
Coating Application and Inspection

Course No: T03-001

Credit: 3 PDH

Gilbert Gedeon, P.E.



Continuing Education and Development, Inc.
22 Stonewall Court
Woodcliff Lake, NJ 07677

P: (877) 322-5800
info@cedengineering.com

Chapter 8 Coating Application

8-1. Introduction

a. Transferring coating materials from the can to the substrate can be accomplished in several ways. Application methods can range from simple brush and roller to sophisticated spraying. All application methods have inherent advantages and limitations.

b. The choice of an application method depends on the type of coating to be applied, the type and size of surface to be coated, and governing environmental regulations. Contracts will either specify the application method to be used or will permit the contractor to choose a method. However, the consistency of some coatings may dictate a particular method. For example, coatings that are excessively viscous may not permit effective application by spray; or a low viscous coating may only be effectively applied by spray. Either the specifications or the manufacturer's instructions usually will indicate the preferred application method.

8-2. Methods of Coating Application

There are various methods of coating application, including brush application, roller application, conventional spray, high volume-low pressure spray, airless spray, plural component spray, and electrostatic spray. The technologies, techniques, advantages and limitations, equipment, typical coating types involved, and safety considerations for each type of application method will be discussed.

a. Brush application.

(1) There are a variety of brush sizes, shapes, bristle types, and uses. The brush most commonly used for structural steel and similar substrate applications is the conventional wall brush. Oval brushes are commonly used for structural and marine applications, particularly around irregular surfaces such as rivets, boltheads, piping, railing, and similar areas. Widths for the conventional wall brush vary from 25.4 to 152.4 mm (1 to 6 in.), but the most commonly used size is 101.62 mm (4 in.) The two types of bristles used in brush assemblies are synthetic (nylon) fibers and natural (hog) bristle fibers. Synthetic bristles have excellent abrasion resistance when coatings are applied to rough, uneven steel; concrete; and masonry surfaces. Although not affected by most solvents, coatings containing such strong solvents as ketones may affect the synthetic fibers. Natural (hog) bristles, although more expensive and water sensitive, provide the best leveling application

characteristics and strong solvent resistance. Proper brush and bristle selection for a specific coating application is imperative for a quality application.

(2) Good brush loading and coating distribution techniques will provide an even application free of laps, runs, drips, and other unacceptable finish characteristics. The brush should be held lightly but firmly, and the paint should be spread over the surface with moderate, even pressure by stroking in one direction, followed by stroking at right angles to the previous coat.

(3) An advantage of brush application is the ability to stripe coat. In many instances, brushing difficult areas (e.g., edges, rivets, corners, boltheads, and welds) prior to the application of a general spray coat is recommended; this process is known as striping. Striping is performed to assure adequate coverage and thickness of the applied coating for areas that are difficult to coat properly by general spray application alone. However, brushing, including brush striping, is not recommended for application of vinyl zinc-rich and epoxy zinc-rich coatings because the zinc must be kept in suspension during application. This is accomplished using agitators in the spray pot or pump. Another advantage of brush application is that it aids in thorough wetting of the substrate, particularly on surfaces that are porous.

(4) Limitations of brush application are that it is slow and tedious, and it may not produce a uniform coating thickness. Brush application of a coating is not practical for large surfaces, and it may leave unsightly brush marks with coatings that do not level well. Brush application of certain coatings, such as high-solids and fast-drying coatings, is difficult and generally is not recommended.

(5) Oil-based and waterborne coatings typically are the most common coating types applied by brush, and their application characteristics are considered good to excellent. The oil-based, slow-drying paint should be brushed out thoroughly to work the coating into cracks, crevices, or other irregular surfaces. Faster drying paints (waterborne) should be brushed out quickly and evenly; otherwise, overbrushing will leave brush marks as the paint dries.

b. Roller application.

(1) The roller assembly consists of a cover and core. Roller covers vary in diameter, length, type of fabric, and fiber length (nap). The 38.1-mm (1-1/2-in.) diameter and 228.6-mm (9-in.) length is the most common size. Polyester, nylon, mohair, and lambskin are typical cover fabrics. Selection of fabric and fiber length depends on the type of coating and the condition of the surface. Woven

fabrics shed fewer lint particles, so they typically are designated for all coatings, especially gloss coating. In addition, longer fibers hold more coating, but they do not provide as smooth a finish. The length of fiber used on steel surfaces varies from 6.35 to 19.05 mm (1/4 to 3/4 in.). Additionally, the roller core must be resistant to strong solvents when applying epoxies, vinyls, urethanes, and similar materials. There are three special types of rollers, including the pipe roller, fence roller, and pressure roller.

(a) The pipe roller is constructed of two to five narrow rollers on a single spring spindle. The rollers readily conform to contoured surfaces, such as piping. The size of the pipe determines the number of segments required, and the threaded handle accommodates the use of an extension pole.

(b) Fence rollers require roller covers with extra long nap (31.75 mm [1-1/4 in.]). These covers enable rapid coating of wire fence from one side because the long nap surrounds the fence wire and coats it on both sides concurrently.

(c) A pressure roller permits continuous coating by steadily supplying coating from a pressurized tank to directly inside the roller. The roller cover is made of a perforated core that enables a coating to pass from inside the roller to the nap. The valve that controls the pressure is located on either the roller handle or the tank.

(2) The roller should be uniformly loaded with paint to provide even application. Skipping will occur when paint is inadequately loaded onto the roller. However, tracking will occur if an excessive amount of paint is loaded onto the roller. Proper application pressure and technique should be used; initially, a zigzag overlapping application should be performed followed by a second coat applied at right angles to the first coat.

(3) Rollers are excellent for large, flat areas (e.g., tank sidewalls and tops, decks, ship hulls, walls, and ceilings) or whenever application does not require the skill needed for brush or spray application. Rollers also are recommended for use in windy conditions to eliminate excessive material loss and overspray. Rollers may be used for indoor application when overspray cannot be tolerated. Roller application on concrete cracks and voids is difficult because of the shape of the roller; therefore, a brush is recommended to work the coating into these areas. Roller application is more rapid than brush application but slower than spray application. A roller generally holds more coating than a brush, and it will provide a more satisfactory finish on smooth surfaces compared with rough or irregular surfaces. Brush or spray application is the preferred method for rough or irregular surfaces.

(4) Roller application characteristics for oil-based and waterborne coatings are excellent, and epoxies and urethanes are considered to be fair to good. Roller application characteristics for high solids coatings and inorganic zinc-rich coatings are considered poor. High performance coatings/linings for immersion are seldom applied by roller because of nonuniform thickness and wicking caused by roller nap residue.

c. Conventional spray application.

(1) Equipment. The conventional method of spraying relies on air for coating atomization. Jets of compressed air introduced into the stream of coating at the nozzle break the coating into tiny droplets that are carried to the surface by the current of air. The transfer efficiency is estimated to be 25 to 30 percent. A typical, conventional spray setup consists of: air compressor, oil and water extractor (separation), pressure feed tank (pressure pot) or paint pump, connecting hoses, and spray gun.

(a) Although the pot regulates both the air and fluid pressures fed to the spray gun, the air compressor generates the necessary pressure for these two flow operations. Air compressors can be of various types, and the size usually depends on the amount of air required in cubic feet per minute to operate the spray gun. Hoses must be properly sized to deliver the right amount of air volume and pressure to the spray gun. Approximately 275.6 to 413.4 kPa (40 to 60 psi) and 4.012 liters/sec (8.5 cfm) are needed to operate most production conventional spray guns with a medium viscosity coating such as latex paints, some lacquers, stains, sealers, alkyds, and conventional epoxies such as those specified in MIL-P-24441A.

(b) A separator should be in line, between the air compressor and the pressure pot, to prevent moisture and oil from reaching the coating. Moisture/oil separation for conventional spray should be considered mandatory. The use of properly sized and maintained moisture and oil separators helps ensure the quality of the finished product. In addition to adhesion defects, oil or moisture in the compressed air will mix with the coating during atomization and create voids, pinholes, and/or fisheyes in the applied film. A blotter test should be conducted at the spray gun prior to application to ensure a clean, dry supply of atomized air.

(c) The amount of fluid material delivered to the spray gun is controlled by the fluid pressure regulator of the feed tank pressure pot, which is a double regulator type. The pressure pot should be 19 or 38 liters (5 or 10 gallons) in size for most jobs. For the application of certain coatings such as zinc-rich coatings, the pot should be equipped with a mechanical agitator to keep the zinc-rich coating in

suspension so the zinc does not settle on the bottom of the pot. If application stops and resumes after 15 minutes when spraying zinc-rich coatings, the entire length of the hose should be whipped to redisperse the coating in the line. If more than 1 hour has passed, all the coating in the line should be blown back into the pot and reagitated prior to use. The mixing and straining of paints are covered in Chapter 9. When coating tall structures, the pot should be kept at nearly the same level as the spray gun so lower pot pressures (55.12 to 82.68 kPa [8 to 12 psi]) can be used. Longer hoses and higher pot pressures are required when the pot is not at the work level. Excessive fluid pressure may cause the fluid stream to exit the fluid nozzle at a higher velocity than the air jets in the air nozzle can properly atomize. When the pot is not placed at or near the work level, the lower pot pressures can be maintained by using a fluid pump to pump the coating from the pot to the gun. These pumps are commonly used with hot spray setups.

