

RECLAMATION

Managing Water in the West

Technical Guide

Guide to Protective Coatings, Inspection, and Maintenance

Second Edition



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Technical Guide

Guide to Protective Coatings, Inspection, and Maintenance



**U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Materials Engineering and Research Laboratory
Denver, Colorado**

April 2012

BUREAU OF RECLAMATION
Technical Service Center, Denver Colorado
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Technical Guide

**Guide to Protective Coatings, Inspection,
and Maintenance**

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Acronyms and Abbreviations

ASTM	American Society for Testing and Materials
CFR	Code of Federal Regulations
CSI	Construction Specification Institute
DBE	dibasic ester
DFT	dry film thickness
EPA	United States Environmental Protection Agency
FRC	foul-release coating
ft/s	feet per second
HVLP	high-volume, low-pressure
MERL	Reclamation's Materials Engineering and Research Laboratory
mg/L	milligrams per liter
ml	milliliter(s)
MSDS	Material Safety Data Sheet
NACE	National Association of Corrosion Engineers
NMP	N-methyl-pyrrolidone
OSHA	Occupational Safety and Health Administration
PCB	polychlorinated biphenyls
PDMS	poly(dimethyl siloxane)
psi	pounds per square inch
Reclamation	Bureau of Reclamation
RSN	required submittal number
SSPC	Steel Structures Painting Council
TSC	Technical Service Center
UV	ultraviolet
VOC	volatile organic compound
WFT	wet film thickness

Symbols

°F	degrees Fahrenheit
μg/m ³	micrograms per square meter
μs/cm	microsiemens per centimeter
μg/L	micrograms per liter

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Preface

In recent years, coating technology has changed dramatically. The driving force behind the change has been regulations affecting the environment and personnel health and safety. For example, regulations related to dust particles from abrasive blasting, volatile organic compound (VOC) emissions, and hazardous materials such as lead, chromate, and other heavy metals have changed. Before the late 1980s, coating materials were more tolerant of less than optimum surface preparation conditions because paint formulation contained high VOCs to allow the material to wet or penetrate steel surfaces. The most successful were red lead primers and vinyl resins; however, regulations have discouraged the use of these materials. Paint manufacturers reformulated their coatings to comply with new regulations. This has led to the development of a wide variety of high-tech coating materials that are much more sensitive to surface preparation and environmental application practices. The Federal Highway Administration has estimated that up to 80 percent of all premature coating failures on bridge structures are partially or completely caused by deficient surface preparation or application practices. Several organizations such as the American Society for Testing and Materials, NACE International, and the Society for Protective Coatings have issued consensus standards to minimize surface preparation and application inadequacies. This guide is not intended to be all encompassing; rather, it is intended to be an introduction to specific reference standards and test procedures related to surface preparation, application, testing, and maintenance of coatings. Explanations and procedures of reference standards cited within this guide are abbreviated to develop a working basis. The user is encouraged to read reference standards and coating manuals for a more thorough understanding. The guide focuses on new construction coatings, existing infrastructure coating maintenance, and galvanized coatings of ferrous substrates for metalwork items coated in the field. In general, this guide follows the Bureau of Reclamation's coating guide specifications.

Chapter I: Introduction and Background

Protective or industrial coatings are the primary means employed by the Bureau of Reclamation (Reclamation) to control corrosion. Hydraulic structures are typically constructed with ferrous metals and are subject to corrosion. Many Reclamation structures are 50 years old, and some are approaching 100 years. These structures are expected to continue functioning into the foreseeable future. Protective coatings influence the life, safety, operating efficiency, appearance, and economy of these structures.

A coating's effectiveness depends on selecting coating material that correctly matches the intended service exposure for the metalwork. In the past, coating material selection was based on Federal, military, or Reclamation formulations; however, nearly all these formulations have been withdrawn. Today, selection is based on service exposure type and the results of accelerated performance testing of commercially available products.

STANDARDS

Formerly, Reclamation provided narrative standards and definitions for specifying materials, surface preparation, application, and inspection. However, Reclamation now adopts industrial standards where applicable. The following organizations (see appendix A for addresses, telephone numbers, and Web sites) are referenced throughout this guide:

- American Society for Testing and Materials (ASTM)
- NACE International (formerly called National Association of Corrosion Engineers) (NACE)
- Society for Protective Coatings (formerly called Steel Structures Painting Council) (SSPC)

COATING REFERENCES

The coating inspector is not expected to have the expertise of a coating formulator or a coating engineer, but should be reasonably familiar with the materials being applied. This guide is intended to provide the most basic background on generic material types, surface preparation, application, and inspection methods. The reader is encouraged to pursue related coating references listed in appendix B.

TERMINOLOGY

The word “coating” is a generic term and includes “paint.” In the most general terms, a “coating” is protection against corrosion and degradation, whereas “paint” may have additional properties such as color or ultraviolet screening pigments. The terms “coating” and “paint” are used interchangeably throughout this guide.

Other terms often used together are “coatings” and “linings.” In general, when describing the interior surfaces of pipes or tanks, the term “linings” is used to identify the interior surfaces, and “coatings” is used to identify the exterior surfaces.

CORROSION

The primary reason for coating steel is to prevent corrosion. Corrosion of metals is an electrochemical reaction that can be controlled by interfering with one or more of the four required elements of a corrosion cell:

1. Anode (corroding area)
2. Cathode (noncorroding area)
3. Electrolyte (water or moisture in atmosphere, immersion, or soil)
4. Metallic path (between two different metals or within the same metal)

Eliminate any one of the four required elements, and the corrosion process will stop.

The most common types of corrosion encountered on Reclamation ferrous metalwork are:

1. ***Uniform corrosion.*** Corrosion that occurs uniformly and results in rust and metal loss over the entire metal surface.
2. ***Galvanic corrosion.*** Corrosion that occurs on the more active metal of two dissimilar metals that are electrically coupled together in the same electrolyte (e.g., water). The more active metal will corrode.

3. ***Crevice corrosion.*** Crevice corrosion is a form of localized corrosion that occurs in crevices where the environment differs from the surrounding bulk environment. The different environments result in corrosion because of differences in concentration (e.g., oxygen, pH, and ferric ions). If there is an oxygen concentration difference, corrosion will proceed at crevices where there is less oxygen than in the environment surrounding the crevice. Crevices are formed when two surfaces are in proximity to one another, such as when two metal surfaces are against one another, when a gasket is against a surface, or when angle irons are placed back to back. Crevice corrosion can occur under deposits (e.g., barnacles, dirt, grease, and slime) on a metal surface.
4. ***Pitting corrosion.*** A form of localized corrosion where the depth of penetration is greater than the diameter of the affected area.
5. ***Cavitation corrosion.*** The metal loss caused by the formation and collapse of vapor bubbles in a liquid near a metal surface. The appearance of cavitation is similar to pitting, except that pitted areas are closely spaced and the surface is considerably roughened.
6. ***Erosion-corrosion.*** The accelerated metal loss from an initial corrosion mechanism associated with high-velocity flows and abrasion. Erosion-corrosion is characterized by grooves, gullies, waves, and rounded ridges or valleys and exhibits a directional flow pattern.
7. ***Dealloying or selective leaching.*** The selective removal of one of the elements of an alloy by either preferential attack or complete dissolution of the matrix, followed by redeposit of the cathodic constituent. The element removed is always anodic to the matrix. With dealloying, there is no metal loss, dimension changes, cracks, or grooves; however, the affected area may be evident because of a color change. The affected area becomes lighter, porous, and loses its original mechanical properties (i.e., it becomes brittle and loses tensile strength). Two common forms of dealloying are:
 - a. ***Dezincification.*** The selective dissolution of zinc from brass alloys. It is recognized by a color change (e.g., from its original yellow brass color to a distinctly red, coppery appearance).
 - b. ***Degraphitization.*** The selective dissolution of iron from some cast irons, usually gray cast irons. It normally proceeds uniformly inward from the surface, leaving a porous matrix alloy that is composed mostly of carbon. Degraphitization can be recognized by a change from an original silver-gray color to a dark gray. The affected metal can be easily cut or pierced with a knife.

SERVICE EXPOSURE

Coatings are specified by service exposure or the environment the coating will be subject to. The following are the basic service exposures defined by Reclamation:

- Atmospheric
 - Interior
 - Exterior
- Burial
- Immersion
 - Erosive
 - Non-erosive
 - Cavitation
- Complete, partial, or fluctuating immersion conditions
- Atmospheric exposure subject to condensation, high humidity, splash, or spray
- The following subexposure conditions may apply to any of the above:
 - *Direct sunlight or ultraviolet (UV) light.* Several coatings, such as epoxies, will deteriorate by chalking when exposed to sunlight.
 - *Chemical resistance.* Exposures may include acidic or alkaline concentrations, industrial smog, acid rain, sewage, or specific chemicals.

Chapter II: Materials

Coating formulation is generally based on organic, inorganic, and hybrid chemistry. It is not the intention of this chapter to discuss coating chemistry but, rather, to provide a basic knowledge of coating components and generic coating types specified by Reclamation.

COMPONENTS OF COATINGS

All coatings consist of three basic components: (1) solvent, (2) resin, and (3) pigment. Not all coatings contain solvent and pigmented components. There are solvent-free (100 percent solids) coatings and clear, pigment-free coatings, but not resin-free coatings.

Coating formulators commonly group solvent, resin, and pigment components into two general categories. The first category combines the solvent and the resin together. The solvent portion is called the “volatile vehicle,” and the resin portion is called the “nonvolatile vehicle.” The combination of the solvent and the resin, where the resin is dissolved in the solvent, is called the “vehicle.” The second category is the pigment. Pigments are additives that impart specific properties to the coating and are subdivided into two general categories: (1) color and (2) inert and reinforced. Figure II-1 illustrates the relationship of these components.

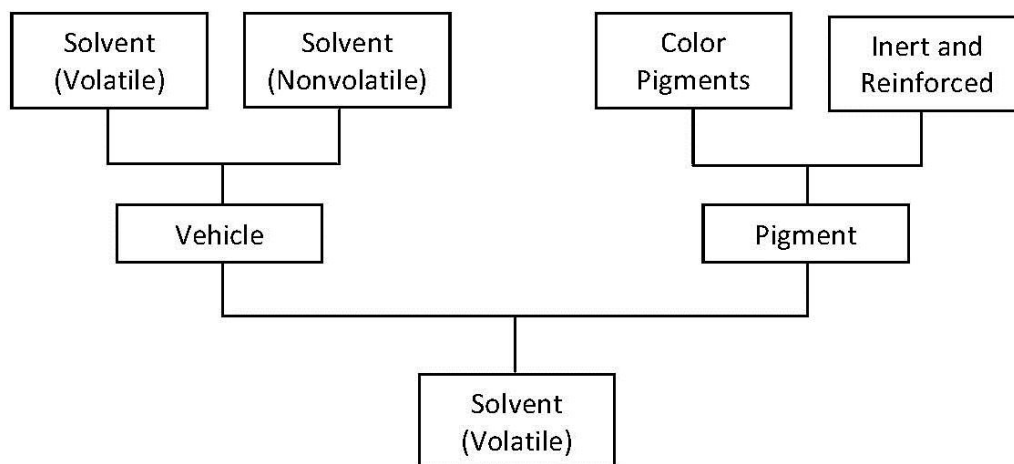


Figure II-1.—Components of coatings.

When a coating is applied, the solvent evaporates during the curing process, leaving only the resin and the pigment components on the substrate. The remaining resin and pigments are sometimes called the “coating solids,” and they form the protective film for corrosion protection.

Solvent

Organic solvents are formulated into coatings to perform three essential functions: (1) dissolve the resin component, (2) control evaporation for film formation, and (3) reduce the coating viscosity for ease of application. Solvents will also affect dry film adhesion and durability coating properties. In general, resins that are less soluble will require either more solvents or stronger solvents to dissolve the resins.

The terms “solvents” and “thinners” are often used interchangeably, but there are distinctions within and between the two terms. The term “solvent” can imply two different usages: (1) the solvent or solvent blends in the coating formulation at predetermined concentration levels or (2) cleaning solvents in strong concentration strength for cleaning brushes, rollers, hoses, and other equipment. The usage of the term “thinner” (a thinner is a solvent) is most often associated with the coating applicator adding a thinner to a coating container (normally about 1 pint thinner to 1 gallon of coating) to reduce the viscosity for ease of application. Adding thinner to a coating in the field is often called “field thinning.”

The manufacturer’s product data sheet will specify a thinner and a maximum amount to be used for each coating type. Use of a thinner not recommended by the manufacturer can cause numerous application problems or premature failures such as separation of components, coagulation, too fast or too slow drying, changes in flow characteristics, or lifting of previous coats. The following common thinners are used with the associated generic coating types:

Table II-1.—Thinners and coatings

Thinners	Coatings
Mineral spirits	Oils and alkyds
Aromatics (Xylene, ethyl benzene, toluene)	Coal tar epoxies, alkyds, chlorinated rubbers
Ketones (MEK, MIBK)	Vinyls, epoxies, urethanes
Alcohols (isopropyl)	Phenolics, inorganic zincs
Water	Waterborne acrylics, some inorganic zincs, waterborne epoxy

Solvents produce vapors that are heavier than air and will collect in tank bottoms or confined areas. The ketones have the lowest flashpoint of the organic solvents; however, any solvent in the right combination with air can create an explosive combination.

