SURFACE PREPARATION AND PAINTING STRUCTURAL STEEL
5-393.450

5-393.451 GENERAL

Painting steel structures serves primarily to protect steel against corrosion (rusting) and, secondarily, to improve its appearance. Weathering steel (Specification 3309) forms a protective surface which limits corrosion to a very low rate under mild to moderate exposure conditions. Corrosion will occur, however, under conditions of severe exposure, and 3309 steel is generally painted beneath deck joints, where it is subject to chloride spray from heavy traffic, and in industrial areas, where air pollution may accelerate corrosion. Steel meeting the requirements of 3306 and 3310 do not form a protective surface and must be painted for corrosion protection.

The theory of corrosion is explained in the Society for Protective Coatings (SSPC) Manual, Volume 1 - Good Painting Practice under the heading "Corrosion of Metals", a copy of which is included in 393.456 (1) thru (11). The Inspector should read this explanation of the causes and effects of corrosion. The explanation will provide the Inspector with a better understanding of the importance attached to the protection of structural steel members. Additionally, it details the necessity for using high quality materials, the insistence on proper surface preparation, as well as the proper application of coating systems.

Coatings inspection includes inspection of surface preparation, checking the paint containers to make certain that only "approved" paints are used, observing the coating operation(s), permitting coating to be done only under proper conditions, requiring adequate drying time between the various coats, and final appearances and clean-up. These are explained more fully in subsequent paragraphs and in the SSPC information on inspection, included in 393.456 (46) through (71).

The Inspector should keep an accurate record of all operations. This is particularly essential on large structures in order that a proper sequence can be assured, without omissions, and so that inspection duties can be readily transferred to another Inspector when necessary. A line layout of the structural members, with the various operations, entered by date, provides an excellent progress record. The Inspector should also require the Contractor to provide documentation of Quality Control measurements, taken by Contractor personnel, in accordance with 2478 or 2479 and their Quality Control Plan (QCP).

The following safety precautions should not be considered to be comprehensive. They are presented here to call to the attention of the Inspector the dangers which exist when steel is being cleaned, painted, cut, or welded. Additional information may be found in the SSPC Manual, Volume I, Good Painting Practice, Chapter 8. Other sources of information should also be utilized when available. It is advisable to obtain and follow recommendations made by manufacturers of the various materials being used, or that are being removed.

Although it is the Contractor's responsibility to provide for safe working conditions for workmen and Inspectors, the Inspector should be alert to conditions that may develop on the job site which might be detrimental to the health of others as well as him or herself. Many of the ingredients used in the manufacture of paints, thinners, removers, etc. contribute to toxic conditions unless properly used.

Adequate ventilation is a basic requirement. Not only can the concentration of fumes from various paint associated ingredients be hazardous to health through inhalation, but they may also have a low flash point, creating a dangerously high explosive potential. This is particularly true within enclosures, but may also occur in other confined areas which tend to trap the fumes. Spray painting is especially conducive to causing highly concentrated fumes and requires special protective equipment.

Application of heat to painted metals, which occurs when torch cutting or welding, may also create toxic fumes. These fumes have been known to cause serious illness through inhalation while working in confined or poorly ventilated areas.

Silicosis is an occupational disease associated with exposure to silicate dust, which may be produced during blast cleaning operations using sand abrasives. Nozzle blast operators are required to wear special helmets connected to a supply of clean, compressed air. Filter type air respirators and goggles should be worn by Inspectors who are exposed to blast dust.

Regardless of the method of application of materials associated with painting, it is important that all individuals wash thoroughly before eating or leaving the job.

5-393.452 MATERIALS

The Inspector should make certain that only paint systems, which have been approved by the Department, are used. Several fundamentally different types of paint systems are used on construction projects. It is important to know which type of system is in use, because materials and handling procedures differ widely among types. Inspectors should read and understand the special provisions and the paint manufacturer's instructions for the specific system in use (the Contractor must furnish these on request), and make sure the painters are following them carefully. Paints used must meet all the requirements of the specifications and special provisions.

The most common paint systems currently used on new steel bridge elements are zinc-rich primers (organic or inorganic) with an epoxy mid-coat and a urethane top coat. The mid-coat and top coat may also be applied over hot-dip galvanizing with proper surface preparation. The primer, intermediate, and top coats shall be by the same manufacturer. Each of the paints used in these systems consist of two or more components that are mixed in limited batches just before use. Exact mixing of components is essential and the Contractor's procedures for mixing should be reviewed to verify that accurate batching is achieved.

Bridge elements may be delivered to the job site unpainted, with only the prime coat, or with a full shop paint system. Components that are fully shop painted may need to be touched up after erection due to shipping and handling damage. The plan and special provisions may also require the fasteners to be painted after installation. Components that have only a shop-applied prime coat will be field painted with the other coats as directed in the special provisions. Most shop priming for later field top coating is done with an inorganic zinc-rich paint. Inorganic primers should not be applied in the field. Handling damage shall be touched up with organic epoxy zinc-rich primer prior to applying the remaining coats. All field painting requires the inspector to closely monitor the procedures found in the paint manufacturer's instructions and the special provisions.

The organic zinc-rich primer system can be used where an SSPC-SP10-Near-White Blast Cleaning surface preparation or SSPC-SP6-Commercial Blast Cleaning, surface preparation has been used. Only paint systems approved by Mn/DOT shall be used. If the Contractor wants to use an unapproved paint system, he must get written approval from the Structural Metals Engineer.

5-393.453 SURFACE PREPARATION

Surface preparation of structural steel members is undoubtedly the most important step in obtaining maximum protection against corrosion. Regardless of the quality of the paint system and the care exercised by the painters in applying the paint, an improperly prepared surface will almost certainly result in an early paint failure, and will require costly maintenance. Therefore, it is essential that a thorough inspection be made of both painted and unpainted steel surfaces immediately prior to starting painting.

The Contractor can often eliminate considerable work by hosing down the steel under a deck slab during and immediately after a deck pour, rather than waiting until the start of painting. Fresh mortar can be easily flushed off, but it is usually difficult to remove after it has dried and hardened. In any event, the Inspector should make certain that the cleaning has been completed before painting is permitted on these surfaces.

Foreign matter should be removed by means which will not be detrimental to the steel, and which will not leave a residual film on the surface that cannot be wiped off. Regardless of the degree of surface operations, grease and oil films should first be removed by the use of solvents or other effective methods. Solvents cover a wide range of materials, such as mineral spirits, naphtha, coal tar solvents, alcohols, ethers, mixed alcoholic-ether compounds, petroleum fractions and many others. Many solvents give off toxic fumes and require adequate ventilation and other precautions during their use. The manufacturer's recommendations should be available, and should be followed, whenever any of these materials are used.

More detailed information on surface preparation, as well as other phases of painting, can be found in The Society for Protective Coatings Manual, Volume I, "Good Painting Practice", which is available at the District Offices.

All visible oil, grease, soil, drawing and cutting compounds and other soluble contaminants should be removed from surfaces to be painted prior to hand tool cleaning, power tool cleaning, or blast cleaning. Heavy deposits should be removed with a scraper followed by scrubbing or wiping with an appropriate cleaning solution. All visible traces of contaminants are to be removed with final wiping performed with clean rags and clean solvent. A discussion of solvent cleaning methods and Specification SSPC-SP1-"Solvent Cleaning" are included in Figure 5-393.456 (12) thru (13).

Surfaces of steel members for which blast cleaning is specified must be blasted in accordance with the requirements of the specifications. Painting metal structures requires that structural steel members for superstructures be blast cleaned on those surfaces which are accessible for blast cleaning; and that those surfaces of these members which are not accessible should be hand-tool cleaned. Blast cleaning should be in accordance with SSPC-SP10-"Near White Blast Cleaning", a copy of which is included as 393.456 (26) thru (31).

"Accessible surfaces" should be considered to mean those surfaces which would be accessible for blast cleaning in the erected structure, using conventional rigging.

Specification 2479, for painting with inorganic zinc-rich paint systems, requires that all surfaces to be prime coated shall be blast cleaned in accordance with SSPC-SP10. Prime coats are required for all contact surfaces including bolted splices, which must be blast cleaned and primed at the fabricator's shop unless specific approval is obtained from the Project Engineer for field painting. If field painting is allowed, splice plates and contact surfaces of steel diaphragms, "X" bracing, etc. must be blast cleaned and painted prior to erection as these areas are not accessible in the erected position. Surface preparation meeting requirements of SSPC-SP10 is critical at the time of paint application for zinc-rich systems as these paints depend on intimate contact with bare steel to provide galvanic protection. A surface profile (roughness) requirement is frequently used for zinc-rich systems.

The Special Provisions may require blast cleaning in accordance with SSPC-SP6, unpainted 3309 steel. Blast cleaning is often required on bolted splice plates to improve friction characteristics. Where uniform appearance of unpainted steel is important, such as on fascia beams, blast cleaning may be required to promote uniform rusting and avoid a "spotty" appearance.

Specification 1717 requires that the Contractor take necessary precautions to prevent pollution of flowing and impounded waters. It further requires compliance with all applicable regulations of the Minnesota Pollution Control Agency and Minnesota Department of Natural Resources. The Special Provisions will contain any specific requirements pertaining to the project. Sand blasting and painting shall be done to minimize the escape of paint solvents, and cleaning solutions into public waters or the atmosphere. The primary emphasis should be on containment within the project area rather than on recovery systems such as floating booms, skimmers, etc. Paint chips and sand, if readily recoverable, are to be cleaned up and transported to a sanitary landfill.

5-393.454 APPLICATION OF INDUSTRIAL COATINGS

Included in 5-393.456 (31) thru (45) are copies of sections of the SSPC Manual dealing with the application of industrial coatings. They are for the Inspector's information and guidance, and for his or her use, providing they are consistent with Mn/DOT Specifications. The Specifications should be followed in the event there is a discrepancy between the Specifications and the SSPC.

The various paint systems in use on bridge elements have system-specific requirements for application. To ensure successful painting results, the painters must follow the requirements of temperature, humidity, surface preparation and cleanliness for each component of the paint system. These and other requirements are addressed in the paint manufacturer's instructions, the Standard Specifications, and the special provisions.

For the zinc-rich systems (specification 2478), the specifications require a technical representative of the paint manufacturer to be on-site or on call during paint application. Inspectors should refer questions about the system requirements to this representative, preferably in a pre-painting conference. An important area in which the technical representative can help the Inspector(s) is in recognizing a properly prepared and cleaned surface.

Intermediate coat & top coat paints may be applied directly to a galvanized surface after thorough cleaning and light sweep blasting as per special provisions. Cleaning shall consist of removal of soil, cement mortar, and other surface dirt with a stiff brush, scraper or other suitable tool. Oil or grease is removed by wiping or scrubbing the surface with rags or brushes wetted with a suitable solvent in accordance with SSPC-SP1-Solvent Cleaning [See 5-393.456 (12) thru (13)]. A light sand blasting sufficient to roughen the surface should be performed.

Paint shall not be applied to metal surfaces when weather conditions are unsatisfactory for the work or the conditions include an air temperature below 4EC (40EF), metal surfaces less than 3EC (5EF) above the dew point, air that is misty, or metal surfaces that are damp or frosted.

Primer may be applied to rivet heads and to bolt heads and nuts during cold, dry weather, to preserve them against corrosion. These areas should be inspected prior to subsequent coating. If any area is found to be defective, it should be removed.

Best results are usually obtained when painting is done during dry, warm weather, with a light breeze. While the ideal combination of these conditions is desirable, it is not realistically attainable insofar as specification requirements are concerned.

Whether it is to be applied at the fabricating plant or elsewhere, the prime coat must be applied immediately after surface preparation, usually the same day. Blast cleaned surfaces, depending upon humidity conditions and the degree of surface brightness of the steel, will develop surface corrosion almost immediately after cleaning. Therefore it is imperative that delays in starting prime coat painting be avoided. If delays are encountered in application of the prime coat, which permits "flash rust" to form on newly cleaned steel, it is necessary to require additional cleaning to remove the newly formed rust.

It is important that "touch up" areas, which are primed after field welding, be thoroughly cleaned by scrubbing and washing with warm water. A mild (5 percent) solution of phosphoric acid followed by water rinsing and drying may also be used.

From the standpoint of protection against corrosion, the prime coat of paint is the most important of the several coats of paint applied to the steel surfaces. It is particularly necessary that special attention be given to its application. The dry film thickness shall be in accordance with the manufacturer's Product Data Sheet (PDS).

Special gages have been purchased and distributed to the Districts for use by the painting Inspector(s). Diligent usage should be made of these instruments to assure that the dry film thickness (dft) of the primer coat has been met. It is important that the coverage be uniform, both in thickness and appearance, since poor workmanship in application of the prime coat will be reflected in subsequent coats. Required thickness of paint may vary and specifications/special provisions should be consulted for each project.

Small cracks and cavities between abutting or mating members or parts, which have not been sealed against admission of moisture prior to applying the second coat, should be filled with approved caulking before the final application.

Spot coating of damaged areas is required prior to application of the finish coat. Damage may result from handling, shipping, erection, welding, bolting and/or falsework or form construction. Damaged areas should be cleaned, as necessary, to meet the surface preparation requirements for the type of paint system.

Before applying any subsequent coat of paint, the previous coat must be cured "to recoat" in accordance with the manufacturer's Product Data Sheet (PDS).

When it has been determined that the previous coat has cured "to recoat", the Inspector should make certain that the surfaces to be painted is first cleaned of dust, dirt, sand, and mortar, and all other foreign matter that may have come upon it since the previous coat was applied. Painting should not be permitted when the wind velocity carries objectionable amounts of dust, sand, and debris. Dusty road surfaces in the area may require treatment or occasional watering.

The top coat shall not be started until after the deck slab concrete has been placed, because of damage resulting from form removal, mortar leakage, and other causes.

The DFT shall be measured with a properly calibrated thickness gage in accordance with SSPC-PA2-measurement of dry coating thickness with magnetic gages. If the coating thickness cannot be satisfactorily determined, a destructive test shall be used in accordance with 2478.3F1.

1. Measuring Devices

Various measuring devices are available for determining the DFT. [For additional information see 393.456 (61) through (67).]

Rotating dial magnetic type gages are available at District Offices for thickness measurements. This gage, when properly used, can be a valuable tool for measuring coating thicknesses on magnetic steel. This gage is expensive and warrants careful handling. Secure anchor cord prior to using. The rotation of the gage dial in a clockwise direction increases spring tension against the magnetic force holding gate probe to the steel. The thicker the paint coating the weaker the magnetic contact.

2. Use of Magnetic Gage

a. Hold the gage very steady against the steel to be tested. Any movement of the gage or vibration in the steel surface will yield readings that are too high.

b. Rotate the gage dial in a counter-clockwise direction until the red probe goes to the down position and stays in that position as dial rotation is reversed.

c. Slowly, in a steady continuous motion, rotate the dial in a clockwise direction until magnetic contact is broken.

d. Note dial reading, reverse dial and take a second reading.

3. Other Gages

Other types of gages are available from the Bridge Office, Office of Construction and Materials Engineering, and some District Offices. Instructions for use of gages should be obtained and reviewed prior to their use.

4. Calibration Procedure for Thickness Gages

While other procedures could be used, this procedure tends to cancel out gage errors and is recommended by the Steel Structures Painting Council.

a. Correction Factor (after sandblasting and prior to painting). Use a 76 micron (3 mil) plastic shim, take thickness readings on each unpainted beam face at 3 locations. Take 3 readings at each location (within a 6 inch circle). Subtract 76 microns (3 mils) from the thickness reading to obtain the correction factor for prime coat thickness measurements. The Correction Factor is an approximate measurement of the profile or roughness of the steel surface due to sandblasting.

b. Repeat 4.a. using a 127 micron (5 mil) shim to determine correction factor for total paint thickness measurement.

c. After the prime coat has been applied, take thickness readings at approximately the same locations measured in 4.a. (Without shim). Subtract prime-coat correction factor.

d. After the required top-coats have been applied, repeat readings and subtract correction factor for total paint thickness measurement.

e. Calibration - Periodic reading should be taken both with and without the above mentioned shims on a polished smooth surface steel plate [minimum dimensions 75 mm (3 inches) x 150 mm (6 inches) x 13 mm (1/2 inch]. This will assure that the gage has not changed its calibration.

5-393.455 FINAL CLEANUP AND MISCELLANEOUS

It is the responsibility of the contractor to remove paint from surfaces which have become stained or blemished by the painting operations. It is better to discuss this with the superintendent or foreman in advance of starting to paint, so that he will be aware of the consequences of carelessness. Some areas such as slope paving, may be covered with tarps, plastic sheets, or other fabric, and thus prevent the need for extensive and difficult cleaning later. In most cases, proper precautions and painting procedures will minimize the amount of cleanup required, and will result in a neater looking job.

Carelessness in paint application is also apt to create a problem in public relations, as well as cause contamination of leaf type vegetables, grasses, fruit trees, and pollution of nearby waters. All practicable means should be used which would help avoid these problems, even to the extent of changing application methods when necessary.

5-393.456 STEEL STRUCTURES PAINTING COUNCIL EXCERPTS

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Index to the Society of Protective Coatings Manuals excerpts

Chapter 1.1
Corrosion of Metals

James F. Jenkins and Richard W. Drisko

Introduction

This chapter describes in basic terms the causes and mechanisms of corrosion. Corrosion is defined as “the chemical or electrochemical reaction between a metal and its environment resulting in the loss of the material and its properties.”[1] Various types of corrosion are discussed and the basic principles behind the use of protective coatings and cathodic protection for corrosion control are also covered. The strategies used in corrosion control by design are briefly discussed as well. This basic knowledge helps in understanding how protective coatings, cathodic protection, and other corrosion control methods can best be used as part of a total corrosion control program. Further information on these corrosion control methods can be found in subsequent chapters.

Why Metals Corrode

With few exceptions, metallic elements are found in nature in chemical combination with other elements. For example, iron is usually found in nature in the form of an ore, such as iron oxide. This combined form has a low chemical energy content and is very stable. Iron can be produced from iron ore by a high temperature smelting process. The heat that is added during smelting breaks the chemical bond between the iron and the oxygen. As a result, the iron and other metals used in structural applications have a higher energy content than they do in their original state, and are relatively unstable.

Corrosion is a natural process. Just like water flows to seek the lowest level, all natural processes tend towards the lowest possible energy states. Thus, iron and steel have a natural tendency to combine with other chemical elements to return to their lower energy states. In order to do this, iron and steel will frequently combine with oxygen, present in most natural environments, to form iron oxides, or “rust,” similar chemically to the original iron ore. **Figure 1** illustrates this cycle of refining and corrosion of iron and steel.

When rust forms on an iron or steel structure, metal is lost from the surface, reducing cross section and strength. Rust is also unsightly and can cause contamination of the environment and industrial products. It is further detrimental in that it is not a stable base for coatings.

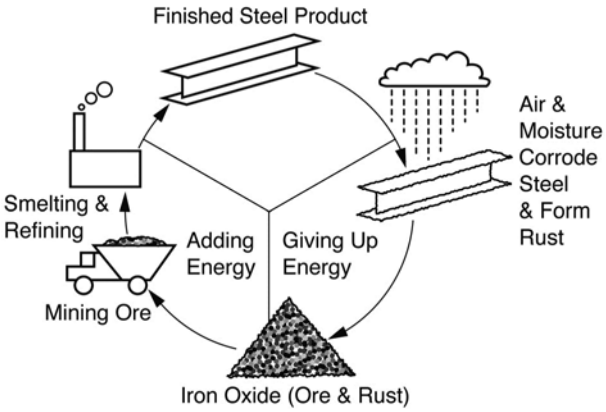


Figure 1. The corrosion cycle.

Immunity and Passivity

Some metals such as gold and platinum have lower energy levels in their metallic form than when combined with other chemical elements. These metals are often found in nature in the metallic form and do not tend to combine with other elements. They are thus highly resistant to corrosion in most natural environments. These materials are said to be immune to corrosion in those natural environments.

Other metals and alloys, while in a high energy state in their metallic forms, are resistant to corrosion due to formation of passive films (usually oxides) on their surfaces. These films form through a natural process similar to corrosion, and are usually invisible to the naked eye. They are, however, tightly adherent and continuous and serve as a barrier between the underlying metal and the environment. Stainless steels, aluminum alloys, and titanium are examples of metals that are in a high energy state in their metallic forms, but are relatively resistant to corrosion due to the formation of passive films on their surfaces. However, particularly in the case of stainless steels and aluminum alloys, this film is not resistant to all natural environments and can break down in one or more particular environments. This breakdown of the passive film often results in rapid, localized corrosion, due to the electrochemical activity of the parts of the surface that remain passive. **Figure 2** shows an example of such rapid, localized corrosion. (Note: This type of rapid, localized corrosion does not occur when paint coatings break down. Although paints provide a similar type of protection to the underlying metal, they are usually not electrochemically active.)

Figure 2. Corroded low-alloy steel bridge where protective outside film has been lost.

The Mechanism of Corrosion

The combination of metals with other chemical elements in the environment—what is commonly called corrosion—occurs through the action of the electrochemical cell. The electrochemical cell consists of four components: an anode, a cathode, an electrolyte, and a metallic path for the flow of electrons. When all four of these components are present as shown in **Figure 3** “cyclic reaction” occurs that results in corro- sion at the anode.

The key to understanding corrosion and corrosion control is that all of the components of this electrochemical cell must be present and active for corrosion to occur. If any one of the components is missing or inactive, corrosion will be arrested.

Anode

At the anode in an electrochemical cell, metal atoms at the surface lose one or more electrons and become positively charged ions. The generic chemical equation for this type of reaction is:

$$M^o \rightarrow M^+ + e^-$$

where M^o is a neutral metal atom, M^+ is a positively charged metal ion, and e^- is an electron. Corrosion occurs as the positively charged ions enter the electrolyte and are thus effectively removed from the metal anode surface. The electrons remain in the bulk metal and can move through the metal to complete other reactions. In the case of iron (Fe) two electrons are usually lost, and the equation is:

$$Fe^o \rightarrow Fe^{++} + 2\ e^-$$

where Fe^o is an iron atom and Fe^{++} is an iron (ferrous) ion. After the iron ions (Fe^{++}) enter the electrolyte, they usually combine with oxygen in a series of reactions that ultimately form rust.

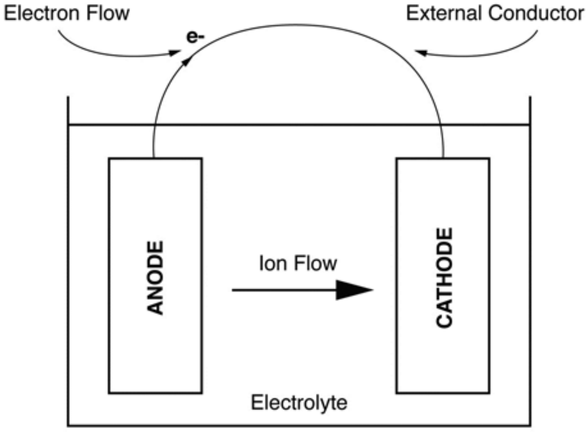


Figure 3. The basic components of the electrochemical cell.

Cathode

At the surface of the cathode in an electrochemical cell, the electrons produced by the reactions at the anode are “consumed,” i.e., used up by chemical reactions. The generic chemical equation for this type of reaction is:

$$R^+ + e^- \rightarrow R^o$$

or

$$R^o + e^- \rightarrow R^-$$

In this equation, R stands for any of a number of possible compounds that can exist in an oxidized form (R^+) and in a reduced form (R^o).

Many cathodic reactions are possible in

natural environments. The cathodic reactions that actually occur are dependent on the chemical composition of the electrolyte. In many instances where the electrolyte is water, the cathodic reaction is:

$$2H_2O+O_2+4e \rightarrow 4OH^-$$

In this reaction, two water molecules (H_2O) combine with one oxygen molecule (O_2) and four electrons to form four hydroxide ions (OH^-). In this case, the water and oxygen are reduced as in the generic cathodic reaction above. These hydroxide ions tend to create an alkaline environment at active cathodic areas.

Metallic Path

A metallic path between the anode and the cathode allows electrons produced at the anode to flow to the cathode. A metallic path is required in the corrosion cell because the electrolyte cannot carry free electrons. In many cases, where the anode and cathode are on the same piece of metal, the metal itself is the “metallic path” that carries the electrons from the anode to the cathode.

Electrolyte

The electrolyte serves as an external conductive media and a source of chemicals for reactions at the cathode, and as a reservoir for the metal ions and other corrosion products formed at the anode. Within the electrolyte, a flow of charged ions balances the flow of electrons through the metallic path. Under atmospheric conditions, the electrolyte consists of just a thin film of moisture on the surface, and the electrochemical cells responsible for corrosion are localized within this thin film. Under immersion conditions, however, much more electrolyte is present, and the electrochemical cells responsible for corrosion can involve much larger areas.

Rate of Reaction

Many factors can affect corrosion, but the bottom line is that the rate at which corrosion occurs is limited by the rate of reaction at the least active component of the electrochemical cell. For example, if there is an incomplete metallic path, this may be the limiting factor in the overall corrosion reaction. In this case, the electrochemical cell responsible for corrosion is similar to that in a flashlight battery when the flashlight is switched off **(see Figure 4).** When a battery is installed in a circuit such as a flashlight, no current flows until the flashlight is switched on. The high effective resistance of the open switch prevents current flow and the electrochemical discharge of the battery. Similarly, an incomplete metallic path prevents corrosion. The nature of the electrolyte may also affect the overall corrosion reaction. If the available electrolyte is very pure water that has relatively few ions, the ion flow can be the limiting factor. In many cases of corrosion under immersion conditions, the amount of oxygen available for the cathodic reaction is the limiting factor. Many methods for controlling corrosion target only one component of the overall electrochemical cell. By controlling the rate of just one of the reactions involved in the overall electrochemical cell, the overall rate of corrosion can be controlled.

It should be noted that temperature has an effect on the rate of the corrosion reaction. However, this effect is very complex, and is beyond the scope of this text. In the case of dissimilar metal corrosion, the potential difference between the metals also has an effect on reaction rate. This is discussed in the galvanic corrosion section of this chapter.

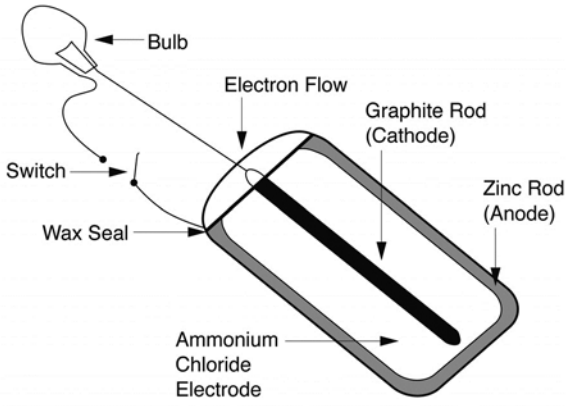


Figure 4. The dry cell battery.

Measuring Corrosion

There are many methods of measuring corrosion:

Weight Loss

Weight loss is one of the most widely used methods of measuring corrosion. A sample is first carefully cleaned to remove all surface contamination. After cleaning, it is weighed. It is then exposed to the environment in question and then recleaned and reweighed after a given period of time. If no corrosion has occurred, there will be no weight loss.

Size Measurement

The dimensions of the sample are measured before and after exposure. No change in dimensions indicates that no corrosion has occurred.

Visual Observation

Even minor amounts of corrosion are readily visible due to roughening of the surface.

Chemical Analysis

Surface deposits and the environments are tested for corrosion products. If surface deposits and the environment test negative for corrosion products (i.e., none present), it can be assumed that no corrosion has occurred.

Forms of Corrosion

No Attack

As stated in section immunity and passivity, some metals and alloys are essentially unaffected by corrosion in certain environments. This may be either because they are more stable in their metallic forms than in a combined forms or because they form natural protective films on their surfaces that provide completely effective passivity. However, just because a given metal or alloy is essentially unaffected by corrosion in one or more environments does not mean that it is resistant to corrosion in all environments. That no corrosion has occurred can be verified by one of the methods described in the previous section.

Uniform Corrosion

Uniform corrosion is a form of corrosion in which a metal is attacked at about the same rate over the entire exposed surface. While considerable surface roughening can take place in uniform corrosion, when the depth of attack at any point exceeds twice the average depth of attack, the corrosion is no longer considered to be uniform.

When a metal is attacked by uniform corrosion, the location of anodic and cathodic areas shifts from time to time, i.e., every point on the surface acts as both an anode and a cathode at some time during the exposure. A schematic representation of uniform corrosion is shown in **Figure 5,** where anodic and cathodic sites periodically reverse. In this case, the metallic path is through the metal itself. The electrolyte may either be a thin film of moisture in atmospheric exposure, a liquid in which the surface is immersed, or water contained in moist earth.

The amount of uniform corrosion is usually measured by weight loss. If weight loss is determined over a given period of time, it can also be used to calculate an average rate of metal loss over the entire surface. This corrosion rate is usually expressed in mils (0.001 inch) per year (mpy) or millimeters per year (mm/yr).

This is a good way to measure the amount and rate of corrosion if the corrosion is truly uniform; however, these average rates can give misleading results if the corrosion is not uniform over the entire surface. (See the section on pitting for further information.) Direct measurement of metal loss through metal thickness is also sometimes performed and can be used to determine corrosion rate in mpy or mm/yr.

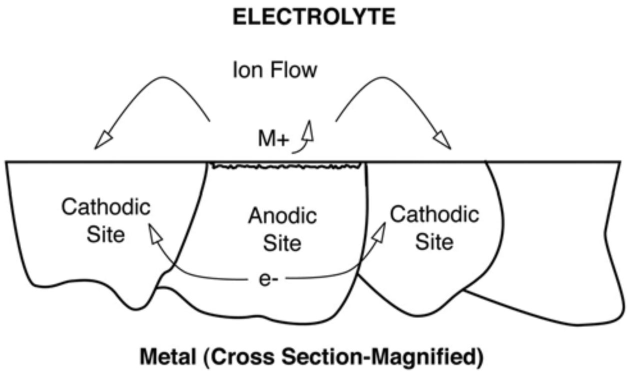


Figure 5. The corrosion cell on a metal surface.

Since corrosion rates commonly vary with time (e.g., slower as corrosion products form protective films), they are usually measured over several different intervals. Corrosion rates can also be measured continuously for extended periods, using electrochemical techniques to determine how the rates are affected by time.

A coating is a very effective tool in combating uniform corrosion because corrosion usually proceeds slowly at local sites where the coating breaks down or is damaged. These areas can therefore be repaired before significant damage occurs, assuming that inspection identifies the defects at an early stage.

