	57	55	53	
70	98	95	93	90	88	86	83	81	79	77	74	72	70	68	66	64	61	59	57	55	53	
71	98	95	93	90	88	86	84	81	79	77	75	72	70	68	66	64	62	60	58	56	54	
72	98	95	93	91	88	86	84	82	79	77	75	73	71	69	67	65	63	61	59	57	55	
73	98	95	93	91	88	86	84	82	80	78	75	73	71	69	67	65	63	61	59	57	55	
74	98	95	93	91	89	86	84	82	80	78	76	74	71	69	67	65	63	61	60	58	56	
75	98	96	93	91	89	86	84	82	80	78	76	74	72	70	68	66	64	62	60	58	56	
76	98	96	93	91	89	87	84	82	80	78	76	74	72	70	68	66	64	62	61	59	57	
77	98	96	93	91	89	87	85	83	81	79	77	74	72	71	69	67	65	63	61	59	57	
78	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	67	65	63	62	60	58	
79	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	68	66	64	62	60	58	
80	98	96	94	91	89	87	85	83	81	79	77	75	74	72	70	68	66	64	62	61	59	

Figure 12-2

Use of Digital Psychrometers to Assess Ambient Conditions

As an alternative to sling and battery-operated psychrometers, digital psychrometers can be used to determine the prevailing weather conditions (*Figure 13-2*). These gages digitally display the air temperature, relative humidity, dew point temperature and surface temperature essentially at the push of a button. One manufacturer features a hot wire probe to monitor wind speed (*Figure 14-2*). Although the digital psychrometers provide “instantaneous” results, before taking any readings, they must be acclimated to the environmental conditions in the location of use for up to 30 minutes. This means you should not take the instrument from an air-conditioned office trailer and expect to take readings a few minutes later outside. This is often overlooked, resulting in inaccurate readings. In comparison, the sling and battery-operated psychrometers do not have to be acclimated to the environment before use.

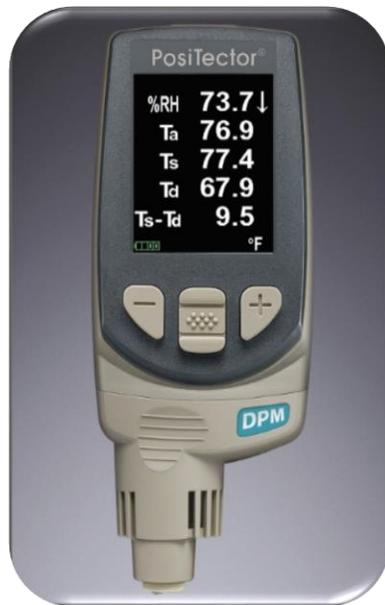


Figure 13-2



Figure 14-2

Use of Surface Temperature Measuring Instruments

There are a variety of instruments for measurement of surface temperature, including analog and digital contact thermometers as well as non-contact infrared pyrometers. As discussed earlier, most digital psychrometers have surface temperature measurement capability.

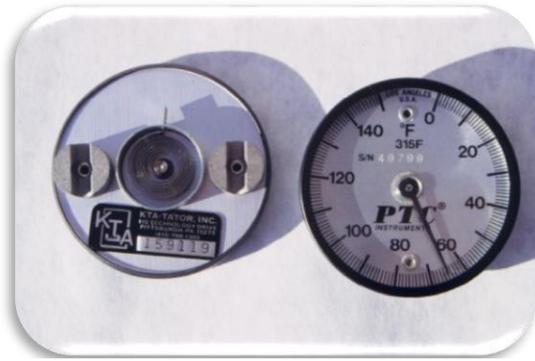


Figure 15-2

A common surface temperature thermometer is analog and contains a bi-metallic, temperature-sensing spring on the back of the thermometer that expands and contracts with the temperature of the surface (*Figure 15-2*). Since the spring is attached to the indicator needle on the front side of the thermometer, the needle moves across the temperature scale, indicating the surface temperature. Magnets attached to the back of the thermometer enable self-attachment to vertical steel surfaces, although this thermometer can be used on

almost any surface, by taping it in place if necessary. Thermocouple digital surface temperature gages are quicker and more accurate than the analog type.



Figure 16-2

Non-contact infrared pyrometers (*Figure 16-2*) can also be used to measure surface temperature. These gages are often equipped with laser sightings, so that the user can target the location on the surface to be measured. However, the further away from the surface that the “gun” is held, the larger the area of measurement, causing potential error. Also, there is a maximum distance, depending on the make and model of the thermometer.

Calibration of Equipment for Measuring Ambient Conditions and Surface Temperature

Calibration and/or verifying the accuracy of any coating inspection instrument is paramount to the reliability of the data it produces. This section describes the calibration and verification procedures for instruments used to assess ambient conditions and surface temperature.

Calibration of Psychrometer Thermometers

The bulb thermometers in sling and battery-operated psychrometers cannot be “calibrated” per se. However, their accuracy can be routinely verified by comparing the thermometer readings with that of a thermometer traceable to the National Institute of Standards and Technology (NIST), or in a controlled temperature chamber.

Cover the bulb thermometers and the traceable thermometer with a dry cloth until stabilization occurs (30 minutes minimum). The wick must be removed from the end of the wet bulb before placing the thermometers beneath the dry cloth. Uncover the thermometers and quickly compare the readings of the two psychrometer bulbs to the traceable thermometer reading. If the readings are outside of the tolerance of the psychrometer bulbs (typically $\pm 1^{\circ}\text{F}$), the psychrometer bulb(s) should be replaced.

Calibrating Analog Surface Temperature Gages

Analog surface temperature gages also cannot be calibrated, but the accuracy against a traceable thermocouple-type surface temperature probe can be plotted on a curve.

Calibrating Digital Psychrometers and Surface Temperature Thermometers/Pyrometers

Digital psychrometers and surface temperature thermometers can be calibrated either by the equipment manufacturer, an accredited calibration laboratory or an authorized service center. Annual calibration is recommended by most manufacturers. Unfortunately, field verification of accuracy is not possible with this type of equipment.



Figure 17-2

container.

Measuring the Coating Temperature

The induction time and pot life of a mixed coating is based on the temperature of the coating material. Additionally, some coating manufacturers list a minimum coating material temperature for application on their product data sheets. So, the ability to measure the temperature of the mixed coating is an important consideration. Stem-type paint thermometers, immersion-type thermocouples and non-contact infrared pyrometers can all be used. The stem-type thermometers (*Figure 17-2*) will require a few minutes to stabilize and the infrared pyrometers only measure the surface of the coating in the

Calculating Wet Film Thickness

Prior to mixing, thinning, and applying the coating, the target wet film thickness (WFT) should be determined. Some coating manufacturers list the WFT on the product data sheet (PDS) but many do not. Even when the target WFT is listed on the PDS, the contractor will need to verify that the dry film thickness (DFT) in the PDS that it is based on is the same as the DFT specified for the product. Further, if the coating will be reduced (thinned), the target WFT must be adjusted based on the amount of thinner added, so the target WFT in the PDS will no longer be accurate. While in most cases the facility owner is concerned with the dry film thickness and not the wet film thickness, the contractor must ensure that the proper wet film thickness is applied so that the specified dry film is achieved. If it is discovered that that the coating is too thin or too thick after it dries, costly rework is often required. It is better to confirm that the proper amount of paint is being applied to begin with.