Federal, State, county, city, and local air quality control districts regulate the amount of volatile organic compounds (VOC) in coatings. As the coating cures, VOCs evaporate into the atmosphere and react with sunlight and air pollutants to form ozone, a known human health hazard. In response, coating manufacturers have reformulated their products with lower solvent content or use exempt solvents to meet current VOC regulations. Exempt solvents are solvents that do not react with UV or other air pollutants to form ozone.

Reclamation specifications require the coatings to meet the VOC regulations “in-the-can” or “as-manufactured” before field thinning. Field thinning of a coating that will exceed the regulated VOC maximum is not permitted. Reclamation specifies coatings based on the current United States Environmental Protection Agency (EPA) VOC limits.

Resin

The resin (frequently called binder) is the film-forming component of a coating. Resins are typically low molecular weight polymers and require two components that react to form large repeating molecules in the cured film. The primary purpose of the resin is to wet the pigment particles and bind the pigment particles together and to the substrate (hence, the term “binder”). The resin imparts most of the coating properties. The various types of resins formulated in a coating will display distinct properties. These properties are:

- Mechanism and time of curing
- Performance in service exposure type
- Performance on substrate type
- Compatibility with other coatings
- Flexibility and toughness
- Exterior weathering
- Adhesion

No single resin can achieve a high degree of success in meeting the above coating properties with wide variations associated with each property. Therefore, generic coating types are generally classified by the primary resin type used in the coating formulation. Typical resins are acrylics, alkyds, epoxy, polyurethane, and polyurea polymers.

Pigment

Pigments are insoluble and are the heavier solid portion of a coating that typically settles to the bottom of the container. Pigments are additives to the coating formulation that impart specific properties to achieve the desired film properties. The following properties are accorded by pigments, and a brief description is provided for each.

- **Color.** Natural earth pigments (kaolin clay, magnesium silicate, calcium carbonate) provide color stability from UV or sunlight deterioration. Natural earth pigments are more UV stable than synthetic organic pigments.
- **Opacity.** Titanium oxide hides the substrate or previous coating color and protects the binder from UV sunlight deterioration.
- **Wet paint.** Silica and talc control viscosity, wet film leveling, and settling, but provide little hiding (opacity) power.
- **Weather and moisture resistance.** Aluminum leafs, micaceous iron oxide, clay, and glass flake increase barrier thickness and force moisture to detour around these plate-like additives.
- **Corrosion resistance.** Pigments added to inhibitive (primer) coatings impede corrosion of ferrous substrates. Past formulations included chromate and lead pigments, but they are seldom used today because of environmental and health concerns. The following chromate and lead pigments are rarely used in current coating formulations:
 - Red lead
 - White lead
 - Basic lead silico-chromate
 - Strontium chromate
 - Zinc chromate

The following are acceptable alternative inhibitive pigments:

- Barium metaborate
- Calcium phosphosilicate
- Zinc oxide
- Zinc phosphate
- Zinc molybdate
- Zinc phosphosilicate
- **Mildew resistance.** Mildewcides prevent mildew growth on the dry film coating.

- **Skid or slip resistance.** Aluminum oxide or mineral aggregate is added in the formulation or applied to the wet film to achieve nonslip surfaces. Aluminum oxide is the better choice because mineral aggregate may be crushed under weight, providing moisture access to the substrate, and promoting further coating degradation and corrosion.
- **Low surface energy.** Teflon micropowders are pigment additives that are sometimes formulated into coatings to reduce the coefficient of friction of the coating surface.
- **Abrasive resistance.** Aluminum oxide, fumed silica, quarts, and silicon carbide can be added into coating formulations to provide an increase in abrasion and erosion resistance.

COATING TYPES

The following are three basic types of coatings:

1. **Barrier.** A coating that forms a barrier between the metal surface and the electrolyte and electrically isolates the metal. Examples are epoxies, coal tar epoxies, and aromatic polyurethanes.
2. **Inhibitive.** Pigment in a coating primer that is slightly soluble in water that forms a chemical inhibitor and effectively interferes with the electrolyte. Examples are red lead and chromate primers (no longer acceptable).
3. **Galvanic.** Zinc-rich primers, zinc metalizing, and galvanized coatings that provide galvanic or cathodic protection to ferrous metal (zinc sacrifices itself to protect the ferrous metal). Galvanic coatings are effective only if applied directly to bare metal.

Generic Coatings

The following generic coatings and general descriptions are typically specified by Reclamation:

1. **Abrasion-resistant coatings.** This class of coatings is used in service environments that have severe abrasion or erosion problems. These coatings are typically epoxy based with a high concentration of hard pigments such as silicon carbide, aluminum oxide, fumed silica, and quartz. Fairly new products that are aromatic polyurethane elastomers have shown great resistance to erosion.

2. **Acrylics.** In waterborne acrylic coatings, the resin is dispersed in water to form a water emulsion. Waterborne acrylics are specified for atmospheric exposures as a primer or topcoat and have excellent color and gloss retention. Acrylics cure by solvent evaporation (water) and coalescence.
3. **Alkyds.** Alkyds are normally natural oils (soybean, linseed, tung, styrenate) that have been chemically modified to improve cure rate, chemical resistance, and hardness. Phenolic-modified alkyds are specified as a primer, and silicone alkyds are specified as the topcoat for atmospheric service exposures. They are not suitable for alkaline (concrete or masonry) surfaces or environments. Alkyds cure by air oxidation of drying oils.
4. **Bituminous.** Bituminous coatings are heavy-bodied materials applied with a cutback solvent. They have good moisture barrier resistance and fair to good chemical resistance, but are not resistant to solvents. Commercial bituminous products are specified on a limited basis by Reclamation for protection of aluminum surfaces in contact with cementitious material or steel and copper cable weld connections. Bituminous coatings cure by solvent evaporation.
5. **Epoxy, amine.** Amine epoxies are two-component coatings that are catalyzed (hardened) by an amine curing agent to produce a hard, tightly bonded, chemical resistant (alkali, acid, and solvent) product, but they are moisture and temperature sensitive during application. They are specified for burial and immersion service exposures, but they will fade and chalk in direct sunlight. Amine epoxies cure by chemical reaction.
6. **Epoxy, polyamide.** Polyamide epoxies are two-component coatings that are catalyzed by a polyamide curing agent to produce superior resistance to water and salt solutions, but they do not provide the chemical resistance of the amine epoxy. Polyamides have a greater flexibility than the amine epoxies. They are specified for burial and immersion service exposures, but they will fade and chalk in direct sunlight. Polyamide epoxies cure by chemical reaction.
7. **Epoxy, coal tar.** Coal tar epoxies are generally an amine or polyamide epoxy modified with coal tar pitch resin to produce a high-build film that has good chemical resistance and excellent water resistance. They have a tendency to become brittle with age and delaminate between coats or beneath repair patches. They are specified for burial and immersion service exposures, but they will fade and chalk in direct sunlight. Coal tar epoxies cure by chemical reaction.

8. ***Epoxy, fusion-bonded.*** Fusion-bonded epoxies (commonly called powder coatings) are complete coatings in powder form. There are two application methods: (1) fluidized-bed and (2) electrostatic. In the fluidized-bed method, the metal items are preheated to a fusion temperature and immersed in the powder-epoxy solution. In the electrostatic method, the epoxy powder particles are charged with high voltage, and the metal item is then sprayed. After spraying, the item is placed in an oven to cure at about 350 to 650 degrees Fahrenheit (°F). Fusion-bonded epoxies are specified for burial and immersion service exposures, but they will fade and chalk in direct sunlight and are brittle. A new material is fusion-bonded nylon. This material is superior to the fusion-bonded epoxy and will be incorporated into Reclamation's specification. Powder coatings cure by fusion (heat).
9. ***Foul-release coatings (FRC).*** These coatings are used to resist the attachment of fouling such as zebra or quagga mussels. These coatings are formulated to have a low surface energy and low elastic modulus to prevent the mussel adhesive to strongly attach to the surface. Normally these coatings are silicone-based systems and require a special tie coat to adhere well to the epoxy primers. One disadvantage of these types of coatings is their inherent softness, which can gouge easily.
10. ***Inorganic zinc primers.*** Inorganic zincs are primers that incorporate a high loading (pounds per gallon) of metallic zinc for pigmentation (hence, the term "zinc-rich") and are either solvent or water based. Depending on the solvent and resins used, the coating may be a zinc-rich epoxy or urethane. These coatings are exclusively primers because they provide galvanic or cathodic protection to steel substrate. Inorganic zincs are specified for atmospheric and immersion service exposures, but they can be topcoated to extend their service life. Suitable topcoat material selection is required to prevent out-gassing from the inorganic zinc that produces small pinholes in the topcoat. Reclamation specifies inorganic zinc coatings only to fraying surfaces or heat-treated metalwork (ASTM A 325 or ASTM A 490). Application requires special skills and knowledge. Inorganic zincs cure by either reaction to water (solvent reducible) or reaction to carbon dioxide (water reducible).
11. ***Moisture-cured urethane.*** Moisture-cured urethane coatings vary widely in formulations for specific service environments and application requirements. They cure from moisture in the atmosphere and can be applied in high-humidity conditions. Limitations of the moisture-cured urethanes are they require a minimum of 30 percent humidity in order to cure; this may limit the uses in the arid West. Moisture-cured urethanes are primarily recommended for atmospheric exposure conditions. The moisture-cured urethanes are not recommended for immersion service due to the premature failures in water immersion.

12. ***Organic zinc primers.*** Organic zincs are primers that incorporate a high loading (pounds per gallon) of metallic zinc for pigmentation with a wide variety of solvents and resins. Depending on the solvent and resins used, the coating may be a zinc-rich epoxy or moisture-cured urethane. These coatings are exclusively primers because they provide galvanic protection to steel substrate or they are used to repair damaged galvanized coatings on steel substrates. Organic zincs are specified for atmospheric service exposures, but are normally topcoated to extend the service life of the coating. Suitable topcoat material selection is required to prevent out-gassing from the organic zinc. Out-gassing produces small pinholes in the topcoat. The way organic zincs cure depends on the coating type.
13. ***Polyurethane, aliphatic.*** Technically, polyurethane is a subclass of urethane. A two-component polyurethane is created by chemically combining a polyisocyanate and a polyol to produce an isocyanate that has a two-mode cure mechanism of solvent evaporation and chemical reaction. Reclamation specifies aliphatic polyurethanes for topcoating compatible (i.e., same manufacturer) amine and polyamide epoxies to protect against direct sunlight or UV and to provide specific colors. Polyurethanes are specified for atmospheric and partial or fluctuating immersion service exposures.
14. ***Polyurethane, aromatic.*** Aromatic polyurethanes normally are cured using an aromatic isocyanate and a polyol (polyether). These coatings are normally 100 percent solids and contain no solvent. Dual-heated line plural component application equipment is required with these materials since the coatings potlife is on the order of seconds to a few minutes. Currently, Reclamation is specifying these coatings systems for water immersion and buried pipe coatings and linings due to their greater impact resistance and durability.

Chapter III: Specifications

Reclamation construction jobs are advertised to contractors to perform the required work, and contractor selection is made by a bid process. The most common bid types are low price, negotiated, fixed cost, and sole source. Once Reclamation accepts a contractor's bid, a contract exists between Reclamation and the contractor. The contract is often called a specification. The specification can be defined as a written, detailed, technical description of work to be performed, describing the materials, quantities, and mode of construction.

Specifications are divided into many divisions to describe the various job requirements and may include general job descriptions, submittals, pre-existing conditions, environmental requirements, and technical, architectural, civil, electrical, mechanical, coating, and cathodic protection disciplines. Each division is sometimes called a technical paragraph or section.

CONSTRUCTION SPECIFICATION INSTITUTE

Reclamation has changed from a narrative paragraph format to the Construction Specification Institute (CSI) format for specifications. CSI format style is more concise and uses imperative language. Reference standards are specified to describe quality of materials, work mode, test methods, and acceptance criteria that are a recognized industry practice, thus reducing the need for lengthy verbiage. The most common reference standards used in the coatings industry are ASTM, NACE, and SSPC.

CSI specifications are divided into 49 divisions for all the building trades, and each division may be further divided into specialty sections. Finishes can be found in Division 9 and include paint, metalizing, and protective coatings. Each section is subdivided into the following basic parts:

Part 1: General.—Includes cost, references, submittals, quality assurance, delivery, storage, handling, and restrictions.

Part 2: Product.—Includes requirements for materials to be used.

Part 3: Execution.—Includes mode of construction, test methods, acceptance criteria, and repair.