(d) Two types of hoses are used in conventional spray coating: the air hose and the fluid hose. The air hose (supply line) from the compressor to the pot typically is red and usually is 19 to 25 mm (3/4 to 1 in.) i.d. The air hose from the pot to the spray gun also is red and should be 6.35- to 7.9-mm (1/4- to 5/16-in.) i.d. and as short as possible. The fluid hose usually is black and has a solvent-resistant liner. The inside diameter should be 7.9 to 9.5 mm (5/16 to 3/8 in.) for medium viscosity materials and also should be as short as possible. Hoses up to 12.7-mm (1/2-in.) i.d. are commonly used. Excessive hose length allows the solids to settle in the line prior to reaching the spray gun. This leads to clogging and the application of a nonhomogeneous film.

(2) Conventional hot spray. Conventional hot spray is similar to the standard conventional spray and is used during cooler temperatures to lower viscosity of the paint without having to add additional thinners. This reduction in paint viscosity is achieved by heating the coating to 66 to 71 °C (150 to 160 °F). The paint is hot when it leaves the spray gun, but the atomizing air cools the paint and evaporates the solvents. When the paint reaches the surface, it usually is only a few degrees warmer than if it was not heated. This process also provides less overspray because the material can be atomized at lower pressures. The hot spray process eliminates the need for additional thinners for application at colder temperatures. Excessive thinners reduce film buildup and cause solvent popping (craters) and orange peel. The equipment used in this process, in addition to the typical equipment, involves a heater and a hose from the heater to the spray gun; therefore, two material hoses are required. Hot spray application generally is restricted to the shop. Application without heating is used in the field because all types of paints can be used, including catalyzed paints.

These catalyzed coatings cannot be used with the hot spray method because the heat will cause the coatings to set up in the equipment.

(3) Spray gun and adjustments. By varying the volume of air and coating at the spray gun, the amount of atomized coating can be regulated. The selection of a fluid nozzle and needle size is another way to regulate the amount of coating exiting the fluid nozzle. Excessive amounts of coating flowing through the fluid nozzle at low pressures (55.12 to 82.68 kPa [8 to 12 psi]) can be reduced by adjusting the material flow knob on the gun. Alternatively, a smaller fluid nozzle/needle combination may be used. Coating manufacturers normally recommend at least one set of sizes known to work for their product. The air nozzle cap can be for either internal mix or external mix. The internal mix involves mixing of the coating and air inside the spray nozzle. The external mix involves mixing of air and paint outside the nozzle between the horns. The most common method is the external mix because it produces a fine atomization and, if properly controlled, will provide the best quality finish. Internal mix nozzles do not provide the same quality finish as the external mix, and they are not recommended for fast-dry-type coatings (lacquer) because the coating tends to clog the nozzle tip, which results in distorted spray patterns. With both types, the atomized air breaks the streams into tiny paint droplets and provides the velocity for the coating to reach the surface. The pattern of the spray (round or oval) is determined primarily by the air adjustments on the gun and the air cap design. The needle valve regulates the amount of coating material that flows through the fluid nozzle. The distance that the needle can be withdrawn from the fluid nozzle is controlled by the fluid control knob on the back of the spray gun. The air valve is operated by the gun trigger. When the trigger is pulled, the air flow begins then the fluid flow follows. This is a major advantage of conventional (air) spray. By half-triggering the gun, the atomized air flows (without coating). This airstream is used to remove dust and loose debris from the surface prior to the coating application. The trigger is fully depressed to apply the coating.

(4) Spray application techniques.

(a) After the fluid and air pressures are properly adjusted, several basic spray techniques should be used to ensure the application of a consistent film of coating. A spray pattern 203.2 to 254 mm (8 to 10 in.) wide should be created by adjusting the air pattern control knob. The spray gun should be held at right angles to the work surface. "Arcing" the gun or flipping the wrist at each end of a pass results in a nonuniform coating film and excessive overspray.

(b) For large flat areas, each stroke should overlap the previous one by 50 percent. This produces a more uniform coating thickness. The stroke length may vary from 457.2 to 914.4 mm (18 to 36 in.), depending on the sprayer's arm length. To build a uniform coating thickness, a cross-hatch technique is usually used. The cross-hatch spray technique consists of a wet spray coat, using 50 percent overlap, followed by another full wet spray coat at right angles to the first.

(c) The spray gun trigger should be released at the end of each pass. At the beginning of a pass, the gun should be in motion prior to pulling back on the spray gun trigger and continued briefly after releasing the trigger at the end of the stroke. This produces a uniform, continuous film. Proper triggering also reduces coating loss; prevents heavy buildup of coating at corners, edges, and ends of strokes; eliminates buildup of fluid on the nozzle and tip; and prevents runs and sags at the start of each stroke.

(d) Proper spray techniques, which are necessary to produce a quality coating application, typically are acquired with experience. Quality coating application also depends on proper thinning of the coating, correct fluid pressure, and proper fluid nozzle size. Using proper techniques, a uniform coating thickness should be attained. Most types of paints, including epoxies and vinyls, can be effectively applied with a nozzle orifice size of 0.070 in. When spraying normal viscosity coatings, the orifice size generally should not exceed 0.070 in. because flooding may occur. Coal tar epoxies can be applied effectively using a 0.086-in. nozzle orifice.

(e) The proper gun-to-surface distance for a uniform wet film generally varies from 203.2 to 254 mm (8 to 10 in.) for conventional spray (compared to 12 to 18 in. for airless spray). If the spray gun is held too close to the surface, the gun must be readjusted or heavy coating application with sags and runs will occur. If the spray gun is held too far from the surface, dry spray will result and cause holidays or microscopic pores in the coating.

(f) Striping by spray also can be performed. A good practice is to apply an extra spray pass (stripe coat) prior to the first general spray coat not only on the edges but also on corners, interior angles, seams, crevices, junctions of joint members, rivets, weld lines, and similar irregular surfaces. This technique will assure adequate film buildup within complex, irregular areas. A full cross-hatch spray coat is applied after this striping.

(5) Advantages. Spray application of coatings is a highly efficient method of applying high performance coating systems to a substrate, and it results in a smoother, more uniform surface than obtained by brushing or rolling

because these application methods tend to leave brush or stipple marks and result in irregular thicknesses. Large amounts of material can be applied in very short periods of time with spray application compared to brush and roller application. The ability to independently vary fluid and air gives conventional spray the ability to provide a wide selection of pattern shapes and coating wetness by infinitely varying the atomization at the gun. Conventional spray application has a high degree of versatility and relies on a combination of air caps and fluid nozzles available for different coatings. Spray gun triggering is more easily controlled for precise spraying of irregular shapes, corners, and pipes than with airless spray. The spray gun also can be used to blow off dust from the surface with compressed air prior to applying the coating. Conventional spraying provides a finer degree of atomization and a higher quality surface finish necessary for vinyl applications.

(6) Limitations. Because larger amounts of air are mixed with the coating during application using conventional spray, coating losses from "bounce back" or "overspray material" that miss the substrate can be high, depending on the configuration of the substrate. This bounce back effect makes coating corners and crevices difficult. Conventional spray also is slower than airless spray application.

(7) Coating types. Most industrial coating materials can be applied using a conventional spray. Fluid tips with various orifice sizes can be used effectively with epoxies, vinyls, and coal tar epoxies. Larger size tips can be selected for more viscous, mastic-type coatings. The coating manufacturer often recommends application equipment and will specify tip sizes for optimum application characteristics.

(8) Equipment care. When coating application is completed, all equipment components should be thoroughly cleaned. To properly care for the spray application equipment, the gun, hoses, and auxiliary equipment should be flushed thoroughly with an appropriate solvent after each use; otherwise, dried/cured coating materials will accumulate and cause the equipment to become inoperable. Thinner or a suitable solvent should be run through the tank, hose, and gun until the solvent runs clean with no visible coating color. All pressure should be released from the tank, line, and gun; and the gun should be disconnected from the line and disassembled. All components should be thoroughly cleaned with solvent, air blown, and reassembled for future use. The exterior surface of the gun should be wiped down with solvent-dampened rags.

(9) Safety considerations. Only recommended pressure and equipment should be used for conventional spray. Also, hose fittings should never be loosened while under pressure.

d. High volume-low pressure spraying. A high volume-low pressure (HVLP) setup consists of a high volume air source (turbine generator or compressed air), a material supply system, and an HVLP spray gun. The spray techniques associated with HVLP are closely compared to that of conventional spray and are a growing trend in coating application techniques. HVLP uses approximately the same volume of air as conventional spray, but lower pressures are used to atomize the fluid. Reducing air pressure at the nozzle effectively reduces the velocity of the airstream and atomized fluid. This reduces the bounce back of coating material from the surface, which results in a significantly higher transfer efficiency (55 to 70 percent) and application into recessed areas. The high transfer efficiency attained reduces material costs and waste, and an HVLP spray is easy to set up and simple to operate. However, HVLP spray has a lower production rate than airless spray; and some coatings are difficult to atomize, which can limit the use of HVLP spray.

e. Airless spray.