The step-by-step instructions provided below are for calculating a target wet film thickness of both un-thinned and thinned coating, based on the specified dry film thickness (from the specification or PDS), the volume solids content of the coating (from the PDS), and when applicable, the amount of thinner added to the coating.

Calculating the WFT when using a coating as manufactured

To calculate wet film thickness, you will need *two* values:

Value No. 1: The target dry film thickness (DFT) from the specification or PDS

Value No. 2: The solids by volume content of the coating material from the PDS

Formula: $WFT = (DFT \div \% \text{ solids by volume})$

Enter the values into the formula to arrive at the wet film thickness range.

Example: DFT range of 2-4 mils with no thinner added (solids by volume of 75%):

2 mils DFT \div 0.75 = 2.7 mils WFT

4 mils DFT \div 0.75 = 5.3 mils WFT

Therefore, the applicator should apply the coating in the range of 3-6 mils WFT to achieve a DFT of 2-4 mils.

Calculating the WFT when using a coating that is thinned

To calculate wet film thickness, you will need *three* values:

Value No. 1: The target dry film thickness (DFT) from the specification or PDS

Value No. 2: The solids by volume content of the coating material from the PDS

Value No. 3: The amount of thinner that will be added to the coating (indicated on the PDS)

Formula: $WFT = DFT \div [\% \text{ solids by volume} \div (100\% + \% \text{ thinner added})]$

This formula has two steps:

Step 1: $[\% \text{ solids by volume} \div (100\% + \% \text{ thinner added})] = \text{adjusted volume solids content}$

Step 2: $DFT \div \text{adjusted volume solids content} = WFT$

Enter the values into the formula to arrive at the wet film thickness range.

Example – DFT range of 4-6 mils, Volume Solids 65% with 15% thinner added:

$(65 \div 115) = 0.57$ adjusted volume solids content

4 mils DFT $\div 0.57 = 7.0$ mils WFT

6 mils DFT $\div 0.57 = 10.5$ mils WFT

Therefore, the applicator should apply the coating in the range of 7-11 mils WFT. Even with the addition of 15% thinner, the coating should reduce to 4-6 mils once dry.

The solids by volume content (as a percentage of the total coating material) remains a key component in the calculation of the wet film thickness. However, the published value may be “theoretical” and based on the formulation or may not account for complete coating film shrinkage. Therefore, the contractor may choose to apply a test area of the coating (thinned if appropriate), measure the wet film thickness, then after the coating dries on the test area, measure the dry film thickness. This will provide the applicators with a “practical” wet film target. If the resulting dry film thickness meets the requirements of the specification, the actual volume solids content of the coating material becomes a moot point. Conversely, if the resulting dry film thickness is too low or too high, the actual percentage of volume solids can be calculated, provided the wet film and dry film thickness is known. Then the revised target wet film thickness can be calculated. This is illustrated below. Concurrently, the applied coating film can be evaluated for flow characteristics, resistance to sag, etc.

Target DFT (from the specification): 5 mils

Calculated Target WFT (based on 50% solids by volume): 10 mils

Actual WFT (measured): 10 mils

Actual DFT (measured): Only 4 mils

$(\text{Actual DFT} / \text{Actual WFT}) \times 100 = \text{Adjusted Percent Volume Solids Content}$

$(4 / 10) \times 100 = .40$ or 40%

Revised Target WFT = 5 mils DFT / 0.40 = 12.5 mils WFT

Precision 4-in-1 WFT Gage



Figure 20-2

Two limitations of traditional WFT gages are: (1) there isn't a single, accurate gage that includes the full range in both mils and microns, and (2) the tolerance of the steps is unknown (Certificates of Accuracy are either not available or very costly). A precision 4-in-1 wet film gage (Figure 20-2) eliminates the need for multiple gages to measure the full range, and the need for a gage in mils and another in micrometers. With mils on one side and microns on the other, the gage essentially has eight faces. Even more importantly each gage comes with a Certificate of Traceability that illustrates the precision of

the gage, making wet film thickness measurement more reliable and reducing the chances for rework.

Precision 4-in-1 WFT Gage

Face	Mils	Micrometers
A ₁	1-5 mils	25-125 μm
B ₁	6-10 mils	150-250 μm
C ₁	11-15 mils	275-375 μm
D ₁	16-20 mils	400-500 μm
A ₂	22-30 mils	550-750 μm
B ₂	32-40 mils	800-1,280 μm
C ₂	42-50 mils	1,050-1,250 μm
D ₂	52-60 mils	1,300-1,500 μm



Figure 21-2

Immediately after the wet coating film is applied, insert measuring face into the wet coating, perpendicular to the surface (*Figure 21-2*). The two “end steps” on the face selected must penetrate down to the previous layer, or the substrate if measuring the thickness of the first coat. Withdraw the gage from the wet film. The two end steps that penetrated down to the previous layer will be coated with paint. Observe the numbered steps between to the two end steps.

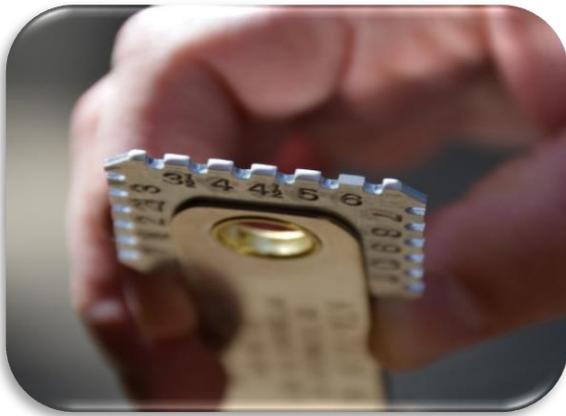


Figure 22-2

The highest numbered step containing wet paint is the wet film thickness (*Figure 22-2*). If all numbered steps are coated, then choose a face on the gage that represents a higher wet film thickness range. If none of the numbered steps are coated, then choose a face on the gage that represents a lower wet film thickness range. Clean the gage, then repeat this step in several other areas and/or as application progresses to verify that the WFT remains consistent.

Measuring Dry Film Thickness (DFT) on Coated Steel

There are two common standards that are frequently referenced in project specifications for measuring DFT, including ASTM D7091, *Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals* and SSPC-PA 2, *Procedure for Determining Conformance to Dry Coating Thickness Requirements*.

The current version of the ASTM standard (2013) focuses on proper gage use, while SSPC-PA2 focuses primarily on the frequency and acceptability of the measurements. These two documents do not contain conflicting information; they were written to complement one another and are designed to be used in conjunction.

Traditional Coating Thickness Measurement

There are two common types of coating thickness gages including Type 1 (magnetic pull-off) (Figure 23-2a) and Type 2 (electronic, with integral probes) (Figure 23-2b).



Figure 23-2a



Figure 23-2b

Type 1 Magnetic Pull-off Gages



Figure 24-2

For the Type 1 magnetic pull-off gages (Figure 24-2, left), a permanent magnet is brought into direct contact with the coated surface. The force necessary to pull the magnet from the surface (created by tightening a calibrated, helical spring) is measured and indicated as the coating thickness on an analog scale. The principle is quite simple - less force is required to remove the magnet from a thick coating, compared to a thinner coating, since the magnet is closer to the steel and will have greater attraction.