RECLAMATION COATING SPECIFICATIONS

The Technical Service Center (TSC) in Denver maintains CSI guideline coating specifications. The guideline coating specifications are the basis for specific project requirements and are based on historical Reclamation structures. The guideline specifications contain instructional notes and footnotes to aid the specification writer in preparing the specifications to meet specific project requirements. The guideline coating specifications are available on Reclamation's Intranet Web site: <[http://intra.do.usbr.gov/guidespecs/CSI-MasterFormat 04/Division 9 - Finishes.pdf](http://intra.do.usbr.gov/guidespecs/CSI-MasterFormat%2004/Division%209%20-%20Finishes.pdf)>. Reclamation uses the following specialty sections for coatings:

Section 09 91 10. Coatings for concrete, masonry, gypsum board, fiberglass, plastic, and wood.

Section 09 96 20. Coatings for new metallic substrates and maintenance coatings for previously coated metallic substrates that include steel, cast, or ductile iron; galvanized aluminum; brass; bronze; or copper.

Section 09 97 15. Metalizing on metallic substrates.

(a) Part 1: General.—Part 1 includes the following general outline:
(Cost provisions for either lump sum or bid item)

- References for industrial standards used in the specification section
- Submittals are required to ensure the contractor is supplying the specified materials. The following submittals are essential:
 - Manufacturer's product data and application sheets
 - Purchase orders, batch numbers, color, and quantities
 - *Certifications.* Some jobs require a contractor to be a certified SSPC QP1 or QP3 painting contractor. A QP1 contractor is certified for field application to complex structures. A QP3 contractor is a certified shop applicator.
 - *Documentation.* This is written evidence of the applicator's qualifications—the data that are required for each individual on the jobsite, not the coating contractor's company. It is important to review at least three recent jobs and contact information for each individual on the jobsite using comparable coating materials.

- *Contractor Quality Testing Data.* The quality test data are important to be able to review the daily work performed and to have quality assurance.
- Quality assurance
- Delivery, storage, and handling
- Environmental restrictions for surface preparation and application

(b) Part 2: Products.—Part 2 includes the following material requirements outline:

- Abrasives
- Coatings
- Fillers and caulks
- Soluble salt removal

(c) Part 3: Execution.—Part 3 includes the following outline requirements to complete work:

- Protection and repair of existing surfaces
- Embedded metalwork in concrete
- Surface preparation methods
- Application equipment
- Coating application requirements
- Inspection methods and acceptance criteria
- Repair of damaged and nonacceptable coated areas
- Coating tabulations and categories (see following section)
- Color schedule

COATING TABULATIONS AND CATEGORIES

The format of the coating tabulations and categories in the CSI specifications will be similar to the old narrative paragraph format. The coating tabulations and

categories change over time because of lower VOC regulations, lead- and chromate-free requirements, new coating technology developments, and other factors. The following sections describe the tabulations and categories.

Coating Tabulations

Coating tabulations are based on Reclamation's historical experience with coating metalwork items, service exposure, and materials used in dams and water conveyance projects. The tabulations are in the following table format:

- Items to be coated are identified.
- Coating materials are identified in the first column by an alphanumeric label for a manufacturer's brand name or a Federal/military specification number. Several equivalent coating materials may be listed within the same material option number. More than one coating material option may be listed in the tabulation. For small jobs, the color may be specified in this column.
- Number of coats (primer, intermediate, and topcoat), thickness of each applied coat, and total dry film thickness (DFT) of the coating system are identified in the second column.
- Surface preparation methods are identified by letter or alphanumeric label in the third column and are defined in the execution part for surface preparation.
- Instructional notes, if specified, are located at either table front or end.

Coating Categories

Coating categories specify, by alphanumeric labels, the manufacturer's brand name or the Federal or military specification number of the coating material listed in the tabulations. The categories are subdivided according to the following three essential characteristics:

1. **Composition.** List the generic chemical coating name.
2. **Physical characteristics.** Weight per gallon, VOC content, minimum application temperature, curing times at specific temperature and humidity, etc.
3. **Performance requirements.** Accelerated ASTM testing and acceptance criteria.

MANUFACTURER'S PRODUCT DATA AND APPLICATION SHEETS

Reclamation specifications require the submittal of the coating manufacturer's product data (sometimes called technical data) and application sheets. These sheets specify the manufacturer's instructions and recommendations. The manufacturer's instructions and recommendations have become specification requirements, unless the specifications are more restrictive. Product data and application sheets should be kept for future reference to verify the material type applied. The product data and application sheets vary in content and format from manufacturer to manufacturer. Some manufacturers combine product data and application into one sheet. However, the sheets provide useful information for the specific material.

- ***Product data sheet.*** The following are the most common items on the product data sheets:
 - Generic chemical coating name (acrylic, alkyd, epoxy, polyurethane)
 - Typical uses, such as on bridges, pipes, or water tanks
 - Service exposure for atmospheric, burial, immersion (fresh water or salt water), and chemical resistance
 - Color and gloss availability
 - Physical or technical properties, such as weight per gallon, solids by volume, VOC content, pigment additives, flashpoint, and service temperature resistance
 - Recommended dry or wet film thickness
 - Theoretical coverage rate per gallon
 - Mix ratio (if multicomponent system), pot-life, and induction or sweat-in time (elapsed time interval to allow the chemical reaction to begin for multicomponent materials before application)
 - Dry, recoat, curing, and full cure time periods at temperature and humidity ranges
 - Performance test results (accelerated ASTM tests that may or may not be listed)
 - Shelf life

- Safety precautions
- Shipping data
- Warranty and limitations of liability
- ***Application sheet.*** The following are the most common items on the application sheet:
 - Substrate types that are compatible with the coating material (e.g., aluminum, concrete, galvanized, steel, cast iron, or existing coated surfaces)
 - Surface preparation method, normally listed as a minimum
 - Thinner product name and amount to be added
 - Pot-life time of multicomponent coating material at various temperature and humidity ranges
 - Lower and upper temperature and humidity range restrictions during application
 - Most manufacturers state that the coating is to be applied only when the substrate temperature is 5 °F, minimum, above the dew point
 - Drying, recoat, and curing times at various temperature and humidity ranges
 - Application method: brush, roller, conventional airless spray, or airless spray. May include specific equipment at recommended pressures, hose diameter sizes, spray gun, nozzle tip sizes, etc.

ADDENDUMS AND MODIFICATIONS

Specifications are sometimes changed to alter designs, correct errors, or redress omissions. The following two general methods are used to revise specifications: (1) addendums (also called amendments) and (2) modifications. Addendums are written page inserts that change part(s) of the specification before bidding occurs, and modifications are written page inserts that modify part(s) of the specification after the contract is awarded. Modifications can incur cost adjustments to the contract and are often called change orders.

Chapter IV: Inspector's Role

The coating inspector ensures that (1) the work is accomplished in a timely manner in accordance with the specifications, (2) work activities are documented, and (3) work is performed safely. The coating inspector at the jobsite is either the contracting officer's or the field engineer's representative.

The inspector should not verbally change the requirements or require more rigid requirements on the contractor than were originally specified. The inspector should contact his supervisor for resolution if the specifications are inadequate. Contractors may request a variant from specifications that may or may not be significant. Regardless of variant significance, the inspector should inform his supervisor of any requested changes. If a coating applicator is not following the specifications, the inspector should not confront the applicator. Instead, he should ask the coating contractor's supervisor to determine why the specifications are not being followed. In some cases, a deviation may have been allowed, or the coating contractor's supervisor may need to correct his own worker's practices.

PRIMARY RESPONSIBILITIES

The following are primary responsibilities of the inspector:

- Verify in writing that coating work is being performed in accordance with the specifications
- Monitor work activity on a daily basis, including deviations from the specifications
- Report and record deficiencies to the field engineer for resolution
- Ensure work is conducted in a safe manner

DAILY RESPONSIBILITIES

The following is a partial list of daily inspection responsibilities:

Preparatory

- Ensure specifications contain all addendums and modifications
- Ensure all specification submittal requirements are met

Presurface Preparation

- Ensure weather conditions are conducive to blasting operations
- Determine preblast surface condition for rust grade
- Ensure that the surface is free of irregularities (weld spatter, slag burrs, sharp edges, pits, laminations, or other objectionable irregularities)
- Ensure that abrasives meet specification requirements and are within contamination limits
- Ensure the air compressor is free of moisture and oil contamination

Postsurface Preparation

- Ensure the surface preparation method meets specification requirements
- Ensure the surface (anchor) profile meets specification requirements
- Ensure the surface is free of contaminants and meets cleanliness specification requirements

Precoating Application

- Ensure all coating materials are approved
- Check storage area for proper environmental and safety requirements
- Ensure environmental conditions (ambient and surface temperatures, humidity, and dew point) meet specification requirements
- Ensure mixing and thinning meet manufacturer's requirements

Coating Application

- Ensure application methods meet manufacturer's requirements
- Ensure intermediate coat and topcoat applications are within the recoat time interval for temperature and humidity ranges and that they meet the specifications or the manufacturer's requirements
- Check ambient temperature and humidity during curing period

Postcoating Application

- Ensure the DFT meets specification requirements
- Inspect dry film for holiday (pinhole) defects
- Ensure that defective, damaged, and deficient areas are repaired to meet specification requirements
- For a more comprehensive list of responsibilities, see appendix C

MATERIAL APPROVAL

Contractor-submitted coating materials are normally reviewed by the Reclamation office that either prepared or issued the specifications. The responsible reviewing office is listed in the required submittal number (RSN) table in Section 01 33 00 (Submittals) of the CSI specifications.

The coating inspector is not usually responsible for approving or disapproving contractor-submitted material. However, the inspector should track contractor and Reclamation correspondence to ensure that only approved materials are used on the jobsite.

If the TSC in the Denver Office is the responsible specification reviewing office, it will provide a contractor submittal with one of the following responses:

- ***Approved.*** Indicates material can be purchased and applied.
- ***Conditionally approved.*** Indicates the material selection is acceptable and the material may be purchased; however, the submittal is incomplete or is missing documentation. Resubmittal of incomplete or missing documentation is required. Conditional approval does not imply acceptance for material application.
- ***Not approved.*** Indicates the selected material is not approved for application.

The inspector should check batch numbers on material containers against the approval letter batch numbers for materials that arrive on the jobsite. Containers with batch numbers that do not correspond to the approved material batch numbers should be removed from the jobsite.

DOCUMENTATION

The inspector should acquire the following documents:

- Specifications that include addendums and modifications.
- The manufacturer's product data, application, and Material Safety Data Sheet (MSDS).
- Reference standards referred to in the specifications that relate to the field inspection.

Reference standards are discussed in more detail for the pertinent inspection method in other chapters. Appendix D lists reference standards cited in this document.

INSTRUMENTS, GAUGES, AND TOOLS

The inspector should acquire the equipment, instruments, and instructional manuals necessary to perform the inspection work. Spare batteries should be available if electronic instruments are used. The types of instruments will be discussed in the following chapters and are listed in appendix E.

Conflicts

At times, there are disagreements between the contractor and the inspector over instrument readings such as surface anchor profiles or DFTs. There may be reasonable explanations for such discrepancies. These discrepancies should be investigated to avoid future conflicts and to develop a working relationship with the contractor. The following are some possibilities for instrument disagreements:

- The two parties are not using the same type of instrument sets:
 - One instrument may be malfunctioning
 - One instrument may be out of calibration
- The two parties are using the same type of instruments, but:
 - They are using different procedures
 - They are taking readings at different locations
 - One instrument may be out of calibration

SUBSTRATE INSPECTION

The inspector should inspect the substrate surface before surface preparation. Ferrous substrates with localized rust or mill scale are more prone to premature coating failure. Rust and mill scale areas should be inspected more thoroughly for cleanliness after surface preparation. If mill scale is noted and abrasive blasting is not specified, notify the field engineer because abrasive blasting is required. For maintenance coating work where overcoating is specified, the existing coating material should be inspected for loose coatings by scraping with a sharpened putty knife. Overcoating loosely adhering to the existing coating will result in premature failure.

For items coated in a shop, the coatings should be inspected and identified for damage and failed coating areas that will require repair either before or after installation.

COATING INSPECTION CHECKLIST SHEET

Reclamation specification coating tabulations (see chapter III, "Coating Tabulations and Categories") identify the items to be coated, coating materials, the DFTs, and the surface preparation methods; however, the inspector may wish to expand on the coating tabulations by creating a coating inspection checklist unique to the job. Since specification coating tabulations can identify several items to be coated within a single tabulation, an inspection sheet can provide for the individual coating operations and for the completed inspection for a single item to be coated, such as a pipeline interior or a radial gate. The checklist can become a permanent record of the job. A checklist example appears in appendix F.