(1) Equipment. Airless spray equipment consists of a power source (an electric motor or air compressor), an air hose and siphon hose, a high pressure fluid pump with air regulator (if a compressor is used), a fluid filter, a high pressure fluid hose, and an airless spray gun with spray tip and safety tip extension. Each of these components will be discussed.

(a) The power source may consist of either an electric motor or an air compressor. An electric motor may be used to drive the fluid pump. The electric airless is a self-contained spray outfit mounted on wheels that operates on 120-V electrical power. Conversely, a remote air compressor can be used to drive the fluid pump. The larger, air-operated units are more commonly used on large USACE structures, and the smaller mobile units are used on small projects. The larger units are required to operate multiple pumps or other air-driven devices; they also provide the larger air supplies necessary to apply mastics and high-build coatings.

(b) A 12.7-mm (1/2-in.) air hose generally is used to deliver air from the compressor to the pump. The most common hose length is 50 ft. However, as hose length and pump size increase, a larger diameter hose should be used.

(c) The material siphon hose should be 12.7- to 19.05-mm (1/2- to 3/4-in.) i.d. to provide adequate fluid delivery. The hose must be resistant to the solvent and coating being used. A paint filter, often with the spray gun, should be used to prevent dirt or other contaminants—including improperly dispersed pigment (slugs)—

from clogging the tip. In some instances the siphon hose is eliminated and the pump is immersed directly into the paint. This is known as a submersible airless pump.

(d) The fluid pump is the most important part of the hydraulic airless system. The fluid pump multiplies the air input pressure to deliver material at pressures up to 31,005 kPa (4,500 psi). A common airless pump has an output-to-input pressure ratio of 30:1; that is, for every pound of input pressure, the pump provides 30 lb of output pressure; therefore, this unit will deliver 20,670 kPa (3,000 lb/in.) of hydraulic pressure with 689 kPa (100 psi) of air pressure. Other pumps with a ratio of 45:1 provide pressures up to 31,005 kPa (4,500 psi) (689 kPa [100 psi] input). Air-operated pumps can produce material output ranging from 793.8 g (28 oz) per minute (one spray gun) up to 11.34 liters (3 gallons) per minute (three to four spray guns).

(e) A double-action, airless pump incorporates an air motor piston, which reciprocates by alternate application of air pressure on the top then the bottom of the piston. The air motor piston is connected directly to the fluid pump by a connecting rod. The fluid section, or pump, delivers fluid on both the up and down strokes.

(f) The high pressure fluid hose is manufactured to safely withstand high fluid operating pressures. The hose typically is constructed of vinyl-covered, reinforced nylon braid and can withstand pressures up to 31,005 kPa (4,500 psi); therefore, it is important not to bend the hose or restrict the material flow in any way or the hose may rupture. The hose also is constructed to resist strong solvents. A wire may be molded into the hose assembly to prevent a possible static electrical charge. The spray gun should be equipped with a high pressure swivel to accommodate any twisting action of the hose. The inside diameter of the hose should be at least 1/4 in. for most common coatings, except the viscous mastic-type coatings. The hose should not be longer than necessary; however, this is not as critical as for conventional spray. High pressure hose diameters up to 12.7 mm (1/2 in.) are used for more viscous mastic-type coatings.

(g) The airless spray gun is designed for use with high fluid pressures. The airless spray gun is similar to a conventional spray gun in appearance, but it has only a single hose for the fluid. The hose may be attached to the front of the spray gun or to the handle. The resulting airless spray (atomization) occurs when fluid is forced through the small orifice of the fluid tip at high pressures.

(2) Airless hot spray. An airless hot spray can be used to apply coatings at higher temperatures to reduce viscosity

without additional thinners. Equipment is similar to that used in the standard airless spray setup, except that a unit to heat the material is required.

(3) Tip size nomenclature. A variety of airless spray tips are available. Tip selection is based on the type of material being sprayed and the size of spray pattern desired. The tip orifice opening and the fan angle control the pattern size and fluid flow. There are no controls on the spray gun itself. Tip orifices vary in size to accommodate the viscosity of the coating being applied. Fan angles range from 10 degrees (101.6 mm [4 in.] spray width) to 95 degrees (431.8 mm [17 in.] spray width). For example, two nozzle tips with the same size orifice but with different spray angles will deliver the same amount of coating over a different area width. For example, two tips with an identical orifice size of 0.381 mm (0.015 in.) but different spray angles (10 and 40 degrees) will provide fan widths of 101.6 and 215.9 mm [4 and 8-1/2 in.], respectively, and will have identical flow rates of 0.0145 liters/sec (0.23 gallons per minute) at 13,780 kPa (2000 psi). Typically, when spraying a dam gate with an epoxy using a 0.381-mm (0.015-in.) orifice tip, fan angles ranging from 10 degrees (101.6 mm [4 in.]) to 50 degrees (254 mm [10 in.]) would be used. The quantity of sprayed coating is determined by the orifice size of the spray tip. A larger orifice results in more fluid being delivered at a faster speed; however, this leads to poorer atomization. Dual or adjustable tips can be used with airless spray equipment. Dual tips frequently are ball tips with two separate orifices. This feature provides the sprayer with the option of two different spray patterns: a narrow fan for smaller surfaces and a wide fan for production spraying. Adjustable tips vary the spray fan and, simultaneously, the tip orifice. The tip size increases as the fan width increases.

(4) Airless spray techniques. Application techniques for airless spray are similar to those for conventional spray, except that the spray gun should be held 304.8 to 457.2 mm (12 to 18 in.) from the surface as opposed to 203.2 to 254 mm (8 to 10 in.) for conventional spray because of the increase in the amount of coating being applied.

(5) Advantages. Airless spray equipment provides higher film buildup capabilities, greater surface penetration, and rapid coverage; it can handle products formulated with higher viscosity without the addition of large quantities of solvents; and it has low pressure loss when the pump is not at the same level as the actual spraying. Also, the single hose can be longer than a conventional sprayer and easier to handle. Mastic-type coatings such as coal tar epoxies (CTEs) are easily atomized by airless spray equipment. When spraying concrete and other masonry surfaces, airless spray efficiently and easily penetrates voids and general porous surfaces. Hydraulic pressure is used to force coating

through an orifice in the spray nozzle. The high degree of pressure atomizes the coating as it is discharged through the spray nozzle without the need for atomized air. The coating beads into small droplets when released under these pressures (2,756 to 31,005 kPa [400 to 4,500 psi]) and results in a finely atomized spray and a transfer efficiency of 30 to 50 percent. Typical pressure for epoxies such as those specified in MIL-P-24441A are 12,402 to 17,225 kPa (1,800 to 2,500 psi), and 19,292 to 20,670 kPa (2,800 to 3,000 psi) for high solid epoxy mastics. Because of the high fluid pressure of airless spray, coatings can be applied more rapidly and at greater film buildup than with a conventional sprayer. The high pressure coating stream generated by an airless spray will penetrate cavities (which are typical on lightweight concrete blocks) and corners with little surface rebound.

(6) Limitations. Variances of the structure being painted in the field may create problems because of the difficulty in changing spray fan patterns and orifice openings in the field. For example, when spraying a large structure, a wide fan width will work well and provide the desired finish; however, when a complex design of a small surface area is encountered (e.g., back-to-back angles and other attachments) a small fan width is necessary to provide a quality finish. Because an airless sprayer does not atomize coatings as well as a conventional sprayer, it should not be used for detail or fine finish work. Additionally, if painters use excessive pressure or improper technique, solvent entrapment, voids, runs, sags, pinholes, and wrinkles may occur.

(7) Safety considerations. The spray gun should never be removed from the hose, or the tip from the gun, until the pressure from the pump and in the line has been released. High pressure through a small orifice can cause paint to penetrate the skin if pressed against the body; therefore, spray gun tips are equipped with trigger locks and tip guards. All high pressure airless systems should be sprayed and flushed in a well ventilated area. These systems also should be grounded to avoid dangerous static sparking, explosion, or fire when spraying or flushing the lines. (See Chapter 10 for a more detailed description of recommended safety practices.)

f. Air-assisted airless spray. The air-assisted airless sprayer was developed to combine some of the advantages of an airless sprayer (e.g., increased production, ability to reach into recesses and cavities without blow-back) and the advantages of a conventional sprayer (finer atomization). An air-assisted airless spray system consists of a spray gun, pump, hoses, and clean, compressed air of adequate pressure and volume. An air-assisted airless sprayer may be used with small containers or with 207.9-liter (55-gallon) drums

using a submersible pump. Basically, an air-assisted airless spray gun combines the features found with both air and airless spray guns. A special fluid nozzle tip similar to that used with the atomization principle of the airless sprayer initiates atomization. Atomization is completed with the introduction of compressed air through the horns and face of an air cap (similar to a conventional spray air cap) that surrounds the airless tip. Without the compressed air, a coarsely atomized and poorly defined pattern would result. The compressed air emitted from the air cap provides a finely atomized coating, which approaches the quality of conventional spray atomization. Therefore, an air-assisted airless sprayer is ideally suited for fillers, glazes, lacquers, and polyurethanes. Medium to heavy consistency coatings require atomizing air pressure close to 68.9 kPa (10 psi). Light consistency coatings only require a few pounds per square inch of air pressure. Equipment maintenance and safety considerations are similar to those for standard airless and conventional spray equipment.

g. Plural component spray application.