Calibration and Verification of Accuracy

The ASTM D7091 standard practice and the SSPC-PA 2 standard describe three steps associated with assuring accurate measurement processes, including gage calibration, verification of accuracy and adjustment. Each of these steps must be completed before coating thickness measurements are made.

Calibration

Coating thickness gages must be calibrated by the manufacturer, an accredited calibration laboratory or a manufacturer's authorized service center. A Test Certificate or other documentation showing traceability to a national metrology institution is required. There is no standard time interval for re-calibration, nor is one absolutely required. Calibration intervals are usually established based upon experience and the work environment. A one-year calibration interval is a typical starting point suggested by gage manufacturers.

Verification of Accuracy



Figure 25-2

To verify the accuracy of Type 1 gages, the thickness of a series of coated reference standards covering the expected range of coating thickness is measured (*Figure 25-2*). To prevent acquiring measurements with an inaccurate gage, the gage should be checked at least at the beginning and the end of each work shift. If the gage is dropped or suspected of giving erroneous readings during the work shift, its accuracy should be rechecked. Unless a gage manufacturer explicitly allows it, certified shims

used to verify the accuracy of Type 2 electronic gages (described later) are not permitted to be used with Type 1 gages.

Single Point Verification

When verifying the accuracy of Type 1 or Type 2 gages, the user can employ a single point or two-point process. For single point verification, a single reference test block is selected that is at or close to the thickness to be measured. For example, assuming the coating thickness to be measured is 4-6 mils, a reference standard of approximately 5 mils should be used to verify gage accuracy.

Two-Point Verification

For two-point verification, two reference standards are selected - one above and one below the expected film thickness to be measured. For example, assuming the coating thickness to be measured is 5 mils, reference standards of 3 mils and 7 mils are appropriate for establishing a range of accuracy.

When documenting gage adjustment processes, the serial number of the gage, the reference standard used, the stated thickness of the reference standard as well as the measured thickness value obtained, and the method used to verify gage accuracy are recorded. If the same gage, reference standard, and method of verification are used throughout a job, they only need to be recorded once, but the stated value of the standard and the measured value must be recorded each time accuracy is verified.

Adjustment

Type 1 gages have nonlinear scales, whereas any adjusting feature is linear. As a result, any adjustment of these gages will limit the DFT range for which the gage will provide accurate readings and is not recommended. Furthermore, the application of a single “correction value” representing the full range of the gage to compensate for a gage that is not measuring accurately is not appropriate, since the correction will also be non-linear. Therefore, if the gage reading is outside of the combined tolerance of the gage accuracy and the coated reference standard accuracy, it should be removed from service and repaired or replaced. For example, if the manufacturer’s stated accuracy for the gage is $\pm 5\%$ and the tolerance of the traceable coated standards is $\pm 3\%$, the combined tolerance is 5.8% (the calculated square root of $[5^2 + 3^2]$). Therefore, the gage reading on a 10-mil coated reference standard can range from 9.4-10.6 mils. A reading outside of this range indicates that the gage is out of tolerance and should not be used, or that the exposed magnetic probe has become contaminated.

Compensating for Surface Roughness



Figure 26-2

Once the Type 1 thickness gage is verified for accuracy, the next step is to measure and record the Base Metal Reading or BMR, since Type 1 gages cannot be adjusted. This is accomplished by placing the gage magnet on the prepared, uncoated substrate and obtaining a measurement (Figure 26-2).

Let’s explore this concept a little closer. The specified dry film thickness of each coating layer is to be measured from the tops of the peaks of the surface profile. However, most coating thickness gages must reach down into the surface roughness to satisfy the magnetic properties of the gage. As a result, the effect of the surface profile (roughness) on the thickness gage must be measured using the same DFT gage and subtracted from the coating thickness measurement. This is known as a base metal reading or BMR. Think of it as a background reading that the prepared, uncoated metal provides.

The BMR is the effect of surface roughness on a coating thickness gage – it is not surface profile. There is no correlation between surface profile depth and the effect of this roughness on a coating thickness gage. The BMR will vary widely, ranging from 0.1 mil to over 1 mil. Therefore, minimum of 10 measurements of the base metal are made and the average BMR is calculated. The average BMR is subtracted from the thickness of each coat, to determine the thickness of the coating film above the peaks of the surface profile.

Type 2 Electronic Gages with Integral Probes

Type 2 electronic gages use electromagnetic principles and electronic circuitry to convert a



Figure 27-2

reference signal and display it as coating thickness (*Figure 27-2*). Generally, Type 2 gages are more accurate than Type 1 gages, are not susceptible to vibration, and data acquisition is typically much faster. Also, most Type 2 gages can store readings and provide statistical analysis of the data, and once the data is generated and stored, it can be uploaded into a computer software program or downloaded to a printer. Measurement frequencies such as those described in SSPC-PA 2 are often programmed into Type 2 gages.

The gage probe is placed onto the coated surface and the measurement is revealed on the display (in mils or micrometers).

Calibration

Like Type 1 gages, Type 2 coating thickness gages must be calibrated by the manufacturer, an accredited calibration laboratory or a manufacturer's authorized service center. A Test Certificate or other documentation showing traceability to a national metrology institution is required. There is no standard time interval for re-calibration, nor is one absolutely required. Calibration intervals are usually established based upon experience and the work environment. A one-year calibration interval is a typical starting point suggested by gage manufacturers.

Verification of Accuracy



Figure 28-2

To verify the accuracy of Type 2 gages, the thickness of a series of coated reference standards covering the expected range of coating thickness is measured (*Figure 28-2*) using either the single point or two-point verification process, described earlier for the Type 1 gage. However, in this case, unless strictly prohibited by the manufacturer, the gage is adjusted to match the thickness of the standards. To prevent acquiring measurements with an inaccurate gage, the gage should be checked at least at the beginning and the end of each work shift. If the gage is dropped or suspected of giving erroneous readings during the work shift, its accuracy should be rechecked. As an alternative to certified coated standards, certified shims placed on a smooth steel surface used to verify the accuracy of Type 2 electronic gages.

Adjustment



Figure 29-2

The final step in verifying gage accuracy is to align the Type 2 gage to a known value to improve gage accuracy on the specific type and design of surface or within a specific measurement range. Some refer to this step as gage optimization. In this case, the gage is adjusted (when permitted by the gage manufacturer) to match the value on a measured shim or certified shim by placing the shim(s) directly onto the prepared, uncoated structure or part under the same conditions of air and surface temperatures that the coating will be measured under (*Figure 29-2*). This also compensates for curvature of the component or structure, the alloy of the steel, surface roughness (profile), proximity to edges or other surface conditions.

Novel Approaches to Dry Coating Thickness Measurement

The traditional methods of dry coating thickness measurement have been in existence for decades. Type 2 electronic gages offer novel approaches to gathering DFT data, including remote probes, microprobes, and scanning/continuous read probes.



Figure 30-2



Figure 31-2

Remote Probes (with a shorter cable attached to the gage; (figure 30-2), enabling easier measurement access, especially on the underside of pipe, and even wireless probes that communicate with a read-out device using Bluetooth technology, including Smart Phones (Figure 31-2).