PRECOATING CONFERENCE

Reclamation coating specifications do not require a precoating conference with the contractor. However, a meeting with the contractor to discuss coating-related issues would be helpful. A precoating conference would allow the contractor to know what is expected and to outline the work program. This meeting should establish a working relationship between the contractor and Reclamation. The following are possible items for discussion at the meeting:

- The contractor's job-specific worker health and safety plan (a submitted written plan is required for lead or other hazardous material removal and disposal)

Guide to Protective Coatings, Inspection, and Maintenance

- The inspector's access and safety
- The contractor's proposed operation, including equipment and personnel
- The contractor's working hours
- The material storage area, including temperature, ventilation, and security
- The approved surface preparation methods, abrasives, coating materials, application methods, and curing times
- The method of dust collection and disposal of used abrasives
- Unfavorable weather related to prepared surfaces, applied coatings, or curing
- The plan for coating inaccessible areas
- Inspection methods and the number of measurements
- The types of inspection instruments to be used
- The NACE/SSPC reference standards that are specified, the visual standards to be met, and the acceptance criteria

Chapter V: Material Storage, Containers, and Shelf Life

Coating materials arrive on the jobsite before application begins, and they require storage. Manufacturers recommend specific provisions for storage to prevent coating deterioration. Coating materials must be used within a specified time from manufacture or shipment.

STORAGE

Coating materials should be stored in a covered, well-ventilated area away from sparks, flames, and direct sunlight. Many coatings require a limited temperature range for proper storage. Cold storage may require a coating to be excessively thinned for application, resulting in low solids content and a less-than-intended DFT. At or below freezing temperatures, coatings (such as water-based materials) can degrade to the point that they are unusable. Materials in cold storage should be moved to a heated area before application. At high temperatures, a material such as a solvent-based coating may gel or become flammable or explosive. The storage site should be monitored using a high/low thermometer.

Coating materials should be stored together by the same batch or lot numbers. Two-component coating systems should be stored close together but be distinguishable from one another. For storage of several months or longer, containers should be inverted on a monthly basis to avoid excessive settling and for ease of future mixing. The oldest coating materials should be used first.

Solvents and thinners should be stored separately from coating materials. Separation of solvents and thinners is a safety concern because many of these materials have lower flashpoint temperatures than most coatings, and they pose a potential fire hazard.

Contractors will often store coating material at the jobsite in trailers. Trailers with no heating, cooling, or ventilation systems are unsuitable for storage because they become cold in the winter and hot in the summer and have limited ventilation. Coating materials should be stored in climate-controlled environments. The following are generally accepted regulations for storing coating materials:

Indoor Storage

- No more than 25 gallons outside of approved cabinets in a single area.

Outdoor Storage

- No more than 1,100 gallons of materials grouped together.
- No more than 60 gallons in individual containers.

For further information on the storage of flammable and combustible liquids, refer to the manufacturer's MSDS and "Reclamation Safety and Health Standards."

CONTAINERS

Containers vary largely in volume and commonly range from 1 quart to 55 gallons. Because of application equipment limitations, the most common containers on a jobsite will be either 1-gallon or 5-gallon pails. Single-component materials are shipped in one container, and two or more component materials are shipped in separate containers, each of which has the capacity to hold the total combined volume.

Any containers that are damaged, leaking, or unlabeled should be rejected and removed from the jobsite.

SHELF LIFE

Shelf life is the length of time after manufacture that a coating material will remain usable when stored in an unopened container, according to the manufacturer. Manufacturers normally specify the shelf life of a coating on the container or use a special code or bar code that specifies the date of manufacture or the expiration date. For special codes or bar codes, the inspector may need to call the manufacturer to read the code. In general, most coatings have a shelf life of between 6 and 12 months at an optimal temperature, but this will vary with manufacturer and material type. Shelf life is noted on the manufacturer's product data sheet. The inspector should check the date of manufacture or the expiration date to determine that the expiration date has not been reached. Coating materials that have exceeded the shelf life should be removed from the jobsite. Consequences of exceeding the shelf life include gelling, odor, changes in viscosity, formation of lumps, pigment settlement, and color or liquid separation.

Chapter VI: Surface Preparation

The service life of a coating depends on the degree of surface preparation achieved as much as it depends on material selection and application. All coating systems will eventually fail; however, premature failures are often the result of inadequate surface preparation. Even surface preparations that achieve an acceptable margin of cleanliness but leave contaminants on the surface will tend to lessen the coating service life. Thus, cleanliness of the substrate is an essential and integral component of a coating system.

SURFACE CONTAMINANTS

Surface contamination is one of the most common causes of coating failures. To achieve the maximum service life of a coating system, it is essential to remove surface contaminants.

Types of Surface Contaminants

The following are the most common types of surface contaminants and the consequences of not removing them:

- ***Rust.*** Rust is the corrosion byproduct (ferrous oxide) of steel and may be loose or may adhere relatively tightly to the substrate. Rust is porous and may include moisture, oxygen, and soluble salts. Rust will expand up to eight times the volume of the base metal consumed and further corrode the steel substrate, thus dislodging any coating applied over it.
- ***Mill scale.*** Mill scale is a heavy oxide layer formed during hot fabrication or heat treatment of metals and is a bluish color. Mill scale will eventually break loose from the steel substrate, taking the coating with it. Steel is anodic to mill scale (steel has a lower electrical-chemical potential difference than mill scale); therefore, steel will corrode (sacrifice itself) to protect the mill scale.
- ***Grease and oil.*** Grease and oil prevent a coating from adhering to the substrate.
- ***Dirt and dust.*** Dirt and dust on the surface prevent the application of a smooth uniform film and weaken the adhesion of the coating to the substrate.

- ***Soluble salts.*** Soluble salts deposited on a surface can remain on the surface even after abrasive cleaning. Soluble salts will increase moisture permeation through the coating (osmotic blistering) and can accelerate the corrosion rate under the coating film (underfilm corrosion or undercutting). The most common soluble salts encountered in the coating industry are chlorides, sulfates, and metallic salts. The chloride ion is the most aggressive.
- ***Water.*** Water will prevent adhesion and may either produce flash rusting before coating application or it may accelerate underfilm corrosion after coating application. Moisture in the liquid or frozen state will prevent adhesion of the coating to the substrate and can disrupt curing reactions of coatings. Moisture contamination can cause several types of failure.
- ***Chalk.*** Chalk is the residue left after the deterioration of the coating's organic binder. Chalk results from exposure of the coating to direct sunlight or artificial UV light. All coatings chalk to some degree, but epoxies are more prone to chalk. Overcoating chalked surfaces will result in poor adhesion and may result in delamination (separation of one coating layer from another coating layer) failure.
- ***Deteriorated coatings.*** Old, loose, deteriorated coatings that are overcoated may peel, delaminate, or lift from the substrate and take the new coating with them.

Compressed Air Contaminants

Air compressors contaminated with moisture and oil can result in adhesion-related failures. The following are two common operations that transfer oil and water contaminants from the compressed air supply to the substrate:

- Abrasive surface preparation operations
- Blowing down the prepared substrate after surface preparation to remove dust before applying the coating

Air compressors should be equipped with in-line moisture and oil separators (traps) on all lines. The inspector should have the contractor check the air supply for contaminants in accordance with ATM D 4285. (See appendix G for this procedure.) It is recommended that the compressed air lines be checked once every 4 hours or after the compressor has been turned off.

Flash Rusting

Flash rusting (sometimes called flashback rusting or rust blooming) is a light oxidation (corrosion) of the ferrous surface after surface preparation has been completed. Flash rusting develops on freshly prepared surfaces in the presence of moisture. After the moisture dries off, any resulting corrosion is called flash rusting and can occur within minutes after surface preparation. The following two circumstances are the most common moisture sources resulting in flash rusting:

- Condensation is occurring
- Water is used in the surface preparation method

Condensation is the formation of liquid water from water vapor in the surrounding air at certain ambient temperatures and humidity ranges. Condensation can occur using any surface preparation method because it is weather dependent. Surface preparation methods that employ water are water jetting and wet abrasive blast cleaning. Flash rusting can be minimized when using water jetting and wet abrasive blast cleaning by the following methods:

- ***Using an inhibitive agent.*** Inhibitive agent or wash primer, normally a phosphate, is injected into the water or blast stream or applied after cleaning. Reclamation does not prohibit the use of inhibitors, but the surface should be thoroughly water washed before coating because heavy inhibitive residues can adversely affect coating adhesion.
- ***Using hot forced (blown) air.*** Dry off the wetted surface immediately after cleaning with hot air blowers.
- ***Using high-pressure, water jet vacuum cleaning method.*** High-water pressure transfers enormous energy to the surface, thus elevating the surface temperature to evaporate any moisture, and the vacuum removes evaporated and liquid moisture away.

To prevent flash rusting, it is a general industrial practice not to proceed with surface preparation unless the steel substrate temperature is 5 °F, minimum, above the dew point. (See Chapter VII: Environmental Conditions.)

Surface preparation standards NACE 1/SSPC-SP-5, NACE 2/SSPC-SP10, NACE 3/SSPC-SP-6, NACE 4/SSPC-SP-7, NACE 8/SSPC-SP14, SSPC-SP15, and SSPC-SP11 provide for recleaning or reblasting to remove flash rusting. The surface preparation standards SSPC-SP2, SSPC-SP3, and NACE 5/SSPC-SP12 do not specifically address flash rusting, but require that the surface be recleaned

according to cleanliness requirements of the standard used if rust forms on the surface. Reclamation specifications require that any surface where flash rust or corrosion byproducts have formed be recleaned.

If flash rusting is suspected and is not visibly noticeable, a good detection method is to inspect the surface with a bright flashlight or spotlight. The light should be held parallel to the surface and shined across it. Rust blooms will appear as darkening on the surface and have a reddish or light brown tint.

PRESURFACE TREATMENT

Prior to actual surface preparations, all steel surface imperfections are to be corrected. This is a Reclamation specification requirement. Weld spatter, slag, burrs, porosity, sharp edges, pits, laminations (slivers), crevices, or objectionable irregularities need to be repaired. Surface depressions, such as pits or crevices, can be a collection point for excessive coating material that may not fully cure. Projections such as weld slag, slag burrs, or sharp edges that may stick out through the coating can result in pinpoint corrosion. All these irregularities are to be repaired by welding, scrapping, grinding, or other specified means.

ABRASIVE BLAST MATERIAL

The abrasive blast material is important because it determines the surface profile produced. There are two general categories of abrasives: metallic and nonmetallic. Metallic abrasives are used primarily to blast clean steel and forged or cast iron where a surface profile is seldom critical on the finished product. Nonmetallic abrasives, depending on the type used, can produce the desired surface profile and cleanliness on hard, dense ferrous metals or on soft metals (aluminum, brass, bronze, or copper) without damaging or altering the metal surface.

Reclamation specifies SSPC-AB 1, “Abrasive Specification No. 1, Mineral and Slag Abrasives,” Class A, either Type I or II. Reclamation specifications do not permit abrasive materials containing toxic heavy metals such as arsenic or soluble salts in excess of 0.04 percent. Abrasive material is not to contain more than 1 percent silica, by volume, because silica sand particles cause silicosis.

Reclamation does not specify metallic abrasives. Metallic abrasives are not field applicable because of high costs and the inability to recycle. However, Reclamation will allow a contract variance, if requested, to use metallic abrasives for shop surface preparation, provided that the metallic abrasive is a dry, clean, angular steel grit.

Nonmetallic Abrasives

There are three basic types of nonmetallic abrasives:

1. Naturally occurring
2. Byproducts
3. Manufactured

The following sections provide a brief description of the typical usage and the degree of dusting produced by nonmetallic abrasives during blasting operations.

Naturally Occurring

- ***Nonsilica or heavy mineral sands (magnetite, olivene rutile, straurolite).*** These sands are typically tough, dense, round-shaped materials. They are effective for blast cleaning new steel, but are not recommended for maintenance coating work. The degree of dusting during blasting operations is medium.
- ***Flint, garnet, novaculite (siliceous rock), and zircon.*** These are dense, tough, angular, or cubic abrasives that, because of their high costs, are used primarily in special cleaning applications. The degree of dusting during blasting operations is medium for flint and garnet and low for novaculite and zircon.

Byproduct

- ***Slags (coal, copper, nickel).*** Slag abrasives are generally a glassy, homogeneous mixture of various oxides that are sharply angular or cubic and are efficient for blast cleaning new, rusted, or painted surfaces. These abrasives are not recycled. The degree of dusting during blasting operations is high for coal and nickel and low for copper.
- ***Agricultural products (corncoobs, peach pits, walnut shells).*** These are generally regarded as tough but lightweight abrasives used in special cleaning applications for removing paint, fine scale, and other contaminants without altering the metal substrate or distorting thin metals. The degree of dusting during blasting operations is low.

Manufactured

- **Synthetic (*aluminum oxide, glass beads, silicon carbide*).** These abrasives can be produced with specific properties for varying degrees of hardness and toughness and with specific shapes. High cost restricts the use of these abrasives to special cleaning applications, and they must be recycled to be economical. The main advantages of using synthetic abrasives are fast cutting capability and nonrusting of the substrate. The degree of dusting during blasting operations is low.