(1) Perhaps the most complex of all spray application methods is plural component spraying. Basically, plural component spray mixes the individual components through careful metering at the spray gun or at the spray tip rather than premixing in the pressure pot. Plural component spray is commonly used for 100 percent solids coating materials and coating materials with limited potlife (such as epoxies).

(2) A plural component spray setup consists of six basic components: proportioning pump, mix manifold, mixer, spray gun, material supply containers, and solvent purge (flush) container. Plural component spray can be sprayed by conventional spray, airless spray, or air-assisted airless spray. The spray gun can be identical to those used with conventional sprayers, airless sprayers, or electrostatic sprayers. However, if the components are mixed at the gun, a special spray gun is required.

(3) Three systems are used to spray polyester materials, including a side catalyst injector system, an air injection system, and a split batch or double nozzle spray system. The side catalyst injector system mixes the polyester components externally in front of the spray gun. With an air injection system, a measured quantity of catalyst is injected into the atomizing air supply. The split batch or double nozzle spray gun system involves two quantities of equal volumes of premixed resin. The two quantities, in equal volumes, are delivered separately to the spray gun and are atomized in such a way that the individual quantities are intimately intermixed either externally or internally.

(4) Some types of plural component coating materials or

adhesives that can be sprayed include polyesters, polyurethanes, vinyl esters, and epoxies. These materials may be mixed in varying ratios and viscosities.

(5) The application technique associated with plural component sprayers essentially is no different than that of conventional air or airless sprayers. However, the prespray procedures require a certain level of expertise in ensuring proper mixing of the individual components and equipment maintenance.

(6) Unlike conventional or airless sprayers, plural component sprayers combine separate fluids that are either mixed internally immediately preceding exit from the gun or externally; therefore, plural component spraying is the ideal system to use with coatings that have a short pot life (i.e., 30 minutes).

(7) A plural component spray setup uses complicated equipment compared to that used in conventional or airless sprayers. Because of the knowledge necessary to successfully apply coatings using plural component sprayers, a more experienced applicator generally is required.

(8) Whenever the equipment is stored, even for a short period of time, it must be cleaned thoroughly; different procedures may be required for overnight versus weekend storage. The system must be kept "wet" (filled with solvent) at all times to prevent the remaining material from setting up when it is exposed to the atmosphere. A solvent that is compatible with the resin materials should be used.

h. Electrostatic spray.

(1) There are several types of electrostatic spray systems, although the typical system involves hand-operated, electrostatic spray guns using air atomization, airless atomization, or air-assisted airless atomization. The equipment used to atomize the coating is similar to that of conventional, airless, or air-assisted spray setups; however, an electrostatic, high voltage supply also is used.

(2) Portable electrostatic spray units are used for coating applications to odd-shaped metal objects, such as wire fencing, angles, channels, cables, and piping. Electrostatic spray units impart an electrostatic charge to the coating, which causes the material to be attracted to a properly grounded object. The charged coating particles travel to the closest grounded object. The particles that miss the target wrap around to coat the opposite side of the target. Particles that strike the product and rebound are retracted to the surface.

(3) Virtually any atomized fluid is capable of accepting

an electrostatic charge. Careful consideration must be given to the type of electrostatic system being used. Each system demands paint formulation consideration acceptable to the process being used. Polar solvents (conductive) are required to improve the degree of atomization.

(4) The advantages to using electrostatic spray include: this method of coating application reduces coating material loss as it utilizes overspray by rebound; it reduces cleanup and maintenance time, increases production rates, and reduces the number of application steps caused by wrap-around; and it results in improved atomization.

(5) The uniformity of coverage will vary depending on the size and contour of the object. Because of the electric field, the exterior corners of items being coated often receive a heavier coating; the interior corners are difficult to coat. Also, coating materials may require special formulation, such as adding special solvents to the coating, to enable it to accept the charge. The item(s) to be sprayed must be grounded at all times. Electrostatic spray guns are limited to the amount of fluid they can efficiently charge in a given period of time. Observing safe operating procedures is extremely important because of spark potential.

Chapter 9 Coatings Inspection

9-1. Introduction

a. Approximately 85 percent of all premature coating failures are a result of poor surface preparation, inadequate mixing, thinning, and/or poor coating application. Onsite quality control inspection during surface preparation and coating application procedures can help prevent failures of these types. Proper inspection techniques must be combined with knowledgeable instrument use, good common sense, and thorough documentation of work activities and inspection checkpoints to help ensure specification compliance.

b. Paint covers a multitude of mistakes. Without a form of onsite quality control, determining the cause of a problem can be difficult: was the surface properly prepared, were the coating materials properly mixed and applied, or was work conducted when weather conditions were satisfactory? Coatings inspection can increase the life of a coating system by reducing the number of shortcuts taken by the painter.

c. Throughout this chapter, the term “inspector” is used to indicate an individual or a group of individuals whose job is to witness and document surface preparation and coating work in a formal fashion. The inspector's responsibility is to ensure that the requirements of the coating specification are met. This is accomplished by providing job documentation, including a commentary on the type and adequacy of equipment at the jobsite, the rate of work progression, 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 of consequence to the quality and progress of the work. (Paragraph 9-2 discusses the aspects and importance of documentation.)

d. The amount of inspection and the specific inspection checkpoints will vary with the type and size of the coating project. Eleven quality control inspection procedures are discussed in this chapter:

- Presurface preparation inspection.
- Ambient conditions.
- Compressed air cleanliness.
- Surface profile.
- Surface cleanliness.
- Paint storage, mixing, and thinning procedures.
- Application techniques.

- Wet and dry coating thickness.
- Pinhole detection.
- Adhesion.
- Cure.

USACERL has developed a series of videotapes designed to educate the USACE inspector in quality assurance inspection. This series includes mixing, thinning, and application of epoxy coatings in documentation; safety in painting; evaluation of containment structures; and evaluation of applied coatings.

9-2. Documentation

a. Simply performing quality assurance inspection during blast-cleaning and coating-application operations is not sufficient. The documentation of the results of these procedures provides a permanent record of contract compliance. Proper, thorough documentation has a twofold purpose. The first is the need for historical recordkeeping of the blast-cleaning and coating-application operations performed on USACE structures. Future maintenance painting operations often rely on thorough historical records that document the coating systems applied to a structure and any difficulties encountered. These records often reveal why a coating exhibited an early failure or unusual performance.

b. Another purpose for thorough documentation is to counter any legal claims brought on by the contractor. Litigation has become commonplace in industry, and the protective coatings industry is not excluded from this trend. Thorough documentation of each step throughout the coatings process, including presurface preparation, ambient conditions, surface profile and cleanliness, wet and dry film thicknesses, adhesion testing, cure, and holiday testing, will help to prove or disprove allegations that may arise in a contract dispute. The USACE has been involved in several legal claims that could have been avoided if sufficient documentation was maintained.

c. “Proper” documentation can take many forms. When common inspection instruments are used, industry standards, including those of the American Society of Testing and Materials (ASTM) or Steel Structures Painting Council (SSPC), often have written methods stating how to test, how frequently to test, and how often to calibrate the equipment. These standards should be followed, especially if contract noncompliance or a potential source for a legal claim is encountered or anticipated. Good documentation is not just written. Today's advances in photography and video enable the USACE inspector to permanently capture the progress and quality of a project on film. Documentation of this type may cause the contractor to be more aware of the concern

over quality, and it can be an invaluable source during litigation.

d. The role of a USACE inspector involves precise and thorough documentation of each inspection in the coatings process. Although not all the quality checkpoints are enforceable on every project, the results of the inspection should be documented. However, in reality, a full-time inspector may not be available due to limited staff and multiple contracts to be administered. Work which is inspected though should be carefully documented.

e. The USACE should clearly identify any discrepancies, irregularities, or unusual occurrences that may lead to premature coating failure. This information will assist in preparing for future coating operations through the preparation of historical records. USACE inspectors should maintain a commentary on work progress as it relates to the project, and they should maintain a chronologically organized record book for each project. This record book can be an invaluable reference if a coating problem or legal claim occurs. Maintaining daily documentation of this type is a critical responsibility of a USACE inspector.