Galvanic Corrosion

When two or more dissimilar metals are connected by a metallic path and exposed to an electrolyte, galvanic corrosion can occur as shown in **Figure 6.** This dissimilar metal corrosion is driven by the difference in electrical potential between the metals. An electrochemical cell is formed in which the more active metal acts as an anode and the less active metal acts as a cathode. In galvanic corrosion, the more active metal corrodes more than if it were not electrically coupled, and the less active metal corrodes less than if it were not electrically coupled.

A "galvanic series" table that lists metals in order of their electrical potential in a given environment can be used to determine which metal in a given combination will act as an anode and which will act as a cathode. **Table 1** is a galvanic series derived from exposure of common metals to seawater. The galvanic activity of metals in other environments is similar to that in seawater, but significant differences may occur. It should be noted that in North America, galvanic series are listed with the most active metals at the top, but the opposite may be true in other parts of the world. To determine which convention has been used in a particular galvanic series table, look for active metals like zinc, magnesium or aluminum and see if they are listed at the top or at the bottom. It should also be noted that some metals, such as the 300 Series stainless steel, are listed twice.

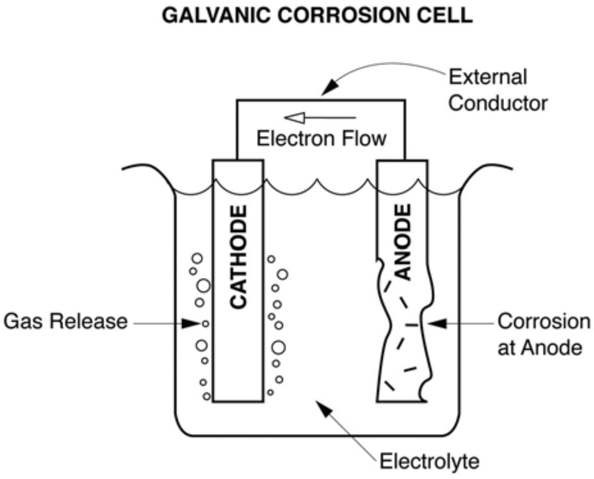


Figure 6. Galvanic corrosion cell.

In atmospheric exposures, the anodic area and cathodic area involved in galvanic corrosion are usually about equal in size. This is because the electrical resistance of the thin film of moisture acting as the electrolyte is very large over distances much more than 1/8 inch or so (1-2 mm). Under immersion conditions, however, the effective resistance of the electrolyte is much less and galvanic corrosion effects have a much greater range. The cathodic reaction is often the limiting factor in corrosion under immersion conditions due to the limited availability of dissolved oxygen.

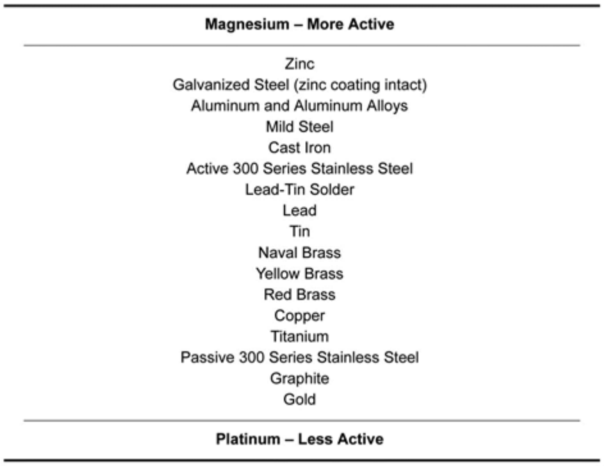
As described in cathode section, in many instances where the electrolyte is water, the cathodic reaction is:

$$2H_2O+O_2+4e \rightarrow 4OH^-$$

2

Thus, the rate at which electrons can be consumed at the cathode limits the rate of galvanic attack in these situations.

Table 1. Galvanic Series Derived from Exposure of Common Metals to Seawater.



Magnesium – More Active
Zinc
Galvanized Steel (zinc coating intact)
Aluminum and Aluminum Alloys
Mild Steel
Cast Iron
Active 300 Series Stainless Steel
Lead-Tin Solder
Lead
Tin
Naval Brass
Yellow Brass
Red Brass
Copper
Titanium
Passive 300 Series Stainless Steel
Graphite
Gold
Platinum – Less Active

The amount of galvanic corrosion that occurs in a given situation can be measured indirectly by monitoring the current flow between the anodes and cathodes. It can also be measured directly by determining the weight loss of the anodic and cathodic materials, or by some other direct means of measurement such as pitting depths or thickness measurements as appropriate to the form of attack.

Relative rates of galvanic attack can be assessed by looking at the distance between the metals in a galvanic series. For example, steel is farther from copper than it is from lead in the galvanic series, so the rate of galvanic attack on a piece of steel would be expected to be higher if coupled to a piece of copper than if coupled to a piece of lead, all other things being equal.

Actual rates of galvanic attack are difficult to predict. They depend on the potential difference between the metals involved and the relative areas of affected anodic and cathodic surface. However, the relative areas of affected anode and cathode surface can, and often do, have a greater effect on galvanic corrosion than the potential difference between the metals involved. If the anode is large and the cathode is small, the low rate at which electrons can be consumed at the cathode results in little acceleration of corrosion on the larger anodic surface. **(Figure 7)** On the other hand, if the anode is small and the cathode is large, a relatively large number of electrons can be consumed at the cathode and this effect is concentrated over a smaller anode, resulting in a substantial acceleration of corrosion at the small anodic area. In this case, there is a large acceleration of corrosion at the anode. The effect of area ratio on galvanic corrosion is shown more graphically in **Figure 8.**

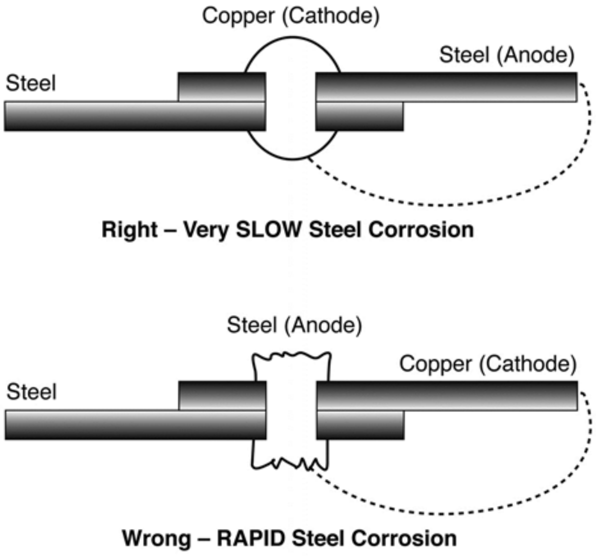


Figure 7. Rate of corrosion.

The area ratio effect is important when using coatings as a means of corrosion control. Coatings can effectively isolate most of the surface of a metal from the electrolyte and can therefore be used to control galvanic corrosion. If galvanic corrosion is active, coating of the anode alone can result in having a small anode and large cathode with catastrophic results. This is because a small break in the coating on the anode will create a small anode-large cathode situation.

Even though the cathodic material may be highly corrosion resistant, it is the galvanic corrosion of the anodic material that is important in such cases. When in doubt, the entire system should be coated; the mistake should not be made of coating only the anodic material and thereby creating an adverse area ratio. When only the cathode is coated, the effective anode/cathode area ratio is increased thus reducing corrosion at the anode.

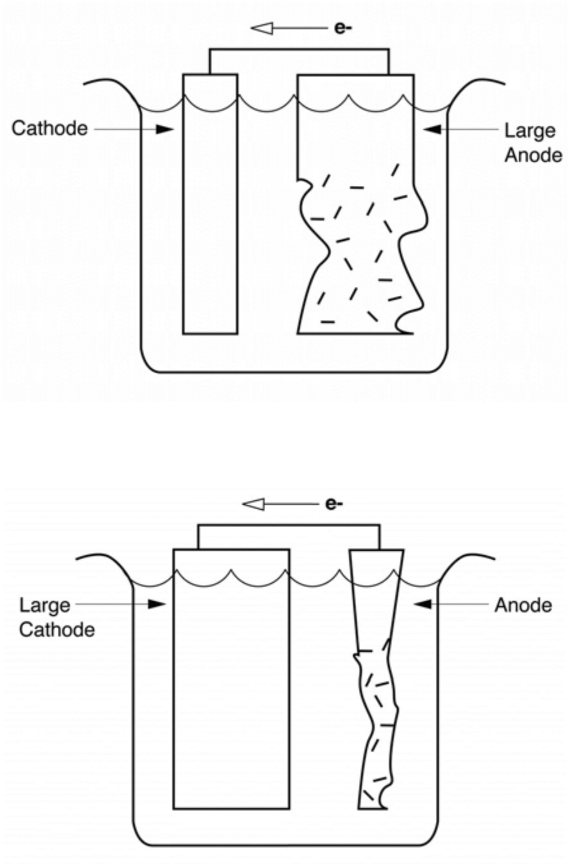


Figure 8. The area effect in galvanic corrosion. Top: “Benign” area ratio—small cathode has little effect on large anode. Bottom: “Adverse” area ratio—large cathode has great effect on small anode.

Pitting

Pitting corrosion (also called simply “pitting”) occurs when the amount of corrosion at one or more points on a metal is much greater than the average amount of corrosion. In some cases, the entire surface is corroded, but unevenly. In other cases, some areas are essentially unattacked. **Figure 9** shows an example of pitting corrosion being measured. Pitting can occur through several mechanisms. Metals are not chemically or physically homogeneous. Some areas may have more of a tendency to be anodic than others and the shifting of anodic and cathodic areas that is necessary for uniform corrosion does not occur. This lack of homogeneity may be due to inclusions within the metal or to the combination of metallurgical phases that are naturally present in many alloys.

Figure 9. Diver using a depth gauge to measure pit depths. Courtesy Underwater Engineering Services, Inc.

Another mechanism of pitting occurs by local breakdown of passive films on a metal. In this case, the area with the passive film is cathodic to the area without the passive film and a type of galvanic (dissimilar metal) corrosion occurs. The potential difference between areas with the passive films and sites lacking the passive film allows active corrosion to occur. This can be seen in Table 1 for 300 Series stainless steel where the 300 Series stainless steels occupy two positions, one much more active than the other. The more active position is occupied by material that is not protected by a passive film and the less active position is occupied by material that is protected by a passive film.

Since pitting attack is, by definition, non-uniform, weight loss is not a suitable method for measurement of pitting corrosion rates. In some cases, uniform corrosion rates in mpy or mm/yr are given for metals that actually have corroded by localized attack such as pitting. Such corrosion rates often greatly understate the actual depth of penetration of corrosion into the metal. In some applications, such as a structural beam, scattered pitting may not cause too much trouble, but a single pit through a tank wall or pipe handling a hazardous liquid can be disastrous even though most of the surface may be relatively unaffected.

The amount of pitting is established by direct measurement of the depth of pits and the number of pits that occur in a given surface area. Pitting is essentially a random process; therefore, statistical sampling and analysis are often performed. Pit depths may be measured in several ways. One of the simplest ways is with a pit depth gauge that uses a dial micrometer and a pointed probe. For pitting corrosion, weight losses are only determined to establish that the deepest pit has more than twice the average metal loss based on weight loss, which is the point where uneven uniform corrosion becomes, by definition, pitting corrosion.

Where pitting occurs at a significant rate, localized corrosion can have disastrous effects (e.g., in the case of a tank). In such cases, coatings alone are seldom effective in controlling corrosion as coating defects and degradation are inevitable. However, when coatings are combined with other forms of corrosion control, particularly cathodic protection, effective control of pitting corrosion is possible.

Concentration Cell Corrosion

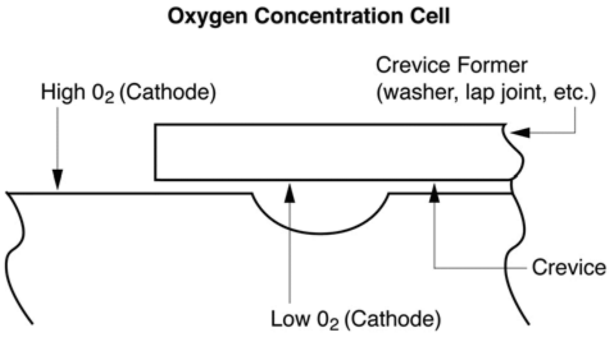
Concentration cell corrosion is often called crevice corrosion because the differences in environment that drive this type of corrosion are often located in and adjacent to crevices. These crevices commonly occur at joints and attachments. Crevices can be formed at metal-to-metal joints or metal to non-metal joints. Deposits of debris or corrosion products can also form crevices.

Concentration cell corrosion commonly occurs by one of two different mechanisms. **Figure 10** illustrates these two types of concentration cell corrosion. The most common is oxygen concentration cell corrosion. In this type of corrosion, the availability of oxygen is less inside the crevice than it is outside the crevice.

This affects the cathodic reaction:

$$2H_2O+O_2+4e^- \rightarrow 4OH^-$$

Low oxygen concentration inhibit this reaction by limiting the availability of one of the reactants. Any factor that inhibits the cathodic reactions on a surface will make the anodic reactions on that surface more prevalent. Thus, in oxygen concentration cell corrosion, the surfaces inside the crevice are exposed to a lower oxygen environment and become anodic with respect to the surfaces outside the crevice and corrosion occurs inside the crevice area. In some cases, the corrosion of the surface outside the crevice is reduced.



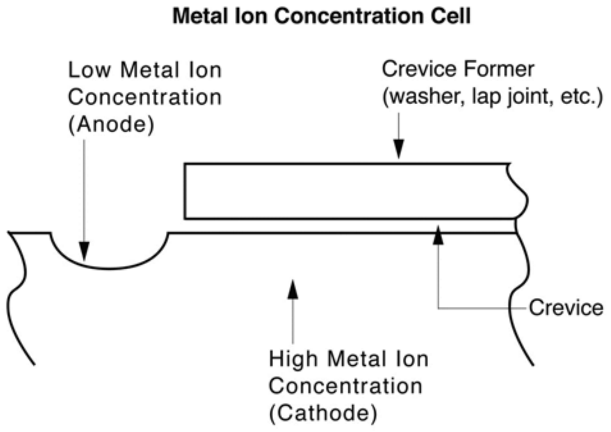


Figure 10. Concentration cell corrosion. Top: Oxygen concentration cell. Bottom: Metal ion concentration cell.

As in galvanic corrosion, oxygen concentration cell corrosion is accelerated by the adverse area ratio between the anode and the cathode. For example, the crevice area formed under a bolt head is usually small with respect to the area of the material being fastened together. Like galvanic corrosion, concentration cell corrosion is normally accelerated under immersion conditions.

Another possible mechanism of concentration cell corrosion is based on differences in metal ion concentration. In this case, the limited circulation inside the crevice causes a buildup of corrosion products. A buildup of metal ions (M^+) will inhibit the generic anodic reaction:

$$M^o \rightarrow M^+ + e^-$$

This is because a buildup of reaction products (M^+) inhibits the reaction. Any factor that inhibits the anodic reaction will cause the area to become more cathodic. In metal ion concentration cell corrosion, the area inside the crevice becomes the cathode and the area outside becomes the anode. This is opposite to the distribution of attack in oxygen concentration cell crevice attack. This form of crevice attack is usually less severe than oxygen concentration cell corrosion because the anode/cathode area ratio is not adverse in this case. There is a large anodic area outside the crevice and only a small cathodic area inside the crevice.

The type of crevice corrosion that occurs in a given situation depends on the metals involved and the environments to which they are exposed. Stainless steels are particularly sensitive to oxygen concentration cell attack and copper alloys are commonly susceptible to metal ion concentration cell attack. Iron and steel show relatively minor effects of crevice corrosion. For iron and most other steels, crevices corrode more than adjacent surfaces under atmospheric conditions primarily because they remain wet more of the time.

Sealants, which are intended to keep the environments out of crevice areas, are sometimes successful in preventing crevice corrosion under atmospheric conditions, but are relatively ineffective in preventing crevice corrosion under immersion conditions. Coating of the external surfaces (the area surrounding the crevice), however, can reduce the intensity of oxygen concentration cell attack by reducing the cathodic area.

Stray Current Corrosion

Stray current corrosion is most commonly encountered in underground environments but can also occur under immersion conditions. In stray current corrosion, an electrical current flowing in the environment adjacent to a structure causes one area on the structure to act as an anode and another area to act as a cathode. Direct current (DC) is the more damaging type of stray current, but alternating current (AC) can also cause stray current attack. In underground soil environments, stray current corrosion can be caused by currents arising from direct current railway systems, mining operations using direct current, welding operations, and underground cathodic protection systems. Stray currents can also be induced naturally on long underground pipelines. This is due to the interaction between the electrically conductive pipeline and the earth's magnetic field. Stray currents can also be induced through improper grounding of electrical systems in buildings. **Figure 11** shows a typical stray current situation caused by an electric railway.

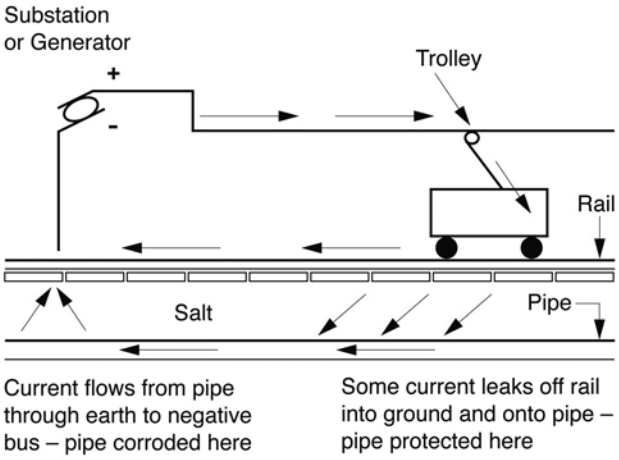


Figure 11. Stray current caused by electric railway.

In this example, the pipeline becomes a low resistance path for the current returning from the train to the power source. Wherever the pipeline is caused to be more positive by the stray current, corrosion occurs at a higher rate.

Stray currents can be detected by electrical measurements. If stray currents are found to be a problem, they can be reduced or eliminated by several techniques including: reducing the current flow in the ground by modifying the current source; electrical bonding to control the current flow; and application of cathodic protection to counterbalance the stray current flow. Coatings are very useful in controlling stray currents as they can effectively electrically isolate the buried structure from the environment so that it does not become a low resistance path. If the structure is coated only in the more positive (anodic) areas, corrosion may become concentrated at defects in these areas, as in the case of galvanic corrosion. This is because the effective cathodic area will be large and the effective anodic areas at coating defects will be small. Very rapid corrosion can occur if stray currents are present and only the anodic areas are coated.

Other Forms of Corrosion

There are many other forms of corrosion, such as:

- Dealloying
- Intergranular attack
- Stress corrosion cracking
- Hydrogen embrittlement
- Corrosion fatigue
- Erosion corrosion
- Cavitation corrosion
- Fretting Corrosion

However, these forms of corrosion are not commonly controlled or affected by the application of protective coatings. More information on these forms of corrosion can be found in References 1 through 3.

Methods for Corrosion Control

Many different methods can be used to control corrosion. By combining some of these methods, the cost of corrosion and its effect on the function of the structure can be minimized.

Protective Coatings

Protective coatings are widely used to control corrosion. In the broadest sense, any material that forms a continuous film on the surface of a substrate can be considered to be a protective coating. Protective coatings control corrosion primarily by providing a barrier between the metal and its environments. This barrier reduces the activity of the chemical reactions responsible for corrosion by slowing the movement of the reactants and reaction products involved.

Organic Coatings. Organic coatings are usually liquid applied coatings that are converted to a solid film after application. The barrier action responsible for the primary protective action of organic coatings is often enhanced by the addition of chemicals that inhibit corrosion, or by loading with zinc to provide galvanic (cathodic) protection to the underlying metal.

Metallic Coatings. Metallic coatings are thin films of metal applied to a substrate. These coatings can be applied by dipping the metal to be coated in a molten metal bath (e.g., galvanizing), by electroplating, and by thermal spray. There are two generic types of metallic coatings, those that are anodic to the underlying metal (called here “anodic metallic coatings”) and those that are cathodic to the underlying metal (called here “cathodic metallic coatings”). Both of these generic types provide barrier protection, but they differ in their ability to provide corrosion protection when they are damaged or defective.

Cathodic Protection

Cathodic protection can provide effective control of corrosion in underground and immersion conditions. In its simplest form, (a sacrificial anode system), cathodic protection is essentially an intentional galvanic corrosion cell designed so that the structure to be protected acts as a cathode. It therefore has a reduced corrosion rate. The anodic material that is intentionally added to the system corrodes at an accelerated rate. Impressed current systems are similar, but instead of using sacrificial anodes, they provide protection by inducing a current in the system from an external power supply.

Cathodic protection, combined with the use of appropriate protective coatings, can provide better control of corrosion than either method used alone. The barrier action provided by the coating reduces the surface area to be protected by cathodic protection. This in turn reduces the cost of the cathodic protection system by decreasing the amount of anodic material that is consumed in sacrificial anode systems, or the amount of current that must be supplied in an impressed current system. It should be noted that the effectiveness of the coating system is also improved because corrosion does not occur at coating defects or damaged areas.

Good Design

Many of the factors that affect how corrosion will attack a given system can be addressed at the design stage. For example, corrosion can be controlled to some degree by avoiding structural features that trap and hold moisture, by avoiding joints that cannot be effectively protected by coatings, and by avoiding sharp edges where coatings are to be used. Particularly in cases where protective coatings are used as a part of the total corrosion control system, another important design factor is to allow for easy coating maintenance. Good design also provides for easy access for coating inspection, surface preparation, and coating application.

Materials Selection. The compatibility of materials with their environments should be a basic consideration in any engineering design. However, it is not always practical or possible to use materials that are highly resistant to corrosion. Materials selection is only one aspect of the overall design process. Other design considerations besides materials selection include the ability of the various types of corrosion control measures to reduce the effects of corrosion and the effect of corrosion on overall system function. A good design balances all of these factors to obtain the desired system performance and lifetime at the least cost.

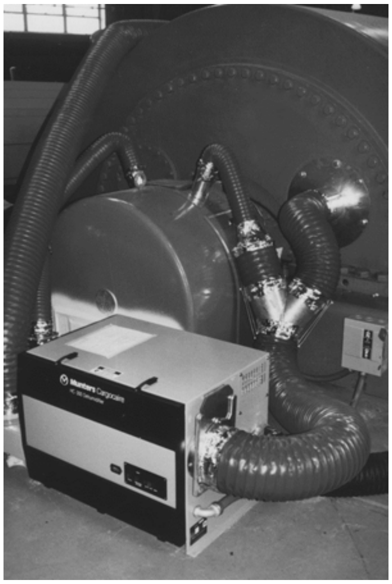


Figure 12. A Munters rental dehumidifier setup to protect the hotwell of the condenser in a power generation plant. Dry air circulates through the equipment, preventing corrosion from occuring. Courtesy Munters Moisture Control Services.

Corrosion Allowance. Except in cases where special highly corrosion-resistant materials are used, some corrosion is always inevitable. Therefore, successful designs will consider the type and extent of corrosion anticipated and will make allowances for the metal loss that will occur. Particularly where uniform corrosion is anticipated, this corrosion allowance is often provided by making the components thicker. While this is often considered to be a “factor of safety,” it actually pro- vides extra metal to compensate for metal losses due to corrosion that is likely to occur when and where the corrosion control methods used are not completely effective. The overall system design must be based on the type and amount of corrosion that will occur. Periodic inspections must be performed to verify that the amount of corrosion is within safe limits. This is a frequent practice in chemical process industries.

Change of Environment. In some circumstances, corrosion is controlled by changing the environment. In liquid handling systems, this may be accomplished by removing oxygen from the system by deaeration, or by the addition of corrosion inhibitors. In other cases, the environment is changed by controlling atmospheric conditions, e.g., dehumidification may be used to control corrosion in interior spaces. An example of a dehumidification system is shown in **Figure 12.** Such corrosion control measures may be required during manufacture of critical equipment or may be used as a temporary means to control corrosion until other corrosion control methods can be applied. Dehumidification of the interior of tanks during and after blast cleaning and prior to the application of a protective coating is one example of this type of environmental control.

Summary

Corrosion is an electrochemical process that naturally occurs on most metals when they are exposed to aggressive environments. Rusting of steel in atmospheric or immersion conditions is a common example of corrosion. The electrochemical process responsible for corrosion involves four components: an anode, a cathode, a metallic path, and an electrolyte. The rate of the overall corrosion reaction can be controlled by limiting the activity of any one of these components. There are many forms of corrosion, which all depend on the activity of electrochemical cells, but differ in the location and distribution of attack.

There are many ways to control corrosion. One way is to select materials that are resistant to attack in the specific exposure environment. Another is to use cathodic protection and/or protective coatings. The application of protective coatings is one of the most important means of corrosion control. In most cases, the best way to control corrosion is to use a combination of two or more appropriate corrosion control methods.

References

1. ASTM G15-83. Standard Terminology Related to Corrosion and Corrosion Testing; ASTM: West Conshokoen, PA.

2. Van Delinder, L.S. Corrosion Basics: An Introduction; NACE: Houston, 1984.

2. Fontana, Mars G. Corrosion Engineering, 3 rd Edition; McGraw Hill: New York, 1986.

3. Atkinson, J.T.N; Van Droffelaar, H. Corrosion and Its Control: An Introduction to the Subject, 2nd Edition; NACE: Houston, 1994.

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5. Munger, Charles G. Corrosion Prevention by Protective Coatings; NACE: Houston, 1984.

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James F. Jenkins retired in 1995 after 30 years of service to the U.S. Navy in corrosion control for shore and ocean-based facilities. Now a consultant, he is a registered corrosion engineer in the state of California. Mr. Jenkins received his BS degree in metallurgical engineering from the University of Arizona.

Dr. Richard W. Drisko

Dr. Richard W. Drisko has been the senior technical advisor to SSPC: The Society for Protective Coatings since January 1995. Prior to this, he was employed for over 40 years at the Naval Civil Engineering Laboratory, Port Hueneme, California, where he conducted research, evaluation, and testing, and served as the Navy’s center of expertise on coatings for shore structures. He is a professional corrosion engineer in the state of California, an SSPC certified protective coatings specialist (PCS), and a NACE International certificated corrosion specialist. Dr. Drisko received his BS, MS, and PhD degrees from Stanford

SSPC: The Society for Protective Coatings

SURFACE PREPARATION SPECIFICATION NO. 1

Solvent Cleaning

1. Scope

1.1 This specification covers the requirements for the solvent cleaning of steel surfaces.

2. Definition

2.1 Solvent cleaning is a method for removing all visible oil, grease, soil, drawing and cutting compounds, and other soluble contaminants from steel surfaces.

2.2 It is intended that solvent cleaning be used prior to the application of paint and in conjunction with surface preparation methods specified for the removal of rust, mill scale, or paint.

3. Surface Preparation Before and After Solvent Cleaning

3.1 Prior to solvent cleaning, remove foreign matter (other than grease and oil) by one or a combination of the following: brush with stiff fiber or wire brushes, abrade, scrape, or clean with solutions of appropriate cleaners, provided such cleaners are followed by a fresh water rinse.

3.2 After solvent cleaning, remove dirt, dust, and other contaminants from the surface prior to paint application. Acceptable methods include brushing, blow off with clean, dry air, or vacuum cleaning.

4. Methods of Solvent Cleaning

4.1 Remove heavy oil or grease first by scraper. Then remove the remaining oil or grease by any of the following methods:

4.1.1 Wipe or scrub the surface with rags or brushes wetted with solvent. Use clean solvent and clean rags or brushes for the final wiping.

4.1.2 Spray the surface with solvent. Use clean solvent for the final spraying.

4.1.3 Vapor degrease using stabilized chlorinated hydrocarbon solvents.

4.1.4 Immerse completely in a tank or tanks of solvent. For the last immersion, use solvent which does not contain detrimental amounts of contaminant.

4.1.5 Emulsion or alkaline cleaners may be used in place of the methods described. After treatment, wash the surface with fresh water or steam to remove detrimental residues.

4.1.6 Steam clean, using detergents or cleaners and follow by steam or fresh water wash to remove detrimental residues.

5. Inspection

5.1 All work and materials supplied under this standard shall be subject to timely inspection by the purchaser or his authorized representative. The contractor shall correct such work or replace such material as is found defective under this standard. In case of dispute the arbitration or settlement procedure established in the procurement documents, if any, shall be followed. If no arbitration or settlement procedure is established, then a procedure mutually agreeable to purchaser and contractor shall be used.

5.2 The procurement documents covering work or purchase should establish the responsibility for testing and for any required affidavit certifying full compliance with the standard.

6. Disclaimer

6.1 While every precaution is taken to ensure that all information furnished in SSPC standards and specifications is as accurate, complete, and useful as possible, SSPC cannot assume responsibility nor incur any obligation resulting from the use of any materials, coatings, or methods specified herein, or of the specification or standard itself.

6.2 This specification does not attempt to address problems concerning safety associated with its use. The user of this specification, as well as the user of all products or practices described herein, is responsible for instituting appropriate health and safety practices and for ensuring compliance with all governmental regulations.

7. Note

Notes are not requirements of this specification.

7.1 A Commentary Section is available and contains additional information and data relative to this specification. The Surface Preparation Commentary, SSPC-SP COM, is not part of this specification. The table below lists the subjects discussed relevant to solvent cleaning and the appropriate Commentary section.

Section Subject	SSPC-SP COM Section
Solvents and Cleaners	5.1.1 through 5.1.3
Steam Cleaning	5.1.4
Threshold Limit Values	5.1.5

SSPC: The Society for Protective Coatings
SURFACE PREPARATION SPECIFICATION NO. 2
Hand Tool Cleaning

1. Scope

1.1 This standard covers the requirements for hand tool cleaning steel surfaces.

2. Definitions

2.1 Hand tool cleaning is a method of preparing steel surfaces by the use of non-power hand tools.

2.2 Hand tool cleaning removes all loose mill scale, loose rust, loose paint, and other loose detrimental foreign matter. It is not intended that adherent mill scale, rust, and paint be removed by this process. Mill scale, rust, and paint are considered adherent if they cannot be removed by lifting with a dull putty knife.

2.3 SSPC-VIS 3 or other visual standard of surface preparation agreed upon by the contracting parties may be used to further define the surface (see Note 8.1).

3. Referenced Standards

3.1 The latest issue, revision, or amendment of the referenced standards in effect on the date of invitation to bid shall govern, unless otherwise specified. Standards marked with an asterisk (*) are referenced only in the Notes, which are not requirements of this standard.

3.2 If there is a conflict between the requirements of any of the cited reference standards and this standard, the requirements of this standard shall prevail.