Sampling and Testing

Abrasive samples should be retained for future reference in the event of coating problems. Samples can be tested and the results retained to either confirm or reject abrasives as a possible cause of failure. Different abrasives used on the same metalwork can produce different appearances. Testing should be conducted on the abrasives before use to ensure that the material does not contain contaminants.

Sampling

The inspector should record the manufacturer's brand name, batch or lot numbers, and abrasive type. Abrasive material should be stored in a dry environment and be clean, uniform in texture, and moisture free. It is recommended that a small sample of each abrasive batch or lot number be kept for future reference in case changes occur in the surface profile.

Testing

Soluble salt concentrations are typically low for mined mineral abrasives (SSPC-AB1, Type I) and slag abrasives (SSPC-AB1, Type II) that are air cooled or quenched in purified water. However, slag abrasives may be quenched in seawater, brackish water, or other salt-contaminated water and, consequently, have a higher soluble salt content. Abrasives with high soluble salt content should not be used because the salts can contaminate the substrate during blasting operations and, thus, cause coating failure.

Mineral and slag abrasives should be tested for the presence of soluble salts by a conductivity meter. Conductivity is the ionic property of a fluid or solid that permits the passage of an electric current. Soluble salts dissolved in water can be measured by a conductivity meter. Conductivity meters measure the conductance of all salts (chlorides, sulfates, ferrous, etc.) in dissolution but cannot detect a

“specific” salt ion (e.g., the chloride ion). Reclamation specifies that mineral and slag abrasives are to be in accordance with SSPC-AB1, and the standard’s conductivity requirement is not to exceed 1,000 microsiemens. The chloride-specific ion in abrasives can be tested using a titration kit. (See appendix H for test procedures.) Testing for toxic metals requires laboratory methods. Certification or analysis of abrasive material content is available from the manufacturer.

Although water is not considered an abrasive, it is used as a surface preparation medium for previously coated metalwork. Water may contain an excessive amount of soluble salts that, if left as residue on the prepared surface, can cause the coating to blister. The water used in water jetting operations should be tested for high chloride ion levels. (See appendix I for procedures.)

NOZZLE BLAST PRESSURE

Reclamation does not require checking the blast nozzle pressure. Industry practice recommends that the blasting pressure be maintained between 90 and 100 pounds per square inch (psi). Reduced pressures can result in a shallow surface profile depth and diminished blast rate efficiency. Excessive pressures can increase the surface profile depth. Consequently, the prime coat may not cover the peaks of the profile, and pinhole failure may result. The critical point of pressure is at the blast nozzle where pressure will be lower than at the air compressor because of hose line pressure losses.

If the nozzle blast pressure is suspect, it is recommended that the inspector request the coating supervisor to check the pressure. (See appendix J for the procedure.)

SURFACE PREPARATION METHODS

The following are the five basic types of surface preparation:

1. Degreasing
2. Hand and power tool cleaning
3. Abrasive (wet or dry) cleaning
4. Water jetting or pressure cleaning
5. Chemical stripping

There are several standards describing the above methods; however, Reclamation has adopted SSPC and joint NACE/SSPC surface preparation standards. The inspector should ensure that the applicable standards are available on the jobsite. After surface preparation, cleanliness shall be based on the specified standard’s cleaning requirements. Visual standards by SSPC and joint NACE/SSPC are a

supplement to aid in determining cleanliness, but are not the sole confirmation requirement. Surface preparation standard requirements shall govern where surface preparation and visual standards conflict. The following are the SSPC and joint NACE/SSPC surface preparation standards in increasing order of cleanliness. An abbreviated summation is provided for each surface preparation standard and the corresponding visual standard to be used.

SSPC-SP1: Solvent Cleaning

Solvent cleaning is used to remove grease, oil, dirt, drawing and cutting compounds, and other contaminants by solvent wiping, water washing, cleaning compounds, and steam cleaning. This procedure is a prerequisite for all other surface preparation methods except NACE 5/SSPC-SP12 (water jetting) and NACE 6/SSPC-SP13 (concrete surfaces). The reason for solvent cleaning is that contaminants left on the surface can be impacted into the substrate surface during preparation using other methods (listed below), resulting in poor adhesion and premature failure.

SSPC-SP2: Hand Tool Cleaning

Hand tools are used to remove loose mill scale, loose rust, loose coatings, weld flux, weld slag, or weld spatter by brushing, sanding, chipping, or scraping. Tightly adhering rust, mill scale, and paint are allowed to remain. The use of hand tools is generally confined to small areas, small repair areas, or small inaccessible areas. The visual standard is determined by comparison to SSPC-VIS 3 reference photographs.

SSPC-SP3: Power Tool Cleaning

Power tools are used to remove loose mill scale, loose rust, loose coatings, weld flux, weld slag, or weld spatter. Tightly adhering rust, mill scale, and coating are allowed to remain if they cannot be removed by lifting with a dull putty knife. The requirements of this method are similar to SSPC-SP2, except that, with power tools, larger areas can be cleaned more efficiently. The visual standard is determined by comparison to SSPC-VIS 3 reference photographs.

SSPC-SP15: Commercial Grade Power Tool Cleaning

Power tools are used to remove all grease, oil, dirt, dust, mill scale, rust coatings, oxides, corrosion byproducts, and other foreign matter that are visible without magnification, except that random stains are allowed on 33 percent of each

9-inch-square area. Stains may consist of light shadows, light streaks, and mild discoloration caused by rust, mill scale, and previous applied coatings. Slight residues of rust and paint are allowed to remain at the bottom of corrosion pits, provided that the original substrate was pitted. This standard requires a minimum surface profile of not less than 1 mil be retained or produced. Currently, there are no visual reference photographs for this standard.

NACE 4/SSPC-SP7: Brushoff Blast Cleaning

Brushoff blast cleaning employs abrasive blasting to remove all grease, oil, dirt, dust, loose mill scale, loose rust, and loose coatings that are visible without magnification. Tightly adhering rust, mill scale, and coatings are allowed to remain if they cannot be removed by lifting with a dull putty knife. The visual standard is determined by comparison to SSPC-VIS 1 reference photographs.

NACE 8/SSPC-SP14: Industrial Blast Cleaning

Industrial blast cleaning employs abrasive blasting to remove all visible grease, oil, dirt, and dust that are visible without magnification. Traces of tightly adhering mill scale, rust, and coating residue are allowed to remain on 10 percent of each 9-inch-square area, provided that the distribution is even. Traces of rust, mill scale, and coatings are allowed to remain if they cannot be removed by lifting with a dull putty knife. Shadows, streaks, and discoloration caused by rust, mill scale, and previously applied coatings are acceptable. The visual standard is determined by comparison to SSPC-VIS 1 reference photographs.

SSPC-SP8: Pickling

Pickling removes all mill scale and rust that are visible without magnification by chemical reaction (acid bath) or electrolysis (anodic electrical current) or both. Acceptance criteria are to be established between contracting parties.

NACE 3/SSPC-SP6: Commercial Blast Cleaning

Commercial blast cleaning employs abrasive blasting to remove all grease, oil, dirt, dust, mill scale, rust, coatings, oxide, corrosion byproducts, and other foreign matter that are visible without magnification, except for random staining. Staining may consist of light shadows, slight streaks, or minor streaks caused by rust, mill scale, or previously applied coatings. At least two-thirds of each 9-inch-square area shall be free of all visible residue, and only the above-mentioned staining may be present in the remainder of the area. The visual standard is determined by comparison to SSPC-VIS 1 reference photographs.

NACE 2/SSPC-SP10: Near-White Metal Blast Cleaning

Near-white metal blast cleaning employs abrasive blasting to remove all grease, oil, dirt, dust, mill scale, rust, coatings, oxide, corrosion byproducts, and other foreign matter that are visible without magnification, except for random staining. Staining may consist of light shadows, slight streaks, or minor streaks caused by rust, mill scale, or previously applied coatings. At least 95 percent of each 9-inch-square area shall be free of all visible residues, and the remainder of the area shall have only the above-mentioned staining. The visual standard is determined by comparison to SSPC-VIS 1 reference photographs.

NACE 1/SSPC-SP5: White Metal Blast Cleaning

White metal blast cleaning employs abrasive blasting to remove all grease, oil, dirt, dust, mill scale, rust, coatings, oxide, corrosion byproducts, and other foreign matter that are visible without magnification. The resulting blasted surface is generally a uniform gray-white color. Variation in color caused by steel type, original surface condition, steel thickness, weld metal, mill or fabrication marks, heat treatment, heat-affected zones, blasting abrasives, or differences in blast pattern is acceptable. The visual standard is determined by comparison to SSPC-VIS 1 reference photographs.

NACE 5/SSPC-SP12: Surface Preparation and Cleaning of Steel and Other Hard Metals by High and Ultrahigh Pressure Water Jetting Prior to Recoating

High and ultrahigh water jet blasting employs water blasting to remove all visible contaminants such as; grease, oil, dirt, dust, mill scale, rust coatings, oxides, corrosion byproducts, and other foreign matter that are visible without magnification. It also removes the nonvisible contaminants such as soluble salts. The standard defines the following four different water pressures: (1) low-pressure water cleaning at less than 5,000 psi, (2) high-pressure water cleaning at 5,000 to 10,000 psi, (3) high-pressure water jetting at 10,000 to 25,000 psi; and (4) ultra-high pressure water jetting at greater than 25,000 psi. The degree of cleanliness is divided into two categories: visible contaminants and nonvisible contaminants. Visible contaminants are subdivided into four classifications, designated WJ-1 through WJ-4 (WJ-1 is the cleanest) on the basis of allowable visible rust, coatings, mill scale, and foreign matter verified without magnification. Nonvisible contaminants are subdivided into three classifications, designated SC-1, SC-2, and SC-3 (SC-1 is the cleanest) on the basis of allowable soluble chloride ions, iron-soluble salts, or sulfate ions. The visible and nonvisible allowable contaminant levels are specified by the designation WJ-x/SC-x; “x” indicates the specified definition number. The visual standard will be

determined by comparison to SSPC-VIS 4/NACE 7 reference photographs.

Reclamation specifies WJ-2/SC-2 for all immersion service exposures.

Water jetting cannot produce a surface profile without the addition of abrasives into the jet flow and, therefore, is not specified for surfaces without a surface profile (e.g., new construction steel). Reclamation specifies this standard only for previously coated surfaces that have an existing surface profile.

This is an excellent method for removing old paint and contaminants using only pressurized water. Water jetting equipment can be vacuum shrouded to prevent spray and have in-line filters to separate out old paint and contaminants. Some manufacturers are experimenting with injecting abrasives into the water jet stream that would be capable of producing a surface profile.

PHOTOGRAPHIC INSPECTION STANDARDS

The inspector should inspect the surface before and after surface preparation to evaluate cleanliness. SSPC and NACE/SSPC standard visual reference photographs are a supplemental aid to evaluating cleanliness, but are not intended as a substitute for surface cleanliness requirements defined in the surface preparation standard used. The reason for inspecting the surface before surface preparation is that different degradations on the same steel surface (e.g., heavy mill scale with light and heavily rusted areas) will have a different appearance after using the same surface preparation method. Thus, steel surfaces that are acceptably clean will appear different, depending on the initial steel condition and the surface preparation method employed. Below are the visual reference standards for abrasive blast cleaning, hand and power tool cleaning, water jet cleaning, and wet abrasive blast cleaning.

This is an excellent method for removing old paint and contaminants using only pressurized water. Water jetting equipment can be vacuum shrouded to prevent spray and have in-line filters to separate out old paint and contaminants. Some manufacturers are experimenting with injecting abrasives into the water-jet stream that would be capable of producing a surface profile.

SSPC-VIS 1: Visual Standard for Abrasive Blast Cleaned Steel

This guide shows a series of photographs of unpainted carbon steel before and after abrasive blast cleaning. Below is an abbreviated explanation of the procedures to follow before and after cleaning the steel. The procedures are followed by an example.

1. Before abrasive blast cleaning, match the existing surface condition with the “initial condition” shown in one of the photographic standards. Initial conditions (or rust grades) are photographs A, B, C, and D and are defined in section 4.1 of the standard. Various areas of the surface to be cleaned may match one or more initial condition photographs.
2. From the specifications, determine the specified surface preparation standard. The surface preparation standard will be one of the following: NACE 1/SSPC-SP5, NACE 2/SSPC-SP10, NACE 3/SSPC-SP6, or NACE 4/SSPC-SP7.
3. From table 1 in the visual standard, select the specified surface preparation standard and the initial condition to obtain the correct photographic designation.
4. Evaluate the finished blast surface against the selected photograph in step 3 above to determine if the surface meets the specified surface preparation requirements for cleanliness.

Example: A steel trashrack has been delivered to the jobsite uncoated and stored outside without protection. The trashrack is showing evidence of uniform corrosion and no pitting before coating. The specified surface preparation method is NACE 2/SSPC-SP10.

- **Step 1:** The existing surface appearance most closely represents rust grade “B.”
- **Step 2:** Table 1 shows that for surface preparation NACE 2/SSPC-SP10 and rust grade “B,” the finished blast surface should correspond to photograph B SP10.
- **Step 3:** Evaluate the finished blast surface against photograph B SP10 to determine if the surface meets NACE 2/SSPC-SP10 cleanliness requirements.