9-3. Presurface Preparation Inspection

a. Prior to starting surface preparation and coating work, it is necessary to determine that the structure is ready for surface preparation and painting. Heavy deposits of grease, oil, dust, dirt, and other contaminants may be redistributed by the blast-cleaning process if they are not removed. Removal procedures are detailed in SSPC-SP 1. The requirements of SSPC-SP 1 are included (by reference) in all SSPC hand-tool and power-tool cleaning specifications including SSPC-SP 2, -SP 3, and -SP 11, and in all abrasive blast-cleaning specifications including SSPC-SP 5, -SP 6, -SP 7, and -SP 10.

b. The specifications may require that weld spatter be removed and sharp edges be rounded (customarily to a 3.18-mm [1/8-in.] radius). Unusual pitting in the steel substrate may require grinding, filling, etc. before blast cleaning. Large-scale repairs of this type, however, can be quite costly and time consuming. A judgment should be made (by a qualified structural engineer) to determine the consequences of bypassing pitting repair procedures. Adjacent areas not required to be cleaned or coated should be masked to protect them from the cleaning and coating operations. Presurface preparation procedures are discussed more thoroughly in Chapter 7.

9-4. Measurement of Ambient Conditions

a. Measuring ambient conditions entails obtaining an air

temperature, surface temperature, percent relative humidity, and dew point temperature. The Civil Works Guide Specifications (CWGS) as well as coating manufacturers have pre-established air temperature and relative humidity ranges outside of which the coating materials should not be applied. The ambient conditions must be obtained, documented, and compared with the established ranges for compliance with the governing specifications. Other ambient conditions affecting painting operations include the potential for industrial or chemical airborne contamination.

b. Many ambient conditions are inspected visually. But air temperature, relative humidity, and dew point are determined by instrumentation, including psychrometers or instruments that give direct read-out recordings of humidity or dew point. Measurements with these instruments are taken before work begins each day and periodically throughout the day. A suggested minimum frequency is every 4 hours, but the readings can be more often if weather conditions appear to be changing.

c. Dew point is 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 to be trapped between coats that may cause premature coating failure (blistering). Accordingly, the industry has established an arbitrary dew point/surface temperature safety factor. Final blast cleaning and coating application should not take place unless the surface temperature is at least 3 °C (34 °F) higher than the dew point temperature. Although theoretically a surface temperature just infinitesimally above the dew point will not permit moisture condensation, the safety factor of 3 °C (34 °F) was established to allow for possible instrument inaccuracies or different locations where readings are taken. For example, thicker steel retains temperature and cold longer, and steel in contact with soil or water remains colder.

d. Various field instruments are used for determining surface temperature. One of the most common is a surface temperature thermometer consisting of a bimetallic sensing element that is shielded from drafts. Other field instruments for determining surface temperature are direct reading thermocouple-type thermometers.

e. With any of the instruments used for determining ambient conditions and surface temperatures, the readings should be taken at the actual location of the work. However, for general readings the coldest and warmest point on the structure should be used to ensure that coatings are not applied outside of their temperature limitations.

f. The date, time of day, location of measurement, and whether or not the work was allowed to commence/continue also should be formally documented.

9-5. Assessing Compressed Air Cleanliness

a. Compressed air used for blast cleaning, blow down, and coating spray atomization must be free from oil and moisture contamination. Contaminants of this type are effectively transferred to the surface with the air and blast-cleaning media (abrasive) or by mixing it with the coating during application. Adequate moisture and oil traps should be used on all lines to ensure that the air is dry and oilfree enough so it does not interfere with the quality of the work. A simple test for determining air cleanliness is outlined in ASTM D4285 and requires holding a clean piece of white blotter paper or a white cloth approximately 457.2 mm (18 in.) from the air supply, downstream of moisture and oil separators. The air is permitted to blow on the blotter paper for a minimum of 1 minute, then the blotter is inspected for signs of detrimental amounts of moisture or oil contamination.

b. A thorough inspection of the surface after blast cleaning for signs of moisture or oil contamination should be made, and these results need to be correlated 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.

9-6. Measurement of Surface Profile

a. The twofold purpose of surface preparation is to roughen and clean the surface. Specifying a certain blast profile does not indicate the blast cleanliness, which must be addressed separately. The surface profile, anchor pattern, or roughness is defined as the maximum average peak-to-valley depth (or height) caused by the impact of the abrasive onto the substrate. Both SSPC-SP 5 and -SP 6 can have a surface profile of 0.025 to 0.10 mm (1 to 4 mils). Surface profile effectively increases the surface area to which the coatings can adhere, and it provides a mechanical anchor that aids in adhesion. As a general rule, thick coatings require a deeper surface profile than thin coatings.

b. Specifying surface profile is critical. A surface roughness that is too shallow can result in adhesion difficulties, and surface roughness (and insufficient coating thickness) that is too deep can result in pinpoint rusting because unprotected peaks of the profile protrude above the surface of the coating. As a general rule, the surface profile should be a nominal 15 to 20 percent of the total coating system thickness (up to 0.38 mm [15 mils]).

c. Surface profile determinations generally are made in the field or shop with one of three types of instruments: visual surface profile comparators, a depth micrometer, or replica tape. The Civil Works Guide Specification requires the use of replica tape.

(1) Keane-Tator and Clemtex anchor pattern comparators. Visual comparators can be used to assess the average peak-to-valley depth after abrasive blast cleaning. Coupons or discs representing various profile depths are compared with the existing surfaces to determine the surface profile. However, different types of abrasive may result in the appearance of a different profile even though the depths might be identical. For example, a shot-blast profile is round when compared with a more angular grit profile. To achieve similar profile depths, the shot, by virtue of its shape, generally will result in greater lateral distance between peaks than will grit; this will result in a lower peak count per given area. The optical effects provide an illusion that the shot-blast-cleaned surface is deeper than the grit-blast-cleaned surface, even when they are identical. Therefore, it is critical to choose a reference disc or coupon that represents the generic type of abrasive used to clean the surface (i.e., grit/slag, sand, shot) prior to determining the surface profile.

(2) Depth micrometer. Another field instrument useful for determining average profile depth is a depth micrometer. This instrument consists of a conical pin that projects from a large, flat base approximately the size of a nickel. The instrument is calibrated on a mirror or plate glass by turning the entire scale reading so the zero lines up with the pointer. Theoretically, when the instrument is firmly placed on the blast-cleaned substrate, the base will rest on the tops of the peaks and the pin will project into the valley. An average profile can be obtained by taking a number of readings. The instrument must be picked up and placed down for each reading, rather than drag it across the profile. Otherwise, the point will become blunted, resulting in erroneous readings.

(3) Replica tape. Surface profiles can be determined by using replica tape. The replica tape consists of an emulsion film of microscopic bubbles attached to a uniform, 0.05-mm (2-mil) film of mylar. The tape is pressed onto the blast-cleaned surface, emulsion side down, and the mylar is rubbed vigorously with a blunt instrument. The peaks of the profile will break the bubbles and ultimately touch, but not alter, the thickness of the mylar, because it is noncompressible. The tape is removed and measured using a lightweight, spring-loaded micrometer that provides a reading from the upper- or outermost surface of the mylar to the high spots on the emulsion which were not totally

crushed (corresponding with the valleys of the profile). The total micrometer reading is adjusted for the thickness of the mylar to provide a direct reading of the maximum average profile. The tape is available in several grades to measure various profile ranges from less than 1.0 to more than 4.0 mil. The replica tape generally will retain the impression indefinitely if it is stored in a cool area with no pressure applied. Replicas of profiles should be kept on file permanently for future reference. The date, time of day, method used, locations of measurements, and profile measurements should be documented.

9-7. Surface Cleanliness

Surface cleanliness is one of the most critical factors in determining the success of a coating system. Unfortunately, it also is the most subjective of all inspection points. Independent of how well the coating materials are formulated, a surface cleanliness less than that stipulated by the governing specification may result in reduced service life and even premature failure. Volume 2 of the Steel Structures Painting Manual contains the SSPC surface preparation specifications. These specifications describe in narrative form the various degrees of surface cleanliness, the percent of the surface to be cleaned, etc. Similarly, the

National Association of Corrosion Engineers (NACE) has published narrative descriptions of surface cleanliness requirements. Table 9-1 describes the SSPC and NACE cleanliness standards.

a. Assessment of visible contamination.

(1) Assessing surface cleanliness using narrative descriptions can be difficult. As a result, the written standards are supplemented by SSPC VIS 1-89, which photographically depicts the appearance of four grades of blast cleaning (SSPC-SP 7, -SP 6, -SP 10, and -SP 5) over four initial mill scale and rust grades.

(2) NACE also provides visual cleanliness standards. However, NACE encapsulates metal test coupons or plates in a plastic media rather than relying on photographs. Each encapsulated plate contains representative surfaces blast cleaned to the four grades of cleanliness. NACE standards are prepared for sand, steel grit, slag, and steel shot abrasives.