3.3 SSPC SPECIFICATIONS:

SP 1	Solvent Cleaning
*SP 3	Power Tool Cleaning
*SP 11	Power Tool Cleaning to Bare Metal
*SP 15	Commercial Grade Power Tool Cleaning
VIS 3	Guide and Reference Photographs for Steel Surfaces Prepared by for Power- and Hand-Tool Cleaning

3.4 INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO):

* 8501-1	Preparation of steel substrates before application of paints and related products: Visual assessment of surface cleanliness—Part I.

4. Surface Preparation Before and After Hand Tool Cleaning

4.1 Before hand tool cleaning, visible deposits of oil, grease, or other materials that may interfere with coating adhesion shall be removed in accordance with SSPC-SP 1 or other agreed-upon methods. Nonvisible surface contaminants such as soluble salts shall be treated to the extent specified by the procurement documents [project specifications] (see Note 8.2).

4.2 After hand tool cleaning and prior to painting, reclean the surface if it does not conform to this standard.

4.3 After hand tool cleaning and prior to painting, remove dirt, dust, or similar contaminants from the surface. Acceptable methods include brushing, blow off with clean, dry air, or vacuum cleaning.

5. Methods of Hand Tool Cleaning

5.1 Use impact hand tools to remove stratified rust (rust scale).

5.2 Use impact hand tools to remove all weld slag.

5.3 Use hand wire brushing, hand abrading, hand scraping, or other similar non-impact methods to remove all loose mill scale, all loose or non-adherent rust, and all loose paint.

5.4 Regardless of the method used for cleaning, if specified in the procurement documents, feather the edges of remaining old paint so that the repainted surface can have a reasonably smooth appearance.

5.5 If approved by the owner, use power tools or blast cleaning as a substitute cleaning method for this standard.

6. Inspection

6.1 Unless otherwise specified in the procurement documents, the contractor or material supplier is responsible for quality control to assure that the requirements of this document are met. Work and materials supplied under this standard are also subject to inspection by the purchaser or an authorized representative. Materials and work areas shall be accessible to the inspector.

6.2 Conditions not complying with this standard shall be corrected. In the case of a dispute, an arbitration or settlement procedure established in the procurement documents (project specification) shall be followed. If no arbitration or settlement procedure is established, then a procedure mutually agreeable to purchaser and material supplier (or contractor) shall be used.

7. Disclaimer

7.1 While every precaution is taken to ensure that all information furnished in SSPC standards and specifications is as accurate, complete, and useful as possible, SSPC cannot assume responsibility nor incur any obligation resulting from the use of any materials, coatings, or methods specified herein, or of the specification or standard itself.

7.2 This standard does not attempt to address problems concerning safety associated with its use. The user of this standard, as well as the user of all products or practices described herein, is responsible for instituting appropriate health and safety practices and for ensuring compliance with all governmental regulations.

8. Notes

Notes are not requirements of this standard.

8.1 Note that the use of visual standards in conjunction with this standard is required only when they are specified in the procurement documents (project specification) covering the work. It is recommended, however, that the use of visual standards be made mandatory in the procurement documents.

SSPC-VIS 3 provides a suitable comparative visual standard for SSPC-SP 2, SSPC-SP 3, SSPC-SP 11, and SSPC-SP 15. ISO 8501-1 may also serve as a visual standard.

8.2 The SSPC Surface Preparation Commentary (SSPC-SP COM) contains additional information and data relevant to this specification. The Commentary is non-mandatory and is not part of this specification. The table below lists the subjects discussed relevant to hand tool cleaning and the appropriate Commentary Section.

Subject	Commentary Section
Film Thickness	10
Maintenance Painting	4.2
Rust, Stratified Rust, Pack Rust, and Rust Scale	4.3.1
Visual Standards	11
Weld Spatter	4.4.1

SSPC: The Society for Protective Coatings

JOINT SURFACE PREPARATION SPECIFICATION

SSPC-SP 6/NACE NO. 3

Commercial Blast Cleaning

Users of this standard are responsible for reviewing appropriate health, safety, and regulatory documents and for determining their applicability in relation to this standard prior to its use. This SSPC/NACE standard may not necessarily address all potential health and safety problems or environmental hazards associated with the use of materials, equipment and/or operations detailed or referred to within this standard. Users of this standard are also responsible for establishing appropriate health, safety, and environmental protection practices, in consultation with appropriate regulatory authorities, if necessary, to achieve compliance with any existing applicable regulatory requirements prior to the use of this standard.

CAUTIONARY NOTICE: SSPC/NACE standards are subject to periodic review and may be revised or withdrawn at any time without prior notice. SSPC and NACE require that action be taken to reaffirm, revise, or withdraw this standard no later than five years from the date of initial publication. The user is cautioned to obtain the latest edition. Purchasers may receive current information on all standards and other publications by contacting the organizations at the addresses below:

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Foreword

This joint standard covers the use of blast cleaning abrasives to achieve a defined degree of cleaning of steel surfaces prior to the application of a protective coating or lining system. This standard is intended for use by coating or lining specifiers, applicators, inspectors, or others whose responsibility it may be to define a standard degree of surface cleanliness.

The focus of this standard is commercial blast cleaning. White metal blast cleaning, near-white blast cleaning, industrial blast cleaning, and brush-off blast cleaning are addressed in separate standards.

Commercial blast cleaning provides a greater degree of cleaning than industrial blast cleaning (SSPC-SP 14/NACE No. 8), but less than near-white blast cleaning (SSPC-SP 10/NACE No. 2).

Commercial blast cleaning is used when the objective is to remove all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products and other foreign matter, leaving staining or shadows on no more than 33 percent of each unit area of surface as described in Section 2.2.

The difference between a commercial blast and a near-white blast is in the amount of staining permitted to remain on the surface. Commercial blast allows stains or shadows on 33 percent of each unit area of surface. Near-white blast allows staining or shadows on only 5 percent of each unit area.

The difference between a commercial blast and an industrial blast is that a commercial blast removes all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products and other foreign matter from all surfaces and allows stains to remain on 33 percent of each unit area of surface, while industrial blast allows defined mill scale, coating, and rust to remain on less than 10 percent of the surface and allows defined stains to remain on all surfaces.

This joint standard was prepared by the SSPC/NACE Task Group A on Surface Preparation by Abrasive Blast Cleaning. This joint Task Group includes members of both the SSPC Surface Preparation Committee and the NACE Unit Committee T-6G on Surface Preparation (now STG 04).

1. General

1.1 This joint standard covers the requirements for commercial blast cleaning of unpainted or painted steel surfaces by the use of abrasives. These requirements include the end condition of the surface and materials and procedures necessary to achieve and verify the end condition.

1.2 The mandatory requirements are described in Sections 1 to 9 as follows:

Section 1	General
Section 2	Definition
Section 3	Referenced Standards
Section 4	Procedures Before Blast Cleaning
Section 5	Blast Cleaning Methods and Operation
Section 6	Blast Cleaning Abrasives
Section 7	Procedures Following Blast Cleaning and Immediately Prior to Coating
Section 8	Inspection
Section 9	Safety and Environmental Requirements

NOTE: Section 10, “Comments” and Appendix A, “Explanatory Notes” are not mandatory requirements of this standard.

2. Definition

2.1 A commercial blast cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products, and other foreign matter, except for staining as noted in Section 2.2.

2.2 Random staining shall be limited to no more than 33 percent of each unit area of surface as defined in Section 2.6, and may consist of light shadows, slight streaks, or minor discolorations caused by stains of rust, stains of mill scale, or stains of previously applied coating.

2.3 Acceptable variations in appearance that do not affect surface cleanliness as defined in Section 2.1 include variations caused by type of steel, original surface condition, thickness of the steel, weld metal, mill or fabrication marks, heat treating, heat affected zones, blasting abrasives, and differences due to blasting technique.

2.4 When a coating is specified, the surface shall be roughened to a degree suitable for the specified coating system.

2.5 Immediately prior to coating application, the entire surface shall comply with the degree of cleaning specified herein.

2.6 Unit area for determinations shall be approximately 5776 mm^2 (9 in^2) (i.e., a square 76 x 76 mm [3 in x 3 in]).

2.7 SSPC-VIS 1 may be specified to supplement the written definition. In any dispute, the written standards shall take precedence over visual standards and comparators. Additional information on visual standards and comparators is available in Section A.4 of Appendix A.

3. Referenced Standards

3.1 The latest issue, revision, or amendment of the referenced standards in effect on the date of invitation to bid shall govern unless otherwise specified.

3.2 If there is a conflict between the requirements of any of the cited reference standards and this standard, the requirements of this standard shall prevail.

3.3 SSPC: THE SOCIETY FOR PROTECTIVE COATINGS STANDARDS:

AB 1	Mineral and Slag Abrasives
AB 2	Cleanliness of Recycled Ferrous Metallic Abrasives
AB 3	Ferrous Metallic Abrasives
PA Guide 3	A Guide to Safety in Paint Application
SP 1	Solvent Cleaning
VIS 1	Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning

4. Procedures Before Blast Cleaning

4.1 Before blast cleaning, visible deposits of oil, grease, or other contaminants shall be removed in accordance with SSPC-SP 1 or other agreed upon methods.

4.2 Before blast cleaning, surface imperfections such as sharp fins, sharp edges, weld spatter, or burning slag should be removed from the surface to the extent required by the procurement documents (project specification). Additional information on surface imperfections is available in Section A.5 of Appendix A.

4.3 If a visual standard or comparator is specified to supplement the written standard, the condition of the steel prior to blast cleaning should be determined before the blasting commences. Additional information on visual standards and comparators is available in Section A.4 of Appendix A.

5. Blast Cleaning Methods and Operation

5.1 Clean, dry compressed air shall be used for nozzle blasting. Moisture separators, oil separators, traps, or other equipment may be necessary to achieve this requirement.

5.2 Any of the following methods of surface preparation may be used to achieve a commercial blast cleaned surface:

5.2.1 Dry abrasive blasting using compressed air, blast nozzles, and abrasive.

5.2.2 Dry abrasive blasting using a closed-cycle, recirculating abrasive system with compressed air, blast nozzle, and abrasive, with or without vacuum for dust and abrasive recovery.

5.2.3 Dry abrasive blasting using a closed cycle, recirculating abrasive system with centrifugal wheels and abrasive.

5.3 Other methods of surface preparation (such as wet abrasive blasting) may be used to achieve a commercial blast cleaned surface by mutual agreement between those responsible for performing the work and those responsible for establishing the requirements. NOTE: Information on the use of inhibitors to prevent the formation of rust immediately after wet blast cleaning is contained in Section A.9 of Appendix A.

6. Blast Cleaning Abrasives

6.1 The selection of abrasive size and type shall be based on the type, grade, and surface condition of the steel to be cleaned, type of blast cleaning system employed, the finished surface to be produced (cleanliness and roughness), and whether the abrasive will be recycled.

6.2 The cleanliness and size of recycled abrasives shall be maintained to ensure compliance with this specification.

6.3 The blast cleaning abrasive shall be dry and free of oil, grease, and other contaminants as determined by the test methods found in SSPC-AB 1, AB 2 and AB 3.

6.4 Any limitations on the use of specific abrasives, the quantity of contaminants, or the degree of allowable embedment shall be included in the procurement documents (project specification) covering the work, because abrasive embedment and abrasives containing contaminants may not be acceptable for some service requirements. NOTE: Additional information on abrasive selection is given in Section A.2 of Appendix A.

7. Procedures Following Blast Cleaning and Immediately Prior to Coating

7.1 Visible deposits of oil, grease, or other contaminants shall be removed according to SSPC-SP 1 or another method agreed upon by those parties responsible for establishing the requirements and those responsible for performing the work.

7.2 Dust and loose residues shall be removed from prepared surfaces by brushing, blowing off with clean, dry air, vacuum cleaning, or other methods agreed upon by those responsible for establishing the requirements and those responsible for performing the work. NOTE: The presence of toxic metals in the abrasives or paint being removed may place restrictions on the methods of cleaning permitted. Comply with all applicable regulations. Moisture separators, oil separators, traps, or other equipment may be necessary to achieve clean, dry air.

7.3 After blast cleaning, surface imperfections that remain (e.g., sharp fins, sharp edges, weld spatter, burning slag, scabs, slivers, etc.) shall be removed to the extent required in the procurement documents (project specification). Any damage to the surface profile resulting from the removal of surface imperfections shall be corrected to meet the requirements of Section 2.4. NOTE: Additional information on surface imperfections is contained in Section A.5 of Appendix A.

7.4 Any visible rust that forms on the surface of the steel after blast cleaning shall be removed by recleaning the rusted areas to meet the requirements of this standard before coating. NOTE: Information on rust-back (re-rusting) and surface condensation is contained in Sections A.6, A.7, and A.8 of Appendix A.

8. Inspection

8.1 Work and materials supplied under this standard are subject to inspection by a representative of those responsible for establishing the requirements. Materials and work areas shall be accessible to the inspector. The procedures and times of inspection shall be as agreed upon by those responsible for establishing the requirements and those responsible for performing the work.

8.2 Conditions not complying with this standard shall be corrected. In the case of a dispute, an arbitration or settlement procedure established in the procurement documents (project specification) shall be followed. If no arbitration or settlement procedure is established, then a procedure mutually agreeable to purchaser and supplier shall be used.

8.3 The procurement documents (project specification) should establish the responsibility for inspection and for any required affidavit certifying compliance with the specification.

9. Safety and Environmental Requirements

9.1 Because abrasive blast cleaning is a hazardous operation, all work shall be conducted in compliance with applicable occupational and environmental health and safety rules and regulations. NOTE: SSPC-PA Guide 3, "A Guide to Safety in Paint Application," addresses safety concerns for coating work.

10. Comments

10.1 Additional information and data relative to this standard are contained in Appendix A. Detailed information and data are presented in a separate document, SSPC-SP COM, "Surface Preparation Commentary." The recommendations contained in Appendix A and SSPC-SP COM are believed to represent good practice, but are not to be considered requirements of the standard. The sections of SSPC-SP COM that discuss subjects related to commercial blast cleaning are listed below.

Subject	Commentary Section
Abrasive Selection	6
Film Thickness	10
Wet Abrasive Blast Cleaning	8.2
Maintenance	4.2
Rust-back (Re-rusting)	4.5
Surface Profile	6.2
Visual Standards	11
Welds and Weld Spatter	4.4.1

Appendix A. Explanatory Notes

A.1 FUNCTION: Commercial blast cleaning (SSPC-SP 6/NACE No. 3) provides a greater degree of cleaning than brush-off blast cleaning (SSPC-SP 7/NACE No. 4), but less than near-white blast cleaning (SSPC-SP 10/NACE No. 2). It should be specified only when a compatible coating will be applied. The primary functions of blast cleaning before coating are: (a) to remove material from the surface that can cause early failure of the coating system and (b) to obtain a suitable surface roughness and to enhance the adhesion of the new coating system. The hierarchy of blasting standards is as follows: white metal blast cleaning, near-white blast cleaning, commercial blast cleaning, industrial blast cleaning, and brush-off blast cleaning.

A.2 ABRASIVE SELECTION: Types of metallic and non-metallic abrasives are discussed in the Surface Preparation Commentary (SSPC-SP COM). It is important to recognize that blasting abrasives may become embedded in or leave residues on the surface of the steel during preparation. While normally such embedment or residues are not detrimental, care should be taken to ensure that the abrasive is free from detrimental amounts of water-soluble, solvent-soluble, acid-soluble, or other soluble contaminants (particularly if the prepared steel is to be used in an immersion environment). Criteria for selecting and evaluating abrasives are given in SSPC-AB 1, "Mineral and Slag Abrasives," SSPC-AB 2, "Cleanliness of Recycled Ferrous Metallic Abrasives," and SSPC-AB 3, "Ferrous Metallic Abrasives."

A.3 SURFACE PROFILE: Surface profile is the roughness of the surface which results from abrasive blast cleaning. The profile depth (or height) is dependent upon the size, shape, type, and hardness of the abrasive, particle velocity and angle of impact, hardness of the surface, amount of recycling, and the proper maintenance of working mixtures of grit and/or shot. The allowable minimum/maximum height of profile is usually dependent upon the thickness of the coating to be applied. Large particle sized abrasives (particularly metallic) can produce a profile that may be too deep to be adequately covered by a single thin film coat. Accordingly, it is recommended that the use of larger abrasives be avoided in these cases. However, larger abrasives may be needed for thick film coatings or to facilitate removal of thick coatings, heavy mill scale, or rust. If control of profile (minimum/maximum) is deemed to be significant to coating performance, it should be addressed in the procurement documents (project specification). Typical profile heights achieved with commercial abrasive media are shown in Table 5 of the Surface Preparation Commentary (SSPC-SP COM). Surface profile should be measured in accordance with NACE Standard RP0287 (latest edition), "Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using Replica Tape,"or ASTM(1) D 4417 (latest edition), "Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel."

A.4 VISUAL STANDARDS: SSPC-VIS 1, "Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning" provides color photographs for the various grades of surface preparation as a function of the initial condition of the steel. The A-SP 6, B-SP 6, C-SP 6, D-SP 6, and G-SP 6 series of photographs depict surfaces cleaned to a commercial blast. Other available visual standards are described in Section 11 of SSPC-SP COM.

A.5 SURFACE IMPERFECTIONS: Surface imperfections can cause premature failure when the service is severe. Coatings tend to pull away from sharp edges and projections, leaving little or no coating to protect the underlying steel. Other features that are difficult to properly cover and protect include crevices, weld porosities, laminations, etc. The high cost of the methods to remedy surface imperfections requires weighing the benefits of edge rounding, weld spatter removal, etc., versus a potential coating failure.

Poorly adhering contaminants, such as weld slag residues, loose weld spatter, and some minor surface laminations may be removed during the blast cleaning operation. Other surface defects (steel laminations, weld porosities, or deep corrosion pits) may not be evident until the surface preparation has been completed. Therefore, proper planning for such surface repair work is essential because the timing of the repairs may occur

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(1) ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

before, during, or after the blast cleaning operation. Section 4.4 of SSPC-SP COM and NACE Standard RP0178 (latest edition), “Fabrication Details, Surface Finish Requirements, and Proper Design Considerations for Tanks and Vessels to be Lined for Immersion Service” contain additional information on surface imperfections.

A.6 CHEMICAL CONTAMINATION: Steel contaminated with soluble salts (e.g., chlorides and sulfates) develops rust-back rapidly at intermediate and high humidities. These soluble salts can be present on the steel surface prior to blast cleaning as a result of atmospheric contamination. In addition, contaminants can be deposited on the steel surface during blast cleaning if the abrasive is contaminated. Therefore, rust-back can be minimized by removing these salts from the steel surface and eliminating sources of recontamination during and after blast cleaning. Wet methods of removal are described in SSPC-SP 12/NACE No. 5. Identification of the contaminants along with their concentrations may be obtained from laboratory and field tests as described in SSPC-Guide 15, "Field Methods for Retrieval and Analysis of Soluble Salts on Steel and Nonporous Substrates.”

A.7 RUST-BACK: Rust-back (re-rusting) occurs when freshly cleaned steel is exposed to moisture, contamination, or a corrosive atmosphere. The time interval between blast cleaning and rust-back will vary greatly from one environment to another. Under mild ambient conditions, if chemical contamination is not present (see Section A.6), it is best to blast clean and coat a surface the same day. Severe conditions may require more expedient coating application to avoid contamination from fallout. Chemical contamination should be removed prior to coating (see Section A.6).

A.8 DEW POINT: Moisture condenses on any surface that is colder than the dew point of the surrounding air. It is, therefore, recommended that the temperature of the steel surface be at least 3°C (5°F) above the dew point during dry blast cleaning operations. It is advisable to visually inspect for moisture and periodically check the surface temperature and dew point during blast cleaning operations and to avoid the application of coating over a damp surface.

A.9 WET ABRASIVE BLAST CLEANING: Steel that is wet abrasive blast cleaned may rust rapidly. Clean water should be used for rinsing. It may be necessary that inhibitors be added to the water or applied to the surface immediately after blast cleaning to temporarily prevent rust formation. The use of inhibitors or the application of coating over slight discoloration should be in accordance with the requirements of the coating manufacturer. CAUTION: Some inhibitive treatments may interfere with the performance of certain coating systems.

A.10 FILM THICKNESS: It is essential that ample coating be applied after blast cleaning to adequately cover the peaks of the surface profile. The dry film thickness of the coating above the peaks of the profile should equal the thickness known to be needed for the desired protection. If the dry film thickness over the peaks is inadequate, premature rust-through or failure will occur. To assure that coating thicknesses are properly measured the procedures in SSPC-PA 2 (latest edition), “Measurement of Dry Coating Thickness with Magnetic Gauges” should be used.

A.11 MAINTENANCE AND REPAIR PAINTING: When this standard is used in maintenance painting, specific instructions should be given on the extent of surface to be blast cleaned or spot blast cleaned to this degree of cleanliness. In these cases, the cleaning shall be performed across the entire area specified. For example, if all weld seams are to be cleaned in a maintenance operation, this degree of cleaning shall be applied 100% to all weld seams. If the entire structure is to be prepared, this degree of cleaning shall be applied to 100% of the entire structure. SSPC-PA Guide 4 (latest edition), “Guide to Maintenance Repainting with Oil Base or Alkyd Painting Systems,” provides a description of accepted practices for retaining old sound coating, removing unsound coating, feathering, and spot cleaning.

SSPC: The Society for Protective Coatings
JOINT SURFACE PREPARATION SPECIFICATION
SSPC-SP 7/NACE NO. 4
Brush-Off Blast Cleaning

This SSPC: The Society for Protective Coatings and NACE International standard represents a consensus of those indi- vidual members who have reviewed this document, its scope and provisions. Its acceptance does not in any respect preclude anyone, having adopted the standard or not, from manufactur- ing, marketing, purchasing, or using products, processes, or procedures not in conformance with this standard. Nothing contained in this standard is to be construed as granting any right, by implication or otherwise, to manufacture, sell, or use in connection with any method, apparatus, or product covered by Letters Patent, or as indemnifying or protecting anyone against liability for infringement of Letters Patent. This standard represents minimum requirements and should in no way be interpreted as a restriction on the use of better procedures or materials. Neither is this standard intended to apply in all cases relating to the subject. Unpredictable circumstances may negate the usefulness of this standard in specific instances. SSPC and NACE assume no responsibility for the interpretation or use of this standard by other parties and accept responsibility for only those official interpretations issued by SSPC or NACE in accordance with their respective governing procedures and policies, which preclude the issuance of interpretations by individual volunteers.

Users of this standard are responsible for reviewing ap- propriate health, safety, and regulatory documents and for determining their applicability in relation to this standard prior to its use. This SSPC/NACE standard may not necessarily ad- dress all potential health and safety problems or environmental hazards associated with the use of materials, equipment and/or operations detailed or referred to within this standard. Users of this standard are also responsible for establishing appropriate health, safety, and environmental protection practices, in con- sultation with appropriate regulatory authorities, if necessary, to achieve compliance with any existing applicable regulatory requirements prior to the use of this standard.

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Foreword

This joint standard covers the use of blast cleaning abrasives to achieve a defined degree of cleaning of steel surfaces prior to the application of a protective coating or lining system. This standard is intended for use by coating or lining specifiers, applicators, inspectors, or others whose responsibility it may be to define a standard degree of surface cleanliness.

The focus of this standard is brush-off blast cleaning. White metal blast cleaning, near-white blast cleaning, commercial blast cleaning, and industrial blast cleaning are addressed in separate standards.

Brush-off blast cleaning provides a lesser degree of cleaning than industrial blast cleaning (SSPC-SP 14/NACE No. 8). The difference between an industrial blast and a brush-off blast is that the objective of a brush-off blast is to allow as much of an existing coating to remain as possible, and to roughen the surface prior to coating application while the purpose of the industrial blast is to remove most of the coating, mill scale and rust, when the extra effort required to remove every trace of these is determined to be unwarranted.

This joint standard was prepared by the SSPC/NACE Task Group A on Surface Preparation by Abrasive Blast Cleaning. This joint Task Group includes members of both the SSPC Surface Preparation Committee and the NACE Unit Committee T-6G on Surface Preparation (now STG 04).

1. General

1.1 This joint standard covers the requirements for brush- off blast cleaning of unpainted or painted steel surfaces by the use of abrasives. These requirements include the end condi- tion of the surface and materials and procedures necessary to achieve and verify the end condition.

1.2 This joint standard allows tightly adherent rust, mill scale and/or old coating to remain on the surface.

1.3 The mandatory requirements are described in Sections 1 to 9 as follows:

Section 1	General
Section 2	Definitions
Section 3	Referenced Standards
Section 4	Procedures Before Blast Cleaning
Section 5	Blast Cleaning Methods and
Operation Section 6	Blast Cleaning Abrasives
Section 7 and	Procedures Following Blast Cleaning Immediately Prior to Coating
Section 8	Inspection
Section 9	Safety and Environmental Requirements

NOTE: Section 10, “Comments” and Appendix A, “Explanatory Notes” are not mandatory requirements of this standard.

2. Definition

2.1 A brush-off blast cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose coating. Tightly adherent mill scale, rust, and coating may remain on the surface. Mill scale, rust, and coating are considered tightly adherent if they cannot be removed by lifting with a dull putty knife after abrasive blast cleaning has been performed.

2.2 The entire surface shall be subjected to the abrasive blast. The remaining mill scale, rust, or coating shall be tight. Flecks of the underlying steel need not be exposed whenever the original substrate consists of intact coating.

2.3 When a coating is specified, the surface shall be roughened to a degree suitable for the specified coating system.

2.4 Immediately prior to coating application, the entire surface shall comply with the degree of cleaning as specified herein.

2.5 SSPC VIS 1 may be specified to supplement the written definition. In any dispute, the written standards shall take precedence over visual standards and comparators. Additional information on visual standards is available in Section A.4 of Appendix A.

3. Referenced Standards

3.1 The latest issue, revision, or amendment of the referenced standards in effect on the date of invitation to bid shall govern unless otherwise specified.

3.2 If there is a conflict between the requirements of any of the cited reference standards and this standard, the requirements of this standard shall prevail.

3.3 SSPC: THE SOCIETY FOR PROTECTIVE COATINGS STANDARDS:

AB 1	Mineral and Slag Abrasives
AB 2	Cleanliness of Recycled Ferrous Metallic Abrasives
AB 3	Ferrous Metallic Abrasives
PA Guide 3	A Guide to Safety in Paint Application
SP 1	Solvent Cleaning
VIS 1	Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning

4. Procedures Before Blast Cleaning

4.1 Before blast cleaning, visible deposits of oil, grease, or other contaminants shall be removed in accordance with SSPC-SP 1 or other agreed upon methods.

4.2 Before blast cleaning, surface imperfections such as sharp fins, sharp edges, weld spatter, or burning slag should be removed from the surface to the extent required by the procurement documents (project specification). Additional information on surface imperfections is available in Section A.5 of Appendix A.

4.3 If a visual standard or comparator is specified to supplement the written standard, the condition of the steel prior to blast cleaning should be determined before the blasting commences. Additional information on visual standards and comparators is available in Section A.4 of Appendix A.

5. Blast Cleaning Methods and Operation

5.1 Clean, dry compressed air shall be used for nozzle blasting. Moisture separators, oil separators, traps, or other equipment may be necessary to achieve this requirement.

5.2 Any of the following methods of surface preparation may be used to achieve a brush-off blast cleaned surface:

5.2.1 Dry abrasive blasting using compressed air, blast nozzles, and abrasive.

5.2.2 Dry abrasive blasting using a closed-cycle, recirculating abrasive system with compressed air, blast nozzle, and abrasive, with or without vacuum for dust and abrasive recovery.

5.2.3 Dry abrasive blasting using a closed cycle, recirculating abrasive system with centrifugal wheels and abrasive.

5.3 Other methods of surface preparation (such as wet abrasive blasting) may be used to achieve a brush-off blast cleaned surface by mutual agreement between those responsible for performing the work and those responsible for establishing the requirements. NOTE: Information on the use of inhibitors to prevent the formation of rust immediately after wet blast cleaning is contained in Section A.9 of Appendix A.

6. Blast Cleaning Abrasives

6.1 The selection of abrasive size and type shall be based on the type, grade, and surface condition of the steel to be cleaned, type of blast cleaning system employed, the finished surface to be produced (cleanliness and roughness), and whether the abrasive will be recycled.

6.2 The cleanliness and size of recycled abrasives shall be maintained to ensure compliance with this specification.

6.3 The blast cleaning abrasive shall be dry and free of oil, grease, and other contaminants as determined by the test methods found in SSPC-AB 1, AB 2, and AB 3.

6.4 Any limitations on the use of specific abrasives, the quantity of contaminants, or the degree of allowable embedment shall be included in the procurement documents (project specification) covering the work, because abrasive embedment and abrasives containing contaminants may not be acceptable for some service requirements. NOTE: Additional information on abrasive selection is given in Section A.2 of Appendix A.

7. Procedures Following Blast Cleaning and Immediately Prior to Coating

7.1 Visible deposits of oil, grease, or other contaminants shall be removed according to SSPC-SP 1 or another method agreed upon by those parties responsible for establishing the requirements and those responsible for performing the work.

7.2 Dust and loose residues shall be removed from prepared surfaces by brushing, blowing off with clean, dry air, vacuum cleaning, or other methods agreed upon by those responsible for establishing the requirements and those responsible for performing the work. NOTE: The presence of toxic metals in the abrasives or paint being removed may place restrictions on the methods of cleaning permitted. The method chosen shall comply with all applicable regulations. Moisture separators, oil separators, traps, or other equipment may be necessary to achieve clean, dry air.

7.3 After blast cleaning, surface imperfections that remain (e.g., sharp fins, sharp edges, weld spatter, burning slag, scabs, slivers, etc.) shall be removed to the extent required in the procurement documents (project specification). Any damage to the surface profile resulting from the removal of surface imperfections shall be corrected to meet the requirements of Section 2.4. NOTE: Additional information on surface imperfections is contained in Section A.5 of Appendix A.

8. Inspection

8.1 Work and materials supplied under this standard are subject to inspection by a representative of those responsible for establishing the requirements. Materials and work areas shall be accessible to the inspector. The procedures and times of inspection shall be as agreed upon by those responsible for establishing the requirements and those responsible for performing the work.

8.2 Conditions not complying with this standard shall be corrected. In the case of a dispute, an arbitration or settlement procedure established in the procurement documents (project specification) shall be followed. If no arbitration or settlement procedure is established, then a procedure mutually agreeable to purchaser and supplier shall be used.

8.3 The procurement documents (project specification) should establish the responsibility for inspection and for any required affidavit certifying compliance with the specification.

9. Safety and Environmental Requirements

9.1 Because abrasive blast cleaning is a hazardous operation, all work shall be conducted in compliance with applicable occupational and environmental health and safety rules and regulations. NOTE: SSPC-PA Guide 3, “A Guide to Safety in Paint Application,” addresses safety concerns for coating work.