SSPC-VIS 3: Visual Standard for Power- and Hand-Tool Cleaned Steel

This guide shows a series of photographs of unpainted and painted carbon steel before and after hand- and power-tool cleaning. Below is an abbreviated explanation of the procedures to follow before and after cleaning the steel. The procedures are followed by an example.

1. Before hand- or power-tool cleaning, match the existing surface condition that most closely represents the appearance with the “initial

condition” shown in one of the photographic standards. Initial conditions (or rust grades) A, B, C, and D are for uncoated surfaces; conditions E, F, and G are for previously painted surfaces. Initial conditions are defined in section 4.1 of the standard. Various areas of the surface to be cleaned may match one or more initial condition photographs.

2. From the specifications, determine the specified surface preparation standard. The surface preparation standard will be one of the following: SSPC-SP2, SSPC-SP3, or SSPC-SP11.
3. Reclamation allows the contractor to choose the type of hand or power tool to accomplish the work. Determine the type of tool to be used from the contractor. The following designation codes are used in the standard to identify various hand and power tools:
 - **SP2.** Hand wire brush.
 - **SP3/PWD.** Power wire brush. (Reclamation does not permit rotary power wire brushing because the tool has the tendency to burnish or polish the metal surface, thus removing any existing surface profile.) However, Reclamation does approve the use of the Bristle Blaster manufactured by MBX. The Bristle Blaster can produce a large profile to steel surfaces.
 - **SP3/SD.** Power sanding disc.
 - **SP3/NG.** Power needle gun.
 - **SP11.** Power rotary flap peen or needle gun (to produce a surface profile). SP11/R: Power tool using nonwoven disks (to restore existing surface profile).
4. From table 1 in the visual standard, select the specified surface preparation standard and the initial condition to obtain the correct photographic designation.
5. Evaluate the finished hand- or power-tool surface against the selected photograph in step 4 above to determine if the surface meets the specified surface preparation requirements for cleanliness.

Example: An existing coated radial gate requires spot repairs. The coating has deteriorated or peeled off in small localized areas and rust is evident, but there is no visible pitting. The specified surface preparation method is SSPC-SP11, and the contractor used a needle gun.

- **Step 1:** The existing surface appearance most closely represents rust grade “C.”

- **Step 2:** Select power tool designation SP11 because a needle gun power tool was used to prepare the surface.
- **Step 3:** From table 1, the finished surface photograph that corresponds to rust grade “C” and surface preparation SSPC-SP11, and the tool used is C SP11.
- **Step 4:** Evaluate the finished surface against photograph C SP11 to determine if the surface meets SSPC-SP11 cleanliness requirements.

NACE 7/SSPC-VIS 4: Guide and Visual Reference Photographs for Steel Cleaned by Water Jetting

This guide shows a series of photographs of unpainted and painted carbon steel before and after water jet cleaning. Below is an abbreviated explanation of the procedures to follow before and after cleaning the steel. The procedures are followed by an example.

1. Before water jet cleaning, match the existing surface condition that most closely represents the appearance with the “initial condition” shown in one of the photographic standards. Initial conditions (or rust grades) B and C (initial condition photographs A and B are not included in the guide) are for uncoated surfaces. Conditions E, F, G, and H are for previously painted surfaces. Initial conditions are defined in section 4.1 of the standard. Various areas of the surface to be cleaned may match one or more initial condition photographs.
2. From the specifications, determine the specified degree of cleaning designated by one the following: WJ-1, WJ-2, WJ-3, or WJ-4. A possible surface preparation method could be NACE 5/SSPC-SP12 WJ-2/SC-3, and the specified degree of cleaning is WJ-2.
3. *Note:* The designation SC-3 in the above example denotes an acceptable degree of cleaning for allowable nonvisible soluble salt contaminants after water jet cleaning. The guide does not attempt to show nonvisible contaminants by photographic illustration. Physical testing is required to determine compliance for nonvisible contaminants and is discussed in chapter IX, “Testing for Chlorides on Prepared Surfaces.”
4. The guide shows photographs of the following four degrees for flash rusting: (1) no rusting, (2) light, (3) medium, and (4) heavy. These degrees of flash rusting are the degrees of rusting allowed to remain on the surface after water jet cleaning. The degrees of flash rusting are denoted in the guide by the following: (1) no letter designation for no

rusting, (2) L for light, (3) M for medium, and (4) H for heavy. For example, if light flash rusting is allowed by the specifications, a possible surface preparation would be NACE 5/SSPC-SP12 WJ-2/SC-3 L, where L is the allowable amount of flash rusting, and it is denoted in the guide photographs as WJ-2 L.

5. From table 1 in the visual standard, select the degree of cleaning, denoted by WJ-1, -2, -3, or -4, corresponding to the initial condition to obtain the correct photographic designation.
6. If the specifications allow flash rusting to remain on the surface, use table 2 in the visual standard to obtain the correct photographic designation. The guide shows photographs for the four degrees of rusting paired only with the initial conditions C and D.
7. Evaluate the finished water jetted surface against the selected photograph in steps 4 and 5 above to determine if the surface meets the specified surface preparation requirements for cleanliness.

Example: The coating on the interior surface of an existing steel pipe has deteriorated, and extensive rusting and pitting is evident. The specified surface preparation method is NACE 5/SSPC-SP12 WJ-2/SC-2 L.

- **Step 1:** The existing surface appearance most closely represents rust grade “D.”
- **Step 2:** From table 1, the finished surface photograph that corresponds to rust grade “D,” and degree of cleaning WJ-2 is D WJ-2.
- **Step 3:** From table 2, the allowable light flash rusting to remain on the finished surface is photograph D WJ-2 L, corresponding to rust grade “D” and light flash rusting “L.”
- **Step 4:** Evaluate the finished water jetted surface against photograph D WJ-2 to determine if the surface meets NACE 2/SSPC-SP10 cleanliness requirements and against photograph D WJ-2 L for allowable remaining surface flash rust.

Note: In the above example, if light flash rusting is not allowed by the specifications (i.e., the surface preparation method is NACE 5/SSPC-SP12 WJ-2/SC-2), selection and evaluation of photograph D WJ-2 L in steps 3 and 4 are excluded.

ALTERNATIVE SURFACE PREPARATION

METHODS

There are alternatives to traditional abrasive blast cleaning methods that may reduce surface preparation costs, dust, or fouling of machinery by small abrasive particles. These alternative methods, unless otherwise noted, assume an existing surface (anchor) profile on the substrate surface does exist. If a surface profile does not exist, or new material requires a deeper profile, traditional abrasive blast cleaning must be employed. The following sections provide alternative cleaning methods with an abbreviated description.

Sponge Abrasive Blasting

This method follows the traditional abrasive blast methods, except that the abrasive particles are encapsulated in a sponge material. The sponge material prevents abrasive particles from breaking up and diffusing on impact, thus reducing the amount of dust. Sponge blasting creates about 10 to 20 percent of the dust that would be created by non-encapsulated abrasive materials. The method does create a surface profile, and the surface cleanliness can be compared to SSPC-VIS 1.

Soda Bicarbonate Blasting

This method propels large crystals of soda bicarbonate (baking soda) by pressurized air or water. It is used mostly as a stripper for cleaning contaminants and for thin coatings. There is no surface cleanliness standard for this method; however, cleanliness can be specified to meet the requirements of a consensus surface preparation (e.g., NACE 3/SSPC-SP6).

Dry Ice Blasting

This method propels dry ice particles by pressurized air. On impact, the dry ice exerts a sheer force across the substrate surface, removing contaminants and thin coatings. If dry ice is used, it should not be used in confined spaces because of carbon dioxide buildup. There is no surface cleanliness standard for this method; however, cleanliness can be specified to meet the requirements of a consensus surface preparation (e.g., NACE 3/SSPC-SP6).

Chemical Strippers

Chemical strippers can be classified into two generic composition types: (1) bond breakers and (2) caustic. Bond breaker strippers work by breaking the paint's molecular bonds between paint layers and between the paint and the substrate so that paint will crinkle up and be easily removed. Bond breaker strippers can contain toluene, methylene chloride, or methyl ethyl ketone that removes paints in a relatively short time, but may be considered hazardous to workers. Less hazardous bond breakers contain N-methyl-pyrrolidone (NMP) or dibasic ester (DBE) compounds, but these remove paint less quickly. Bond breaker strippers will remove all coatings except oil-based, inorganic, and metallic coatings. Caustic strippers work by softening the entire paint system rather than breaking molecular bonds. Caustic strippers can contain sodium, calcium, and magnesium hydroxide. Caustic strippers are restricted to oil-based paints, but will not work on oil-based paints that are pigmented with aluminum flakes because hydrogen gas is generated when caustic compounds come in contact with aluminum, thus preventing the caustic stripper from penetrating the paint system.

Chemical strippers are commonly used for small areas where power is not available, abrasive and water jet blasting is not economically feasible, hose distance is too great to achieve necessary air pressure for blasting operations, or where accessibility is limited. Chemical strippers are also used to minimize airborne paint particles for organic paints or heavy-metal based paints (e.g., lead). In general, chemical strippers may be messy, may require repetitive applications to remove all foreign matter from the substrate, and may leave a residue on the substrate that requires solvent cleaning. There is no surface cleanliness standard for this method; however, cleanliness can be specified to meet the requirements of a consensus surface preparation (e.g., NACE 3/SSPC-SP6).

Chapter VII: Environmental Conditions

Cold weather, high humidity, water, fog, frost, mist, rain, ice, and snow are some of the environmental factors detrimental to the performance of coatings. Coatings should be applied under optimum environmental conditions, but the weather can abruptly change. The prevailing environmental rule-of-thumb is that evaporation should be occurring. Common sense, the manufacturer's instructions, and industry practices appear to be the most commonly followed guidelines regarding environmental conditions during coating application and the curing period. Failure to conform to environmental restrictions results in a variety of application failures.

ENVIRONMENTAL FACTORS AFFECTING COATINGS

The following are five environmental factors that require monitoring during coating application and the cure period. (See appendix K for test procedures on the factors below.)

Ambient Temperature

During the application of coatings, Reclamation specifications require that the air and surface temperature be 50 °F or higher and within the manufacturer's upper temperature limit or according to the manufacturer's instructions, whichever is the more restrictive requirement. Exceptions are made for coatings formulated for cold weather applications. Ambient (air) temperature is important for successful film formation and curing. Some epoxy coatings applied below 50 °F will not cure, and curing will not proceed even if temperatures exceed 50 °F at a later time.

A general rule-of-thumb in the coating industry is to apply coatings at ambient temperatures between 40 and 95 °F, depending on the coating material.

Surface Substrate Temperature

Reclamation specifications require that coatings be applied when temperatures are 50 °F or higher and within the manufacturer's upper limit or according to the manufacturer's instructions. The more restrictive requirement will be followed. In general, industry practice requires surface temperature between about 40 and 125 °F.

Relative Humidity

Reclamation does not specify limits for relative humidity; rather, it specifies that the coating be applied within the manufacturer's recommended humidity range. General industry practice requires a maximum relative humidity of about 80 to 85 percent, except for those coatings that are less moisture sensitive or are moisture cured. However, as a general rule-of-thumb, the closer to the optimum relative humidity, the more likely to achieve the designed service life.

Dew Point

The dew point determines if moisture will form on the ferrous substrates by condensation or if moisture will evaporate. Moisture will form on ferrous substrate surfaces when the dew point is higher than the surface temperature. Conversely, moisture will not form when the surface temperature is higher than the dew point. Dew point is a function of ambient temperature, substrate temperature, and relative humidity. All three of these environmental conditions must be known to determine the dew point.

Reclamation specifications require that the ferrous substrate temperature be a minimum of 5 °F higher than the dew point when coatings are applied. The coating industry imposes the same dew point restriction. Reclamation specifications require surfaces that are not thoroughly dry to be heated or the environment controlled by dehumidifying and heating equipment to drive off moisture.

Moisture condensation will begin when the substrate temperature is less than the dew point. To allow for possible instrumentation error or variation, a minimum safety margin of 5 °F substrate temperature above the dew point is regarded as a general industry requirement.

Wind

Reclamation does not specify a maximum wind velocity restriction in coating applications. Wind becomes a factor when it overcomes the spraying operation and carries coating particles away from the intended surface. This problem is known as airborne overspray. Airborne overspray may result in premature drying of the coating before reaching the intended surface, a lower DFT at the spray application point, a higher DFT downwind, or spray being carried to adjacent vehicles, homes, or other surfaces not intended to be coated. Common sense should be used to avoid airborne overspray problems.

Chapter VIII: Application and Curing

Coating application is next in importance after surface preparation and accounts for most failures. A coating is not a finished product until it has been successfully applied to the steel substrate and cured. Coating performance is affected during application and curing by temperature, relative humidity, and dew point. (See Chapter VII: Environmental Conditions.) Mixing, number of coats and thickness, and application technique will also affect coating performance. Not observing the environmental restrictions or improper application techniques can result in defects, premature failure, or reduced service life.