Micro-Probes

Traditionally we have been instructed to stay at least 1" away from all edges when measuring coating thickness. However, coating build on edges, known as edge retention, is a concern particularly in immersion environments. And many gage manufacturers now produce micro probes measuring coating thickness on small parts, these probes are less affected by proximity edges (Figure 32-2, above). Appendix 6 in SSPC-PA 2 describes a procedure for measuring coating thickness on edges and suggests a minimum of three gage readings along 1.5 linear inches, which is equivalent to a spot measurement. The number of spots will vary depending on the total length of the edge. SSPC Guide 11, *Protecting Edges, Crevices, and Irregular Steel Surfaces by Stripe Coating* addresses edge preparation, stripe coating procedures and the use of edge-retentive coatings.



Figure 30-2

for
as
to

Scanning Probes

Several manufacturers of electronic coating thickness gages have incorporated “scanning probe” technology, and the associated support software, into the data acquisition process. This newer technology enables the gage operator to obtain large sets of coating thickness data in a relatively short time frame. To illustrate this concept, data was obtained by a certified coatings inspector on a recoating project that included 12 batches of readings (nearly 600 readings) obtained in just under 8 minutes (measurement time only). So, it may be possible to obtain a greater, more representative sampling of the coated area without impeding production. However, there are concerns with acquiring such large data sets, such as management of the data, handling outliers, determining the statistical significance of the data (i.e., what is an acceptable standard deviation), etc. SSPC-PA 2, Appendix 10, *Procedure for Obtaining a Greater Population of Thickness Measurements Using Type 2 Gage Continuous Read/Scanning Probe Technology* addresses this technology.

Frequency of Measurement (SSPC-PA 2, Appendix 7)

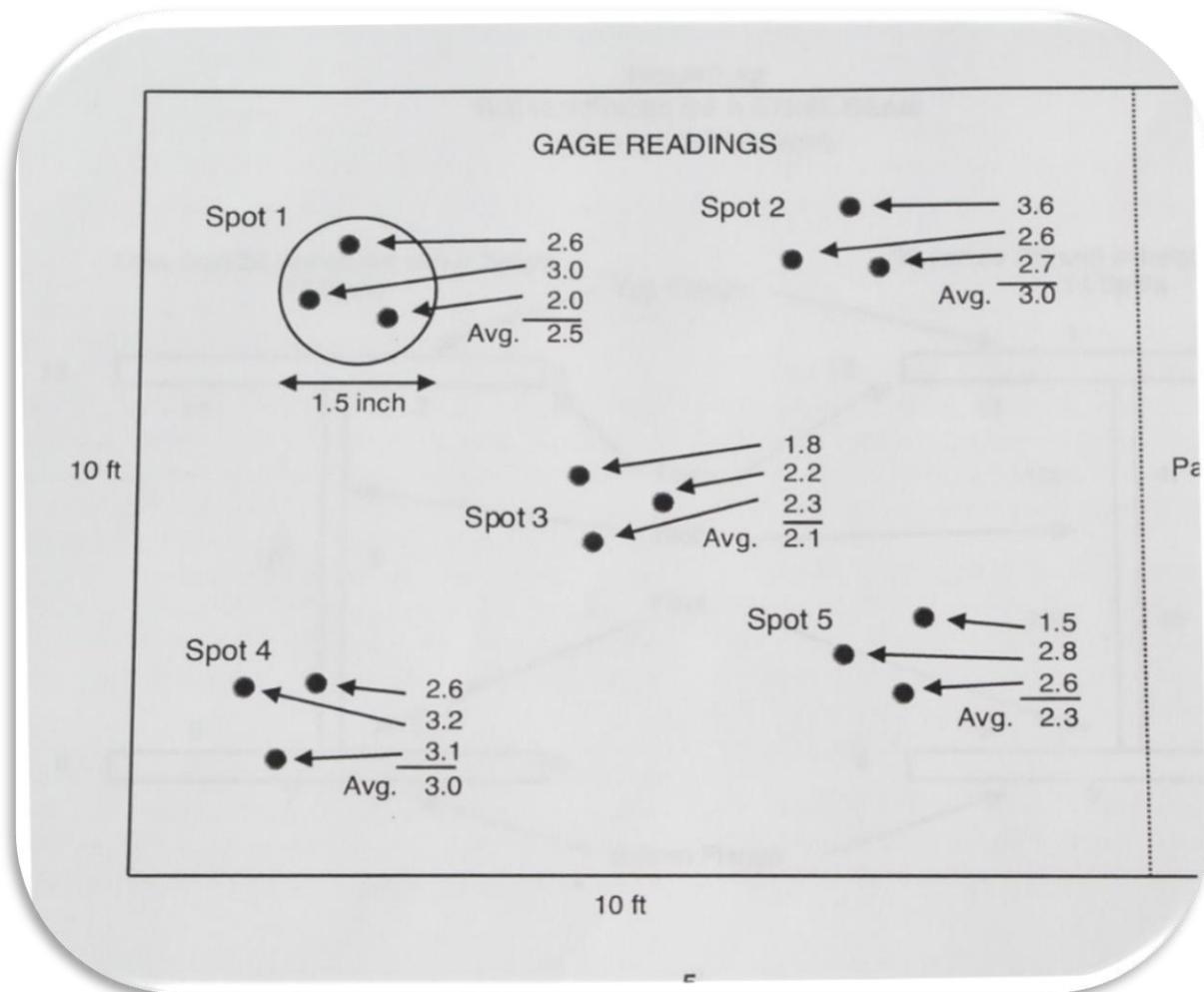


Figure 33-2

SSPC-PA 2 describes a frequency of coating thickness measurements. Figure 33-2 was extracted from the standard. It illustrates three gage readings taken in each of 5 spots in an area of approximately 100 square feet. The average of the three gage readings in each of the 5 spots has been calculated. The number of 100 square foot areas that are to be measured is based on the total square footage of the coated area:

- *For areas of coating not exceeding 300 square feet, each 100-square foot area is measured. As a result, the maximum number of areas to be measured will be 3.*
- *For areas of coating greater than 300 square feet but not exceeding 1000 square feet, three 100 square foot areas are arbitrarily selected and measured.*
- *For areas of coating exceeding 1000 square feet, three 100 square foot areas are measured in the first 1000 square feet. For each additional 1000 square feet or portion thereof, one additional 100 square foot area is arbitrarily selected and measured.*

Conclusion

While surface preparation is considered the foundation for the performance of the coating system, proper installation of the system is critical to the protection of the substrate, and to prevent premature coating failure and preserve structural integrity. This includes verifying that the coating system is applied according to the manufacturer's instructions, and that the wet film and resulting dry film thickness is achieved for each coating layer. This involves quality control check points to verify compliance with the specification and to correct deviations before they become nonconformities.

Chapter 3

Verifying the Quality of the Application of Protective Coatings Post-Application



Introduction

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

- Holiday Detection
- Hardness Testing
- Adhesion Testing



Figure 1-3 – Courtesy of Pipeline Inspection Company

Holiday Detection

Project specifications for the application of coatings and linings to liquid and gas pipelines, tanks, vessels, tank cars 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 frequently refers to this procedure as “jeep” testing (Figure 1-3). 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 out-gassing (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 μm) 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 coating).

Low Voltage (wet sponge) Holiday Detection



Figure 2-3



Figure 3-3 – Courtesy of DeFelsko Corporation

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 2-3). 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 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.