10. Comments

10.1 Additional information and data relative to this standard are contained in Appendix A. Detailed information and data are presented in a separate document, SSPC-SP COM, “Surface Preparation Commentary.” The recommendations contained in Appendix A and SSPC-SP COM are believed to represent good practice, but are not to be considered requirements of the standard. The sections of SSPC-SP COM that discuss subjects related to brush-off blast cleaning are listed below.

Subject	Commentary Section
Abrasive Selection	6
Film Thickness	10
Wet Abrasive Blast Cleaning	8
Maintenance	4.2
Rust-back (Re-rusting)	4.5
Surface Profile	6.2
Visual Standards	11
Welds and Weld Spatter	4.4.1

Appendix A. Explanatory Notes

A.1 FUNCTION: Brush-off blast cleaning (SSPC-SP 7/NACE No. 4), provides a lesser degree of cleaning than industrial blast cleaning (SSPC-SP 14/NACE No. 8). It should be used when the service environment is mild enough to permit tight mill scale, coating, rust, and other foreign matter to remain on the surface. The primary functions of blast cleaning before coating are (a) to remove material from the surface that can cause early failure of the coating and (b) to obtain a suitable surface roughness and to enhance the adhesion of the new coating system. The hierarchy of blasting standards is as follows: white metal blast cleaning, near-white blast cleaning, commercial blast cleaning, industrial blast cleaning, and brush-off blast cleaning.

A.2 ABRASIVE SELECTION: Types of metallic and non-metallic abrasives are discussed in the Surface Preparation Commentary (SSPC-SP COM). It is important to recognize that blasting abrasives may become embedded in or leave residues on the surface of the steel during preparation. While normally such embedment or residues are not detrimental, care should be taken to ensure that the abrasive is free from detrimental amounts of water-soluble, solvent-soluble, acid-soluble, or other soluble contaminants (particularly if the prepared steel is to be used in an immersion environment). Criteria for selecting and evaluating abrasives are given in SSPC-AB 1, “Mineral and Slag Abrasives,” SSPC-AB 2, “Cleanliness of Recycled Ferrous Metallic Abrasives,” and SSPC-AB 3, "Ferrous Metallic Abrasives”

A.3 SURFACE PROFILE: Surface profile is the roughness of the surface which results from abrasive blast cleaning. The profile depth (or height) is dependent upon the size, shape, type, and hardness of the abrasive, particle velocity and angle of impact, hardness of the surface, amount of recycling, and the proper maintenance of working mixtures of grit and/or shot. The allowable minimum/maximum height of profile is usually dependent upon the thickness of the coating to be applied. Large particle sized abrasives (particularly metallic) can produce a profile that may be too deep to be adequately covered by a single thin film coat. Accordingly, it is recommended that the use of larger abrasives be avoided in these cases. However, larger abrasives may be needed for thick film coatings or to facilitate removal of thick coatings, heavy mill scale, or rust. If control of profile (minimum/maximum) is deemed to be significant to coating performance, it should be addressed in the procurement documents (project specification). Typical profile heights achieved with commercial abrasive media are shown in Table 5 of the Surface Preparation Commentary (SSPC-SP COM). Surface profile should be measured in accordance with NACE Standard RP0287 (latest edition), “Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using Replica Tape, “ or ASTM(1) D 4417 (latest edition), “Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel.”

A.4 VISUAL STANDARDS: SSPC-VIS 1 "Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning," provides color photographs for the various grades of surface preparation as a function of the initial condition of the steel. The series A-SP 7, B-SP 7, C-SP 7, D-SP 7 and G-SP 7 depict surfaces cleaned to brush-off blast grade. Other available visual standards are described in Section 11 of SSPC-SP COM.

A.5 SURFACE IMPERFECTIONS: Surface imperfections can cause premature failure when the service is severe. Coatings tend to pull away from sharp edges and projections, leaving little or no coating to protect the underlying steel. Other features that are difficult to properly cover and protect include crevices, weld porosities, laminations, etc. The high cost of the methods to remedy surface imperfections requires weighing the benefits of edge rounding, weld spatter removal, etc., versus a potential coating failure.

Poorly adhering contaminants, such as weld slag residues, loose weld spatter, and some minor surface laminations may be removed during the blast cleaning operation. Other surface defects (steel laminations, weld porosities, or deep corrosion pits) may not be evident until the surface preparation has been completed. Therefore, proper planning for such surface repair work is essential because the timing of the repairs may occur before, during, or after the blast cleaning operation. Section 4.4 of SSPC-SP COM and NACE Standard RP0178 (latest edition), “Fabrication Details, Surface Finish Requirements, and Proper Design Considerations for Tanks and Vessels to be Lined for Immersion Service” contain additional information on surface imperfections.

A.6 CHEMICAL CONTAMINATION: Steel contaminated with soluble salts (e.g., chlorides and sulfates) develops rust-back rapidly at intermediate and high humidities. These soluble salts can be present on the steel surface prior to blast cleaning as a result of atmospheric contamination. In addition, contaminants can be deposited on the steel surface during blast cleaning if the abrasive is contaminated. Therefore, rust-back can be minimized by removing these salts from the steel surface, preferably before blast cleaning, and eliminating sources of recontamination during and after blast cleaning. Wet methods of removal are described in SSPC-SP 12/NACE No. 5. Identification of the contaminants along with their concentrations may be obtained from laboratory and field tests as described in SSPC-TU 4 "Field Methods for Retrieval and Analysis of Soluble Salts on Substrates.”

A.7 RUST-BACK: Rust-back (re-rusting) occurs when freshly cleaned steel is exposed to moisture, contamination, or a corrosive atmosphere. The time interval between blast cleaning and rust-back will vary greatly from one environment to another. Under mild ambient conditions, if chemical contamination is not present (see Section A.6), it is best to blast clean and coat a surface the same day. Severe conditions may require more expedient coating application to avoid contamination from fallout. Chemical contamination should be removed prior to coating (see Section A.6).

A.8 DEW POINT: Moisture condenses on any surface that is colder than the dew point of the surrounding air. It is, therefore, recommended that the temperature of the steel surface be at least 3°C (5°F) above the dew point during dry blast cleaning operations. It is advisable to visually inspect for moisture and periodically check the surface temperature and dew point during blast cleaning operations and to avoid the application of coating over a damp surface.

A.9 WET ABRASIVE BLAST CLEANING: Steel that is wet abrasive blast cleaned may rust rapidly. Clean water should be used for rinsing. It may be necessary that inhibitors be added to the water or applied to the surface immediately after blast cleaning to temporarily prevent rust formation. The coating should then be applied before any rusting is visible. The use of inhibitors or the application of coating over slight discoloration should be in accordance with the requirements of the coating manufacturer.

CAUTION: Some inhibitive treatments may interfere with the performance of certain coating systems.

A.10 FILM THICKNESS: It is essential that ample coating be applied after blast cleaning to adequately cover the peaks of the surface profile. The dry film thickness of the coating above the peaks of the profile should equal the thickness known to be needed for the desired protection. If the dry film thickness over the peaks is inadequate, premature rust-through or failure will occur. To assure that coating thicknesses are properly measured the procedures in SSPC-PA 2 (latest edition), “Measurement of Dry Coating Thickness with Magnetic Gauges” should be used.

A.11 MAINTENANCE AND REPAIR COATING: When this standard is used in maintenance painting, specific instructions should be given on the extent of surface to be blast cleaned or spot blast cleaned to this degree of cleanliness. In these cases, the cleaning shall be performed across the entire area specified. For example, if all weld seams are to be cleaned in a maintenance operation, this degree of cleaning shall be applied 100% to all weld seams. If the entire structure is to be prepared, this degree of cleaning shall be applied to 100% of the entire structure. SSPC-PA Guide 4 (latest edition), “Guide to Maintenance Repainting with Oil Base or Alkyd Painting Systems,” provides a description of accepted practices for retaining old sound coating, removing unsound coating, feathering, and spot cleaning.

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SSPC: The Society for Protective Coatings

JOINT SURFACE PREPARATION SPECIFICATION

SSPC-SP 10/NACE NO. 2

Near-White Blast Cleaning

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CAUTIONARY NOTICE: SSPC/NACE standards are subject to periodic review and may be revised or withdrawn at any time without prior notice. SSPC and NACE require that action be taken to reaffirm, revise, or withdraw this standard no later than five years from the date of initial publication. The user is cautioned to obtain the latest edition. Purchasers may receive current information on all standards and other publications by contacting the organizations at the addresses below:

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Foreword

This joint standard covers the use of blast cleaning abrasives to achieve a defined degree of cleaning of steel surfaces prior to the application of a protective coating or lining system. This standard is intended for use by coating or lining specifiers, applicators, inspectors, or others whose responsibility it may be to define a standard degree of surface cleanliness.

The focus of this standard is near-white metal blast cleaning. White metal blast cleaning, commercial blast cleaning, industrial blast cleaning and brush-off blast cleaning are addressed in separate standards.

Near-white blast cleaning provides a greater degree of cleaning than commercial blast cleaning (SSPC-SP 6/NACE No. 3), but less than white metal blast cleaning (SSPC-SP 5/NACE No. 1).

Near-white blast cleaning is used when the objective is to remove all rust, coating, and mill scale, but when the extra effort required to remove all stains of these materials is determined to be unwarranted. Staining shall be limited to no more than 5 percent of each unit area of surface.

Near-white blast cleaning allows staining on only 5 percent of each unit area of surface, while commercial blast cleaning allows staining on 33 percent of each unit area of surface. White metal blast cleaning does not permit any staining to remain on the surface.

This joint standard was prepared by the SSPC/NACE Task Group A on Surface Preparation by Abrasive Blast Cleaning. This joint Task Group includes members of both the SSPC Surface Preparation Committee and the NACE Unit Committee T-6G on Surface Preparation (now STG 04).

1. General

1.1 This joint standard covers the requirements for near-white blast cleaning of unpainted or painted steel surfaces by the use of abrasives. These requirements include the end condition of the surface and materials and procedures necessary to achieve and verify the end condition.

1.2 This joint standard allows random staining to remain on no more than 5 percent of each unit area of surface as defined in Section 2.6.

1.3 The mandatory requirements are described in Sections 1 to 9 as follows:

Section 1	General
Section 2	Definition
Section 3	References
Section 4	Procedures Before Blast Cleaning
Section 5	Blast Cleaning Methods and Operation
Section 6	Blast Cleaning Abrasives
Section 7	Procedures Following Blast Cleaning and Immediately Prior to Coating
Section 8	Inspection
Section 9	Safety and Environmental Requirements

NOTE: Section 10, "Comments" and Appendix A, "Explanatory Notes" are not mandatory requirements of this standard.

2. Definition

2.1 A near-white metal blast cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products, and other foreign matter, except for staining as noted in Section 2.2.

2.2 Random staining shall be limited to no more than 5 percent of each unit area of surface as defined in Section 2.6, and may consist of light shadows, slight streaks, or minor discolorations caused by stains of rust, stains of mill scale, or stains of previously applied coating.

2.3 Acceptable variations in appearance that do not affect surface cleanliness as defined in Section 2.1 include variations caused by type of steel, original surface condition, thickness of the steel, weld metal, mill or fabrication marks, heat treating, heat affected zones, blasting abrasives, and differences in the blast pattern.

2.4 When a coating is specified, the surface shall be roughened to a degree suitable for the specified coating system.

2.5 Immediately prior to coating application, the entire surface shall comply with the degree of cleaning specified herein.

2.6 Unit area for determinations shall be approximately 5776 mm^2 (9 in^2) (i.e., a square 76 mm x 76 mm [3 in x 3 in]).

2.7 SSPC-VIS 1 photographs A SP-10, B SP-10, C SP-10 or D SP-10 may be specified to supplement the written definition. In any dispute, the written standards shall take precedence over visual standards and comparators. Additional information on visual standards and comparators is available in Section A.4 of Appendix A.

3. Referenced Standards

3.1 The latest issue, revision, or amendment of the referenced standards in effect on the date of invitation to bid shall govern unless otherwise specified.

3.2 If there is a conflict between the requirements of any of the cited reference standards and this standard, the requirements of this standard shall prevail.

3.3 SSPC: THE SOCIETY FOR PROTECTIVE COATINGS STANDARDS:

AB 1	Mineral and Slag Abrasives
AB 2	Cleanliness of Recycled Ferrous Metallic Abrasives
AB 3	Ferrous Metallic Abrasives
PA Guide 3	A Guide to Safety in Paint Application
SP 1	Solvent Cleaning
VIS 1	Guide and Reference Photographs for Seel Surfaces Prepared by Dry Abrasive Blast Cleaning

4. Procedures Before Blast Cleaning

4.1 Before blast cleaning, visible deposits of oil, grease, or other contaminants shall be removed in accordance with SSPC-SP 1 or other agreed upon methods.

4.2 Before blast cleaning, surface imperfections such as sharp fins, sharp edges, weld spatter, or burning slag should be removed from the surface to the extent required by the procurement documents (project specification). Additional information on surface imperfections is available in Section A.5 of Appendix A.

4.3 If a visual standard or comparator is specified to supplement the written standard, the condition of the steel prior to blast cleaning should be determined before the blasting commences. Additional information on visual standards and comparators is available in Section A.4 of Appendix A.

5. Blast Cleaning Methods and Operation

5.1 Clean, dry compressed air shall be used for nozzle blasting. Moisture separators, oil separators, traps, or other equipment may be necessary to achieve this requirement.

5.2 Any of the following methods of surface preparation may be used to achieve a near-white blast cleaned surface:

5.2.1 Dry abrasive blasting using compressed air, blast nozzles, and abrasive.

5.2.2 Dry abrasive blasting using a closed-cycle, recirculating abrasive system with compressed air, blast nozzle, and abrasive, with or without vacuum for dust and abrasive recovery.

5.2.3 Dry abrasive blasting using a closed cycle, recirculating abrasive system with centrifugal wheels and abrasive.

5.3 Other methods of surface preparation (such as wet abrasive blasting) may be used to achieve a near-white blast cleaned surface by mutual agreement between those parties responsible for establishing the requirements and those responsible for performing the work. NOTE: Information on the use of inhibitors to prevent the formation of rust immediately after wet blast cleaning is contained in Section A.9 of Appendix A.

6. Blast Cleaning Abrasives

6.1 The selection of abrasive size and type shall be based on the type, grade, and surface condition of the steel to be cleaned, type of blast cleaning system employed, the finished surface to be produced (cleanliness and roughness), and whether the abrasive will be recycled.

6.2 The cleanliness and size of recycled abrasives shall be maintained to ensure compliance with this specification.

6.3 The blast cleaning abrasive shall be dry and free of oil, grease, and other contaminants as determined by the test methods found in SSPC-AB 1, AB 2 and AB 3.

6.4 Any limitations on the use of specific abrasives, the quantity of contaminants, or the degree of allowable embedment shall be included in the procurement documents (project specification) covering the work, because abrasive embedment and abrasives containing contaminants may not be acceptable for some service requirements. NOTE: Additional information on abrasive selection is given in Section A.2 of Appendix A.

7. Procedures Following Blast Cleaning and Immediately Prior to Coating

7.1 Visible deposits of oil, grease, or other contaminants shall be removed according to SSPC-SP 1 or another method agreed upon by those parties responsible for establishing the requirements and those responsible for performing the work.

7.2 Dust and loose residues shall be removed from prepared surfaces by brushing, blowing off with clean, dry air, vacuum cleaning, or other methods agreed upon by those responsible for establishing the requirements and those responsible for performing the work. NOTE: The presence of toxic metals in the abrasives or paint being removed may place restrictions on the methods of cleaning permitted. Comply with all applicable regulations. Moisture separators, oil separators, traps, or other equipment may be necessary to achieve clean, dry air.

7.3 After blast cleaning, surface imperfections that remain (e.g., sharp fins, sharp edges, weld spatter, burning slag, scabs, slivers, etc.) shall be removed to the extent required in the procurement documents (project specification). Any damage to the surface profile resulting from the removal of surface imperfections shall be corrected to meet the requirements of Section 2.4. NOTE: Additional information on surface imperfections is contained in Section A.5 of Appendix A.

7.4 Any visible rust that forms on the surface of the steel after blast cleaning shall be removed by recleaning the rusted areas to meet the requirements of this standard before coating. NOTE: Information on rust-back (re-rusting) and surface condensation is contained in Sections A.6, A.7, and A.8 of Appendix A.

8. Inspection

8.1 Work and materials supplied under this standard are subject to inspection by a representative of those responsible for establishing the requirements. Materials and work areas shall be accessible to the inspector. The procedures and times of inspection shall be as agreed upon by those responsible for establishing the requirements and those responsible for performing the work.

8.2 Conditions not complying with this standard shall be corrected. In the case of a dispute, an arbitration or settlement procedure established in the procurement documents (project specification) shall be followed. If no arbitration or settlement procedure is established, then a procedure mutually agreeable to purchaser and supplier shall be used.

8.3 The procurement documents (project specification) should establish the responsibility for inspection and for any required affidavit certifying compliance with the specification.

9. Safety and Environmental Requirements

9.1 Because abrasive blast cleaning is a hazardous operation, all work shall be conducted in compliance with applicable occupational and environmental health and safety rules and regulations. NOTE: SSPC-PA Guide 3, “A Guide to Safety in Paint Application,” addresses safety concerns for coating work.

10. Comments

10.1Additional information and data relative to this standard are contained in Appendix A. Detailed information and data are presented in a separate document, SSPC-SP COM, “Surface Preparation Commentary.” The recommendations contained in Appendix A and SSPC-SP COM are believed to represent good practice, but are not to be considered requirements of the standard. The sections of SSPC-SP COM that discuss subjects related to near-white blast cleaning are listed below.

Subject	Commentary Section
Abrasive Selection	6
Film Thickness	10
Wet Abrasive Blast Cleaning	8.2
Maintenance Repainting	4.2
Rust-back (Re-rusting)	8.
Surface Profile	6.2
Visual Standards	11
Weld Spatter	4.4.1

Appendix A. Explanatory Notes

A.1 FUNCTION: Near-white blast cleaning (SSPC-SP 10/NACE No. 2) provides a greater degree of cleaning than commercial blast cleaning (SSPC-SP 6/NACE No. 3) but less than white metal blast cleaning (SSPC-SP 5/NACE No. 1). It should be used when a high degree of blast cleaning is required. The primary functions of blast cleaning before coating are: (a) to remove material from the surface that can cause early failure of the coating system and (b) to obtain a suitable surface roughness and to enhance the adhesion of the new coating system. The hierarchy of blasting standards is as follows: white metal blast cleaning, near-white blast cleaning, commercial blast cleaning, industrial blast cleaning, and brush-off blast cleaning.

A.2 ABRASIVE SELECTION: Types of metallic and non-metallic abrasives are discussed in the Surface Preparation Commentary (SSPC-SP COM). It is important to recognize that blasting abrasives may become embedded in or leave residues on the surface of the steel during preparation. While normally such embedment or residues are not detrimental, care should be taken to ensure that the abrasive is free from detrimental amounts of water-soluble, solvent-soluble, acid-soluble, or other soluble contaminants (particularly if the prepared steel is to be used in an immersion environment). Criteria for selecting and evaluating abrasives are given in SSPC-AB 1, “Mineral and Slag Abrasives,” SSPC-AB 2, “Cleanliness of Recycled Ferrous Metallic Abrasives,” and SSPC-AB 3, “Ferrous Metallic Abrasives

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A.4 VISUAL STANDARDS: SSPC-VIS 1, "Guide and Reference Photographs for Seel Surfaces Prepared by Dry Abrasive Blast Cleaning," provides color photographs for the various grades of surface preparation as a function of the initial condition of the steel. The series A-SP 10, B-SP 10, C-SP 10, D-SP 10 and G-SP 10 photographs depict surfaces cleaned to a near-white blast grade. Other available visual standards are described in Section 11 of SSPC-SP COM.

A.5 SURFACE IMPERFECTIONS: Surface imperfections can cause premature failure when the service is severe. Coatings tend to pull away from sharp edges and projections, leaving little or no coating to protect the underlying steel. Other features that are difficult to properly cover and protect include crevices, weld porosities, laminations, etc. The high cost of

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the methods to remedy surface imperfections requires weighing the benefits of edge rounding, weld spatter removal, etc., versus a potential coating failure.

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A.7 RUST-BACK: Rust-back (re-rusting) occurs when freshly cleaned steel is exposed to moisture, contamination, or a corrosive atmosphere. The time interval between blast cleaning and rust-back will vary greatly from one environment to another. Under mild ambient conditions, if chemical contamination is not present (see Section A.6), it is best to blast clean and coat a surface the same day. Severe conditions may require more expedient coating application to avoid contamination from fallout. Chemical contamination should be removed prior to coating (see Section A.6).

A.8 DEW POINT: Moisture condenses on any surface that is colder than the dew point of the surrounding air. It is, therefore, recommended that the temperature of the steel surface be at least 3 °C (5 °F) above the dew point during dry blast cleaning operations. It is advisable to visually inspect for moisture and periodically check the surface temperature and dew point during blast cleaning operations and to avoid the application of coating over a damp surface.

A.9 WET ABRASIVE BLAST CLEANING: Steel that is wet abrasive blast cleaned may rust rapidly. Clean water should be used for rinsing. It may be necessary that inhibitors be added to the water or applied to the surface immediately after blast cleaning to temporarily prevent rust formation. The use of inhibitors or the application of coating over slight discoloration should be in accordance with the requirements of the coating manufacturer. CAUTION: Some inhibitive treatments may interfere with the performance of certain coating systems.

A.10 FILM THICKNESS: It is essential that ample coating be applied after blast cleaning to adequately cover the peaks of the surface profile. The dry film thickness of the coating above the peaks of the profile should equal the thickness known to be needed for the desired protection. If the dry film thickness over the peaks is inadequate, premature rust-through or failure will occur. To assure that coating thicknesses are properly measured the procedures in SSPC-PA 2 (latest edition), "Measurement of Dry Coating Thickness with Magnetic Gauges" should be used.

A.11 MAINTENANCE AND REPAIR PAINTING: When this standard is used in maintenance painting, specific instructions should be given on the extent of surface to be blast cleaned or spot blast cleaned to this degree of cleanliness. In these cases, the cleaning shall be performed across the entire area specified. For example, if all weld seams are to be cleaned in a maintenance operation, this degree of cleaning shall be applied 100% to all weld seams. If the entire structure is to be prepared, this degree of cleaning shall be applied to 100% of the entire structure. SSPC-PA Guide 4 (latest edition), "Guide to Maintenance Repainting with Oil Base or Alkyd Painting Systems," provides a description of accepted practices for retaining old sound coating, removing unsound coating, feathering, and spot cleaning.

Chapter 5.1
Application of Industrial Coatings

Frank W. G. Palmer

Introduction

Proper application of coatings is as critical as their selection and surface preparation in producing long-term protective films. The new low-VOC products are especially difficult to apply. This chapter describes different recommended methods of applying industrial coatings. A detailed specification covering the general requirements for high-performance paint application is given in SSPC-PA 1.[1] Applicator Training Bulletins published in the Journal of Protective Coatings and Linings provide additional information on coating application.[2] Publications of spray equipment manufacturers were also used in preparing this chapter.[3-7] Application of coatings to concrete structures, not covered in this chapter, is described in SSPC's The Fundamentals of Cleaning and Coating Concrete.[8]

Preparing Coatings for Application

Mixing

During storage, the relatively heavy pigments in coatings tend to settle and cake at the bottom of cans. Coatings in this condition must be mixed thoroughly and uniformly so that they can be applied in an even, continuous film. Improper or inadequate mixing can result in inadequate or non-uniform film thickness, uneven color, limited adhesion, and checking or cracking of the film.

Mixing can be done manually or mechanically. Mechanical mixing is usually preferred because it is faster and more efficient, especially with large volumes and viscous materials. In both cases, it is necessary to first break up clumps with a wooden paddle by rubbing them against the interior can wall and then lift settled materials from the bottom of the can. Also, any surface skins must be removed.

When stirring mechanically:

- Use appropriately sized equipment (e.g., for a 55-gallon drum, a 1/2 hp motor that drives a three-bladed propeller, eight inches in diameter on a 36-inch shaft).
- Form a relative small vortex in the coating
- Use slow speed stirrer (never a mechanical shaker)

Entrapment of air bubbles (foaming) during mixing can result in bubbles, craters, and voids in cured films. Water-borne coatings are especially susceptible, because they contain wetting agents (dispersants). Also, some of the bubbles can escape if the mixed coating is allowed to sit for an extended period of time before use.

Thinning (Reducing) Mixed Coatings

Most coatings are formulated for application without thinning under normal conditions. Thinning may be required on cold days because viscosity is inversely related to temperature. Two-package coatings should be thinned only after combining and mixing the components. If thinning is necessary, the coating manufacturer's recommendations for the type and amount of thinner should be followed. Also, thinning must not cause the coating to exceed VOC limits. Overthinning can result in a runny consistency that may produce less than the desired film thickness. Use of the wrong thinner can cause the coating to gel or have other adverse effects.

Tinting

Adjacent coatings in a multiple-coat systems are sometimes tinted differently in order to more easily detect skips in the topcoat film. In such cases, the coating manufacturer's instructions should be fol- lowed, since not all tints are compatible with all coatings. It is safer to obtain adjacent coatings in different colors.

Straining

Paints should always be strained whenever it becomes apparent that lumps, skins, or other non-uniformities are present. Inorganic zinc-rich coatings should always be strained to remove coarse or agglomerated zinc particles. Straining is the last step before application. It should be done using a fine (e.g., 80-mesh) sieve or a commercial paint strainer.

Brush Application

Brushes are available with natural and synthetic fibers such as nylon or polyester. Typically, natural bristle brushes are used for applying solvent-based coatings, and synthetic fiber brushes are used for applying water-based coatings. Organic solvents will attack and degrade synthetic fibers, and water slowly degrades natural fibers.

Use of high-quality natural bristle brushes such as Chinese hog bristles will result in better quality work. The flagged (split) ends of these bristles hold more paint and thus increase greater productivity. Some tips for optimum brush application are:

- Before painting, shake loose any unattached fibers by spinning between the palms of the hands
- Remove any stray fibers with a putty knife
- Dip the brush in the paint to cover no more than one-half of the bristle length
- Remove excess paint by tapping the brush on the edge of the can
- Apply even strokes lightly with the bristle tips
- Hold the brush at a 75° angle, much like holding a pencil
- Apply paint from top to bottom always finishing in the same direction
- Start and finish at natural boundaries and always keep a wet edge to minimize lap marks

Typically, brush application is the slowest of all methods used for applying coatings, and has the potential to apply the coating with the most irregular mil thickness and the greatest amount of surface texture (e.g., brush marks). The brush application method has the advantage of being the cheapest equipment to purchase, requires the least amount of time and effort to clean up, and can be applied to surfaces in close contact to other surfaces without needing to tape or cover those surfaces. Brushes are used to apply stripe coats to edges and welds prior to spray application as paint will draw back from an edge or will not fill the voids found in welds applied by spray. The advantages and limitations are:

Advantages

- Good transfer efficiency
- No overspray
- Good for tight and irregular areas
- Inexpensive, light-weight equipment
- Used for striping

Limitations

- Low application rate
- Difficult to apply uniformly thick film
- Difficult to apply many high-performance coatings

Roller Application

Applying coatings with a roller is typically done when large, flat, or curved surfaces are to be coated and when spray application is prohibited or uneconomical. Roller application may be as much as four times faster than brush application. The finish obtained by a roller is not of even mil thickness, as may be obtained by spray application. Rollers, if used carefully, can also be effective when it is critical that the surrounding areas do not receive any of the applied coating in an overspray.

A paint roller consists of a cylindrical sleeve or cover that slips over a rotatable cage with an attached handle. Rollers vary in width from 1-18 inches (25-450 mm) in the nap of lambswool, nylon, polyester, Dynel, or Dacron fiber cover. The nap fiber length typically varies from 1/4 to 3/4 inch (6 to 18 mm). The core of the roller is usually made from either phenolic- reinforced fiberboard or metallic fiberboard.

Rollers can be dipped directly into a pail of coating and the surplus paint worked off on a grid or screen in the pail, or the coating can be taken from a tray that has a grid to remove surplus paint.

The use of rollers may be limited if the coating being applied contains extremely strong or fast-evaporating solvents, or if the loss of some of the roller fibers into the coating jeopardizes its integrity or performance.

Rollers also lack the ability to force the coating into the pores or profile of a surface and have the resins wet out on the surface. In addition, rollers have the potential to load air into the coating just as it is being deposited on the surface. If the air is unable to escape from the coating, it has the potential to form voids and cause a premature loss of coating or fail an inspection for holidays. The advantages and limitations of roller applications are:

Advantages

- Good transfer efficiency
- No overspray
- Better application rate that brush application on flat spaces
- Inexpensive, light-weight equipment

Limitations

- Slower application rates than spraying
- Difficult to apply uniform thicknesses and thick coatings
- Difficult to apply many high-performance coatings (mostly used for oil-based and water based paints)

Spray (General)

Spray application is the process by which coatings are atomized into fine particles and deposited upon a surface. It is considered to be the most effective method of applying coatings to produce continuous, smooth, aesthetically pleasing protective barriers. The two basic types of spray systems are air spray (conventional) and airless spray. All other spray systems are variations of these.

Spray application has inherent dangers to both humans and the environment. The worker must be aware of these dangers and take proper precautions during application using any type of spray system. There are also regulations that govern the use and operation of spray equipment in order to offer protection to the surrounding air, water, and soil. A worker skilled with the spray gun practices four basic principles:

- Keeping the gun at the distance from the surface recommended by the gun manufacturer (typically, 6-8 inches [15-20 cm] for conventional air and 12-14 inches [30-35 cm] for airless spray)
- Holding the gun perpendicular to the surface; arcing will result in varying film thicknesses
- Overlapping strokes 50% will result in a smooth film of uniform thickness
- Triggering the strokes (The trigger is pulled just before the gun reaches the edge of the work and is released just after the gun passes the other edge of the work.)

Conventional (Air) Spray

To understand conventional spraying, it is very important to understand the role of the compressed air used. Whichever power source is used (electricity or gasoline) to operate the compressor, it is nonetheless compressed air that operates the spray equipment. Compressed air is a very powerful source of energy. When used in conventional spraying, it moves material from the container to the gun and atomizes it at the spray gun head.

Applicators, when spraying with conventional systems, require compressed air to be maintained at a specific pressure. Not only is a specific air pressure required, but the ratio of air volume to spray coatings must be correctly set. Pressure is defined in pounds per square inch (psi) and volume is identified in cubic feet per minute (cfm). It is important to maintain both the correct volume and pressure at the spray gun head to ensure correct material application. Incorrect settings of either the volume or pressure will result in a faulty spray pattern.