APPLICATION TEMPERATURE AND HUMIDITY RESTRICTIONS

Environmental conditions are not always controllable. Weather may abruptly change, and conditions may violate the manufacturer's temperature and humidity restrictions. Unless conditions can be controlled by dehumidifying, heating, or a combination of both, field application should proceed only during favorable weather. Coating in high humidity areas, such as the interiors of vaults or pipes, should be performed only when the environment is controlled by dehumidifying, heating, or both. Reclamation specifications provide the following temperature and humidity restrictions, unless the manufacturer's instructions are more stringent:

- Air and substrate temperatures shall be above 50 °F during application and curing and within the manufacturer's upper temperature limit.
- Surfaces shall be a minimum of 5 °F above the dew point temperature at the time of coating application.
- Relative humidity shall be within the manufacturer's limits.

COATING LAYERS

Reclamation typically specifies the number of coats to be applied in the coating tabulations. The following terms provide a description of the coating layers:

- ***Stripe coat.*** Stripe coats are applied to prepared bare metal edges, boltheads, welds, corners, and similar edges before the prime coat is applied. Stripe coats are necessary because, as the coating dries, tensile forces are created at the edges, forcing the coating to pull away from the edge in both directions, resulting in a thinner coating at the edge. Stripe coats provide an additional thickness buildup to prevent thin, DFT at edges.
- ***Prime coat.*** Prime coats are applied over the entire surface to be coated, including stripe coated areas. The prime coat must cover the peaks of the surface profile. The consequence of not covering the peaks is pinpoint rusting.
- ***Intermediate coat.*** Intermediate coats are applied over the primer to provide additional protection or to seal the primer. Multiple intermediate coats can be applied to build up the film thickness.
- ***Topcoat.*** Topcoats or finished coats are applied over the primer or intermediate coat for color aesthetics or to protect the underlining coating material from sunlight and UV light.
- ***Base coat.*** “Base coat” is a term often used to describe a self-priming material applied in multiple coats. The term, “base coats,” is used instead of “primer,” “intermediate,” and “topcoat” because all three coats are of the same material. Base coats are not normally considered sunlight or UV resistant.

MIXING

Before application, the coating materials require mixing to make the paint homogeneous and uniform. Liquids and pigments of different densities may separate, settle, or form a skin within the shipping container. Mixing is to be performed according to the manufacturer’s instructions.

Coatings are either single component or multiple component. Most multiple-component coatings are two component. Epoxies are an example of a two-component coating. They contain a resin and a hardener. The components of a multiple-component coating can be in equal proportions (e.g., 1:1) or unequal proportions (e.g., 1:4). Proportions are determined by volume. Components must be shipped in separate containers. Regardless of the proportion volume for multiple-component materials, the manufacturer will ship one container large enough to hold all the components for mixing.

The following are common mixing methods:

- Manually paddling (the most inefficient method)
- Mechanically agitating or paddling
- Shaking
- Boxing (requires pouring the material from the original shipping container into an empty container and repeating the process several times). It is most often used for single-component, moisture-cured materials.

If the manufacturer recommends thinners, they are added in the recommended amounts during mixing. After mixing, some multiple-component materials require a 10- to 30-minute induction period to allow chemical reactions to begin before application.

APPLICATION METHOD

Once the surface substrate has been properly prepared and environmental conditions are within specified tolerances, the application of the coating material may proceed. There are several equipment choices for transferring the coating from the container to the substrate. Application equipment may be dictated by the material type and the size of the surface area. The manufacturer's instructions will normally provide the preferred application method for small and large areas.

The following is a description of application equipment and methods.

Brush

There two general types of brushes: (1) wall and (2) sash. They come in various sizes, shapes, and bristle types. For steel substrates, wall brushes are normally used for small areas, repair areas, and crevices or gaps. Wall or oval brushes are well suited for stripe coating irregular surfaces such as edges, corners, boltheads, and similar areas. Sash brushes are better suited for coating narrow areas.

Mitten

Mitten or paint pads hold more coating than a brush, but they require a tray. This application method is used for small, irregularly shaped structures such as handrails.

Roller

Rollers consist of two general parts: (1) cover and (2) core. The cover is the section that applies the coating and will vary in diameter, length, fabric type, and fiber length (nap). Rollers are normally used for large flat areas (horizontal and vertical surfaces) that are too large for brush application or where overspray cannot be tolerated. Three basic types of rollers are discussed below.

Pipe Roller

Pipe rollers consists of two or more rollers hinged together to conform to a curved surface such as a small-diameter pipe.

Fence Roller

Fence rollers have an extra long nap so that when applying a coating from one side of a hurricane or wire fence, the long nap will cover both sides.

Pressure Roller

Pressure rollers feed a perforated core with a steady supply of coating material from a pressurized tank.

Conventional Spray (Applied Cold or Hot)

Equipment

An air compressor, an oil and water separator, a pressure tank (pot) or pump, air and fluid hoses, and a spray gun are needed. For hot spray, a heater is added to heat the material to about 150 to 160 °F.

Working Principle

Compressed air is introduced into the coating stream at the spray gun nozzle, thus breaking down the coating into tiny droplets (coating atomization) and propelling the coating to the surface substrate.

Advantages

This method provides more finely atomized coating particles, resulting in a smoother and more uniform film. Large areas can be covered in a relatively short time. Operator control of the spray gun is excellent. The spray gun has a high degree of versatility regarding different coating materials and spray patterns. Striping can be accomplished by this method.

For hot spray application, the viscosity is lowered to improve application or to meet minimum material temperature.

Disadvantages

This method uses large amounts of air. Consequently, transfer efficiency is low (material is lost) because of bounce back (rebound) and overspray. The rebound makes it difficult to coat corners and crevices. This method is not generally suitable for high-build coating materials without excessive thinning.

Use

This method is used on nearly all Reclamation structures where overspray is not a concern. The hot spray method is used during cooler weather.

High-Volume, Low-Pressure Spray

Equipment

This method requires a high-volume air supply (compressed air or turbine generator), a material supply system, and a high-volume, low-pressure (HVLP) spray gun.

Working Principle

A high volume of air atomizes the coating material at a low pressure and transfers the atomized coating particles to the substrate by low pressure.

Advantages

This method has a better transfer efficiency (less material lost) than the conventional spray method, and bounce back and overspray are reduced. The HVLP spray gun is more controllable than other spray guns. The method works well with high-solids coating material.

Disadvantages

The coverage or production rate is less than with other spray methods, and the method may not atomize certain coating materials.

Uses

This method is limited to smaller areas or surfaces that contain numerous recesses.

Airless Spray (Applied Cold or Hot)

Equipment

This method requires a power source (electric motor or air compressor), a hydraulic pressure pump, a high-pressure fluid hose, and an airless spray gun with a safety extension tip.

Working Principle

Atomization of the coating is achieved by forcing the material through a small orifice using hydraulic pressure rather than air pressure. The high-pressure pump multiplies the input pressure by a minimum factor of 30, such that the output pressure at the spray gun produces pressures up to about 6,000 psi. The spray gun has a fixed orifice size and various fixed angles to allow several spray fan patterns and thicknesses to be applied with the same amount of material.

Advantages

This method provides greater capacity for applying high-build coatings, greater surface penetration because of high application pressures, high coverage or production rates, the capacity to atomize high-viscosity material, reduced overspray and bounce back, and the potential for reduced oil and water contamination.

Disadvantages

This method does not produce the finely atomized coating particles that are produced by conventional spray, and it is not suited for high-quality finishes. The operator has less control of the spray gun than with the conventional spray method, and there is a higher potential for application defects than with the conventional spray method. The high pressures are cause for safety concerns.

Uses

This method is best suited to large surface areas where overspray is not a concern. It is used on nearly all Reclamation structures. The hot spray method is used for application during cooler weather.

Air-Assisted Airless Spray

Air-assisted airless spray application equipment was developed to combine some of the advantages of conventional and airless spray systems into one system.

Equipment

This method requires a hydraulic pressure pump (500 to 1,000 psi), hoses, an air compressor (10 to 15 psi), and a spray gun.

Working Principle

The atomization of the coating is similar to the atomization of the airless sprayer, but the pressure is lower at the orifice of the spray gun with this method, normally at about 10 psi.

Advantages

This method provides more finely atomized coating particles, a lower potential for application defects, and better operator control of the spray gun than the airless method. Also, transfer efficiency is better than with the conventional sprayer.

Disadvantages

This method is not suited for high-quality finishes because atomization approaches, but does not equal, atomization with the conventional sprayer method. This method produces overspray and rebound.

Uses

This method is suitable for medium to large surface areas where overspray and rebound are not a concern.

Electrostatic Spray

Equipment

The equipment used in the electrostatic spray method is similar to conventional, airless, and air-assisted sprayer equipment, except that an electrostatic, high-voltage supply is required.

Working Principle

Atomized coatings are applied to the substrate by conventional, airless, or air-assisted spray equipment, which is connected to an electrostatic power source. The coating material is positively charged, and the substrate is negatively charged (conventional electrical theory). Sprayed, positively charged, atomized coating particles are attracted to negatively charged substrate.

Advantages

The electrostatic spray method is capable of applying coatings to odd shapes and around corners, and overspray and rebound material in confined spaces are reattracted to the substrate. This method has a high transfer efficiency rate and produces a uniform finish.

Disadvantages

The wind may carry the coating material away, this method allows only one thin coat, the coverage and production rate are less than with the other spray methods, a conductive coating formulation is usually required, this method is unsuitable for large structures, and this method presents a potential electrical shock hazard.

Uses

This method is suited to small areas behind corners, recessed areas, irregular areas, or areas that cannot be coated by conventional-type application equipment.

Plural Component Spray

This spray application method is the most complex of the spray equipment group and should be used by applicators who are trained and certified by the coating manufacturer. This application method is commonly used to apply two or more component materials (hence, the term “plural”) such as polyurethanes and polyureas that can have an extremely short set period (3 to 30 seconds for material to harden).

Equipment

This method requires a proportioning pump, a mix manifold, a mixer, a spray gun, material supply containers, and a solvent purge (flush) container. Material can be applied by conventional, airless, or air-assisted spray equipment, but special spray guns are required. The equipment and materials may be heated to decrease the cure period and allow for cleanup.

Working Principle

Individual components are mixed through a metering system that includes a proportioning pump, if mix ratios are other than one-to-one, and delivered at the spray gun or at the spray tip. This method eliminates premixing in a pressure pot.

Advantages

With this method, it is possible to apply high-build, high-viscosity materials in one pass, eliminate limited pot-life, and it may provide reduced cure times.

Disadvantages

This method requires precise presetting of proportioning and temperature systems. It requires immediate and thorough cleaning of equipment after use to prevent material from setting up. It is impractical for small jobs; it requires trained operators familiar with the specific equipment and material to be used. The gun cannot be triggered due to the materials becoming slightly off ratio. Therefore,

coating systems that require plural component application should only be used on pipeline, outlet works, penstocks, or large flat pieces of steel. No complex structures should be applied with plural component coatings.

Uses

It is suitable for large surfaces that are subject to burial, immersion, and chemical exposures requiring thick barrier coating material.

Cartridge Gun

This spray application method is used for spot repair or smaller surface areas. This application method is commonly used to apply two or more component materials and is capable of applying plural component systems such as 100 percent solids epoxy and polyurethanes that can have a short set period (1 to 30 minutes for material to harden).

Equipment

The application gun is a pneumatic gun that runs off of compressed air at 90 psi. The gun has interchangeable plunger discs that can easily change the mix ratios. This method has dual plastic cartridges that are prefilled with individual components. The cartridges are usually a 1:1, 1:2, 1:3, or 1:4 ratio by volume. A plunger pushes the coating through a plastic static mixer that mixes the coating, which then is atomized through a venture nozzle. All plastic components are disposable, and there is minimal cleanup.

Working Principle

A plunger pushes the coating out of the pre-filled cartridge through a plastic static mixer that mixes the coating, which is atomized through a venture nozzle. The initial material (3–5 seconds of spray) that is pushed through the static mixer should be discarded due to a slight off ratio of the materials. Triggering the gun is not acceptable due to the slight off ratio of the materials. To reduce the viscosity of the coating, the cartridges can be preheated in an oven up to 125 °F. This allows for the coating to flow better and produce a smoother finish.

Advantages

With this method, it is possible to apply high-build, high-viscosity materials in one pass, materials are can be good for low temperature cure, and it may reduce cure times. All plastic components are disposable, and there is minimal clean up.

Disadvantages

This method was designed for spot repairs of plural component systems. It is very practical for small jobs, but impractical for large jobs. Each cartridge contains between 375 ml and 600 ml, depending on ratio, so the surface area that can be coated with one cartridge is very small. The gun cannot be triggered due to the materials becoming slightly off ratio. The gun is very long, nearly 2 feet in length, limiting its usefulness to primarily flat surfaces. Complex structures should not be coated with plural component coatings. A whip hose can be used to apply coatings in tight areas; however, the air pressure would have to be reduced in order to not blow the coating around on the surface. Brushing or rolling the coating in these tight areas would be a more practical approach.