(3) Evaluation of hand- and power-tool cleaned surfaces is accomplished using SSPC VIS 3-93, which photographically depicts the appearance of several grades of

Table 9-1
Surface Cleanliness Specifications

Methods	SSPC Designation	NACE Designation	Definition (as of 1/94)
Solvent cleaning	SSPC-SP 1		Removal of grease, oil, dirt, and other foreign matter by solvents. May entail high pressure water(prerequisite to all other cleanliness specifications).
Hand-tool cleaning	SSPC-SP 2		Removal of all loose materials, tight materials may remain if they cannot be loosened by a dull putty knife.
Power-tool cleaning	SSPC-SP 3		Removal of all loose materials, tight materials may remain if they cannot be loosened by a dull putty knife.
Power-tool cleaning to bare metal	SSPC-SP 11		Removal of all materials from the surface using power tools. A minimum 0.025-mm (1-mil) surface roughness must remain.
Brush-off blast cleaning	SSPC-SP 7	NACE #4	Removal of all loose materials, tight materials may remain if they cannot be loosened by a dull putty knife.
Commercial blast cleaning	SSPC-SP 6	NACE #3	Sixty-six percent of every square inch (surface area) cleaned to white metal; 33 percent of each square inch (surface area) may have stains, streaks, discolorations only. Pitted steel may have traces of rust/paint in pits.
Near-white metal blast cleaning	SSPC-SP 10	NACE #2	Ninety-five percent of every square inch (surface area) cleaned to white metal; 5 percent of each square inch (surface area) may have stains, streaks, discoloration only.
White metal blast cleaning	SSPC-SP 5	NACE #1	One hundred percent of every square inch (surface area) must be clean and have a gray-white appearance.

hand- and power-tool cleaning over seven initial mill scale, rust, and paint grades.

(4) Agreement on the desired appearance of a cleaned surface using commercially available standards may be difficult to achieve because of shadows and hues caused by the abrasive, the pattern and degree of prior rusting, and numerous other factors unique to each project. As a result, jobsite standards frequently are developed. Sections of the structure (or test panels of a similar nature) are prepared, and all parties involved ultimately select one of the panels or areas that represents the desired end result.

(5) Cleanliness after surface preparation also is important. Residual traces of abrasive must be blown, swept, or vacuumed from the surface prior to prime coating. Dust must be removed from the surface prior to painting, particularly the fine film of dustlike spent abrasive often held to the blast-cleaned surface by static electricity. Many painters who are using conventional spray equipment use the spray gun to blow down the surface prior to the paint application; this cannot be done in the same manner if airless spray equipment is used. Any scaffolding, staging, or support steel above the area to be coated must be blown down and cleaned to prevent abrasive dropping onto the freshly cleaned surface, or later contaminating the freshly primed surface. Concurrent blast cleaning and painting should not be permitted, unless the blast cleaning is adequately isolated to prevent contamination of the freshly painted surface.

(6) Inaccessible areas (back-to-back angles, areas between rivets and support members, etc.) can be difficult to properly clean for application, compared to the relatively accessible, large, flat areas. Careful inspection of these inaccessible areas is required and can be evaluated using small inspection mirrors. The worker may have to use special blast nozzles (abrasive exits from the side, not end) or other tools to sufficiently clean the inaccessible areas. During evaluation of surface cleanliness, the inspector should wear gloves to prevent contamination of the steel. Although it is impractical to inspect every square inch of a structure, the inaccessible areas discussed here must be thoroughly inspected and the accessible areas should be spot-checked for contract compliance.

(7) The date, time of day, location, and cleanliness achieved should be documented as well as the standard used to evaluate the degree of cleanliness.

b. Assessment of invisible (chemical) contamination.

(1) Coating over even small amounts of soluble salt contamination can result in premature coating failure. Salt

is hygroscopic and, when trapped beneath a coating film, will osmotically pull moisture from the atmosphere through the semipermeable membrane (coating.) This commonly results in underfilm corrosion and/or osmotic blistering.

(2) Evaluation of the surface for invisible contamination can be accomplished in a number of ways. Perhaps the most common field method is a technique in which a premeasured area of the surface is swabbed with a known amount of deionized water, using a cotton ball, and handling with tweezers or plastic gloves. The test water is analyzed using silver-nitrate-treated test strips, which precipitate a white coloration when placed in contact with sodium chloride. The resulting parts per million are converted to micrograms of chloride by multiplying the parts per million by the amount of water used in the swabbing. Micrograms of chloride are divided by the area sampled to achieve micrograms per square centimeter of chloride.

(3) The amount of chloride that can be tolerated depends on the coating type and the service environment. However, as a general rule, the threshold for an acceptable surface lies at or below 5 micrograms per square centimeter ($\mu\text{g}/\text{cm}^2$) of chloride.

(4) Effective methods of removing chemical contamination include high-pressure water washing and steam cleaning prior to other methods.

c. Removal of burrs, slivers, hackles, etc. Abrasive blast-cleaning procedures may result in the development of burrs, slivers, hackles, and other surface irregularities, particularly if a large, angular abrasive is used. Burrs, slivers, and hackles may protrude above the coating film and expose unprotected steel to the atmosphere, resulting in pinpoint corrosion. Grinding is typically required for removal of these surface defects. However, the surface must be reblasted to restore the original profile after grinding.

9-8. Paint Storage, Mixing, and Thinning

Material receipt inspection and inspection of mixing and thinning procedures are two of the most simple, yet crucial, steps in the coatings process. Each step requires some knowledge of the procedure.

a. Material receipt inspection. On receipt of all coating materials, the inspector should document the number of components received for each material; confirm the manufacturer, product, and color; and record the batch number from the can label. The inspector should compare the batch numbers with those on the test reports to ensure that the proper batches were received. Leaking or damaged

containers should not be used, particularly if a catalyzed paint is involved because some of the components necessary for a complete cure may have leaked out, and proper proportioning may not be obtainable. Containers with illegible labels should not be used. The inspector should confirm that the shelf life of the material has not expired and that the manufacturer's product data sheets and material safety data sheets (MSDS) were received with the shipment. Paint more than 1 year from date of manufacture should be retested. Paint storage areas should be maintained with proper ventilation and temperature controls to prevent excessive heat or freezing conditions. Paint stock should be rotated to facilitate the use of older materials first, if the shelf life is still current.

b. Inspection of mixing and thinning procedures.

(1) Improper mixing or thinning will affect the coating's ability to resist the service environment. There should be some means to ensure that all components of the multicomponent paint system have been added, that mixing is thorough and proper, and that any required induction times have been met. An induction time (cook time; sweat-in-time) is required by some coating types to allow a chemical reaction to initiate, prior to application. Induction times are temperature dependent; typically the warmer the temperature, the shorter the required induction because heat increases the rate of reaction.

(2) Mixing should be done until the paint becomes smooth, homogeneous, and free of surface swirls or pigment lumps (agglomerations). Many paints settle out on prolonged storage. Boxing (repetitive emptying of the contents of one container into a second empty container) of these paints is beneficial to ensure that all pigment settled on the bottom of the container is incorporated in the mixed paint. Paint mixer blades mounted in a pneumatically operated power tool provide sufficient agitation.

(3) All paints should be strained prior to spraying to eliminate skins, improperly mixed pigments, or agglomerations of zinc particles. This usually is accomplished by passing the mixed paint through a disposable cheesecloth bag filter prior to putting the paint into the spray pot. Coarse filters are common on the intake line of conventional spray equipment, and fine filters typically are built in to airless systems. When adding zinc to a multicomponent coating, it is common to sift the dry powder through a screen into the liquid portion while mixing.

(4) Coatings that contain heavy pigments, such as zinc dust, frequently require constant agitation throughout the application process. The agitator should be run as rapidly

as necessary to maintain pigment suspension, but not rapidly enough to entrain air into the paint. After spraying has started, a flow of the material through the lines should be maintained to prevent the heavy pigment from settling out. Some coating manufacturers recommend hoses be whipped or emptied if spraying is interrupted for specified lengths of time.

(5) Preferably, only complete kits of multicomponent paints should be mixed. If this cannot be done, the coating manufacturer should be consulted to assure that partial mixing of the materials is permitted, and it is imperative that the components be carefully measured.

(6) The temperature of the mixed coating material should be measured and documented. Typically a metal "dip stick" paint thermometer is used.

(7) Thinners, if permitted, 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 amount of thinner used should be recorded by the inspector because the addition of thinner reduces the volume of the solid content of the mixed paint and may violate VOC regulations.

(8) Measurement of viscosity assures that proper thinning ratios are used, and that the thinning has not been changed significantly from pot to pot. There are many ways to measure the viscosity of a paint. Common viscosity cups are simply small cups of known volume with precisely sized orifices in the center. Viscosity cups place a numerical value (time) on the viscosity of a paint material. The coating manufacturer can be consulted about what orifice size to use 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 so it will pass through a specific viscosity cup in 20 to 30 seconds. Temperature greatly influences viscosity, and the temperature of the material should be noted when conducting viscosity measurements.

(9) High viscosity materials may not atomize properly if they are not adjusted with thinner, and low viscosity materials may run or sag on application if they are not properly reduced. The paint applicator is generally the best judge of proper thinning ratios to achieve a smooth, wet coat without runs or sags. The viscosity of some high buildup coatings cannot be measured with viscosity cups, and the manufacturer should be contacted for a recommendation. Alternatively, coatings can be thinned by volume with a percentage of the recommended thinner, based on a known volume of coating material.