The air cap at the gun head is the only component of the spray system that uses compressed air; therefore, the air cap must be matched to the size of the compressor output. All spray equipment manufacturers will identify the amount of air volume that each individual air cap requires. It is important that information be obtained from individual suppliers to establish the size of the compressor required for each individual air cap. The advantages and limitations of conventional air spray are:

Advantages

- Finer atomization and finish
- More operator control and versatility (use of air only for minor blow-down, easier change of fan width and amount of material for tight places, etc.)
- Lower initial investment
- Usually better with filled (e.g., textured) coatings
- Easier change of colors by changing suction cups

Limitations

- Lower transfer efficiency
- Lower application rate
- More overspray
- Viscous materials may be more difficult to spray

A conventional spray system consists of a spray gun, a material container, a compressor, fluid and air hoses, and air-controlling devices.

Spray Gun

The spray gun delivers specific amounts of paint and atomizing air to the gun nozzle, producing a controllable pattern of atomized coating. In external mixing guns (most commonly used) the compressed air and paint are mixed as they are sprayed from the air cap and fluid tip. In internal mixing guns, the air and paint are mixed inside the air cap as spraying occurs. Gun components are discussed next.

Air Cap

Air caps direct the jets of compressed air into the stream of material from the fluid tip to atomize the coating and form the spray pattern and are either an internal or an external mix type. The air cap fits over the fluid tip and is connected to the gun by a threaded ring. The air cap and fluid tip are selected according to the type of coating to be used and the desired application rate. The external mix air cap can be identified by the protruding sides, commonly called horns, that extend from the air cap. Air from the holes found on the face of the air cap partially atomizes the paint, and the air from the horn holes completes the atomization and shapes the spray pattern.

Fluid Tip and Needle

The fluid tip is a nozzle directly behind the air cap that meters and directs the material into the air streams. The fluid tip forms a seat for the fluid needle, which shuts off the flow of material. Fluid tips are available in a variety of nozzle sizes to properly handle materials of various types and to pass the required volume of material for different speeds of application.

When the trigger is pulled, the needle is drawn out of the fluid tip and the paint is allowed to flow to the air cap. When the trigger is released, the needle seats itself in the fluid tip, stopping the flow of the coating. Flow rate adjustments may be made by either increasing or decreasing the air pressure to the paint tank, or by changing to another size of fluid tip and needle. The fluid adjustment valve can be used when the operator needs to make minor adjustments to reduce or increase the paint flow.

Trigger

The trigger operates the air valve and the fluid needle. It acts as a switch to turn the atomizing air and fluid on and off.

Air Valve

The air valve controls the movement of air through the spray gun. It is the stem directly behind the trigger that is moved by the trigger. The air valve is the “on and off” control for the atomizing air.

Spreader Adjustment Valve

The spreader adjustment valve controls the air supply within the air cap and also controls the size and shape of the spray pattern. It controls the air flow to the holes in the horns of the air cap as well.

Air and Fluid Inlets

The air inlet on the gun handle connects the atomizing air hose to the air supply, which is either a compressor or a transformer. The fluid inlet connects the material supply container or hose to the fluid inlet behind the air cap on the spray gun.

Material Containers

The material for conventional spraying is supplied by a suction- or pressure-feed attached cup or pressure-feed remote pot. Suction-feed cups are used when colors must be changed frequently and when only small amounts of coating are needed.

Pressure-feed systems are assembled with zero, one, or two regulators and require two independent supplies of compressed air. One source of compressed air is used to pressurize the container to move the coating into and out of the gun. The other supply is used at the gun as the atomizing air source. With both regulators situated at the pot, the material is easier to control. For materials with heavy pigments (e.g., a zinc-rich coating), use a container equipped with an agitator.

Compressor

Compressors are needed to generate the energy used to move and atomize the coating. There are several different air compressor designs—diaphragm, piston, vane, screw, and turbine—all of which are effective for operating a conventional spray system. The most commonly used compressors are the piston, vane, and screw. Compressors must generate enough volume and pressure of clean, dry air to operate the system properly.

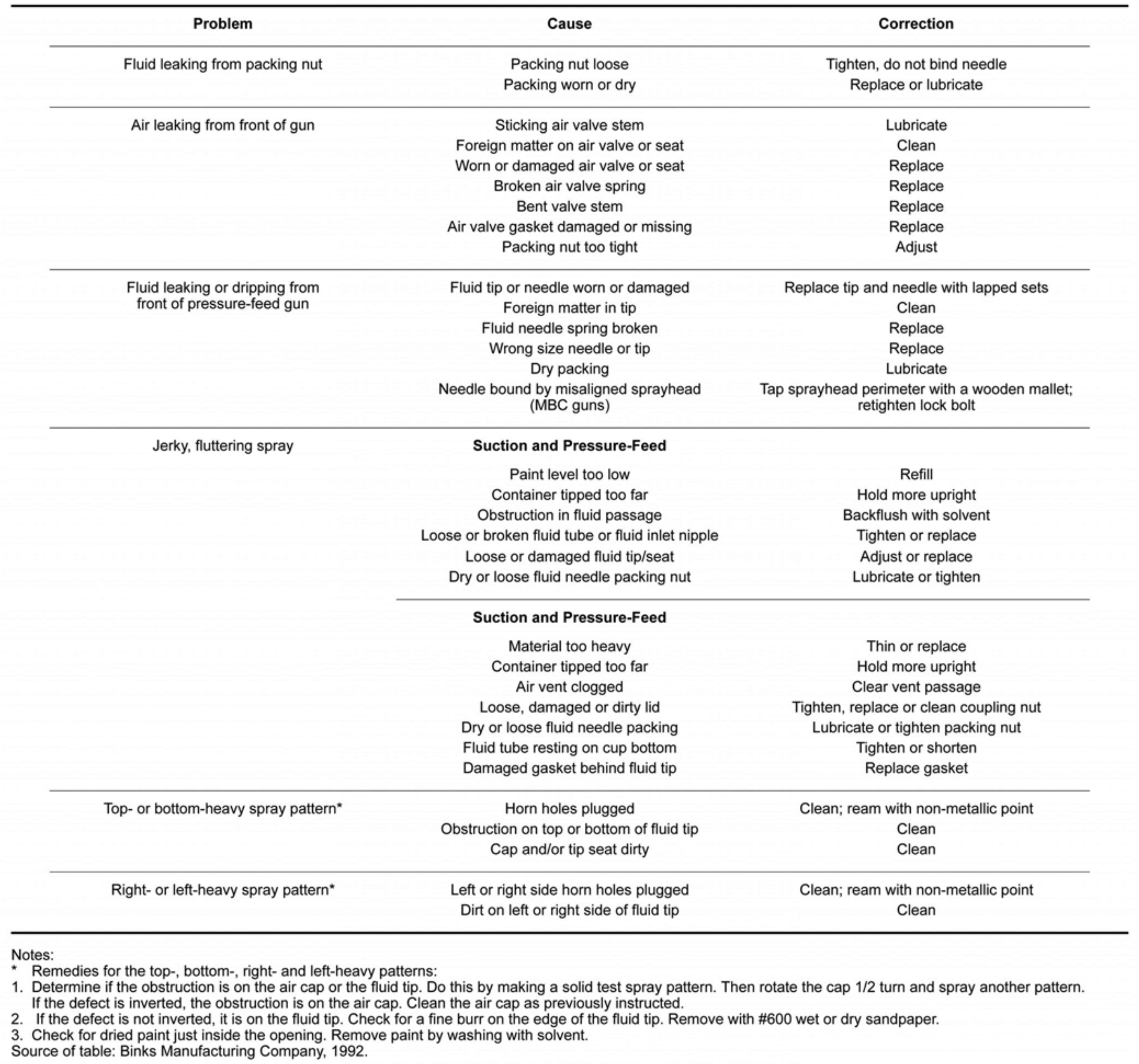
Fluid and Air Hoses

The fluid and air hoses carry specific volumes of atomizing air or coating. These hoses are specially constructed with liners that protect the hoses from attack by the strong solvents used in coatings and by any moisture or oil from a faulty compressor. Air hoses are usually red and material hoses are black.

Air-Controlling Devices

Regulators, transformers, separators, and filters are used in conventional spray systems between the compressor, the material container, and the gun.

Table 1a. Problems Encountered During Application of Coatings with a Conventional Spray System.



Problem	Cause	Correction
Fluid leaking from packing nut	Packing nut loose	Tighten, do not bind needle
	Packing worn or dry	Replace or lubricate
Air leaking from front of gun	Sticking air valve stem	Lubricate
	Foreign matter on air valve or seat	Clean
	Worn or damaged air valve or seat	Replace
	Broken air valve spring	Replace
	Bent valve stem	Replace
	Air valve gasket damaged or missing	Replace
	Packing nut too tight	Adjust
Fluid leaking or dripping from front of pressure-feed gun	Fluid tip or needle worn or damaged	Replace tip and needle with lapped sets
	Foreign matter in tip	Clean
	Fluid needle spring broken	Replace
	Wrong size needle or tip	Replace
	Dry packing	Lubricate
	Needle bound by misaligned sprayhead (MBC guns)	Tap sprayhead perimeter with a wooden mallet; retighten lock bolt
Jerky, fluttering spray	**Suction and Pressure-Feed**	
	Paint level too low	Refill
	Container tipped too far	Hold more upright
	Obstruction in fluid passage	Backflush with solvent
	Loose or broken fluid tube or fluid inlet nipple	Tighten or replace
	Loose or damaged fluid tip/seat	Adjust or replace
	Dry or loose fluid needle packing nut	Lubricate or tighten
	Suction and Pressure-Feed	
	Material too heavy	Thin or replace
	Container tipped too far	Hold more upright
	Air vent clogged	Clear vent passage
	Loose, damaged or dirty lid	Tighten, replace or clean coupling nut
	Dry or loose fluid needle packing	Lubricate or tighten packing nut
	Fluid tube resting on cup bottom	Tighten or shorten
	Damaged gasket behind fluid tip	Replace gasket
Top- or bottom-heavy spray pattern*	Horn holes plugged	Clean; ream with non-metallic point
	Obstruction on top or bottom of fluid tip	Clean
	Cap and/or tip seat dirty	Clean
Right- or left-heavy spray pattern*	Left or right side horn holes plugged	Clean; ream with non-metallic point
	Dirt on left or right side of fluid tip	Clean

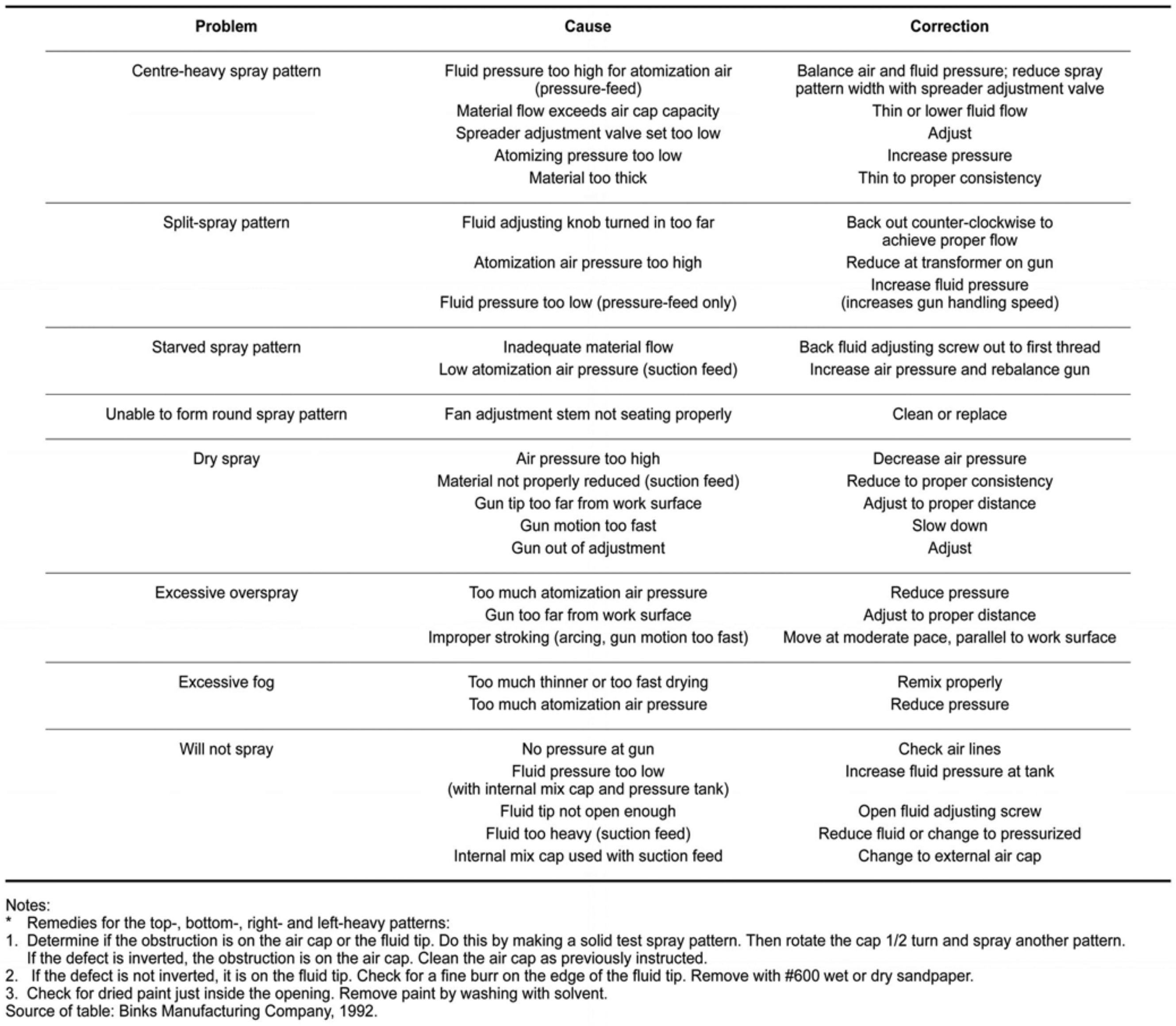
Notes:

* Remedies for the top-, bottom-, right- and left-heavy patterns:

1. Determine if the obstruction is on the air cap or the fluid tip. Do this by making a solid test spray pattern. Then rotate the cap 1/2 turn and spray another pattern. If the defect is inverted, the obstruction is on the air cap. Clean the air cap as previously instructed.
2. If the defect is not inverted, it is on the fluid tip. Check for a fine burr on the edge of the fluid tip. Remove with #600 wet or dry sandpaper.
3. Check for dried paint just inside the opening. Remove paint by washing with solvent.

Source of table: Binks Manufacturing Company, 1992.

Table 1b. More Problems Encountered During Application of Coatings with a Conventional Spray System.



Problem	Cause	Correction
Centre-heavy spray pattern	Fluid pressure too high for atomization air (pressure-feed)	Balance air and fluid pressure; reduce spray pattern width with spreader adjustment valve
	Material flow exceeds air cap capacity	Thin or lower fluid flow
	Spreader adjustment valve set too low	Adjust
	Atomizing pressure too low	Increase pressure
	Material too thick	Thin to proper consistency
Split-spray pattern	Fluid adjusting knob turned in too far	Back out counter-clockwise to achieve proper flow
	Atomization air pressure too high	Reduce at transformer on gun
	Fluid pressure too low (pressure-feed only)	Increase fluid pressure (increases gun handling speed)
Starved spray pattern	Inadequate material flow	Back fluid adjusting screw out to first thread
	Low atomization air pressure (suction feed)	Increase air pressure and rebalance gun
Unable to form round spray pattern	Fan adjustment stem not seating properly	Clean or replace
Dry spray	Air pressure too high	Decrease air pressure
	Material not properly reduced (suction feed)	Reduce to proper consistency
	Gun tip too far from work surface	Adjust to proper distance
	Gun motion too fast	Slow down
	Gun out of adjustment	Adjust
Excessive overspray	Too much atomization air pressure	Reduce pressure
	Gun too far from work surface	Adjust to proper distance
	Improper stroking (arcing, gun motion too fast)	Move at moderate pace, parallel to work surface
Excessive fog	Too much thinner or too fast drying	Remix properly
	Too much atomization air pressure	Reduce pressure
Will not spray	No pressure at gun	Check air lines
	Fluid pressure too low (with internal mix cap and pressure tank)	Increase fluid pressure at tank
	Fluid tip not open enough	Open fluid adjusting screw
	Fluid too heavy (suction feed)	Reduce fluid or change to pressurized
	Internal mix cap used with suction feed	Change to external air cap

Notes:

* Remedies for the top-, bottom-, right- and left-heavy patterns:

1. Determine if the obstruction is on the air cap or the fluid tip. Do this by making a solid test spray pattern. Then rotate the cap 1/2 turn and spray another pattern. If the defect is inverted, the obstruction is on the air cap. Clean the air cap as previously instructed.
2. If the defect is not inverted, it is on the fluid tip. Check for a fine burr on the edge of the fluid tip. Remove with #600 wet or dry sandpaper.
3. Check for dried paint just inside the opening. Remove paint by washing with solvent.

Source of table: Binks Manufacturing Company, 1992.

Regulators and transformers are used to control air pressure and to allow for multiple compressor hook-ups. Separators and filters are used to clean oil and dirt from the air supply and to extract moisture in the air.

Airless Spray

Airless, or hydraulic, spray painting gets its name from the fact that no compressed air is used with the paint to form the spray. Instead, atomization occurs when the paint is pumped at high pressures (up to 7,400 psi [51,800 kPa]) through a small orifice in the gun nozzle. The pressure in airless spray painting is created by fluid pumps that are able to deliver between 28 oz. and 7 gallons of paint per minute. These pumps drive the paint through high-pressure hoses (typically 3/8-inch inside diameter) specifically designed for the airless system. The advantages and limitations of airless spray are:

Advantages

- High application rate
- Higher transfer efficiency (less overspray) than conventional air spray
- Easier than conventional air systems to use with high-viscosity materials

Limitations

- Hazardous spray pressures
- Reduced operator control
- Reduced quality of finish
- More expensive to maintain

The basic components of the airless spray system are an electric-, air-, or gasoline-powered fluid pump, high-pressure fluid (material) static-dissipating hose filters and screens, and the airless spray gun. Basic equipment designs of electric- and air-powered airless spray systems are very similar.

Airless Spray Fluid Pumps

Airless spray fluid pumps have gears, a diaphragm, or pistons to draw the paint from the container, and force it through the paint hoses and airless spray gun. Piston design pumps are more common than other pumps because they are better able to resist the abrasive and corrosive actions of the paint. The fluid pump may be mounted on a lid that can be attached to a paint drum; on a wheeled cart so that the pump head can be set inside a paint container; or the pump may use a siphon hose to draw the paint from the container.

Pump Classification

Airless spray pumps are identified by the ratio of paint pressure produced to that of the air pressure used. For example, a pump that delivers paint at a pressure of 4 psi (28 kPa) for each 1 psi (7 kPa) of air pressure would be identified as having a 4:1 ratio. Some fluid pumps in the painting industry will use 80 psi (560 kPa) of air pressure to generate a paint pressure of 2400 psi (16,800 kPa), resulting in a 30:1 pump ratio. Pumps are also classified by the volume of paint delivered per minute. A heavy-duty pump may be capable of delivering as much as 7 gallons of paint per minute. Paint pressure is regulated by adjusting the pressure regulator on the pump. The pressures on airless spray equipment cannot be regulated as precisely as that on conventional air spray equipment.

Electric Fluid Pump

An electrically driven pump motor can be plugged into a standard grounded outlet. The electric fluid pumps have adjustable paint pressure settings. In one type of electric pump, the motor moves a piston sunk in an oil chamber. The pressure thrust on the oil by the piston opens and closes a diaphragm that draws the paint into the paint chamber, where it is pressurized.

Spray Tip

The selection of a spray tip is based on the volume of fluid produced by the paint pump, i.e., there must be a match between the pump volume produced and the tip spraying rate. The pump must be capable of delivering more than the tip can use. This permits the pump to run slower than its maximum speed and thus reduce wear on its parts, while providing a reserve capacity of pressure in case a change is made to a larger spray tip or a longer hose. A reversible tip has a key than can turn 180° to blow out clogs.

The larger the spray tip orifice, the more speed and spray coverage that will be possible. Therefore, the airless spray painter chooses the spray tip according to the type of paint being used and the film thickness desired. An orifice that is too large used with a low viscosity paint, for example, would cause the paint to flood the surface. Generally, the paint manufacturer will list recommended spray tip orifice sizes for use with specific coating materials. Each airless tip is defined by the three numbers located on it, such as 517:

- The first number (5) when doubled (10) indicates the approximate fan width in inches when spraying 12 inches (300 cm) from the surface.
- The second number indicates the tip has a flow rate in water equal to a 17 mil (0.43 mm) diameter hole. The coating flow rate through the tip will vary with the orifice size. It will also vary with the coating pressure and viscosity.

High-Pressure Fluid Hoses and Fittings

The paint hoses used in airless spray painting are specially constructed to withstand high-fluid pressure. The materials passing through airless hoses at high pressures and speeds build up static electricity through friction. For this reason, these hoses have a grounding wire located in the outer skin to dissipate the static electricity. The hose connections and couplings used for airless spray work are also designed for use on high-pressure equipment.

Filters and Screens

Airless spray systems require that the material sprayed is free of lumps of extra-heavy pigment. Because the orifice size of the spray tip is small, filters or screens are placed:

- At the base of the siphon hose
- Inside the surge tank
- In the material hose
- Sometimes behind the spray tip

It is important that the screens or filters are sized to the orifice in the spray tip.

Gun

The airless gun is not adjusted unless the tip is changed. The size and shape of the tip will determine the fan size and shape. There are two safety features on all guns: a tip guard to keep fingers away from the high-pressure spray and a trigger lock to prevent accidentally activating the trigger.

Airless Spray Techniques

Because the airless spray system produces a heavy application of coating, the airless spray painter must develop proper spraying techniques to avoid runs and sags. One such technique is to hold the spray gun farther from the surface than a conventional air spray gun, usually a distance of 12 to 14 inches.

Since the shape of the airless spray pattern is determined by the built-in angle of the fluid tip, the operator must change the spray tip in order to change the shape of the spray pattern. In general, airless spray patterns have cleaner, sharper edges than conventional air spray patterns, because all the paint particles in the airless spray system travel at the same speed while air spray paint particles tend to lose speed at the outside edges of spray patterns.

Insufficient application pressure will result in tails (fingers), an incomplete fan with coating concentrated at the top and bottom. Increasing the pressure will resolve this problem.

Figure 1. Air-assisted airless gun.

Air-Assisted Airless Spray

The air-assisted airless concept uses a combination of the air and airless methods. A pump is used to force material through a small orifice or tip at low hydrostatic pressure.

Air-assisted airless sprayers operate at pressures under 950 psi. However, most materials cannot attain quality atomization at these low spray pressures and fan patterns are usually incomplete, with “tails” formed at each end. To complete the atomization and eliminate the “tails,” low-pressure (10–30 psi [70–210 kPa]) compressed air is added to the airless spray through an air cap. The chief advantages of air-assisted airless spray are:

- Finer atomization and finish than airless spray

- Better operator control than airless spray
- Better transfer efficiency than conventional air spray
- Application rates comparable to airless spray

Figure 2. Air-assisted airless guns. Note tip guard, trigger lock, and reversible (switch) tip on bottom gun.

Parts of Air-Assisted Airless Gun

The basic parts of an air-assisted airless gun are:

- **Gun body—**Contains air and fluid passages
- **Trigger—**Opens air and material valves
- **Trigger safety lock—**Prevents discharge from gun not in use
- **Air inlet—**Connects to air supply
- **Air control valve—**Controls amount of air at air cap
- **Pattern-adjusting valve—**Controls spray pattern
- **Fluid inlet—**Connects to material supply
- **Fluid needle—**Forms seat with fluid valve seat
- **Fluid Tip—**Directs material into air stream
- **Air cap—**Forms the spray pattern
- **Air separator**—Filters and directs air

Gun Body

The gun body is made of forged aluminum and the fluid passages are stainless steel. Fluid and air inlet ports, the hanger hook, and the trigger safety lock are located on the gun body. The hanger hook provides for proper storage when the gun is not in use.

Trigger

The trigger has a two-finger design. It opens the air control valve, allowing air to flow into the gun and it unseats the fluid needle from the valve seat, allowing fluid to flow. The trigger assembly is designed to produce a “lead-and-lag” air flow. As the trigger is pulled, air is turned on before the fluid flow begins. As the trigger is released, air is turned off after the fluid stops flowing. The “lead and lag” can be felt when the trigger is pulled. This feature helps to keep the top of the tip free and the air horns cleaner.

Trigger Safety Lock

The trigger safety lock is permanently affixed to the gun handle. The trigger cannot be pulled when set in this position. To release, push the lever toward the trigger and to a vertical position.

Air Inlet

Air enters the gun body handle through a specially designed fitting.

Air Control Valve

The air control valve is located in the handle of the gun body, directly behind the trigger. A positive return spring on the stem keeps the valve closed until the trigger is pulled. When the trigger is pulled, the valve opens, allowing air to flow. The air control valve provides no air pressure regulation. When the valve is closed, no air enters the front portion of the gun. When the valve is opened, full air pressure is admitted. The air pressure is controlled entirely by a pressure regulator located between the compressor and the gun.

Pattern-Adjusting Valve

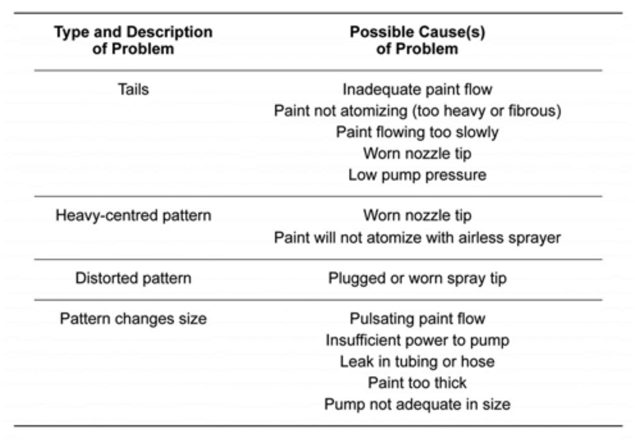
The maximum width of the spray pattern is typically determined by the pattern width specification of the fluid tip. The pattern-adjusting valve can decrease this dimension, but cannot increase the tip specification. This valve is located above the gun handle. The knurled adjusting knob is directly behind the hanger hook.

The stem of the pattern-adjusting valve seats in the air separator chamber in the front of the gun body. When the valve is turned counter-clockwise (closed), the pattern will be at maximum width. When it is turned clockwise (open), the pattern width will be reduced.

Fluid Inlet

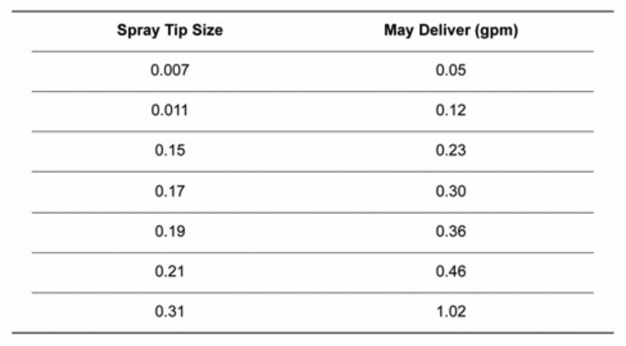
Fluid enters the stainless steel fluid passages of the gun body through the specially designed fluid inlet. The fluid is contained in the forward portion of the body by three pieces of packing, the ball of the needle, and the cone of the seat. Pressure of the needle spring against the packing assembly ensures proper seal of the fluid. Pulling the trigger engages the needle assembly and pulls the ball of the needle off the cone of the valve seat assembly, allowing the fluid to flow.

Table 2. Airless Spray Pattern Shape Problems.



Type and Description of Problem	Possible Cause(s) of Problem
Tails	Inadequate paint flow Paint not atomizing (too heavy or fibrous) Paint flowing too slowly Worn nozzle tip Low pump pressure
Heavy-centred pattern	Worn nozzle tip Paint will not atomize with airless sprayer
Distorted pattern	Plugged or worn spray tip
Pattern changes size	Pulsating paint flow Insufficient power to pump Leak in tubing or hose Paint too thick Pump not adequate in size

Table 3. Pump Delivery.



Spray Tip Size	May Deliver (gpm)
0.007	0.05
0.011	0.12
0.15	0.23
0.17	0.30
0.19	0.36
0.21	0.46
0.31	1.02

Fluid Needle

The fluid needle consists of four main parts:

- Needle stem and ball
- Spring
- Hex nut
- Air needle nut

The air needle nut fits over the hex nut and the stem of the air control valve. When the trigger is pulled, the air needle nut moves back.

Fluid Tips

The proper fluid tip is necessary to achieve the highest quality and efficiency with the air-assisted airless gun. Fluid delivery requirements (ounces/ minimum) and fan pattern widths to accommodate production requirements are the basic criteria. Operating pressures are considerably lower than normal airless spray so material viscosity and fluid pressure will affect the delivery rates of the fluid tip.

Air Cap

The atomizing holes of the air cap are typically located in the horns of the cap, and the pattern-adjusting holes are typically located in the cap's face. The spray pattern can be adjusted to vertical or horizontal by loosening the safety-retaining ring and rotating the air cap 90°. The tip will rotate with the air cap.

Air Separator

An air separator divides the pattern air and atomizing air. It is made of a durable material and screws onto the front of the gun body. The air cap fits onto the separator, which has a snap ring seal.