Figure 4-3 – Courtesy of Tinker & Razor Company

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 4-3) 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 the respective standards listing coating thickness ranges and corresponding test voltage ranges, it is best to contact the coating manufacturer to obtain the recommended voltage setting or calculate the required test voltage (discussed next), 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



Figure 5-3 -Courtesy of Tinker & Razor Company

in air varies with the conductivity of the air at the time the test is conducted. Newer digital detectors (Figure 5-3) enable the operator to select or “dial-in” the exact test voltage, versus the older models (Figure 6-3) that have 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.



Figure 6-3

Calculating the test voltage is straightforward. Simply calculate the square root of the thickness of the applied coating (T_c), 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 μm); the constant of 1250 is used when the applied coating thickness is greater than or equal to (\geq) 40 mils. An example of each is shown below:

Tc: 25 mils (square root is 5)

$5 \times 525 (K) = 2,625$ volts (2.6 kV)

Tc: 50 mils (square root is 7.1)

$7.1 \times 1250 (K) = 8,875$ 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 the voltage is set. The electrode is scanned across the coated surface (Figure 7-3) 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



Figure 7-3 – Courtesy of Pipeline Inspection Company

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 should be carefully considered because of possible spark-through, 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 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-3/8b-3). 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.



Figure 8a-3 – Courtesy of Tinker & Rasor Company



Figure 8b-3 – Courtesy of Tinker and Rasor Company

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. A Shore D Durometer is a small hand-held analog device (Figure 9-3), or an electronic device (Figure 10-3) with a remote probe that is used to measure the indentation hardness of various materials like hard rubber, plastics, soft metals, and epoxy coatings. A small cone-shaped indentor protrudes from the pressor foot (the base of 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 indentation is displayed on the gage dial or digital display as a hardness value.



Figure 9-3



Figure 10-3

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 11-3) represents 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 are required to be reported by the ASTM standard, there is no correction of the hardness values based on the prevailing ambient conditions.



Figure 11-3 – Courtesy of DeFelsko Corporation

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 applied using even, steady hand/thumb pressure (Figure 12-3) 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 ¼ inch apart), the average indentation 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



Figure 12-3

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 13-3). 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 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), ASTM D3359, and ASTM D6677.



Figure 13-3 – Courtesy of DeFelsko Corporation

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 inner-strength 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 $\frac{1}{4}$ 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 14-3 a and b). Once the adhesive (glue)



Figure 14-3 a



Figure 14 b

cures, a vertical load is applied to the loading fixture, 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 non-mandatory). Each annex describes the proper use of a different apparatus.

Fixed Alignment Adhesion Testers (Annex A1)

A fixed alignment adhesion tester (Figure 15-3) 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 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 16-3). 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



Figure 15-3



Figure 16-3

value is read from the scale on the black column (Figure 17-3). The 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.



Figure 17-3



Figure 18-3

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 self-aligning 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 18-3 and 20-3), or actuator (Figure 19-3) is coupled to 22-3 and 23-3) 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. the head of the

loading fixture and hydraulic pressure is applied.



Figure 19-3

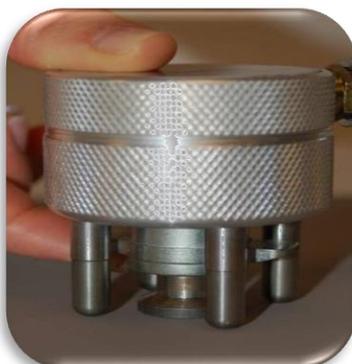


Figure 20-3

The adhesion tester shown in Figure 21 3 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 21-3 - Courtesy of DeFelsko Corporation



Figure 23-3 – Courtesy of M.E Taylor Engineering, Inc. /SEMico Division



Figure 22-3 – Courtesy of DeFelsko Corporation

Self-Aligning Adhesion Testers – Pneumatic (Annex A3)

Pneumatic adhesion testers use an air-operated piston threaded onto the shaft of a specially-designed loading fixture to apply perpendicular, tensile force (Figure 24-3). 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,

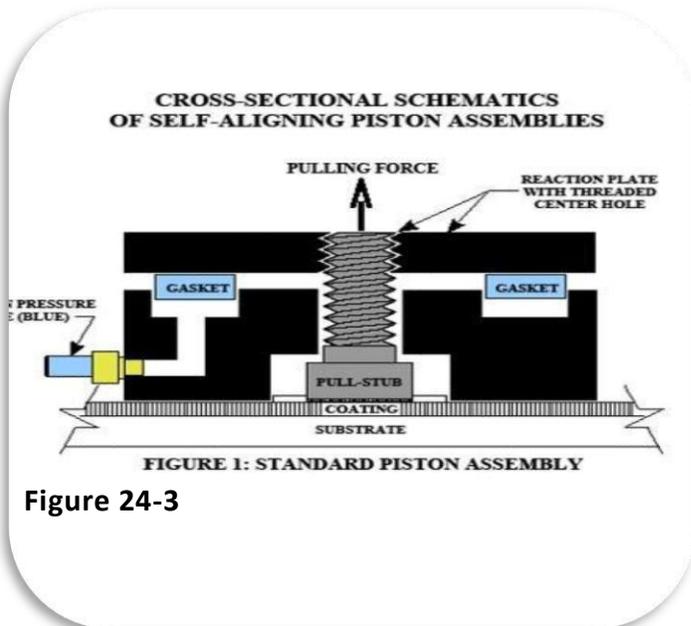


Figure 24-3



Figure 25-3

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 26-3). There is no “universal” fixture.



Figure 26-3

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 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:

Twenty-millimeter (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. Fifty-millimeter (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 specially-manufactured 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/convex-shaped 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).

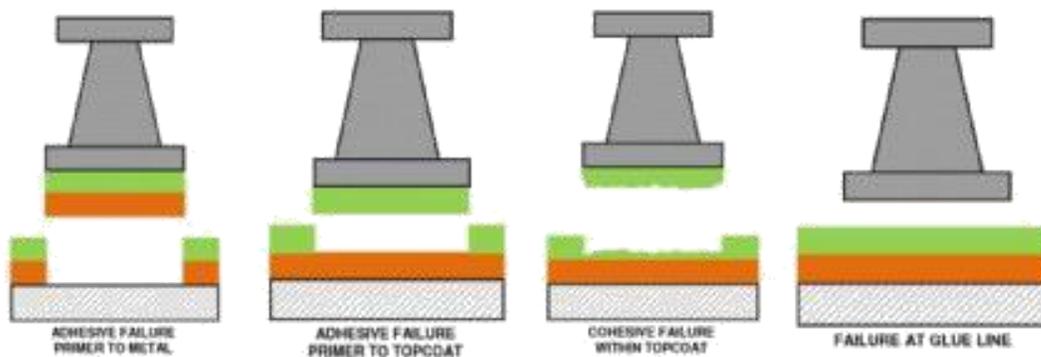


Figure 27

Figure 28

Figure 29

Figure 30

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

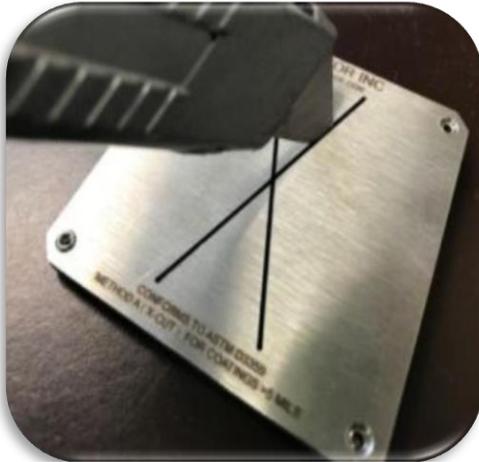


Figure 31-3

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 to make a 1.5” long cut through the coating system (down to the substrate) followed by a second cut across 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 (Figure 31-3).