(10) The potlife of a coating material also must be monitored by the inspector. Potlife is unique to multicomponent coatings; it is the time period within which the mixed coatings material may be used. The potlife varies from coating to coating and is temperature dependent. The warmer the temperature, the shorter the potlife. The inspector also must keep in mind that an induction time uses a portion of the potlife. The remaining material must be discarded when the potlife is expired. The end of the potlife usually can be detected by the increased viscosity of the coating. This is not always true; therefore, the potlife should be monitored based on time and temperature. To counteract the increase in viscosity as the potlife nears the end, contractors may add thinner to the mixed coating. The coating manufacturer should be consulted to ensure that this practice does not adversely affect the paint material.

9-9. Coating Application Technique

Aside from surface preparation, the actual coating application is the most visible and important aspect of the coating work. Accordingly, the inspector should be knowledgeable about the various application techniques. These will be reviewed here briefly and are discussed in more detail in Chapter 8.

a. When spraying with conventional (air atomized) equipment, the spray gun should be held 203.2 to 254 mm (8 to 10 in.) from the surface and maintained perpendicular to the surface throughout the stroke. The distance should be 304.8 to 457.2 mm (12 to 18 in.) for airless spray application. Holding the spray gun further from the surface may result in overspray and dryspray; holding the spray gun too close may cause excessive application (runs, sags, and entrapped air and solvents.) In addition to spray gun distance, the spray pressures should be maintained as low as possible to prevent overspray and flooding of the surface, yet high enough to support atomization. At the end of each pass, the spray gun trigger should be released so the passes feather into one another. Each spray pass should overlap the previous one by 50 percent to create uniformity and, when possible, a cross-hatch technique should be used. This requires a duplicate series of passes 90 degrees to the first to ensure complete and uniform coverage. Proper cleaning of equipment is important to ensure that there is no contamination of a new coating by residues of the previous coat passing through the equipment or by incompatible cleaning solvents. Proper cleaning of the equipment is particularly important when using zinc-rich vinyls, since the vinyl topcoats are incompatible with the zinc pigment.

b. For brush application, the brush should be dipped approximately one half of its bristle length into the coating. The bristle tips should be brushed lightly against the side of

the container to prevent dripping, and as fully a loaded a brush as possible should be maintained. This will result in a more even coating film and help ensure thorough wetting of the surface. Brushing is more effective than spraying for working paint into depressed irregularities, pits, or crevices. Care should be taken to ensure that the coating is not brushed out too thin, especially on projections and corners.

c. In general, the inspector should ensure that, independent of the application method, the equipment used is providing a quality coating film. The inspector also should reference the coating manufacturer's product data to ensure that the application equipment complies with the recommendations of the manufacturer. For example, brush or roller application of an inorganic, zinc-rich primer generally would not be an acceptable practice because coating thickness using these methods is too difficult to control, and the coating itself is too heavily pigmented to apply using brush/roller techniques.

9-10. Measurement of Wet Coating Thickness

The wet thickness of an applied coating film should be measured to ensure that sufficient dry coating will be present after solvent evaporation and curing. Guessing or approximating the amount of wet coating to apply will almost certainly result in insufficient or excessive coating thickness. A wet film thickness gage can be used to monitor the amount of wet coating applied. However, without incorporating the specified dry coating thickness and percentage of solids by volume of the coating into a calculation, wet film thickness data are meaningless. This calculation is explored in the following discussion.

a. A coating is formulated using three basic components: a resin or binder, pigment, and solvent. The resin (binder) and pigment comprise the solids portion of the coating. The solvents comprise the volatile portion of the paint. When calculating wet film thickness, the solids by volume (pigment/resin content by volume) is an important figure and is typically derived from the manufacturer's product data sheets. The basic formula for calculating wet coating thickness is found in Equation 9-1.

$$\text{Wet film thickness} = \frac{\text{dry film thickness}}{\% \text{ solids by volume}} \quad (9-1)$$

Equation 9-1 is accurate if the solids by volume of the material is accurate. However, the percentage will change 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, to achieve a comparable dry film thickness, a heavier wet film application of the thinned material is required.

b. Because the use of a wet film thickness gage depends on the solids by volume, and the solids by volume is considered the “in can” percentage, wet film thickness readings must be taken as soon as a film is applied to the surface. During spray application, between the time the material leaves the spray gun and reaches the surface, some of the solvents will already have evaporated, changing the percent of solids by volume slightly. For most applications, this change is not too significant; however, the rapid evaporation rate of the solvents used in lacquer materials, such as vinyl and chlorinated rubber paints, makes wet film thickness measurements of these coatings meaningless. The longer the amount of time before a measurement is taken, the less accurate the measurement becomes. For highly pigmented coatings (such as zinc-rich), wet film thickness readings may be unreliable because, even though the coating contains a percentage of solvent, the shrinkage from solvent loss may be low. Obviously, on 100 percent solids coatings, the wet film thickness will equal the dry film thickness.

c. The wet film thickness gage is generally of a standard notch configuration. The notch-type gage 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 then withdrawn. The two end points will be wetted by the coating material, as well as some of the steps in between. The wet film thickness is considered as the last wetted step before the next adjacent, higher dry one.

9-11. Nondestructive Measurement of Dry Coating Thickness

a. Dry coating thickness readings on steel substrates are commonly taken using magnetic gages. Nonmagnetically operated equipment is used for nonferrous metallic substrates. Calibration of all coating thickness gages and measurement of coating thickness should be performed in accordance with ASTM D1186 or ASTM D1400.

b. Determination of the thickness of each coat in a multicoat system should be an inspection point, especially when each coat is generically different. For example, if an inorganic zinc primer/epoxy intermediate/urethane topcoat system is specified, each layer should be measured to ensure proper thickness because coating thickness gages will not

yield individual layer thickness after subsequent coats are applied. When using nondestructive gages to measure multicoat systems, the average thickness of the first coat must be determined prior to application of the second coat. Readings taken after the second coat is applied obviously will be the total 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.

c. It is 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 by the coating applicator. Possible methods are brush application of a light tinted coat of the same paint, compatible felt tip marking pens, chalk, or other material that can be readily removed. Wax crayons or incompatible spray paints should not be used.

d. Thickness readings are taken to provide reasonable assurance that the specified thickness has been achieved. However, it is not possible to measure every square inch of the surface. Both ASTM D1186 and D1400 state that, when using coating thickness gages, five separate spot measurements should be made over every 9.3-sq-m (100-sq-ft) area. Each spot measurement consists of an average of three gage readings taken within a 12.7-mm- (1/2-in.-) diameter circle.

e. Nondestructive dry film thickness measurement instruments fall into three basic categories: magnetic pull-off, electromagnetic probe, and eddy current probe. Destructive dry film thickness gages are addressed separately.

(1) Magnetic pull-off gages.

(a) Magnetic pull-off gages commonly 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 and the opposite end contains a counterbalance.

(b) The spring tension overcomes the attraction of the magnet to the substrate and lifts the magnet from the coating surface. The spring tension is calibrated so 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 converted to mils (or microns.) The thickness reading represents the gap between the magnet and the substrate. This gap is considered to be the coating thickness. However, this reading could be compromised by

voids, rust, embedded contaminants, mill scale, etc. Therefore, a thorough visual inspection needs to be included during the work to ensure that the coating is applied over a clean surface and does not become contaminated during drying.

(c) Magnetic pull-off coating thickness gages should be calibrated, or at least calibration verified, prior to, during, and after each use to assure that they are measuring accurately. Calibration is described in ASTM D1186. Plastic shims of known thicknesses are placed directly onto the blast-cleaned surface, and the gage is adjusted to closely match the shim thickness. One or two shims that represent the actual field coating thickness should be chosen so calibration can be performed in the range of use. The user must bear in mind that the accuracy of magnetic pull-off gages ranges from 5 to 10 percent of the reading, and that minor deviations from the specified thickness is not cause for rejection.

(2) Electromagnetic probe.

(a) Electromagnetic probe gages for ferrous surfaces are described in ASTM D1186. These gages also are calibrated prior to use with the nonmagnetic (plastic) shim method. Most of the coating thickness gages used in the corrosion control industry are of this type. They are accurate (± 3 to 5 percent of reading, depending on manufacturer), provide a digital display of the thickness, and eliminate user interpretation of an analog scale. Also, this type of gage commonly is equipped with a microprocessor capable of storing measurements in memory and performing statistical evaluations of the stored data including mean, standard deviation, highest and lowest readings, and total number of readings obtained. These data frequently can be downloaded to a computer and/or printer, and can save considerable amounts of time related to hand documentation of measurements, as well as averaging and determining thickness ranges. However, because these gages are electronic, they are more delicate and more susceptible to field damage compared to the mechanical pull-off gages. Also, these gages are more sensitive to rough surfaces than mechanical types.

(b) Eddy current probe gages, described in ASTM D1400, measure the thickness of nonconductive coatings applied to nonferrous metal substrates. The probe is energized by alternating magnetic fields within the metal and 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 the gage meter as coating thickness. The eddy current probe gages are calibrated in a manner similar to that for the electromagnetic probe gages using the plastic shims on a nonferrous metal

substrate. Some gages combine both electromagnetic probe and eddy current probe capability in one unit.