Electrostatic Spray Systems

Electrostatic spraying permits the application of coatings to irregularly shaped, electrically conductive structures and components with a very high transfer efficiency. Non-conductive surfaces (e.g., wood, plastics, and composites) may receive a surface treatment or coating to render them conductive. Although all coatings may be electrostatically sprayed, some formulations must first be modified to improve their electrical properties. Electrostatic spray has these advantages and limitations:

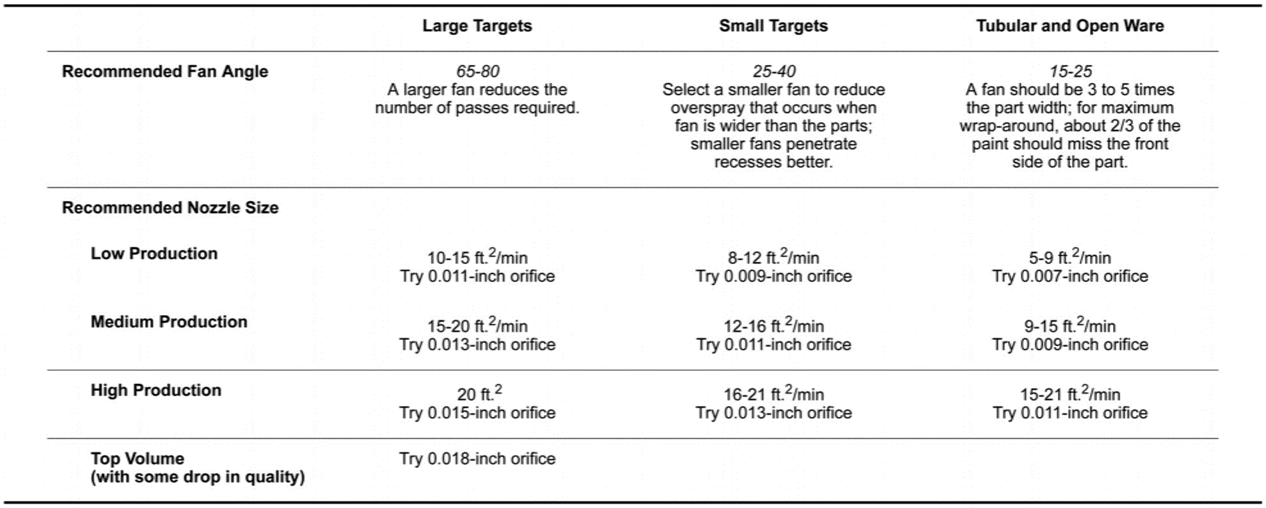
Advantages

- Wrap-around of edges
- High transfer efficiency
- More uniform application
- Material savings

Limitations

- High initial/maintenance costs
- More suited for automation work
- Skilled operator required
- Safety precautions required
- Normally limited to one coat
- Limited to exterior surfaces
- Require conductive surface

Table 4. Airless Nozzle Selection Guide for Electrostatic Spraying.



	Large Targets	Small Targets	Tubular and Open Ware
Recommended Fan Angle	*65-80* A larger fan reduces the number of passes required.	*25-40* Select a smaller fan to reduce overspray that occurs when fan is wider than the parts; smaller fans penetrate recesses better.	*15-25* A fan should be 3 to 5 times the part width; for maximum wrap-around, about 2/3 of the paint should miss the front side of the part.
Recommended Nozzle Size			
Low Production	10-15 $ft.^2/min$ Try 0.011-inch orifice	8-12 $ft.^2/min$ Try 0.009-inch orifice	5-9 $ft.^2/min$ Try 0.007-inch orifice
Medium Production	15-20 $ft.^2/min$ Try 0.013-inch orifice	12-16 $ft.^2/min$ Try 0.011-inch orifice	9-15 $ft.^2/min$ Try 0.009-inch orifice
High Production	20 $ft.^2$ Try 0.015-inch orifice	16-21 $ft.^2/min$ Try 0.013-inch orifice	15-21 $ft.^2/min$ Try 0.011-inch orifice
Top Volume (with some drop in quality)	Try 0.018-inch orifice		

Electrostatic spray guns are available that apply the electrostatic charge by either one of these two processes:

- The paint is electrically atomized and charged as it leaves the edge of a spinning bell
- The electrical charge is applied to paint particles already atomized either by air spray or airless methods, or applied to the paint stream just prior to atomization

Spinning-Bell Method

Most solvent-based, free-flowing paints may be applied by the spinning-bell method. The flow of coating to the bell is provided by the usual regulated paint supply system. An electric motor in the gun rotates the atomizing bell so that the material flows uniformly to its outer edge. Atomization occurs under the influence of the electrostatic field as the paint flows from the edge of the bell, forming a spray pattern of electrically charged particles. These charged particles move at slow speeds and tend to deposit on the object at points of maximum electrostatic attraction. The paint applications will thus be thinner in cavities and depressions on the surface, and heavy on edges or protruding points. This represents a definite advantage when applying protective coatings. Non-electrostatic methods of painting application (brush or spray) tend to leave thin coatings on edges, where early coating failure usually occurs.

Paint application rates by the spinning bell method are too limited for most high production rate applications of maintenance paints and protective coatings. The bell with the largest capacity (6 inches) has an approximate maximum paint delivery rate of 6 oz/min. However, these rates are ample for painting open grills, chain link fences, etc.

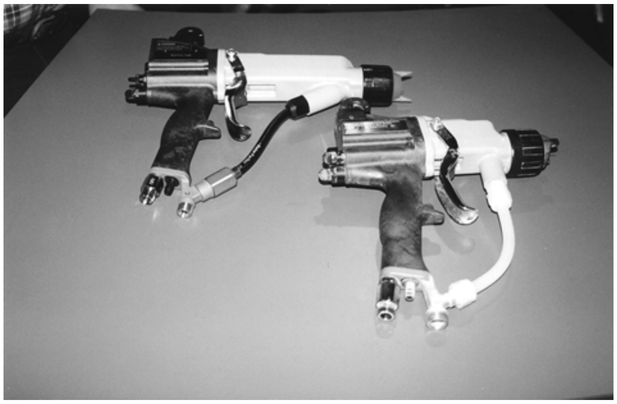


Figure 3. Electrostatic spray guns.

Air Atomizing and Airless Electrostatic Spray Methods

Air atomizing and airless electrostatic spray methods are more suitable for the field application of maintenance paints and coatings since higher deliveries are possible. The forces of electrostatic attraction result in a more uniform coverage over regular surfaces than is otherwise obtained, and furthermore, these guns may be used as ordinary spray guns whenever desired. Such electrostatic spray methods exhibit all the inherent advantages of the conventional air and airless spray methods, with the added advantages of electrostatic attraction, paint savings, little if any fog and overspray, and less cleanup and protection of nearby objects.

The electrostatic charge is applied either by an electrode protruding in front of the gun and extending into the paint atomizing zone, or by an electrode extending into the paint stream in the gun just before atomization. Depending upon the manufacturer, ionizing voltages range from 30,000–90,000, with approximately 60,000 volts employed by several prominent manufacturers. These are usually fixed voltages that cannot be varied. Air spray and airless electrostatic guns may be fed by conventional paint pumps or pressure tanks. However, special electrostatically conductive hoses must be employed.

When electrostatic spray equipment is operating properly and the paint conductivity is within the range suitable for electrostatic spraying, a marked wrap-around effect occurs. If there is only a weak wrap-around or none at all, the paint conductivity may be too high, the power supply may not be operating, or there may be some electrical trouble with the high-voltage cable or gun.

Safety Features of Electrostatic Spray Systems

Although high voltages are used, the equipment, when property set up, is safe to operate. There is no voltage applied to the gun electrode when the trigger is not pulled. Upon pulling the trigger, high voltage is present, but with most equipment this decreases as the electrode approaches a grounded object until, when contact is made, the voltage difference becomes zero. Consequently, holding the gun in one hand and touching the electrode with the other will produce no shock. The fluid hose must contain a special grounding wire or the jacket must be conductive to electrostatic charges. In air-atomized spray, the fluid hose contains a conductive ground wire embedded in the carcass.

The painter is grounded when gripping the gun handle since the handle is connected to ground through the high-voltage cable as well as through the hose. Consequently, the painter cannot wear gloves, which would insulate hands from the gun handle, unless the palm of the glove is cut out to ensure contact with the handle.

There is very little paint fire hazard with modern electrostatic spray equipment that has been properly installed and is operated as recommended. Although gun voltages are high, only microamperes of current are required to charge the paint particles. It has been demonstrated that there is so little energy present in a spark from the gun electrode on some equipment that tests have failed to ignite hexane vapors.

However, the control of energy in the electrostatic equipment does not apply to nearby conductive objects that may be insulated from ground. These objects can develop high voltages with appreciable energy as they are contacted by charged air molecules and paint particles. A spark from such objects may easily contain sufficient energy to ignite solvent vapors. Consequently, it is essential that all electrically conductive objects, including personnel, be grounded when located within 10–15 feet of the gun operating area. In addition to grounding the power supply, it is recommended that the unit be located as far as possible from the spray area (at least 20 feet).

Metallic items must be removed from pockets (e.g., coins, keys, pencils, nail clips, etc.). There have been occasions where these overlooked items have acquired a sufficient charge to ignite solvent vapors as they sparked through the pocket when the painter moved close to the grounded paint bucket.

Application Procedure

Application techniques are, in many ways, simpler with electrostatic spraying than with straight air or airless spraying. Lapping is less critical in applying an even coat, and, for many applications, careful attention to triggering is not necessary. Overspray is essentially eliminated by the electrostatic attraction of the coatings.

With air electrostatic spraying, lower atomizing air pressures are required, both because of thinning and because the electrostatic charge aids in paint particle formation. Likewise, considerably lower fluid pressures are necessary with airless electrostatic spraying, and the degree of atomization is usually finer than without the electrostatic charge. Because the viscosity of most paints to be applied electrostatically has been adjusted to the desired range, only two or three spray nozzle setups satisfy most air electrostatic application requirements. A selection of airless spray nozzles is needed, however, depending upon the object shape and application rates desired.

The inclusion of an orifice spray insert is helpful with paints that are difficult to atomize to a fine spray without using excessive fluid pressure. The insert tends to reduce the forward velocity of the paint through the nozzle, providing a “softer” spray with increased electrostatic efficiency. An insert may be useful for spraying tubular and open items. The spray insert orifice size should be equal to or slightly larger than the nozzle size, but never smaller.

When painting, it is recommended to hold the electrostatic gun at the manufacturer’s recommended distance from the surface (e.g., 6–10 inches with air spraying and when using the spinning bell gun, and 8–12 inches for airless atomization). The distance should never be much greater than 12 inches; otherwise, the sprayed paint particles may be attracted preferentially to the painter’s grounded hand rather than to the object being painted. This is one reason for the somewhat longer gun barrel on air and airless electrostatic spray guns.

Paints must be kept from accumulating on the electrode wire and on the face of the nozzle. Paint deposits may be removed with a bristle brush and solvent, but only after the high voltage has been turned off. For more extensive maintenance and service of electrostatic spray equipment, refer to the manufacturers’ service manuals.

Solvents Recommended for Coatings Applied by Electrostatic Spray Systems

The standard formulations of most solvent-based paints can be sprayed successfully by air and airless electrostatic spray methods, providing that the paint conductivity is not so high as to form a grounding path for the high voltage. Paints are conductive either because conductive (polar) solvents are used or metallic pigments are present.

Paints that have solvents too conductive for air and airless electrostatic spray application can seldom be successfully modified in the field by adding non-conductive (non-polar) solvents. The paint formulation must be revised by the supplier. All water-based paints and many paints with metallic pigments cannot be applied by electrostatic hand guns because of their conductivities.

In addition to considerations of paint conductivity, it has been found that optimum electrostatic attraction results when the paint viscosity is adjusted from 20–24 seconds with a No. 2 Zahn cup (or 14–22 seconds with a No. 4 Ford cup). This is lighter than the viscosity of most paints supplied for conventional spraying. Xylene, or other nonpolar or low-polar solvents compatible with the paint system, are recommended for thinning purposes.

Since lower spray pressures are generally used, the charged paint particles move more slowly to the surface being painted than when applied by conventional methods. Consequently, slower-drying solvents must be used in the paint formulation to ensure that a wet paint film is being applied. Furthermore, a paint particle that dries enroute to the surface quickly loses its charge and so will not be electrostatically attracted to the surface.

Figure 4. Plural-component proportioning system.

Plural-Component Spray

The plural component method of spraying coatings combines at the nozzle those components of thermosetting coatings that cure by chemical reaction. Each component is automatically proportioned as recommended by the manufacturer and combined in either a manifold/mixing chamber immediately before spraying or immediately after spraying with an airless or conventional air spray gun. The basic components of plural-component spray systems are:

- Coating material feed system for each component
- High-performance proportioning pump
- Appropriately sized, chemically resistant hoses for unmixed components
- Mixer manifold assembly
- Whip hose
- Airless or conventional air spray gun
- Solvent-purge system
- Filters
- Heaters (optional)
- Off-ratio alarm/shut-down (optional)

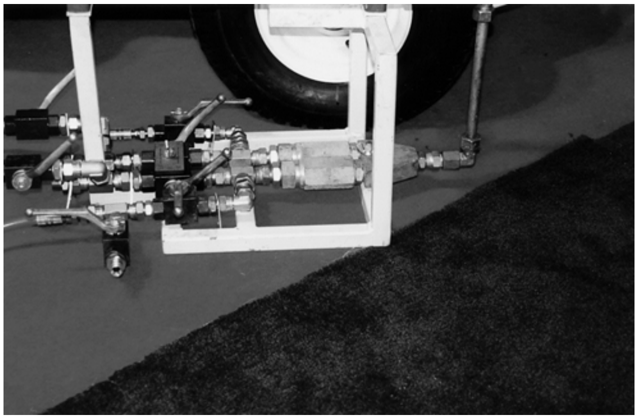


Figure 5. Manifold of plural-component system.

Fixed-ratio systems are used most often in production plants where the same operation is performed daily with no variance. Industrial coating contractors more commonly use a variable-ratio system because they apply, either in the shop or in the field, a variety of plural-component coatings with different mixing ratios. Typical plural-component materials applied include, but are not limited to, coatings with resins of epoxy, polyurethane, polysulfide, and silicone.

The spray system may be airless or conventional, or a combination of both. In many applications, the material is heated to reduce the viscosity. Use of this equipment requires special training and extra safety precautions.

Technology has made available control devices to monitor and control the mix ratio of the plural-component materials used in a variety of applications. These devices measure the positive displacement of the volume of solids flowing through the system, and automatically adjust the mix ratio to keep it within selected tolerances. If the desired mix ratio cannot be maintained, delivery of the material is stopped and an alarm message is issued.

Figure 6. HVLP spray gun.

High-Volume, Low-Pressure Spray

High-volume, low-pressure (HVLP) spray systems require a high volume of low pressure air to atomize the material being applied. The chief reason for developing HVLP spray was to produce a high transfer-efficiency system and thus reduce the amount of coating used and the amount of organic solvent entering the atmosphere.

In exterior appearance, HVLP spray equipment resembles a conventional air spray system, especially the actual spray gun. The air cap, fluid needle, fluid tip, fluid adjusting screw, spreader adjusting valve trigger, and gun body are similar. Spray application is slower, although some units (with the proper combination of air cap, fluid tip, and fluid needle) will deliver up to 18 oz/min. (0.5 L/min.). This delivery can be compared to using a 74:1 airless spray pump with a large orifice opening in the spray tip, which will deliver approximately 1.25 gal/min. (4.98 L/ minute). Because of the high volume (at least 20 cfm) of air required with some industrial HVLP spray systems, a two-stage compressor is required if the system is to be productive.

In the process of applying industrial coatings to large areas, such as storage vessels, ships, etc., HVLP cannot accomplish the high application rate that is possible with high-volume airless equipment. However, HVLP is used extensively in the wood finishing, farm equipment manufacturing, and automotive industries, and for commercial and residential application, but will not achieve the production level of other spray systems. The advantages and limitations of HVLP are:

Advantages

- Good transfer efficiency
- Reduced overspray and bounceback
- Good with high-solids coatings
- Good gun control

Limitations

- Reduced application speed
- High initial/maintenance costs
- May require special training

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About the Author

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This information has been prepared by Frank Palmer of Frank Palmer Consultants Limited and Cheryl McArthur of Perfect Words, both of Calgary, Alberta. Frank Palmer has specialized in designing training programs and seminars and writing specifications for more than 20 years. He has over 25 years of practical industry experience and was the first Canadian to obtain an SSPC protective coatings specialist (PCS) certification.

Chapter 7
Inspection

Kenneth A. Trimber and William D. Corbett

Introduction

The purpose of this chapter is to outline the inspections required to assure quality coating work. In addition, paint inspection equipment is described and summarized.

The Function of the Coating Inspector

Throughout this discussion the term "inspector" shall be used to indicate an individual or a group of individuals whose job it is to witness, report, and document coating work in a formal fashion. While painters themselves may conduct informal inspections, this will not be discussed. Instead inspectors providing a quality control (QC) function, or first line inspection of each aspect of the coating work will be described.

QC inspectors are specially trained contractor personnel or employees of a third-party hired by the contractor or owner to provide QC services. The quality assurance (QA) personnel working for the facility or company can also perform spot checks of work or any or all of the steps addressed herein.

The inspector's purpose is to verify that the requirements of the coating specification are met. This is analogous to that of a police officer: the inspector enforces the rules (specification) without exception even if these rules are deemed inadequate. An authorization to deviate from the specification is the responsibility of the "judge," usually the specification writer, contract administrator, or engineer in charge of the job. The inspector certainly may venture an opinion to the engineer and provide recommendations, but cannot unilaterally deviate from the specifications at the working level.

Besides specification enforcement, a QC coatings inspector provides thorough project documentation including a commentary on the type and adequacy of equipment at the job site, the rate of work progress, information regarding ambient conditions and controls, and verification that the surface preparation, coating application, coating thickness, and curing are as required. This is supplemented with any other information deemed to be of consequence to the quality and progress of the work.

The amount and type of QA inspection on behalf of the facility owner often varies according to the size of the project and the type of application contract. There are a number of types of contracts, but for simplicity two general categories, "fixed price" and "cost plus" will be addressed.

QA inspection under a "fixed price" application contract takes place to ensure that the contractor does not "cut corners" in order to hurry the job. While an evaluation of the equipment, work procedures, and sequence, etc. is important, the equipment and methods by which the contractor accomplishes the job are essentially at the contractor's discretion, provided the requirements of the specifications are met. When performing QA inspection services for a "cost plus" application contract, a knowledgeable inspector must be able to evaluate the contractor's equipment for adequacy and assess whether the rate of progress is reasonable.

Safety Considerations

Safety is paramount on any job. Coating inspectors should be aware of basic safety requirements and should have received personal protection training. If lighting, scaffolding, or equipment malfunctions present safety hazards, or appropriate protection from toxic substances or falls is not provided, the appropriate safety personnel should be notified. Paint application inherently presents dangers because the solvents used can be flammable and because many objects to be painted are relatively high or difficult to access. The inspector must be assured of the safety of these appurtenances before becoming involved.

Inspection Sequence

Inspection often begins with a pre-job conference where the ground rules are set. The inspector is responsible for witnessing, verifying, inspecting, and documenting the work at various inspection points:

- Inspecting Pre-Surface Preparation
- Measuring Ambient Conditions and Surface Temperature
- Evaluating Compressor (Air Cleanliness) and Surface Preparation Equipment
- Determining Surface Preparation (Cleanliness and Profile)
- Inspecting Application Equipment
- Witnessing Coating Mixing
- Inspecting Coating Application Techniques
- Determining Wet and Dry Film Thickness
- Evaluating Cleanliness Between Coats
- Testing for Pinholes and Holidays
- Testing Adhesion
- Evaluating Cure

Inspecting Pre-Surface Preparation

Prior to surface preparation or other coating activities, it may be necessary to confirm that the work is ready to be prepared and painted. Heavy deposits of grease, soil, dust, dirt, cement splatter, and other contaminants must be removed, according to SSPC-SP 1, so that they are not redeposited onto freshly cleaned surfaces. This is particularly important when recycled abrasives are used so the abrasive itself does not become contaminated.

The specification may require that weld splatter be ground or otherwise removed and that sharp edges be rounded. Laminations in plate steel, if detected prior to blast cleaning, may have to be opened and, if deep enough, could require weld filling. If sufficient deterioration has occurred to the structure, replacing some structural members, “fish plating,” or other repair may be necessary. Responsibility for such repair should be specified in procurement documents. Although this work is not ordinarily considered to be part of the coating contract, the inspector should confirm that it has been performed before the surface preparation and painting work. As a prelude to most painting operations, taping and masking is used to protect adjoining surfaces not to be painted. The NACE Visual Comparator for Surface Finishing of Welds Prior to Coating, as referenced by NACE RP 0178, may be used to inspect lap and butt welds, primarily for immersion service lining systems.

If the work involves maintenance painting, a determination of the percentage of rusting in an area may be helpful. Assessments can be made in accordance with SSPC-Vis 2, Standard Method of Evaluating Degree of Rusting on Painted Steel Surfaces.

Perhaps the best method of determining coating compatibility is a test patch application of the new coating over the old, a few months or more in advance of production painting. The test patch is then evaluated for adhesion, and examined for signs of wrinkling, lifting, or other evidence of incompatibility.

Details regarding overcoating and test patch assessments can be found in SSPC TU 3, Overcoating, and ASTM D5064, Practice for Conducting a Patch Test to Assess Coating Compatibility.

Measurement Of Ambient Conditions

It is implicit that surface preparation and coating work be done only under suitable ambient conditions of temperature, humidity, and dew point. For most catalyzed coatings, specific minimum temperatures must be met. Many inorganic zinc-rich coatings (ethyl silicate), or moisture-cure urethanes require minimum humidity levels as well. The inspector should be cognizant of weather forecasts (particularly if coating work is to be done outdoors) and the temperature and humidity restrictions of the specific coating material(s) being applied to the surfaces.

Other ambient conditions that might affect painting operations should be noted such as potential industrial or chemical airborne contamination, water spray downwind from a cooling tower, leaking steam or chemical lines, and contamination from normal plant or adjacent operations.

Often, heating or dehumidification equipment is used to control (and maintain) ambient conditions for painting operations within tanks or contained areas. Ideally, a heater should be indirect fired so it does not contaminate the surface with products of combustion. Ventilation, if required, should provide for sufficient air flow and adequate ventilation of all areas where work is being performed. Most solvents are heavier than air; thus, the dangers of explosion and flammability are frequently the greatest in low-lying areas. Control of airborne contaminants such as dust and abrasive must also be effective in order to prevent contamination of the painted surfaces or unacceptable worker exposures.

While much of the above is inspected visually or with specially designed equipment for determining solvent concentrations, the ambient conditions of air temperature, relative humidity, and dew point for surface preparation and painting quality are determined using instrumentation. This includes psychrometers **(Figure 1 and 2)** or instruments that give direct read-out recordings of humidity **(Figure 3)** and dew point. Measurements with these instruments are taken before the work begins each day and periodically throughout the day. A suggested minimum frequency is every four hours, or sooner if weather conditions appear to be worsening.

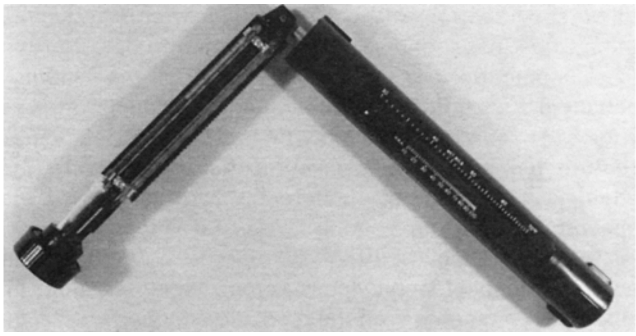

Figure 1. Sling psychrometer used for measuring wet and dry bulb temperatures in order to establish relative humidity and dew point. The instrument is spun in the air to reach termperature stabilization.

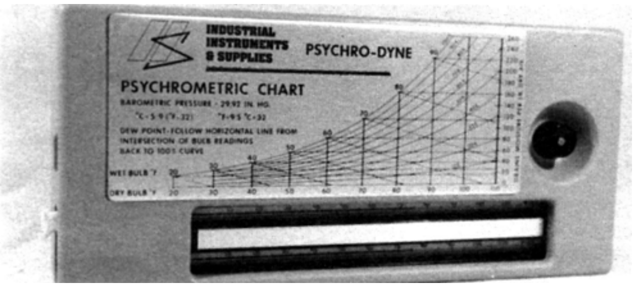

Figure 2. An electric psychrometer uses a fan to draw air across therrmometer bulbs, providing the wet and dry bulb temperature readings.

The psychrometer consists of two identical tube thermometers, one of which is covered with a wick or sock that is saturated with water. The covered thermometer is called the "wet bulb" and the other is the "dry bulb." The dry bulb gives the ambient air temperature while the wet bulb temperature provides results from the latent heat loss of water evaporation from the wetted sock. The faster the rate of water evaporation, the lower the humidity and dew point. There are generally two types of psychrometers: the sling psychrometer, shown in Figure 1, and the fan or motor-driven psychrometer, shown in Figure 2. Electronic psychrometers are also gaining in popularity.

When using the sling psychrometer as detailed in ASTM E 337, the wet bulb sock is saturated with water, the instrument whirled rapidly for approximately 20 seconds, and a reading of the wet bulb quickly taken. The cycle is repeated (spinning/ reading without additional wetting) until the wet bulb temperature stabilizes. Stabilization occurs when three consecutive readings of the wet bulb remain the same. At this time both the dry and wet bulb temperatures are recorded.

When using the fan-operated psychrometer, the wet bulb sock is saturated with water and the fan is started. Approximately two minutes are required for stabilization, and one need only observe the wet bulb thermometer and record both temperatures when the wet bulb temperature remains unchanged.

When the instruments are used in air temperatures less than freezing—32°F (0°C), the accuracy of the readings is questionable. The wet bulb thermometer will drop below 32°F (0°C) to a certain point (e.g., 27°F [-2.7°C]), then "heat up" rapidly to the freezing point. Quite often when using a sling psychrometer, this will take place as the instrument is whirled; therefore, a wet bulb temperature of 32°F (0°C) may always be obtained. When using the motor-driven psychrometer, one can observe the wet bulb temperature drop below freezing, then rise rapidly to 32°F (0°C). However, the low value may still be incorrect. Thus if the temperature is below 32°F (0°C), the ambient conditions will have to be established by other means. This could be accomplished by obtaining the dew point and relative humidity on a direct read-out instrument using more sophisticated equipment **(Figure 3).** Alternatively, the tube psychrometers can be supplimented with inexpensive direct reading humidity indicators. The psychrometer would be used only to determine the ambient temperature (dry bulb). These two values (dry bulb and humidity) can then be used to determine the wet bulb and dew point temperatures by plotting out this information "in reverse" on charts or tables.

After the dry bulb and wet bulb temperatures are determined, a psychrometric chart or table is used to determine the relative humidity and dew point temperatures. Charts require plotting the dry bulb and wet bulb temperatures on different lines and interpolating the relative humidity and dew point from their intersection.

Figure 3. A digital hygrothermometer gives instant readout of air temperature, relative humidity, and dewpoint.

The U.S. Department of Commerce Weather Bureau has created individual psychrometric tables for relative humidity and dew point. To use the tables, the wet bulb temperature is subtracted from the dry bulb temperature and the difference found along the top row of the table labeled "depression of the wet bulb thermometer." The dry bulb (air) temperature is found down the left column and the intersection of the two is either the humidity or the dew point, depending upon which table is used. The U.S. Department of Commerce NOAA-WSTA B-0-6E (5-72) Relative Humidity and Dew Point Table includes both sets of information on one table.

Dew point is defined as the temperature at which moisture will condense. Dew point is important in coating work because moisture condensation on the surface will cause freshly blast cleaned steel to rust, or a thin, often invisible film of moisture trapped between coats may cause premature coating failure. Accordingly, the industry has established a dew point/ surface temperature safety factor. Surface preparation and coating application should not take place unless the dew point is 5°F (-15°C).

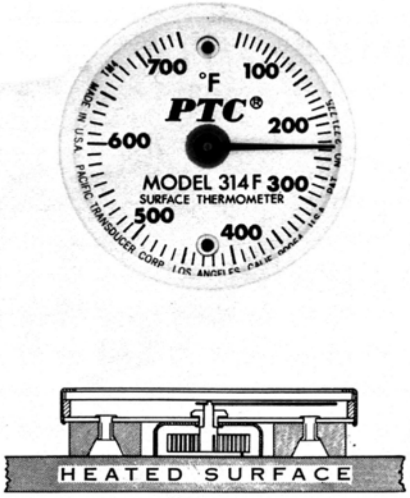

Figure 4. A surface temperature thermometer establishes the temperature of substrates during blast cleaning and painting.

Different field instruments are used for determining surface temperature. One of the most common is a surface temperature thermometer **(Figure 4),** which consists of a bimetallic sensing spring that is shielded from drafts. The instrument includes two magnets on the sensing side to attach to ferrous substrates. For non-ferrous surfaces, attach the thermometer using tape across the face of the gauge. A minimum of two minutes is required for temperature stabilization. Other field instruments for determining surface temperature are direct reading thermocouple/ thermisters **(Figure 5a).** These instruments utilize a sensing probe that is touched to the surface, resulting in a direct temperature readout. Only a few seconds are required for a temperature reading to stabilize. Non-contact infrared (IR) thermometers are also available for use **(Figure 5b).** Accurate temperature readings can be obtained from a few inches to many feet away from the surface by simply pointing the IR beam at the surface. Some models contain a laser sighting.

With any of the instruments used for determining ambient conditions and surface temperatures, the readings should be taken at the actual locations of the work. For general readings where dew point is the concern, however, one should consider the coldest point on the structure because a surface temperature/dew point relationship problem will occur there first. Air and surface temperature considerations are also important to ensure that coatings are not applied outside of their temperature limitations—in areas too cool or too warm. Accordingly, readings for this purpose should be made at the coolest or warmest areas.

Typical requirements for ambient painting conditions are given in SSPC-PA 1. Specific requirements are provided in the project specification and/or the coating manufacturer's product data sheets.

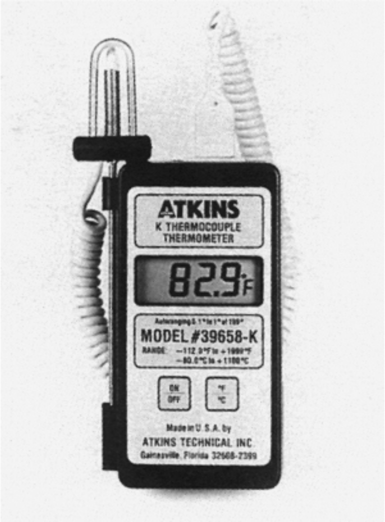

Figure 5a. Direct reading thermocouple/thermister.

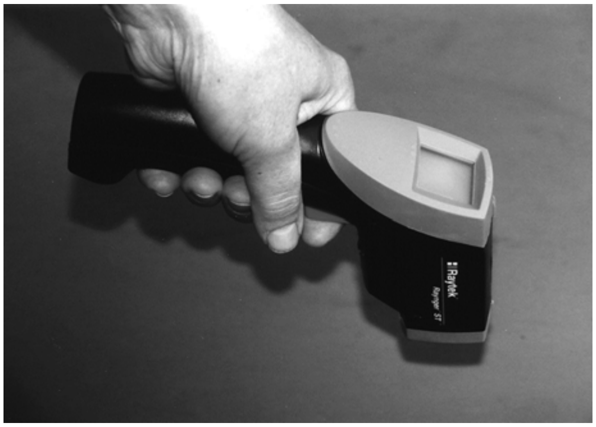

Figure 5b. Non-contact infrared (IR) thermometer.

Evaluating Surface Preparation Equipment

The air compressor and other equipment used for blast cleaning and any hand or power tools should be inspected. The inspector need not have an extensive technical background on the equipment, but should have enough familiarity to verify its suitability.