Figure 32-3

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 32-3).

The adhesion is rated on a scale of 10 to 0 (Figure 33-3).

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” x 1/16” to 1/8” x 1/8” removed with difficulty
6	Coating is somewhat difficult to remove. Coating chips from 1/8” x 1/8” to 1/4” x 1/4” removed with slight difficulty
4	Coating is somewhat difficult to remove. Coating chips in excess of 1/4” x 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”

Figure 33-3

Measuring Adhesion by the Tape Test (ASTM D3359)

If the project specification or other document requires you to perform an adhesion test according to ASTM D3359, "Adhesion by Tape Test," a metal ruler or guide, a utility knife with a new razor blade, a small brush, adhesive tape, pencil eraser, and a copy of the ASTM test method are required.

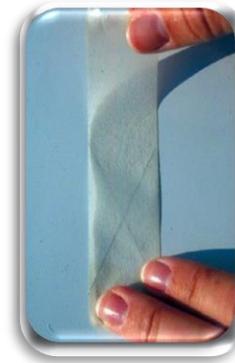
Select a Test Area. Selecting a test area is perhaps the most difficult part of testing adhesion, particularly when evaluating an older coating system that has been maintained by spot or area touch-up painting over many years. Consider testing several areas and perform replicate tests in each area to ensure representative adhesion data. If testing the adhesion of a new coating system, minimize the number of locations to reduce the amount of touch-up required. However, replicate testing (at least 3) in each area selected is recommended. Ensure the areas are free of grease, oil, dirt, chalking, or water that will interfere with the adhesion of the tape.

Determine the Thickness of the Coating System. Determine the total thickness of the coating system.

Select a Testing Method. Based on the thickness of the coating system, select a test method (A or B). Method A ("X-Cut") and is used to test the adhesion of a coating system that is greater than 5 mils thick; Method B ("Cross-cut") and is used to test the adhesion of a coating system that is less than, or equal to 5 mils thick.

Measuring the Adhesion using Method A (X-Cut)

1. Mount a new razor blade in a utility knife holder and extend the blade outward. Use a straight edge and make a 1.5" long cut through the coating system (down to the substrate). Make a second 1.5" long cut across the first cut to form an "X." The legs at the top and bottom of the "X" should be approximately 1" apart. The intersection of the "X" should be close to a 30-45° angle. Remove any debris from the "X" area using a soft brush.
2. Remove two complete wraps of adhesive tape and discard. Carefully remove a piece of the adhesive tape and apply it to the "X" area.
3. Using a soft pencil eraser, rub the tape over the X-Cut to help ensure good contact between the tape and the coating surface.



4. Within 90 (+/- 30) seconds, remove the tape from the X-cut smoothly and rapidly, 180° back across the X-Cut (i.e., peel back, do not pull upwards).
5. Examine the X-Cut area for coating delamination and rate the condition of it according to the table below.



Rating	Description
5A	No peeling or removal
4A	Trace peeling or removal along the incisions
3A	Jagged removal along the incisions up to 1/16" (1.6mm) on either side
2A	Jagged removal along most of the incisions up to 1/8" (3.2 mm) on either side
1A	Removal of most of the coating from the area of the "X" under the tape
0A	Removal of coating beyond the area of the "X"

Classify the location of the delamination as "adhesion" (A distinct break between coating layers or a distinct break between the substrate and the first coating layer) or cohesion" (A split within a coating layer). Usually this can only be done if the adhesion is rated 3A or lower.

Measuring the Adhesion using Method B (Cross-Cut)

1. Mount a new razor blade in a utility knife holder and extend the blade outward. Use a straight edge or the KTA Cross-Cut Guide and make a series of 6 or 11 parallel knife blade cuts through the coating system (down to the substrate). The number of cuts and the amount of space between the cuts is based on the total thickness of the coating system. Determine the number of cuts and the spacing between the cuts using the chart below.

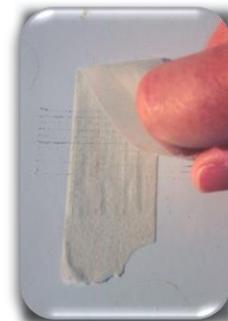
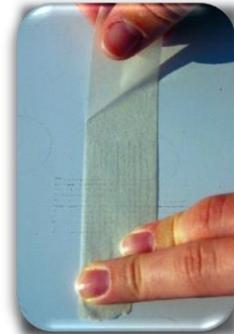


Coating Thickness	Number of Cuts	Spacing Between Cuts
Up to 2 mils	11	1 mm
2-5 mils	6	2 mm
>5 mils	6	5 mm or X-Cut (Method A)

Turn the straightedge or guide 90° and make a second series of parallel knife cuts over top of the first set of cuts, but perpendicular to the first set to form a grid, cross-hatch or “Cross-Cut” pattern. If 11 cuts are made, a 10 x 10 grid, or 100 squares will be generated; If 6 cuts are made, a 5 x 5 grid, or 25 squares will be created. Remove any debris from the “Cross-cut” area using a soft brush.



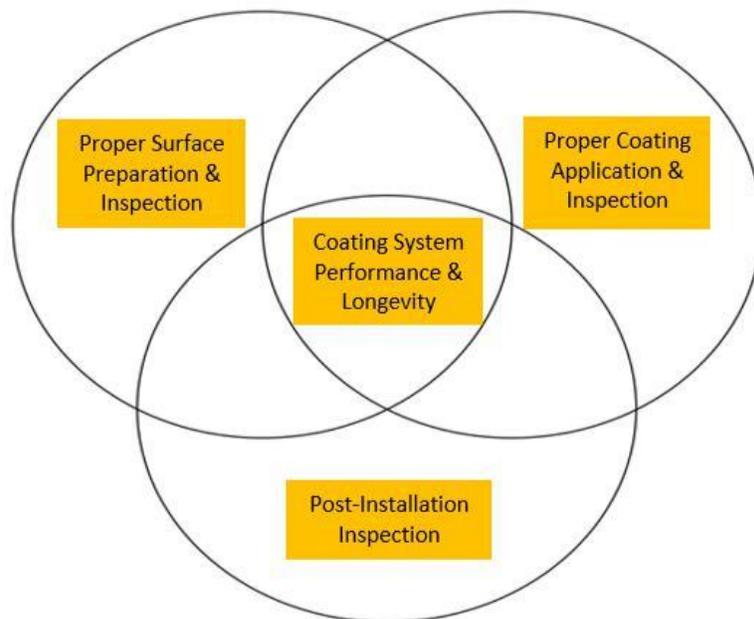
- Remove two complete wraps of adhesive tape and discard. Carefully remove a piece of the adhesive tape and apply it to the “Cross-cut” area.
- Using a soft pencil eraser, rub the tape over the cross-cut area to help ensure good contact between the tape and the coating.
- Within 90 (+/- 30) seconds, grasp one end of the tape and remove it from the cross-cut area smoothly and rapidly, 180° back across the grid (i.e., peel back, do not pull upwards).
- Examine the cross-cut area for coating delamination and rate the condition according to the table below. The ASTM D3359 standard provides a chart similar to the one shown below that illustrates the various percentages of delamination described in the table. Classify the location of the delamination as “adhesion” or “cohesion” described earlier.