(3) Precautions. Some precautions are necessary when using any instrument with a magnet. The magnet is exposed; therefore, it is susceptible to attracting iron filings, steel shot, or grit particles. The magnet must be cleaned of any contaminants during use, or the contaminants will cause incorrect readings. If the instrument is used on a soft coating film, a plastic shim can be placed on top of the surface to prevent the magnet from deforming the coating. The shim thickness is subtracted from any subsequent readings. Vibrations in the area of instrument use can cause the magnet in pull-off gages to be released from the surface prematurely, which can result in an erroneously high thickness reading. Dry coating thickness instruments should not be used any closer than 1 in. to an edge of the surface; residual magnetism in the structure on which the coating is measured can have an erroneous effect on the readings. The scale dial-type instruments (magnetic pull-off) have an additional "human error" problem during use because it is easy to continue to turn the dial beyond the point the magnet has lifted from the surface, which would result in an incorrect thickness measurement. Therefore, it is imperative that the dial be stopped as soon as the magnet releases from the surface.

f. The inspector should document the date and location of measurements, the type of coat being measured (primer, intermediate, topcoat), the product and the type of gage being used, the calibration method, and whether or not the area inspected meets the specification.

9-12. Destructive Measurement of Dry Coating Thickness

Destructive thickness testing entails the use of the Tooke¹ gage (or paint inspection gage). The Tooke gage measures the thickness of nearly any coating applied to ferrous and nonferrous metals and other nonferrous surfaces, including masonry, plastic, wood, etc. The gage consists of a 50X microscope that is used to look at slits in the coating made by precision cutting tips supplied with the instrument. The principle of the Tooke gage is basic trigonometry. By making a cut through the coating at a known angle and viewing perpendicularly to the 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 (if the layers are alternating or different colors) and eliminates many of the

¹ Tooke Gage; Micro-Metrics; Atlanta, Georgia.

drawbacks of the magnetic instruments that are caused by magnetic fields, proximity to edges, irregular surfaces, magnetic effect of the substrate and profile, etc. The instrument can be used on coating thicknesses up to 1.27 mm (50 mils) if the coating is not too brittle or elastic for a smooth cut to be made. The Tooke gage has limitations. The use of the gage can be tedious and slow, and it creates voids (cuts) in the coating system that must be repaired. The gage becomes impractical on large field structures where paint thickness often lacks uniformity. However, the Tooke gage is often used as a final determination of thickness at specific, selected locations.

9-13. Cleanliness and Time (Cure) Between Coats

When more than one coat is to be applied, a determination of the cleanliness of the surface immediately prior to application of the next coat is required. In addition to dirt and dust, dry spray or overspray may cause a problem. All dirt, dust, and other contaminants should be removed because their presence can result in reduced adhesion between coats and porosity in the subsequent coat, which could render the coating less resistant to environmental effects. The surface also should be inspected for any adverse contamination from the environment. In addition to intercoat cleanliness, the recoat window also must be observed. Recoating too soon may cause solvent entrapment, wrinkling, and other film defects; exceeding the recoat window may result in intercoat adhesion difficulties (common with CTE and moisture cure urethane systems). Evaluation of cure is discussed in paragraph 9-16.

9-14. Holiday/Pinhole Detection

a. A holiday is a skip or miss on the coating film, while a pinhole is typically a microscopic hole in the coating film. Holiday, pinhole, or spark testing can be used to find the nicks, scrapes, and pinholes in the coating film. Pinholes can be present in any coating layer and should be closed before the next coat is applied. Pinhole testing is common when the coating is intended for immersion service. Holiday testing may be required after application of either the next to the last, or last, coat of paint. Usually when such testing is specified, the test is done when the coating is sufficiently dry but before final cure has occurred so that repair material will successfully bond to the underlying coats.

b. Pinhole and holiday detectors are of two general types: low-voltage wet sponge and high-voltage.

(1) Low-voltage wet sponge pinhole detectors. The low-voltage wet sponge pinhole detectors are used for finding discontinuities in nonconductive coatings applied to

conductive metal surfaces. Pinhole testing also can be used to locate conductivity on rivets, bolt threads, etc. This testing should be followed by a visual examination for the deficient area(s.) The low-voltage detector is suitable for use on coatings up to 0.51 mm (20 mils) in thickness. 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. When the electrode is moved across the entire surface, the water permits a small current to flow through the pinholes down to the substrate. When the current reaches the substrate, the circuit is completed to the detector unit and an audible signal indicates that a pinhole or discontinuity is present. When coatings are above 0.254 mm (10 mils), a nonsudsing, wetting agent (such as a photographic developing fluid) may be added to the water to increase the wetting properties. Compatibility of the wetting agent with the coating to be applied must be verified. If the coating system is found to be outside the 0.51-mm (20-mil) thickness limits, high-voltage holiday detection equipment should be used. Pinhole testing has certain limitations. For example, in some situations, pinholes can be visually detected, though the detector does not sound, because the pinholes do not penetrate to the substrate. Conversely, the detector may sound to indicate the presence of a void when none exists because the coating itself may be conductive as a result of metallic pigmentation or entrained solvent.

(2) High-voltage holiday detectors. High-voltage detectors basically function on the same operating principle as the low-voltage units, except a sponge is not used. The instrument consists of a testing unit capable of producing various voltage outputs, a ground cable, and an electrode made of neoprene, rubber, brass, or steel. High-voltage units are available up to 20,000 V and more. High-voltage holiday inspection frequently is required on pipelines and other critical applications. A spark will jump from the electrode through the coating down to the substrate at pinholes, holidays, or missed areas and simultaneously trigger an audible and/or visual signaling device in the unit. The rule of thumb for high-voltage testing is 100 to 125 V per mil. For example, a 1.02-mm (40-mil) coat will require a test voltage of 4,000 to 5,000 V. Too high a test voltage may damage the coating film. Even when the test voltage is properly set, a spark may penetrate a thin, intact area of the coating and create a void that must be repaired.

9-15. Adhesion Testing

a. Occasionally, there is a need to test the adhesion characteristics of the coating film after application and cure. Adhesion testing is commonly conducted using either of two field methods: tensile adhesion and knife (tape) adhesion.

Tensile adhesion is performed in accordance with ASTM D4541-89. Tensile adhesion requires that a pull stub be adhered to the coating surface using an epoxy adhesive. The pulling force (measured in pounds per square inch) required to disbond the pull stub is a measure of the coating system's tensile adhesion. Additionally, the break in the coating system is described as adhesion (a break between layers or between the substrate and first layer), cohesion (a break within a coating layer), or glue (failure of the pull stub to adequately bond to the surface of the coating). Knife (tape) adhesion requires making an X-cut or a series of parallel and perpendicular knife cuts through the coating (cross-hatch grid), pulling tape from the X or grid, and evaluating the percentage of disbanded coating. The grid or cross-hatch method is used for coatings 0.127 mm (5 mils) or less. The X-cut is used for coating systems in excess of 0.127 mm (5 mils).

b. Adhesion test data will not predict the performance life of a coating system. A coating system with good-to-excellent adhesion probably will protect the substrate longer, but a coating system with marginal adhesion may protect just as long if the coating remains intact. Adhesion testing can be used as one tool to determine whether or not an existing coating system is a candidate for overcoating. Adhesion testing should be performed prior to applying test patches of candidate overcoat systems, and it can be used to evaluate the performance of the overcoating candidates after it is applied and cured.

9-16. Evaluating Cure

a. When a coating is designed for immersion service, the applied coating film must be allowed to cure prior to being placed into service. This curing time generally is

shown on the manufacturer's product information. Alternately, forced-heat curing may be used to reduce the time between curing and service.

b. Determining the cure of coatings generally is difficult. ASTM D1640 is one method, but there are no universally reliable field tests for such purposes. Because a coating is dry or hard does not necessarily mean it is cured. In fact, hardness is not synonymous with cure for most coatings. The only types for which this is true are the solvent-deposited coatings such as the chlorinated rubbers and vinyls. Residual retained solvents (and moisture in water-emulsion coatings), under certain atmospheric conditions of temperature and/or humidity, may require a longer period of time to escape from the paint film. Final attainment of film properties will be acquired only on satisfactory loss of these entrapped solvents. In some situations this evaporation process may take as long as 2 to 3 weeks or more.

c. Solvent rub tests and sandpaper tests can be used to approximate the degree of cure. When most coatings are suitably cured, rubbing them with sandpaper will produce a fine dust. If the sandpaper gums up, depending on the coating, it may not be cured properly. A solvent rub test is frequently performed to check the cure of inorganic zincs. For this test, a cloth saturated with MEK is rubbed onto the coating a specific number of times.

d. Epoxies, urethanes, and other generic coatings (catalyzed and noncatalyzed) can be evaluated for cure according to ASTM D1640, which describes procedures for conducting set-to-touch, dust-free, tack-free, dry-to-touch, dry hard, dry through, dry-to-recoat, and print-free dry/curing times.