Air Compressor and Air Cleanliness

When an air compressor is used for blast cleaning, power tool cleaning, or spraying equipment, the compressor should be appropriately sized and have a suitable volume (ft.^{3}/min.) to maintain the required air pressures. Abrasive blast cleaning equipment suppliers have charts and data available that are excellent aids for determining required sizes of compressors, air and abrasive lines, nozzles, and so forth.

The compressed air used for blast cleaning, blowdown, and air atomization for spray application should be checked for contaminants. Adequate moisture and oil traps should be used on all lines to assure that the air is sufficiently dry and oil-free in order to avoid interfering with the quality of the work.

A simple test for determining air cleanliness requires positioning an "absorbent collector" (clean white piece of blotter paper) within 24 inches of the air supply, downstream of moisture and oil separators.

ASTM cautions the tester to avoid personal contact with the air stream. Therefore, it is helpful to mount the paper on a rigid frame (e.g., 1/2-inch plywood) using duct tape. The air is permitted to blow on the blotter paper for a minimum of one minute followed by inspection for signs of moisture or oil contamination on the blotter. Obviously, if there is no discoloration on the blotter paper, the quality of the air is excellent, while streams of moisture and oil running down the sheet indicate unsatisfactory air.

Unfortunately, the point where good air becomes "bad" is difficult to determine. However, by using blotter paper (or a clean cloth), one can make judgments as to the air quality. Inspec the surface thoroughly for moisture or oil contamination after preparation or painting and correlate these results with the results of the blotter test.

In addition, the proper functioning of in-line moisture and oil traps can be evaluated on a comparative basis from the results of the blotter test. For work requiring that absolutely no moisture or oil be permitted in the compressed air, oil-less compressors and sophisticated air drying equipment are available.

Blast Cleaning Machine

The blast cleaning machine mixes the abrasive with the air stream. The abrasive metering valve regulating the flow of abrasive into the air stream is perhaps one of the most overlooked but important considerations affecting the rate of production. Generally, too much abrasive is fed into the air stream, resulting in both decreased production and increased abrasive costs. The machine must be equipped for “dead man” capability so that it automatically shuts down if the nozzle is dropped [OSHA 29 CFR 1910.244(b)]. It should also be equipped with moisture and oil separators, or external separators should be provided. Since the tank of the blast cleaning machine is a pressure vessel, it should be constructed according to pressure vessel codes.

Abrasive

There are a wide variety of abrasives available for blast cleaning. The size, type, and hardness have a significant impact on the surface profile and speed of cleaning. Metallic shot and grit abrasives are commonly used for rotary wheel blast cleaning because they can be recycled. Iron and steel shot, grit, aluminum oxide, and non-traditional abrasives such as glass beads can be recycled and used in field operations as well, provided appropriate equipment is available to separate fines, paint, rust, and mill scale from the collected abrasive. Various slag abrasives are widely used in field applications, and in some cases, silica sand is still being used. However, its use as a blast cleaning abrasive is declining because of the potential silicosis hazards. Sand and slag abrasives are expendable and should not be recycled.

It is important that all abrasives be clean and free of moisture at the time of use. Abrasives should be stored off the ground and protected from the elements. Only expendable abrasives that have been washed at the manufacturing and packaging plant should be used. The washing should be done using fresh water only; if brackish water is used, chloride contamination of the cleaned surface can result, with subsequent rust bloom in humid environments as well as the potential for osmotic blistering of the coating film once in service.

Figure 6. Testing for the presence chlorides.

Although there is no inspection apparatus for determining the cleanliness of the abrasive used, a visual inspection can be made to ensure that it is not damp or contaminated. When abrasive recycling systems are used, a simple test for the presence of oil or grease contamination can be conducted by dropping some of the abrasive (e.g., a handfull) into a small vial of water (e.g., 8 ounces) and shaking the vial vigorously. The top of the water is inspected for a film of grease or oil which will be present if the abrasive is contaminated. Dirt and dust in the abrasive can be assessed in the same manner. Small abrasive “fines” will be held by surface tension at the meniscus, and a dirty abrasive will color the water or cause turbidity. However, water-soluble contaminants such as salt will not be detected using this test. If water-soluble contaminants are present, a litmus paper test of the water in the vial will tell if they are acidic or alkaline. If neutral, a drop of 5% silver nitrate solution can be added to the water. The formation of a white precipitate will indicate the presence of chlorides. Alternatively, allow the water to evaporate and look for salt crystals, or use a chloride indicator strip to quantify the amount of chloride present in the water extract **(Figure 6).** Another field method for determining the presence of soluble salts in the abrasive involves the use of a conductivity meter to test a mixture of water and the abrasive. This test is described in ASTM D 4940. Commercially available kits specifically designed for the detection of chloride contamination on abrasive media and in wash water (used during pressure washing, waterjetting, or wet abrasive blast cleaning) can also be employed **(Figures 7a and 7b).**

Figures 7a and b. Commercial tests kits for detecting chloride contamination on abrasive media (a) and in wash water (b).

Forced Air and Abrasive Hoses

Sharp constrictions or bends in these lines should be eliminated, and they should be kept as short as possible to avoid friction and loss of pressure. For safety purposes, the couplings must be wired together to ensure secure closure and to prevent the connections from working loose and coming apart. Wire cables (whip checks) are also used to help maintain safety, in the event that the hoses come uncoupled during blast cleaning. Blast hoses must also be equipped with static wire grounding, as a considerable amount of friction is generated by abrasive flowing though the blast hose.

Blast Cleaning Nozzles And Nozzle Pressure

A great variety of nozzle sizes, types, and lengths are available for cleaning purposes. The specific nozzle chosen will depend upon the specific cleaning job. Venturi type nozzles provide a higher abrasive velocity and a larger blast pattern than straight barrel types of the same orifice size. In general, the longer the barrel and the larger the orifice, the faster the cleaning rate provided an ample volume of compressed air is available to maintain high pressures at the nozzle. Cracked nozzles and worn nozzles, even if not cracked, will reduce the rate of blast cleaning. As a rule of thumb, a nozzle that has been worn beyond 25% of its original inside diameter (I. D.) should not be used. A nozzle orifice gauge **(Figure 8)** is available for determining the orifice size after use. The number etched on the nozzle housing indicates the size when new (in sixteenths of an inch). For example, a No. 8 nozzle is equivalent to 1/2 inch inside diameter, when new.

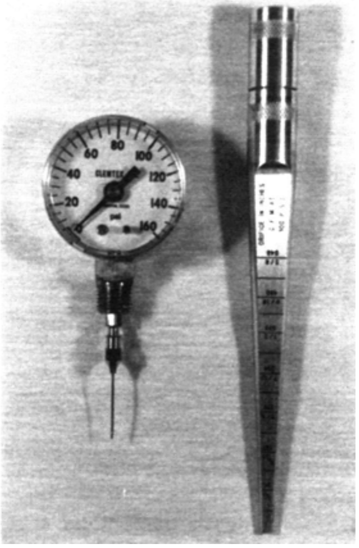

Figure 8. Nozzle orifice gauge (right) measures the nozzle orifice and indicates CFM of air required for the size. Hypodermic needle pressure gauge (left) measures air pressure at the nozzle when the needle is inserted through the blast hose.

The amount of air pressure at the blast nozzle is a determining factor in cleaning rate production. The optimum nozzle pressure is 90 to 100 psig for most abrasives, although there are some exceptions. Optimum pressures when using steel grit, for example, may be 125 psig or even higher. The blast cleaning air pressure should be determined at the nozzle rather than at the gauge on the compressor because there will be pressure drops in the system due to hose length, bends, restrictions, air fed to the blast pot, moisture traps, and multiple blasters using the same compressed air source. Air pressure at the blast nozzle can be determined using a hypodermic needle air pressure gauge.

The gauge needle is inserted through the blast hose as close to the nozzle as is practical. The direction of needle placement should be toward the nozzle. Pressure readings are taken with the nozzle in operation (abrasive flowing). At the same time, all other pneumatic equipment using the same compressor system must be in operation, and multiple blasters must operate their nozzles simultaneously, in order to obtain an accurate measurement.

Rotary Wheel Blast Cleaning Equipment

Many fabricating shops and painting sites are equipped with rotary wheel blast cleaning equipment in order to efficiently prepare a surface for painting. The number of wheels directly affects the area that can be cleaned, and the type of structural shapes that can be cleaned.

Adjustments can be made to direct the abrasive stream from each wheel to the desired location in order to provide a uniform cleaning pattern. The speed through the machine determines the degree of cleaning; the slower the material goes through the machine, the greater the degree of cleaning.

Complex structural shapes are particularly hard to clean using automated equipment. The interior of box girders, enclosed shapes, and shielded mem- bers cannot be cleaned, unless cleaning is done prior to fabrication. In many instances, fabricators will employ handheld blast cleaning equipment in tandem with the automated equipment to reach the limited access areas.

Surface preparation methods such as vacuum blast cleaning, water blasting with and without abrasive injection, wet abrasive blast cleaning, and hand and power tool cleaning are discussed in other chapters of this book.

Determining Surface Preparation Cleanliness and Profile

Cleanliness

All surfaces should be inspected after surface preparation to ensure compliance with the specification. SSPC's surface preparation specifications describe hand and power tool cleaning, abrasive blast cleaning, waterjetting, etc., including the type and percentage of residues permitted to remain on the surface. It is important that this inspection be timely, in order to avoid any rusting of cleaned surfaces prior to applying the primer **(Figure 9).**

Figure 9. A selection of SSPC visual standards.

The written definitions for abrasive blast cleaned surfaces are supplemented by SSPC Vis1, which photographically depicts the surface appearance of various grades of blast cleaning over four initial mill scale and rust conditions on steel. The standards are visually compared with the prepared surface to determine the degree of cleanliness. ISO also has visual standards for evaluating surface cleanliness.

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, job site 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. When inspecting the quality of surface preparation, much of the effort should be spent on areas that are difficult to access such as the back sides or undersides of angles or supporting steel.

Cleanliness after surface preparation must also be examined. Residual traces of abrasive must be blown, swept, or vacuumed from the surface prior to primer application. It is also important to ensure that dust is removed from the surface prior to painting, particularly the "fine" film of dust-like spent abrasive often held to the blast cleaned surface by static electricity. Any scaffolding, staging, or support steel above the area to be coated must be blown down and cleaned to prevent abrasive and debris from dropping onto the freshly cleaned surface, or later contaminating the freshly primed surface. Adjacent blast cleaning and painting should not be perfomed concurrently unless permitted by the governing specification, and provided the blast cleaning operations are adequately isolated to prevent contamination of the freshly painted surfaces. The surface may also be inspected to determine if it is chemically clean and free of detrimental concentrations of soluble salts. This is discussed in a separate chapter of this book.

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. A white metal blast can have a 1, 2, 3, or 4 mil profile; likewise, a commercial blast can have a 1, 2, 3, or 4 mil profile. Specifying a certain blast cleanliness says nothing of the profile requirement. It must be addressed separately.

Surface profile is important because it increases the surface area to which the coatings can adhere, and provides a mechanical anchor to enhance coating adhesion. As a general rule, heavier coatings require a deeper surface profile than thinner coatings. Surface profile determinations are generally made in the field or shop using one of three instruments: a surface profile comparator, a depth micrometer, or replica tape. All three methods are described in ASTM D 4417. Magnetic measurements of surface profile have been attempted with little success. More sophisticated laboratory methods include a profilometer and a depth measuring microscope. SSPC's Surface Profile for Anti-Corrosion Paints discusses a standardized method of measuring profile using a microscope.

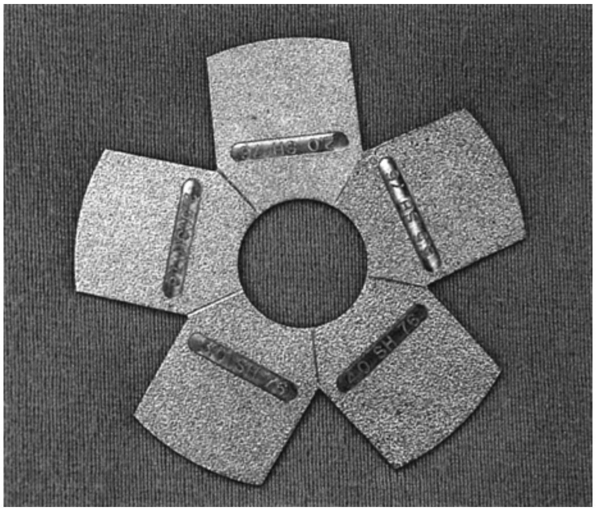

Figure 10. The surface profile comparator consists of a lighted magnifier and reference disk (shown) for visually comparing the anchor pattern of blast cleaned steel. Reference disks are available for sand, grit, or shot abrasives.

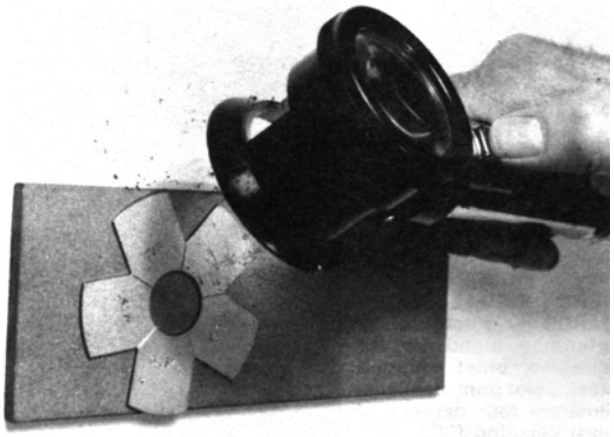

Figure 11. Surface comparator in use measuring surface profile.

The most common surface profile comparator is the Keane-Tator Surface Profile Comparator **(Figures 10 and 11),** which consists of a reference disc and a 5-power illuminated magnifier. The disc is held magnetically against the magnifier, through which prepared surface and disc segments can be viewed simultaneously. The reference disc has five separate leaves or segments, each of which is assigned a number representative of the profile depth of the particular leaf. Each disc is a high purity nickel electroformed copy of a master. The master disc was measured microscopically at SSPC to establish its profile depth.

The reference disc is compared with the surface through the 5-power magnifier. The leaf or leaves that most closely approximate the roughness of the surface are considered to be the profile of that surface. For example, the profile may be 2 mils, or perhaps from 2 to 3 mils if the surface roughness appears to lie between the 2 and 3 mil leaves.

There are three reference discs available. The one to use for measurement depends upon the type of abrasive. Different abrasives generate a different surface profile appearance, although the peak-to-valley depths may be identical. For example, shot is round when compared with a more angular grit. In order to achieve similar profile depths, shot, by virtue of its shape, will generally result in greater lateral distances between the peaks than grit provides, resulting in a lower peak count per given area. The optical effect provides an illusion that the profile of the shot-blast cleaned surface is deeper than the grit-blast cleaned surface (because the peaks are wider apart), even when the depths are essentially identical. Therefore, it is critical that the correct reference disc be selected.

The designations for the three reference discs available with the instrument are: S for sand; G/S for metallic grit or slag; and SH for shot. The numbering system on each leaf consists of a number followed by a letter designation, then another number. The first number represents the profile depth of that leaf, the letter(s) represents the abrasive type used (sand, grit/slag, or shot), and the final number represents the year that the master disc was formed. For example, 1S70 indicates that that leaf was prepared to a 1 mil profile using sand as the abrasive and that the master disc was formed in 1970. The year that the master disc was formed is only significant if it were to be replaced at a later date. Another field instrument used for this purpose is a pit depth finder.

Surface profile depth can also be determined by using replica tape. Replica tape consists of compressible foam attached to a uniform 2 mil film of mylar. The tape is pressed onto the blast cleaned surface, foam side down, and the mylar rubbed vigorously with a blunt instrument, such as a swizzle stick or burnishing tool. 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. The tape is removed and measured 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). The total micrometer reading is adjusted for the thickness of the mylar by subtracting 2 mils from the result to provide a direct reading of the maximum average profile. The tape is available in four ranges: “coarse” for profile measurements from 0.8 to 2.0 mils; “paint grade” for measurements from 1.3 to 3.3 mils; “x-coarse” for measurements from 1.5 to 4.5 mils; and “x-coarse plus” for measurements from 4 to approximately 6.5 mils.

The replica tape will retain the impression indefinitely, provided it is stored in a cool area with no pressure ever applied. Conceivably, replicas of profile depths could be kept on file permanently for future reference.

It is important that the inspector realize that each method has its limitations. For example, the comparator can be subjective, and persons using it could be biased by the results of others. The peaks of the profile may be too close together to permit the projecting pin of the surface profile gauge (depth micrometer) to reach the valleys, or the surface might be irregular or wavy, holding the base of the instrument slightly above the plane of the profile, giving erroneously high readings. Replica tape cannot be used for profile depths less than 0.8 mil nor exceeding 6.5 mils, and if there is any dirt or dust contamination on the surface, it will be picked up and incorrectly read as additional profile depth on a spring-loaded micrometer. Finally, it is important to realize that there may not be exact correlation among each of the above methods because each takes in a different peak count or surface area for its measurement. Therefore, it is advisable that all parties concerned agree upon the method that will be used to determine the surface profile and not deviate from it. Coating manufacturers will occasionally supply a profile reference coupon representative of the roughness necessary for their product or alternatively may specify the use of a specific instrument. Oftentimes project specifications will dictate the method (and frequency) of surface profile measurements.

Inspecting Application Equipment

The inspector must also be familiar with the methods and equipment used for coatings application.

Spray Application Equipment

Spray equipment for traditional industrial coatings is classified as either air atomized or airless. With air atomization equipment, the paint is fed through the fluid line at relatively low pressures, and compressed air is directed at the fluid stream through an air cap to atomize it. Adjusting the fluid stream and air pressure enables the painter to adjust the spray pattern. Only the minimum pressures necessary to adequately atomize the paint should be used. The proper fluid tip and needle must be chosen, as well as an air cap design, all based on the coating manufacturer's recomendations. Because the compressed air mixes with the coating, filters must be used to ensure a clean air supply.

In airless spraying, hydraulic pressure (1000-3000 psi and higher) is used to atomize the paint through a small diameter spray tip, much in the same manner as water is dispersed into droplets when passing through a garden hose spray nozzle. For airless spray, variations in the spray pattern can be attained only by changing the spray tip (fluid orifice), although some adjustable tips are available. Choice of the appropriate tip, as well as variation in fluid pressure, can result in a wide range of spray patterns suitable for almost any application. As a general rule, airless spray tips have an identification number indicating the orifice size and spray pattern size. For example, a 4017 tip is 0.017 inch in size and produces an 8 inch spray patten (2x the first I.D. number) at a 12 inch distance from the spray tip to the surface to be coated.

The coating manufacturer's application instructions usually recommend the appropriate spray tips and air caps for air spray and spray tip sizes and fluid pressures for airless application. These are only recommendations and under certain conditions, other tip or air cap combinations may be more appropriate. Care should be taken when cleaning the tip and air caps as the orifices can be easily damaged.

The predominant malfunction of spray equipment is attributable to lack of cleanliness, both of the spray gun itself and of fluid lines. Paint chips or agglomerations and blast cleaning abrasive particles are of sufficient size to clog the small diameter orifices.

Additionally, cleanliness of mixing pots, spray pots, spray lines, spray guns, or other application equipment is necessary for good paint application. Dirty equipment can cause new paint to become contaminated with old. Dislodged particles can clog the spray gun, perhaps allowing the pot life to be exceeded, or even result in the deposition of incompatible traces of previously applied material in the new paint film. Cleanliness of all spray application equipment should be verified prior to mixing the paint to avoid problems with clogging or contamination.

Spray Pot

The spray pot should be clean and in good working order prior to use. Many types of paints, particularly zinc-rich primers, require the use of an agitated pot (one equipped with a stirring paddle) in order to keep the paint components in suspension. Air and fluid pressure gauges should be available and functional on conventional (air) spray pots. The pressure release valve should also be operative. The conventional pot should be equipped with diaphragm pressure regulators, making it possible to control both air and fluid pressure to the spray gun from the pot. A variation of conventional spray equipment, high-volume low-pressure (HVLP) spray guns, are typically equipped with a pressure regulator close to the spray gun with the atomization pressure maintained between 0.1 and 10 psi.

Mixing Paint Material

Mixing is perhaps one of the most important, yet one of the most underappreciated operations. Improper mixing or thinning can affect the coating's ability to perform. However, mixing is not always specified as an inspection “hold point” in painting contracts. Regardless, there should be some means to ensure that all components of a multi-component paint system have been added, that mixing is thorough and proper, and that any required induction times have been met. Leaking or damaged containers should not be used, particularly with catalyzed paints as some of the components necessary for complete cure may have leaked out or evaporated and proper proportioning may not be achievable. Containers with illegible labels should not be used. Mixing should continue until the paint becomes smooth, homogeneous, and free of surface “swirls” or pigment lumps or agglomerations. Unless prohibited by the manufacturer, use mechanical stirrers. Some paints tend to settle out upon prolonged storage, so “boxing” is beneficial to ensure that all pigment settled on the bottom of the container is incorporated in the mixed paint.

When adding zinc dust to the vehicle of zinc-rich primers, it is good practice to sift the zinc dust through a screen into the liquid portion while mixing. This helps to reduce a problem when spraying two-component zinc-rich primers; that is, gun clogging caused by pigment agglomerations that are not properly dispersed. For such heavily pigmented coatings, it is also important that the spray pot agitator is operable to keep the zinc in suspension.

Figure 12. Zahn viscosity cup.

Only complete kits of multi-component paints should be mixed. If this cannot be done, the manufacturer must be consulted to ensure that partial mixing of their material is permitted. If allowed, it is imperative that the components be carefully measured using graduated containers or even scales. Most manufacturers now prohibit partial mixing of kits.

Thinners (if required) and should be well mixed into the paint material. The type and amount of thinner should be in accordance with the coating manufacturer’s recommendations. The inspector should record the amount of thinner used, as the addition of any thinner effectively reduces the volume solids content of the mixed paint and affects the target wet film thickness.

Measuring viscosity helps ensure that the proper amounts of thinner are used and that the thinning has not changed significantly from pot to pot. A common viscosity cup (Zahn), as shown in **Figure 12,** is simply a small cup of known volume with a precisely sized orifice in the bottom center.

Generally five orifice sizes are available and so numbered. The coating manufacturer can be consulted as to the orifice size to use for the material, and the time (in seconds) for the volume of properly thinned material held by the cup to pass through the orifice. For example, the manufacturer might stipulate that the material should be thinned such that it will pass through a No. 3 Zahn cup in 20-30 seconds at a given liquid paint temperature.

The clean cup is fully immersed in the coating material and withdrawn quickly. A timer is started at the precise moment that the top of the cup leaves the level of the liquid. The material will flow steadily through the orifice. When the solid stream first breaks at the base of the cup, the timer is stopped instantly. It is important to hold the cup 1 or 2 inches above the surface of the liquid so that it remains in the solvent atmosphere and away from drafts. The amount of thinner in the mixed paint is adjusted accordingly so that volume of paint held by the cup will flow through the orifice within the stipulated time range. The viscosity of some high-build thixotropic coatings cannot be measured with the Zahn cup, but other viscometers can be used. In this case, the coating manufacturer should be contacted for a recommendation.

Viscosity measurements are of value for quick field determinations of thinning and will reveal if significant changes in the viscosity occurred from pot to pot of material. While the paint applicator is generally the best judge of the proper amount of thinner to add to ensure the application of a smooth wet coat without runs or sags, the coating manufacturer’s maximum thinner amount should never be exceeded. The coating, at application, must also comply with VOC regulations. Adding a thinner effectively increases the quantity of solvent emissions into the atmosphere. Restrictions on the type and amount of solvent emissions vary from area to area, and local air quality regulations must be followed. As a result, VOC regulations may prohibit adding thinners to a coating, even though the manufacturer recommends it.

Coating Application

The actual application of the coating is the most visible aspect of the painting project, and is equally as important as surface preparation. Accordingly, the coating inspector should be familiar with various application techniques.

When spraying with air atomized (conventional or HVLP) equipment, the spray gun should typically be held from 6 to 10 inches from the surface and maintained perpendicular to the surface throughout the stroke. For airless application, the distance should be from 12 to 18 inches. At the end of each pass, the gun trigger should be released. Each spray pass should overlap the previous one by 50%, and where possible, a cross-hatch technique should be used. This requires a duplicate series of passes 90° to the first series to ensure complete and uniform coverage.

In brush application, the brush should be dipped approximately two-thirds of its bristle length into the coating. The bristle tips should be brushed lightly against the side of the container to prevent dripping, maintaining as fully loaded a brush as possible. Brushing is more effective than spraying for working paint into depressed irregularities, pits, or crevices, and is effective for striping welds and around rivets, bolt heads, and nuts. However, care should be taken when striping edges to ensure that the coating is not brushed out too thin and actually pulled away from the surface.

Other application methods include plural-component spray, rolling, using mitts or pads, dipping, electrostatic spraying, powder coating (using fluidized bed or electrostatic spray), and roller coating using automated facilities for flat sheets. Each has its own specific technique as described elsewhere in this book.

Besides ensuring proper application technique, additional care is necessary when inspecting coating work where atmospheric contamination is present. Often water washing between coats or application of the topcoat within a minimum time interval is necessary. Otherwise, contaminants often invisible to the unaided eye may be coated over, leading to reduced coating life or premature coating failure.

Deficient and excessive coating thicknesses in multicoat systems should be observed. In cases where a topcoat is applied over a generically similar (e.g., non-rust inhibitive) primer, deficient primer thickness can be “built up” by additional topcoat thickness. However, where the primer contains rust inhibitors or is a different generic type, an additional coat of the primer or previously applied coating must be used before the topcoat can be applied.

Another common practice is to use coatings of a different color, or to tint each coat. This is an excellent aid to the applicator and inspector to ensure that complete coverage is achieved. Upper thickness limits are also specified in some cases. When paint thickness exceeds that specified, the excess should be removed by grinding or sanding, as appropriate. After this, reapply a thin coat to seal irregularities. Excessive or unsightly runs, sags, drips, and other film deficiencies should be brushed out during application or removed after drying. This again is done by grinding or sanding. In some cases, complete removal of the excessive coating (by abrasive blast cleaning) is required.

Determining Wet Film Thickness

Wet film thickness readings are used to aid the painter (and in some cases the inspector) in determining how much material to apply in order to achieve the specified dry film thickness. Wet film thicknesses on steel and most other metallic substrates are considered “guideline” thicknesses, with the dry film thickness being the thickness of record. However, when coating concrete or nonmetallic substrates, the wet film thickness is often used as the accepted value.

The wet film thickness gauge is generally a standard “notch” configuration **(Figure 13),** although circular dial gauges are also available. The notch gauge consists of two end points on the same plane with progressively deeper notched steps in between. Each step is designated by a number representing the distance in mils (or microns) between the step and the plane created by the two end points. The instrument is pressed firmly into the wet film perpendicular to the substrate and withdrawn. In every case, the two end points will be wetted by the coating material. The wet film thickness is considered as being between the last wetted step and the next adjacent higher dry one. For example, if the "3 mil' step is wetted and the "4 mil" step is dry, the wet film thickness is between 3 and 4 mils. If none of the steps or all of the steps in between the end points are wetted, it is necessary to turn the gauge to a different face, as the wet film thickness is outside of that particular range.

When using this instrument, it is necessary to stay away from any surface irregularities that could distort the readings. If determinations are being made on curved surfaces, it is important that the gauge be used along the length of the curve rather than across its width, as the curve itself could cause irregular wetting. The gauge must also be cleaned thoroughly after each use to ensure the accuracy of future measurements.

Wet film thickness gauges are of value only if the applicator knows how heavy a wet film to apply. The wet film thickness/dry film thickness ratio is based on the percent solids by volume of the specific material being applied.

The theory of doubling the desired dry film thickness to determine the wet film to be applied is only correct if the solids by volume of the coating material is 50% and no field thinner is added. The solids by volume of the coating material is information readily available from the manufacturer and is commonly included in their product data sheets. The basic formula is:

$$\text{Dry Film Thickness} = \text{Wet Film Thickness} \times \text{\% Solids By Volume}$$

Because the dry film target is known and the wet film target is the unknown value, a more workable formula showing the required wet film thickness for the desired dry film thickness is:

$$\text{Wet FilmThickness} = \frac{\text{Desired Dry Film Thickness}}{\text{\% Solids by Volume}}$$

The above formula is accurate provided the solids by volume of material is accurate. The percentage will change, however, if any thinner is added to the coating. When thinner is added, the total volume of the material is increased without any corresponding increase in the amount of solids. Therefore, the thinned material will result in a lower percentage of solids by volume. Thus, when comparing thinned versus unthinned material in order to achieve a comparable dry film thickness, a heavier wet film application of the thinned material will be required. This formula, which incorporates the "adjusted" solids by volume should be used to determine the required wet film thickness when the coating is thinned:

$$\text{WFT} = \frac{\text{Desired Dry Film Thickness}}{\dfrac{\text{\% Solids by Volume}}{(100\% + \text{\% Thinner Added})}}$$

For example, assume a coating contains 78% solids by volume and is to be applied in one coat to a dry film thickness of 8 mils. Without thinner added, the required wet film thickness is determined:

$$\text{WFT} = \frac{8}{0.78} = 10.25 \text{ mils}$$

If the coating in the previous example is thinned 20%, the adjusted wet film is calculated as:

$$\text{WFT} = \frac{8}{\dfrac{0.78}{1.2}} = \frac{8}{(0.65)} = 12.3 \text{ mils}$$

Thus, without thinning, 10.25 wet mils are required to obtain 8 mils dry. After thinning, the solids by volume drops from 78% to 65% and the required wet film thickness increases by 2 mils.

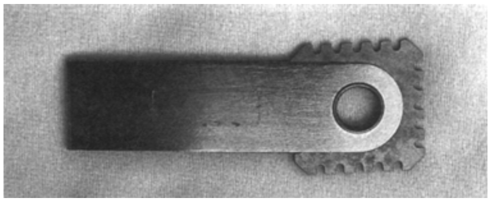

Figure 13. "Notch" wet film thickness gauge.

Because the use of the wet film thickness gauge is dependent on the solids by volume, and the solids by volume is considered to be the "in can" percentage, it is essential that wet film thickness readings be taken as soon as a film is applied to the surface. Actually, during spray application, some of the solvents will already have evaporated by the time the material that has left the gun reaches the surface, thus changing the percent of solids by volume slightly. For practical applications when measuring wet film thickness, this change is not very significant. However, the longer one waits before taking a reading, the less accurate that reading becomes. For highly pigmented coatings (such as zinc-rich), or very fast drying coatings, wet film thickness readings may be unreliable.