Rating	Percent Delamination	Description
5B	0% (none)	Edges of the cuts are completely smooth
4B	< 5%	Small flakes of coating are detached at the intersections
3B	5-15%	Small flakes of coating are detached along the edges and intersections
2B	15-35%	Coating has flaked along the edges and on parts of the square
1B	35-65%	Coating has flaked along the edges of the cuts in large ribbons and whole squares have detached
0B	>65%	Flaking and detaching worse than Rating 1B

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 steel integrity. This approach to quality is illustrated in the Venn Diagram below.



About the Author



Bill is the Chief Operations Officer for KTA-Tator Inc. (KTA), where he has been employed since 1979. He holds an AD in Business Administration from Robert Morris University. He is an SSPC Certified Protective Coating Specialist, an SSPC Level 3 Certified Protective Coatings Inspector, an SSPC Level 2 Certified Bridge Coatings Inspector, as well as a NACE Level 3 Certified Coatings Inspector. He is an approved training course instructor for both SSPC and KTA. Bill authored the first, second and third editions of the KTA publication, Using Coatings Inspection Instruments, as well as this Supplement. He received SSPC's Coating Education Award in 2006, the SSPC John D. Keane Award of Merit in 2011, an ASTM Committee D01 Award of Appreciation in 2016, and the SSPC

President's Lecture Series Award in 2017. He is the Chair of the SSPC Dry Film Thickness Committee and Chair of the SSPC Education and Certification Committee. He is also a member of ASTM Subcommittees D01.23 and D01.46.

GLOSSARY

Abrasive. Mineral or man-made granules used to clean and/or roughen a surface. For industrial applications, the abrasive is propelled against the surface using air pressure or centrifugal force.

Adhesion. The ability of a coating material to bond to other coating layers and/or to the underlying surface.

Adhesive Strength. A measurement of the bond between coating layers and/or between the substrate and the first layer.

Alkalinity. A condition where the pH is greater than 7.

Ambient Conditions. The prevailing conditions on the project site, including air temperature, relative humidity, and dew point temperature.

Amides. A family of materials of which the polyamides are used as curing agents for epoxy coatings.

Amine Blush. A surface exudate on epoxy coating films caused by a reaction of amine co-reactant with carbon dioxide and water to form amine carbamate.

Amines. An organic compound derived from ammonia by replacement of one or more hydrogen atoms with hydrocarbon radicals. It is frequently used as a curing agent for epoxy resins (polyamine epoxy).

Anchor Pattern. The average peak-to-valley depth generated by some power tools and by abrasive blast cleaning. Resulting surface “anchors” the coating system to the substrate. Also known as surface profile.

Anhydrous. Without water.

ASTM. American Society for Testing and Materials

Bar. A measurement of pressure. British equivalent to pounds per square inch (1 Bar = 14.50377 psi)

Barometric Pressure. The prevailing pressure of the surrounding air corrected to sea level.

Base Metal Reading (BMR). A measurement of the effect of surface profile or anchor pattern on a coating thickness gage.

Calibration. The controlled and documented process of measuring traceable calibration standards and verifying the results are within the tolerance of the gage.

Calibration Adjustment. The process of aligning and optimizing a gage's readings to match a known thickness.

Centimeter. One one-hundredth of a meter. One centimeter = 0.39 inch. *Symbol: cm*

Centrifugal Blast. A process wherein abrasive media is thrown or hurled towards a surface using rotating wheels with a center-loading hub and abrasive delivery vanes.

Chloride. A compound of chlorine with another substance (e.g., with sodium, sodium chloride).
Symbol: Cl

Cohesive Strength. A measurement of the internal bond of a single coating layer.

Conductive. The ability of a coating film or substrate to conduct electricity.

Conductivity. A measurement of the ability of a solution to conduct electric current.

Couplant. A gel placed on a coated surface to improve the transmittal of an ultrasound signal when measuring coating thickness over concrete or other non-metal surfaces.

Delamination. Peeling or disbonding of a coating or coating system from the underlying surface.

Dew Point Temperature. The temperature at which moisture in the surrounding air will form droplets of condensation on a surface.

Dry Bulb Temperature. The air temperature as measured using a sling or battery-powered

psychrometer.

Dry Film Thickness. The thickness of a coating film after it has dried or cured.

Emissive Power. The total thermal energy emitted per second from a unit area of a surface at a fixed temperature.

Emissivity. The ratio of the emissive power of a surface to that of a black surface at the same temperature.

Ferrous. A magnetic surface such as carbon steel. Also known as ferro-magnetic.

Ferrous Ion. Iron ions in an aqueous solution.

Flash Rusting. Surface rusting caused by exposure of prepared steel to moisture prior to application of a protective coating.

Holiday. A skip or missed area of a coating film that exposes the underlying coating or substrate.

Infrared Spectroscopy. A laboratory technique which uses vibrational spectroscopy (interaction of light with vibrating molecules) to generate a spectrum. The technique is used to identify coating types and some types of surface contamination.

KiloPascals (KPa). A measurement of pressure. Metric equivalent to pounds per square inch (1 KPa = 0.1450377 psi)

Knife Adhesion. A measurement of the adhesion of coating layers to one another and to the underlying substrate using subjective probing with the tip of a knife blade.

MegaPascals (MPa). A measurement of pressure. Metric equivalent to pounds per square inch (1 MPa = 145.0377 psi).

Microgram. One millionth of a gram. *Symbol: μg .*

Micrometers or Microns (μm). A measurement of surface profile depth and/or wet and dry film thickness. Metric equivalent to mils (25.4 microns = 1 mil).

Micrometer. An instrument used to measure the thickness of a material, or the depth of surface profile.

Microseimen. A measurement of the conductivity of a solution.

1 microsiemen = 1 micromho. *Symbol: μS .*

Mil. A measurement of surface profile depth and/or wet and dry film thickness. English equivalent to micrometers (1 mil = 25.4 microns).

Mill Scale. A cathodic, blue/gray oxidation layer that naturally forms on hot-rolled carbon steel during the hot-rolling and cooling process in the steel mill.

Milliliter. One one-thousandth of a liter. 1 milliliter = 1 cubic centimeter.

1 milliliter = 0.034 ounce. *Symbol: mL*

Mylar®. A proprietary, non-compressible polyester film used in the manufacturing of Testex® surface profile replica tape.

NACE. NACE International. Formerly National Association of Corrosion Engineers.

NIST. National Institute of Standards and Technology

Non-conductive. The inability of a coating film or substrate to conduct electricity.

Non-ferrous Metal. A non-magnetic metal surface such as aluminum.

Optimization. Changing an ultrasonic coating thickness instrument's sound velocity constant to match that of a known sample. Also, adjustment of a coating thickness gage to a known thickness over a known substrate.

Osmotic Blistering. Blistering of a coating film due to liquid migration through the film. Typically caused by entrapped solvents in the film or soluble contamination on the substrate beneath the coating film.

Parallax. A distorted view caused by reading a gage dial at an angle rather than straight-on.

pH. The measure of the acidity or alkalinity of an aqueous solution.

Pinhole. A tiny void in the coating or lining that penetrates to the underling layer or through all coating layers to the substrate.

Pinpoint Rusting. Minute corrosion sites caused by exposure of the steel substrate to moisture through the coating film.

Pitting. Section loss of a substrate in a small area caused by a lack of corrosion protection.

Pounds per Square Inch (psi). A measurement of pressure. English equivalent to Bar, KiloPascals (KPa) and MegaPascals (MPa). (1 psi = 0.06894757 Bar; 6.894757 KPa; and 0.006894757 MPa).

Psychrometer. A manual or electronic device used to measure the prevailing weather conditions at a project site.

Psychrometric Tables. A book of charts containing relative humidity and dew point temperature data, based on wet and dry bulb temperatures from a psychrometer. Originally published by the US Weather Bureau.

Pull-off Adhesion. An evaluation of the adhesion properties of a coating or coating system measured by applying a perpendicular, continuous, incremental loading of force. Measured in psi, Bar, MPa or KPa.

Pull Stubs. Aluminum or stainless-steel fixtures attached to a coated surface using an adhesive. Used to conduct pull-off adhesion testing.

Relative Humidity. The ratio of the amount of moisture present in the air to complete saturation of the surrounding air (expressed as a percentage).

Rust. Corrosion products present on a carbon steel surface.

Rust Inhibitors. Chemicals or chemical solutions added to water to prevent the formation of surface rust.

Solids By Volume. The non-volatile or non-evaporative volume content of a coating, (e.g., the resin, pigment and additives). Typically stated as a percentage.

Specification. A legal document that governs a painting project, detailing what is to be done, how it is to be done, and what methods will be used to verify that the work was done correctly.

SSPC. Society for Protective Coatings (formerly Steel Structures Painting Council)

Substrate. The surfaces to which coatings are applied.

Surface Cleanliness. The level or degree to which rust, paint, mill scale and other surface

contaminants are removed prior to coating application.

Surface Profile. The average peak-to-valley depth generated by some power tools and by abrasive blast cleaning. Resulting surface profile “anchors” the coating system to the substrate. Also known as anchor pattern.

Theoretical Coverage Rate. The theoretical number of square feet that can be coated with one gallon of coating material at the recommended dry film thickness.

Thinner. A solvent that is added to a coating during the mixing process to reduce the viscosity of the coating and/or improve the application and flow-out characteristics.

Ultrasound. A signal that is used to quantify the thickness of a coating applied to a non-metal surface such as concrete, plastic or wood.

Verification of Accuracy. Obtaining measurements on a reference standard prior to gage use for the purpose of determining the ability of the gage to produce reliable values, compared to the combined gage manufacturer’s stated accuracy and the stated accuracy of the reference standard.

Waterjetting. A process of coating removal and/or surface preparation using water under various pressures.

Wet Abrasive Blast Cleaning. A process of coating removal and/or surface preparation using abrasive with water injected into the blast nozzle. Also known as slurry blasting.

Wet Bulb Temperature. A measurement of the latent heat loss caused by water evaporation from a wetted sock on the end of a bulb thermometer in a psychrometer. Value is used to determine the relative humidity and dew point temperature from psychrometric tables.

Wet Film Thickness. The thickness of a coating measured as it is applied to a surface.

Zinc-rich Paint. An industrial protective coating containing a high loading of zinc powder or dust.

INDEX OF INDUSTRY STANDARDS

ASTM D3359, “Standard Test Methods for Measuring Adhesion by Tape Test”

ASTM D4414, “Standard Practice for Measurement of Wet Film Thickness by Notch Gages”

ASTM D4417, “Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel”

ASTM D4138, “Standard Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross-Sectioning Means”

ASTM D4541, “Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Testers”

ASTM D5162, “Standard Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates”

ASTM D6132, “Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Applied Organic Coatings Using an Ultrasonic Gage”

ASTM D6677, “Standard Test Method for Evaluating Adhesion by Knife”

ASTM D7091, “Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals”

ASTM D7234, “Standard Test Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers”

ASTM D7682 Standard Test Method for Replication and Measurement of Concrete Surface Profiles Using Replica Putty

ASTM E337, “Standard Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)”

ASTM F1869, “Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride”

ASTM F2170, “Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes”

NACE SP0188, “Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates”

NACE SP0287, “Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape”

SSPC-PA2, “Procedure for Determining Conformance to Dry Coating Thickness Requirements”

SSPC-SP1, “Solvent Cleaning”

SSPC-SP2, “Hand Tool Cleaning”

SSPC-SP3, “Power Tool Cleaning”

SSPC-SP5/NACE No. 1, “White Metal Blast Cleaning”

SSPC-SP6/NACE No. 3, “Commercial Blast Cleaning”

SSPC-SP7/NACE No. 4, “Brush-Off Blast Cleaning”

SSPC-SP8, “Pickling”

SSPC-SP10/NACE No. 2, “Near-White Blast Cleaning”

SSPC-SP11, “Power Tool Cleaning to Bare Metal”

SSPC-SP13/NACE No. 6, “Surface Preparation of Concrete”

SSPC-SP14/NACE No. 8, “Industrial Blast Cleaning”

SSPC-SP15, “Commercial Grade Power Tool Cleaning”

SSPC-SP 16, “Brush-Off Blast Cleaning of Galvanized Steel, Stainless Steel and Non-Ferrous Metals”

SSPC-SP 17, “Thorough Abrasive Blast Cleaning of Non-Ferrous Metals”

Waterjet Cleaning of Metals

SSPC-SP WJ 1/NACE-WJ 1 – Clean to Bare Substrate

SSPC-SP WJ 2/NACE-WJ 2 – Very Thorough Cleaning

SSPC-SP WJ 3/NACE-WJ 3 – Thorough Cleaning

SSPC-SP WJ 4/NACE-WJ 4 – Light Cleaning

Wet Abrasive Blast Cleaning Standards

SSPC-SP 5 (WAB)/NACE WAB-1, White Metal Wet Abrasive Blast Cleaning

SSPC-SP 10 (WAB)/NACE WAB-2, Near-White Metal Wet Abrasive Blast Cleaning

SSPC-SP 14 (WAB)/NACE WAB-8, Industrial Wet Abrasive Blast Cleaning

SSPC-SP 6 (WAB)/NACE WAB-3, Commercial Wet Abrasive Blast Cleaning

SSPC-SP 7 (WAB)/NACE WAB-4, Brush-off Wet Abrasive Blast Cleaning

SSPC Guide 15, “Field Methods for Retrieval and Analysis of Soluble Salts on Steel and Other Non-Porous Substrates”

SSPC VIS 1, “Guide and Reference Photographs for Steel Surfaces Prepared by Abrasive Blast Cleaning”

SSPC VIS 2, “Standard Method of Evaluating Degree of Rusting on Painted Steel Surfaces”

SSPC VIS 3, “Guide and Reference Photographs for Steel Surfaces prepared by Power and Hand Tool Cleaning”

SSPC VIS 4/NACE VIS 7, “Guide and Reference Photographs for Steel Surfaces Prepared by Waterjetting”

SSPC VIS 5/NACE VIS 9, “Guide and Reference Photographs for Steel Surfaces Prepared by Wet Abrasive Blast Cleaning”