Determining Dry Film Thickness

Dry film thickness readings on steel substrates are commonly obtained non-destructively using magnetic gauges. For non-ferrous metallic substrates, eddy current equipment is used. Calibrate magnetic thickness gauges in accordance with SSPC-PA 2, Method for Measurement of Dry Paint Thickness with Magnetic Gages. Although the standard is written for magnetic gauges, many of the principles of operation and calibration apply to eddy current instruments as well.

Determining the thickness of each coat in a multicoat system should be an inspection “hold point.” When using magnetic gauges to measure multi-coat systems, the average of the first coat must be determined prior to applying the second coat. Readings taken after the second coat is applied will obviously be the cumulative thickness of the two coats combined, and the specific thickness of the second coat can only be determined by subtracting the average thickness obtained from the first coat reading. The second coat thickness cannot be determined precisely, however, because it is highly unlikely that specific readings taken on the second coat will be over an area of the first coat that is coincidentally the first coat average. Therefore, with magnetic gauges, unless precise locations are measured for each coat, it is nearly impossible to specifically determine the thicknesses of coats applied after the first. For example, if the specification requires 2-4 mils of primer, 4-6 mils of intermediate coat, and 2-3 mils of topcoat, the inspector should ensure the coating thickness is between 2 and 4 mils for the first coat, 6-10 mils for the primer and intermediate coat combined, and 8-13 mils for all three coats combined.

It is often a good idea, where practical, to provide a means to indicate coating thickness in areas where it is either thin or thick, so appropriate repair can be done. Possible methods are brush application of a contrasting color of the same paint, compatible felt tip marking pens, chalk or other material that can be readily removed, or graphic plotting and notations on charts and records.

Thickness readings are taken to provide reasonable assurance that the specified or desired dry film thickness has been achieved. However, it is not possible to measure every square inch of the surface. SSPC-PA 2 states that when using magnetic gauges, five separate spot measurements should be made over every 100 ft.^{2} in area. Each spot measurement consists of an average of three gauge readings next to one another. The average of the five spot measurements must be within the specified thickness, while the spot measurements (average of three gauge readings) are permitted to underrun or overrun the specified thickness by 20% (i.e., must be no less than 80% of the specified minimum thickness, nor any greater than 120% of the specified maximum thickness for each coat).

The single gauge readings making up the spot measurement can underrun or overrun by a greater amount. For example, a specification calls for 10 to 12 mils. The five spot measurements (each a cluster of three gauge readings) are: Spot 1 (10,11,12; average 11); Spot 2 (7, 8, 9; average 8); Spot 3 (12, 12, 12; average 12); Spot 4 (7,12,11; average 10); Spot 5 (12, 13, 11; average 12). This measured area would be acceptable because the average of the five spots is 10.6 mils and within specification. According to SSPC-PA 2, unless otherwise specified, the 8 mil spot measurement would be acceptable because “no single spot measurement . . . shall be less than 80% of the specified thickness” (8 mils is exactly 80%), and the 7 mil reading is acceptable because “single gauge readings . . . may underrun by a greater amount.”

Dry film thickness instruments fall into four basic categories: magnetic pull-off, magnetic-constant pressure probe, eddy current-constant pressure probe, and destructive. Each of the four categories is addressed separately.

Magnetic Pull-Off Gauges

The Mikrotest **(Figure 14)**, PosiTest, or Elcometer 211 magnetic pull-off gauges consist of a lever running through the center of a scale dial that houses a helical spring. The scale dial is located at the fulcrum point of the lever. One end of the spring is attached to the lever and the other end to the scale dial. One side of the lever contains a permanent magnet while the opposite end contains a counterbalance **(Figures 15 and 16).**

Figure 14. Mikrotest magnetic pull-off gauge.

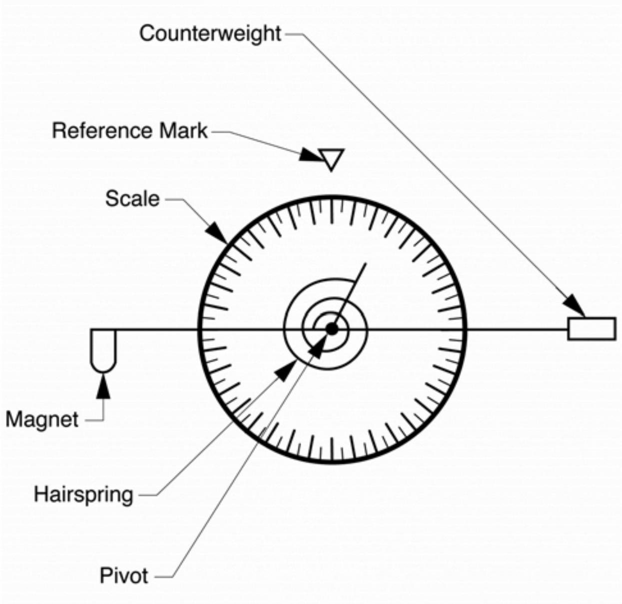

Figure 15. Principle of magnetic pull-off gauge.

To operate, the scale dial is turned counterclockwise and the magnet brought into direct contact with the metal substrate (through the coating or non-magnetic barrier). Next, the scale ring is turned clockwise (manually or automatically), increasing the spring tension, which applies a pulling force onto the magnet. Ultimately, the spring tension overcomes the attraction of the magnet to the substrate, lifting the magnet from the surface. The spring tension is calibrated so that the point where the magnet breaks contact with the surface can be equated to the distance of the magnet from the surface. This distance is read directly from the scale dial or digital read-out in mils (or microns). The calibrated spring tension is an inverse logarithmic relationship of the distance between the magnet and the substrate (i.e., the greater the spring tension required to remove the magnet, the thinner the coating).

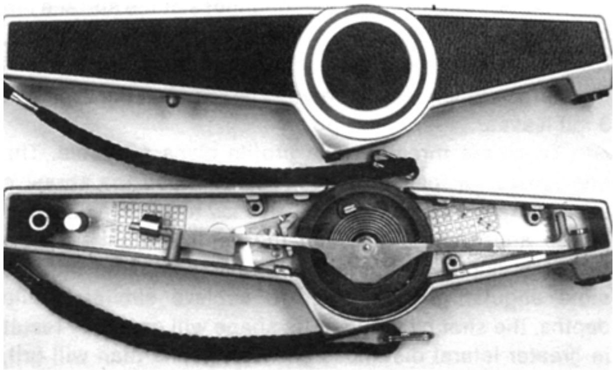

Figure 16. Inside of Mikrotest magnetic pull-off gauge with components corresponding to schematic in previous figure.

Note that the thickness reading shown on the gauge when the magnet breaks contact with the surface represents the gap between the magnet and the substrate. This gap is considered to be the coating thickness. However, it could also be comprised of voids, rust, embedded contaminates, etc. Therefore, one must include a thorough visual inspection during the work to ensure that the coating is applied over a clean surface and does not become contaminated during drying. Also, coating thickness gauges measure galvanizing as coating thickness, as they are not capable of distinguishing one layer from another (galvanizing is non-magnetic). Therefore, if the inspector only wants to measure only the “coating” thickness, baseline measurements of the galvanizing must be obtained prior to coating application, then subtracted from the gauge readings to obtain coating thickness values exclusive of galvanizing.

The Mikrotest, PosiTest, and Elcometer 211 gauges should be calibrated, or at least have their calibration verified prior to, during, and after each use to ensure that they are measuring accurately. SSPC-PA 2 defines the pull-off instruments as Type 1 gauges. Calibration test blocks similar to those supplied by the National Institute of Standards and Technology (NIST), chrome and copper plated steel, are used to verify the accuracy of Type 1 gauges. The use of plastic shims is not recommended. It is essential that the instrument is verified for accuracy in the desired thickness range of use. If a coating is being measured in the thickness range of 2 to 4 mils, calibration should be verified in that range rather than at 20 mils.

Calibration with NIST plates requires that the gauge reading be matched against the readings on the plates. Next, a series of gauge readings on the bare, uncoated substrate is obtained after blast cleaning (or other surface preparation). The instrument will generally read between 1/10 and 2/10 of a mil up to 1 mil or more over the bare steel. Therefore, any coating thickness readings taken must be corrected by this base metal reading, or BMR in order to determine the coating thickness above the peaks of the profile. Adjust subsequent thickness readings by subtracting the BMR. For example, if the instrument is calibrated to a 4 mil NIST Standard, and a 0.5 mil BMR is measured, a paint thickness reading of 3.5 mils indicates that the true coating thickness above the peaks of the surface profile is actually only 3 mils. The BMR does not represent surface profile depth. Rather, it represents the effect of the surface profile on a paint thickness gauge. It is very important that the inspector not subtract the surface profile measurement from the coating thickness, as the thickness will be reported as being too low. Using this example, if the surface profile measured with the Keane-Tator Comparator is 2 mils, and this were subtracted from the thickness reading, it would be assumed that the coating thickness was 1.5 mils, rather than the true 3 mils.

Another type of magnetic pull-off gauge, based on a similar principle is the pencil pull-off gauge **(Figure 17).** Basically, the instrument housing is similar to a large pencil with a magnet at the bottom. An extension spring is attached to the magnet and to the top of the instrument housing. The instrument is held perpendicular to the surface and the magnet brought into contact with the substrate. As the housing is lifted, the magnet remains attached to the substrate until the spring tension overcomes the attraction of the magnet, popping it from the surface. The tension on the spring required to lift the magnet is read from the scale in mils or microns **(Figure 18).** This instrument cannot be adjusted, although calibration should be verified. In this case, however, a calibration correction curve is necessary if the instrument does not read correctly on the standards. The preferred method for verifying calibration is the use of calibration test blocks (e.g., NIST). Pencil-style gauges provide a quick check of coating thickness, but for most of these gauges, considerable judgment is involved in determining the point at which the magnet breaks from the surface, as most do not retain the measurement once the magnet is detached.

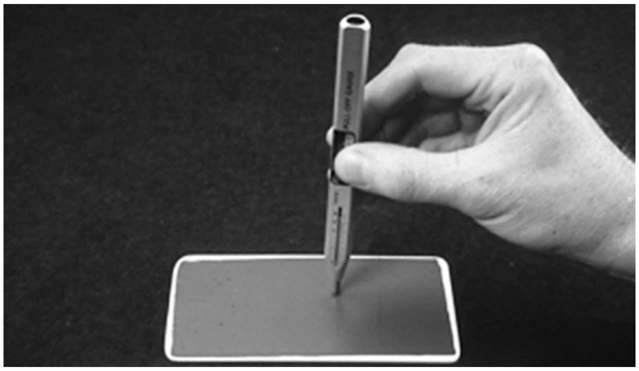

Figure 17. Pencil pull-off gauge.

Special precautions are necessary when using any instrument that involves a magnet. First, the magnet is exposed and therefore susceptible to attracting iron filings, or steel shot and grit particles. The magnet must be cleaned of any contaminants during use, or the contaminant will incorrectly be read as coating thickness. This is extremely important in shop work where grinding operations are common. Iron filings attach to the exposed magnet often requiring that the magnet and coating surface be cleaned before each thickness reading. If the instrument is used on a soft film, allowing the magnet to sink into the surface, a thinner coating thickness will be recorded. This is because the coating itself may be tacky, holding the magnet beyond the point where the spring should have lifted it from the surface, or the coating under the depression caused by the magnet actually will be thinner. In this case, place a plastic shim on top of the surface to prevent the magnet from deforming the coating and subtract the shim thickness from any subsequent readings. In addition, if there are

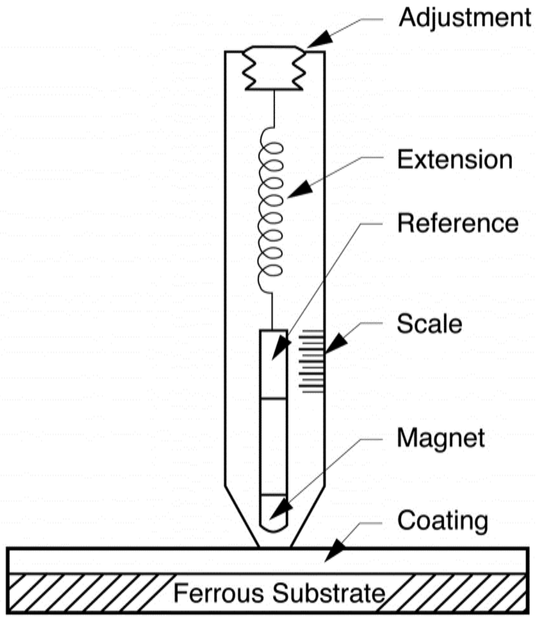

Figure 18. Principle of pencil pull-off gauge.

any vibrations in the area of instrument use, they could cause the magnet to be detatched from the surface prematurely, giving an erroneously high thickness reading. Finally, residual magnetism in the structure on which the coating is measured can have an adverse effect on the readings.

Scale dial instruments have an additional "human error" problem during use. It is easy to continue to turn the dial beyond the point that the magnet has lifted from the surface giving an incorrect thickness reading. It is imperative then that the dial be stopped as soon as the magnet lifts from the surface. Automatic versions of the Mikrotest have addressed this problem by incorporating a self-winding mechanism that automatically retracts the thumb wheel.

Constant Pressure Probe Gauges

SSPC-PA 2 describes constant pressure probe gauges as "Type 2" gauges. They include the Elcometer 456 **(Figure 19),** Positector 6000 **(Figure 20),** QuaNix 2200 **(Figure 21),** QuaNix Keyless **(Figure 22),** QuaNix 1500 **(Figure 23),** eXacto **(Figure 24),** Minitest 4100 **(Figure 25),** Elcometer 355 **(Figure 26)**. Type 2 gauges also must be verified for calibration prior to use. Calibration verification is accomplished using the non-magnetic shim method described here or the NIST calibration plates described previously. When calibrating using the plastic shim method, verify the shim thickness with a micrometer. Hold the shim firmly on the bare cleaned substrate and measure it with the instrument. If the instrument does not read the shim thickness, adjust the gauge or address the discrepancy according to the manufacturer's instructions, keeping in mind that some gauges cannot be field calibrated. Check the calibration by using shims of lesser and greater thickness to determine the range of accuracy. The

Figure 19. Elcometer 456.

Figure 20. Positector 6000.

Figure 21. QuaNix 2200.

Figure 22. QuaNix Keyless.

Figure 23. QuaNix 1500.

Figure 24. eXacto.

Figure 25. Minitest 4100.

Figure 26. Elcometer 355.

instrument is now ready to measure thicknesses within that range over the same substrate and surface preparation. If a section of the bare substrate is unavailable, clean small steel test panels (e.g., 1/8X4X6 inches) to obtain the same or a similar anchor pattern and cleanliness, protect them from corrosion using a rust-inhibitive paper or other suitable means, and use the panels for calibration. The instrument will correctly record the thickness of the coating material. Any effect of surface roughness is calibrated into the instrument because it was adjusted over the bare steel, thus eliminating the need for a BMR correction factor.

These gauges experience some of the same problems as pull-off gauges: lower than actual thickness readings on soft or tacky films and difficulty in keeping the magnet clean. In addition, SSPC-PA 2 cautions the user to stay at least 1 inch in from all edges, unless the gauge has been specifically calibrated for these locations.

Figure 27. PosiTest 100 ultrasonic gauge.

Eddy Current Gauges

Eddy current instruments—PosiTector 6000N and the QuaNix Keyless, among many others—measure the thickness of non-conductive coatings on non-ferrous metal substrates. The probe is energized by alternating current, inducing eddy currents in the metal. These currents create opposing alternating magnetic fields within the metal, modifying the electrical characteristics of the probe coil. The extent of these changes is determined by the distance of the probe from the substrate and is shown on a display as coating thickness. Eddy current instruments are calibrated using the plastic shim method. Most gauge manufacturers supply gauges that will measure coating thickness on both ferrous and non-ferrous metal surfaces.

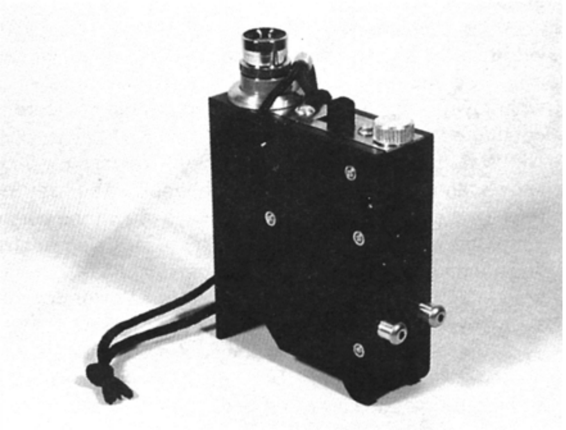

Figure 28. Tooke scratch gauge for determining dry film thickness by cutting a cross-section through the film and viewing it under magnification.

Figure 29. Modified Tooke gauge with all three cutting tips mounted on the instrument body and three bulbs to improve lighting.

Ultrasonic Coating Thickness Gauges

Coating thickness measurements over non-ferrous, nonmetallic surfaces such as concrete and wood can be obtained non-destructively using a coating thickness gauge that operates on an ultrasonic principle. The PosiTest 100 **(Figure 27)** can measure total coating thickness on these surfaces, and in some cases can distinguish coating layers. A gel or couplant must be applied to the probe prior to measurement, and must be wiped from the coated surface to prevent contamination when applying subsequent coats.

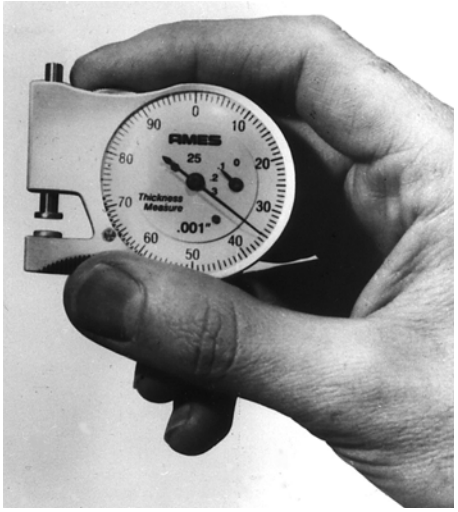

Figure 30. A hand-held, spring-loaded micrometer useful for measuring the thickness of coating chips.

Destructive Coating Thickness Instruments

Destructive thickness testing includes the use of the Tooke, or paint inspection, gauge (PIG) **(Figures 28 and 29),** micrometers **(Figure 30),** or microscopes **(Figure 31).** The Tooke gauge consists of a 50X microscope that is used to look at scribes in the coating made by precision cutting tips supplied with the instrument. The principle of the Tooke gauge is basic trigonometry. By making a cut through the coating at a known angle and viewing perpendicular to that cut, the actual coating thickness can be determined by measuring the width of the cut from a scale in the eyepiece of the microscope. The instrument can be used for determining the thickness of underlying coats in multicoat systems and eliminates many of the drawbacks of the magnetic instruments caused by magnetic fields, proximity to edges, irregular surfaces, magnetic effect of the substrate, profile, and so forth. The instrument can be

used on coating thicknesses up to 50 mils provided the coating is not too brittle or elastic for a smooth cut.

Figure 31. Pocket-sized 30X microscope with integral light source.

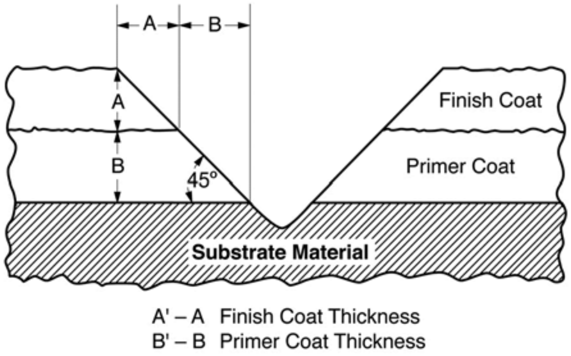

Figure 32. Measurement principle of Tooke gauge.

Cutting tips of different angles are available. They are designated as either 1X, 2X, or 10X. The tip used determines the thickness equivalent for each line or division in the microscope eyepiece. The number of divisions corresponding with the coating is divided by the number of the tip used. Therefore, 1 division when using the 1X tip is equivalent to 1/1 or 1 mil; 1 division with the 2X tip is 1/2 or .5 mil; and 1 division with the 10X tip is 1/10 of 1 mil (0.1). Thus, if the coating cross-section covers 7 divisions and the 2X tip is used, the thickness is 7/2 or 3.5 mils **(Figures 32 and 33).**

Another means of destructively measuring coating thickness is to remove a sample of the coating from the substrate and measure the thickness using a standard micrometer. The coating chips could also be returned to a laboratory for microscopic thickness determinations. The Tooke gauge may also be used for this purpose. When viewing the edge (cross section) of a disbonded chip through the Tooke gauge lens, each division of the microscope is equivalent to 1.0 mil.

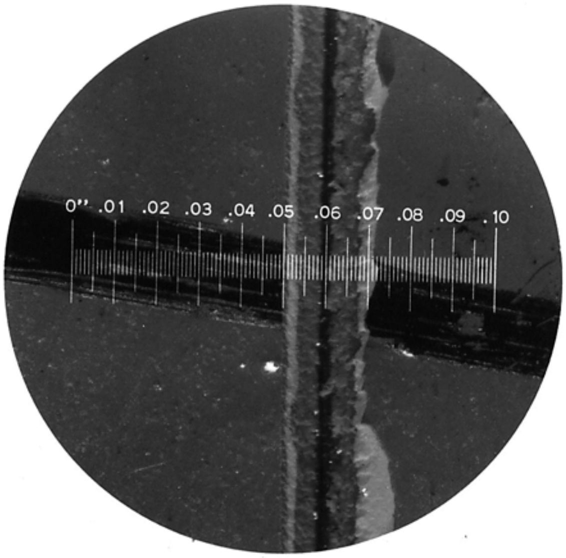

Figure 33. View through Tooke gauge microscope. The interface of the coating/substrate is one division to the left of .06 on the scale. Coating thickness is measured from this point on the left ending at the black bench mark at .05.

Cleanliness Between Coats

Where more than one coat is to be applied, an important inspection "hold point" is determining surface cleanliness immediately prior to applying the next coat. In addition to dirt and dust, dry spray or overspray can cause overcoat problems.

All contaminants should removed because their presence can result in reduced adhesion between coats and coating film porosity, rendering the coating less resistant to the effects of the service environment. The surface should also be inspected for any contamination from the environment (e.g., residue from chemical facilities, salt, etc.)

Pinhole and Holiday Detection

After all coats of paint have been applied, the inspector should verify that the appropriate clean-up is done, and that any abrasions, nicks, or scrapes are repaired. Often holiday, pinhole, or spark testing is used to find nicks, scrapes, and pinholes in the coating film, particularly if the coating is intended for immersion service. A "holiday" is a skip or missed area on the structure. Holiday testing may be required after application of either the next to last, or the last coat of paint. When performed between coats, however, there is the risk of spreading contamination that could influence the performance of the subsequently applied coat. Usually when such testing is specified, it is done before final cure has occurred so that any repair will successfully bond to the underlying coat.

Figure 34. Tinker-Rasor low-voltage wet sponge holiday detector used for finding pinholes and holidays in non-conductive paint films up to 20 mils thick when applied to conductive substrates.

Pinhole and holiday detectors fall into three categories: low-voltage wet sponge **(Figures 34 and 35),** DC high-voltage **(Figures 36 and 37),** and AC electrostatic types.

The low voltage wet sponge holiday detectors are used for locating discontinuities in nonconductive

Figure 35. Using a low-voltage wet sponge holiday detector to locate discontinuities in non-conductive coatings applied to conductive metal substrates.

Figure 36. Spy high-voltage holiday detector for uncovering flaws in thick coating systems. Voltages are available up to 22,000 volts DC. A spark jumps from the electrode through the coating at deficient areas.

Figure 37. D.E. Stearns high-voltage holiday detector used for non-conductive coatings applied to conductive substrates.

coatings applied to conductive metal surfaces. The low voltage detector is suitable for use on coatings up to 20 mils. The basic unit consists of the detector itself, a ground cable, and a sponge electrode. The ground cable is firmly attached to the bare substrate and the sponge electrode is saturated with tap water. The electrode (wetted sponge) is moved across the entire surface, the water permitting a small current to flow through the pinholes down to the substrate. Once the current reaches the substrate, the circuit is completed to the detector unit and an audible signal can be heard indicating that a pinhole or discontinuity is present. When coatings are in the range of 0 to 20 mils, a non-sudsing wetting agent (such as Eastman Kodak Photo-Flo) may be added to the water to increase the wetting properties. If the coating system is found to be greater than 20 mils, high-voltage holiday detection equipment should be used.

High-voltage detectors consist of a testing unit capable of producing various voltage outputs, a ground cable, and an electrode made of conductive materials such as neoprene, brass, or steel. High-voltage units are available up to 35,000 volts and are used for nonconductive coatings applied to conductive substrates. The ground wire is firmly attached to a section of the bare substrate and the electrode is passed over the entire surface. A spark will jump from the electrode through the air gap down to the substrate at pinholes, holidays, or missed areas, simultaneously triggering audible and/or visual signaling device on the unit. It is important to use only the voltage level recommended by the coating manufacturer for the coating thickness. Otherwise, damage to “good” coating could occur. A rule of thumb is to apply

100–125 volts per mil of coating.

For exterior pipeline work, many times the ground wire of the holiday detector is permitted to drag across the earth provided the pipe itself is grounded to the earth. However, the preferred method of testing is to attach the ground wire directly to the substrate whenever possible.

When testing conductive linings applied over steel substrates (i.e., conductive rubber linings), the AC Tesla coil electrostatic tester is generally used. It has a variable voltage output (preferably, the voltage is indicated) but does not require the use of a ground wire.

The unit constantly emits a blue corona, but emits a white spark whenever it passes over a break in the lining. Note that surface contaminants or dampness may also cause a color change or spark; therefore, it is advisable to clean and retest questionable areas to confirm that a holiday or pinhole is truly present.

Field Adhesion Testing

Occasionally, there is a need to test coating adhesion after application. In flame spray and electric arc metallizing, adhesion testing is common. The different types of adhesion testing methods used range from a simple penknife to more elaborate testing units. A penknife generally requires a subjective evaluation of the coating adhesion based on some previous experience. Generally, one cuts through the coating and probes at it with the knife blade, trying to lift it from the surface to ascertain whether or not the adhesion is adequate. ASTM D 6677 describes this method with a rating scale.

A more common field method for adhesion testing is the tape and knife test as described in ASTM D 3359, Measuring Adhesion by Tape Test. This testing consists of cutting an “X” or a number of small “squares” through the coating down to the substrate. Tape is rubbed vigorously onto the scribed area and removed firmly and quickly. The test area is evaluated according to the amount of coating removed. The “X” cut (Method A) is used for coatings in excess of 5 mils and the “cross-cut” (Method B) is used for coatings less than 5 mils, although the cross-cut can be used for heavier coatings if the spacing between cuts is adjusted. The distance between the parallel knife cuts for Method B is based on the thickness of the coating being tested (0–2 mils = 1 mm spacing; 2–5 mils = 2 mm spacing). Although not addressed in the ASTM standard, spacing of 5 mm is common for coatings heavier than 5 mils.

There are also instruments available for testing the tensile (pull-off) adhesion strength of coatings. They apply a value to the adhesion strength in pounds per square inch (psi), kilopascals (kPA), or megapascals (mPA), thus eliminating some of the subjectivity of the other tests. Instruments for tensile testing include mechanical, pneumatic, and hydraulic adhesion testers **(Figure 38).** The tensile adhesion test kits consist of the test unit itself and aluminum or stainless steel pull stubs. The pull stubs are cemented to the coating surface with adhesive. After the adhesive has cured, the test instrument is attached to the pull stub. It applies a pulling force on the stub, ultimately breaking it from the surface. The point of the break is read from the scale on the instrument, then converted to psi, kPA, or mPA. This method is described in ASTM D 4541.

Figure 38. Tensile adhesion test kit.

Not only is the numerical value of importance when using this method, but also the type of break. For example, there is a significant difference in the test results if one finds a clean break to the substrate or between coats, compared to finding a cohesive break within a coat. Adhesive failure may also occur. This then establishes that the coating tensile adhesion strength is at least as good as that pressure that broke the adhesive. Attaching a second set of pull stubs may be necessary, depending on the value obtained.

It is generally recommended that two-component epoxy adhesives are used instead of single-component fast drying cyanoacrylates. When testing zinc-rich coatings, for example, it has been found that the thin cyanoacrylates may have a tendency to penetrate and bond the zinc particles together, resulting in a much higher tensile pull than should be expected. In other cases, the adhesive appears to soften and cause premature coating system failure. Adhesives that cure by UV light are also available and show promise for conducting tests within minutes of attaching the pull stub.

Evaluating Cure

The applied coating film must be allowed to cure for a given length of time prior to being placed into service. This cure time is generally shown on the manufacturer's product information sheet. Alternately, forced-heat curing may be used to reduce the time between final curing and service.

Determining the cure is generally difficult. When most coatings are suitably cured, rubbing them with sandpaper will produce a fine dust. If the sandpaper gums up, depending upon the coating, it may not be thoroughly cured. Certain phenol-containing coatings may discolor upon heating—and the cure of phenolic tank lining coatings is often determined by comparing their color with color reference coupons supplied by the coating manufacturer.

Pencil hardness (ASTM D 3363) is recommended by some coating manufacturers as a method for determining cure, and ASTM D 4752 describes a solvent rub test (using methyl ethyl ketone or MEK) for characterizing the cure of ethyl silicate inorganic zinc-rich primers. ASTM D 5402 describes a similar solvent rub test for use on organic coatings and ASTM D 1640 describes another cure test.

Because a coating is "dry" or hard does not necessarily mean that it is cured. In fact, for most coatings, hardness is not synonymous with cure. The only coating types for which this is true are solvent-deposited coatings, such as chlorinated rubbers and vinyls. Even then, residual retained solvents (and moisture in water-borne coatings), under certain atmospheric conditions of temperature and/or humidity may take a long time to escape from the paint film. Final film properties require satisfactory solvent evaporation. In some cases, this evaporation process may take as long as two or three weeks or more, depending on the prevailing conditions.

Conclusions

There are a wide variety of inspection instruments available to help ensure the adequacy of the ambient conditions, surface preparation, wet and dry film thicknesses, and final coating continuity and integrity. The instruments all have advantages and limitations, but the overriding factor in their successful use is the knowledge and ability of the individual using them.

It is important that the instruments be cared for, calibrated, and used properly. However, inspection using instrumentation is only part of the total process. It must be combined with good common sense and visual inspections of misses, skips, runs, sags, surface contaminants, overspray, dry spray, and any other defects that may be objectionable for the intended service. Finally, all of the results of any inspection should be thoroughly documented (in writing) to prove that the specified requirements have been met. Future maintenance or the removal and maintenance of a failed coating system may be dependent on the factual reporting of every phase of the work.

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