Uses

It is suitable for small surfaces that are subject to burial, immersion, and chemical exposures requiring thick barrier coating material. It is mainly for spot repair of damaged plural component coatings. It can also be used to apply plural component coatings that have fast cure times and that can cure at low temperatures.

APPLICATION TECHNIQUE

Reclamation does not specify the procedure or technique to apply the coating. Reclamation requires only that the coating be applied in accordance with the manufacturer's instructions. These instructions are provided in the manufacturer's application sheet. The application technique used by the applicator will vary slightly with the type of equipment and material. Most coating jobs are accomplished using brush, rollers, sprayers, or a combination of these tools; however, spray equipment is the most commonly used method. Several "good practice" tips for spray applications are discussed below.

Pot Pressures

The pressure pot should have two pressure gauges: one for pot pressure and one for atomization of the coating material. The pressure pot regulator should provide sufficient pressure to move coating material through the hose to the spray gun. The atomization pressure regulator should be set high enough to atomize the coating material. A setting that is too low will cause the material to clump or possibly clog the spray gun.

Air Compressor

Compressed air should flow at a steady rate. Pulsation of material from the spray gun normally indicates an inadequate air supply.

Spray Gun Technique

The spray gun should be held perpendicular to and about 18 inches away from the substrate. This distance may vary slightly with different spray apparatus. Angling, tilting, or holding the gun too close or too far away could cause the coating to sag or dry before hitting the surface. The spray pattern should overlap the previous pass by approximately 50 percent, and the stroke length of each pass should be between 18 to 36 inches. The applicator should make a pass of the spray gun by moving the arm and body rather than by rotating the wrist to fan the gun.

DRYING, RECOATING, AND CURING

Drying and curing are not interchangeable terms as they relate to coatings. SSPC defines cure as, “The process of changing the properties of a paint from its liquid state into a dry, stable, solid protective film by chemical reaction with oxygen, moisture, or chemical additives, or by the application of heat or radiation.” According to this definition, coatings that form protective films without chemical reaction do not cure, but only dry to form a film. Drying is the loss of solvent or water, and the process may or may not form a protective film. Curing will always produce a protective film.

Once the coating has been applied, the inspector can do little, except to protect newly coated surfaces from being damaged and note temperature and humidity during the curing period to ensure that proper cure is obtained. Manufacturer’s instructions may list a variety of time periods for drying, recoating, and curing at various temperature and humidity combinations. These time periods are discussed below.

Drying

Drying is the period when a coated item can be moved or when it can accept traffic without damaging the coating before full cure at a referenced temperature and humidity. Most manufacturer's product data sheets refer to drying times as "tack free," "to touch," "to handle," or, "to stack" (to stack items one on top of another [e.g., pipe stacking]), meaning the time between application and when the surface is tack free or dry enough to touch, to handle, or to stack. Reclamation specifications consider a coating to be dry "when it cannot be distorted or removed by exerting substantial, but less than maximum, pressure with the thumb and turning the thumb through 90 degrees in the plane of the coating film."

Recoating

This is also referred to as "to recoat" or "recoat window." This is the time period in which a previous coating can receive an intermediate coat or a topcoat at a referenced temperature and humidity. When the recoat window has been exceeded, the coating surface may require further surface preparation for which most manufacturer's recommend abrading the surface or solvent application or both. Recoat windows vary widely, from a few minutes to a month or longer, depending on the type of coating material. If temperature and humidity are not shown or are outside the listed values on the manufacturer's instructions, the coating manufacturer should be consulted. Reclamation specifications specify the manufacturer's recommended recoat window because recoat windows vary greatly with material type.

Curing

This is the necessary time period at a referenced temperature and humidity combination to allow the coating to complete the chemical reaction and to achieve structural integrity so that it will be ready for the intended service exposure. Excessive moisture and low or high humidity or temperature can stop or retard the curing process. Most manufacturer's instruction sheets provide information for cure time and cure time to immersion.

Currently, there is no all-encompassing method to determine if a coating has completely cured.

Chapter IX: Field Inspection and Testing

Field inspection and testing is necessary to ensure coating performance and to verify specification acceptance. Field inspection and testing are performed in the following coating areas: (1) surface preparation, (2) wet paint, (3) hardened paint, and (4) destructive testing

SURFACE PREPARATION TESTS

The following tests are performed on prepared surfaces before coating applications and are in addition to the photographic standards (see chapter VI, “Photographic Inspection Standards.”)

Testing for Chlorides on Prepared Surfaces

Soluble salts, especially the chloride ion, if left on prepared surfaces, can cause coatings to blister. If chloride contamination is suspected, Reclamation specifications require testing to determine the presence and concentration of chloride ions after the surface preparation of previously coated metalwork. (See appendix L for procedures.) If NACE 5/SSPC-SP12 surface preparation is specified, the standard requires testing for soluble salts. For immersion service exposure, the acceptance criterion for chlorides is 7 micrograms per square centimeter or less.

Surface Profile and Adhesion

Surface profile (or anchor pattern) is the topography of the finished, abrasively blasted surface. When viewed perpendicular to the surface plane, jagged peaks and valleys can be observed. Various peak heights and valley depths can be achieved by the type and size of the abrasive materials used. Surface profile is classified by depth and texture produced. Depth is the measurement of the average distance between the peaks and the valleys. Texture is the angular finished appearance of the peaks and valleys, ranging from jagged to rounded. A jagged texture will normally produce better adhesion.

The purpose of the surface profile is to promote adhesion of the coating to the substrate. Abrasive blasting of a surface increases the surface area, thus producing a greater area for coating adhesion. Adhesion strength is primarily achieved by mechanical bonding between the coating and the substrate. Intercoat adhesion is achieved chiefly by covalent bonding. In general, thick coatings require a deeper profile than thin coatings. There is an optimum surface profile

depth for the specified coating material. If a profile is too shallow, the coating may not achieve proper adhesion. If a surface profile is too high, the coating may not cover the profile peaks, resulting in pinpoint rusting. The manufacturer's product data sheet recommends the surface profile for each specific coating primer.

The profile may be measured with any of the following:

- Surface profile comparator
- Dial surface profile gauge
- Spring micrometer and replica impression tape

Reclamation specifies the spring micrometer and replica impression tape method using NACE RP 0287, "Standard Recommended Practice for Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape." (See appendix M for the procedure.)

Some older versions of Reclamation specifications specify ASTM D 4417, "Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel," Method C. Essentially, NACE RP 0287 and ASTM D 4417 are equivalent, provided that the correct mil range replica tape is used.

During inspections, protective gloves should be worn to avoid contaminating the finished prepared surface with oil and salt perspiration. Where foot traffic is unavoidable, such as within pipe interiors, plastic slipcover booties are recommended.

Dust

ISO 8502-3 Assessment of dust on steel surface prepared for painting (pressure-sensitive Tape Method) uses clear cellophane tape (office variety) to determine the amount of dust from abrasive blasting and other sources that has not been blown or vacuumed off. Press the tape on the surface, peel off, and visually observe the amount of dust that sticks to the tape. Clean the test area with acetone or alcohol to remove tape adhesive from the prepared surface. The test tape showing the dust particles can be documented by applying it to the daily inspection report or another field report.

WET FILM THICKNESS

Reclamation does not require testing the wet film thickness (WFT). WFT is measured in accordance with ASTM D 4414. (See appendix N for the procedure.) However, it is a useful measurement for the following purposes:

- To verify that a consistent thickness is being applied. A consistent WFT should dry into an even DFT.
- To predict the resulting DFT. Some manufacturer's instructions state a WFT coating applied at a certain number of mils will result in a predetermined DFT. For example, a coating applied 10 mils wet will result in a DFT of 8 mils. However, if the manufacturer's instructions do not state the DFT that will result from the WFT, it can be calculated. (See appendix O for formulas and examples.)

Measuring the WFT on quick drying materials, such as inorganic zincs, may yield less than accurate readings.

HARDENED PAINTED SURFACES

Once a coating system has dried or hardened, but before the recoat window has expired, Reclamation specifications impose two criteria for acceptance. The first is to meet the minimum and maximum DFT, and the second is to detect and repair any pinholes in the coating or damaged areas.

Dry Film Thickness

The DFT of a coating can be measured when the material dries or hardens but before the recoat window has expired. The thickness is commonly specified in mils, although some manufacturer's instruction sheets will also use micrometers (or microns) in the metric system. The following provides conversions of these units:

- 1 mil = 0.001 inch = 25.4 micrometers
- 1 micrometer = 0.000001 meter = 0.039 mil

Reclamation specifies that the hardened coated surface shall meet a minimum and maximum specified thickness. DFT is measured for quality control and specification DFT acceptance criteria. There are numerous types of DFT gauges available on the commercial market. These gauges measure the thickness of a nonconductive coating on a magnetic conductive (ferrous) or nonmagnetic conductive (aluminum, brass, bronze, copper, etc.) substrate. There are DFT gauges available that will read only magnetic or nonmagnetic substrates and gauges that will measure both. The inspector should ensure that the correct substrate gauge is being used and that the gauge range is within the film thickness to be measured.

SSPC-PA2

Reclamation specifies that the DFT is to be measured in accordance with SSPC-PA2, “Measurement of Dry Coating Thickness with Magnetic Gages.”

DFT Gauges

The types of DFT gauges are determined by the specific magnetic properties of the instrument being used in measuring the coating thickness rather than by the readout mode (analog or digital). The standard does not cover DFT gauges using an eddy current method.

The following sections describe DFT gauges within the standard:

- ***Pulloff gauges.*** In general, pulloff gauges use a permanent magnet in contact with the coated surface and a calibrated scale to measure the force required to pull the magnet from the coated surface. The scale is nonlinear. The following are two types of pulloff gauges and their approximate thickness ranges:
 - Banana gauge (0 to 200 mils)
 - Pencil gauge (0 to 30 mils)
- ***Constant pressure probe gauges.*** The general working principle of the constant pressure probe gauge is that a probe exerts a constant pressure on the coated surface, and electronic circuitry converts a reference signal into a coating thickness that is displayed on an analog or digital screen.
- ***Terminology and definition.*** The procedure for determining the DFT involves taking a number of gauge readings at random locations. These readings are called spot measurements. It is important to understand gauge reading and spot measurement terminology because without comprehending the meaning of the terms, the SSPC-PA2 DFT procedure could be conducted incorrectly. Definitions of “gauge reading” and “spot measurement” are presented below:
 - *Gauge reading.* A single reading at one point.
 - *Spot measurement.* The average of at least three gauge readings taken at different points within a 1.5-inch-diameter circular area.
- ***Outline procedure.*** The following is an abbreviated outline of the SSPC-PA2 procedure:

(See appendix P for calibration and procedures for each gauge type and a DFT procedure example.)

1. Take five spot measurements (at least three gauge readings per spot measurement) spaced randomly within each 100-square-foot area for DFT measurements. The number of 100-square-foot areas where the spot measurements are to be taken is based on the total coated surface area. The 100-square-foot areas are randomly selected within the total coated area. Table IX-1 provides the criteria for determining the number of 100-square-foot areas for spot measurements corresponding to total coated surface area.

Surface areas of irregularly or oddly shaped structures, such as trashracks, channels, and I-beams, may exceed 1,000 square feet because these structural members are many sided. The inspector should roughly calculate the area to determine the total coated surface area.

2. Calibrate the DFT instrument for the anticipated DFT range.
3. Measure the hardened coated surface with the calibrated DFT instrument at the number of spot measurements indicated in table IX-1. Disregard inconsistent high or low readings that cannot be repeated. The following are the number of gauge readings, spot measurements, and averaging per 100-square-foot area:
 - (a) Determine the five spot measurement locations required per 100-square-foot area.
 - (b) Take three gauge readings per spot measurement and average the three readings. This is a total of 15 gauge readings, minimum (3 gauge readings x 5 spot measurement locations per 100-square-foot area).
 - (c) Average the five individual spot measurements to obtain a single averaged value for the 100-square-foot area.

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Table IX-1.—Number of spot measurements based on total coated surface area

Total coated surface area	Number of 100-square-foot areas for spot measurements
Less than 300 square feet	Each 100-square-foot area within the total area
Greater than 300 square feet but less than 1,000 square feet	Three 100-square-foot areas within the total area
Equal to and greater than 1,000 square feet	Three 100-square-foot areas for the first 1,000 square feet within the total area plus One 100-square-foot area for each additional 1,000 square feet of coated areas or fraction thereof

4. Repeat steps 2 through 5 for the remaining 100-square-foot areas.
5. Determine minimum and maximum thickness acceptance criteria.
6. Minimum acceptance.

- a. Any number of individual gauge readings may be less than 80 percent of the specified thickness.
- b. No single averaged spot measurement in the 100-square-foot area may be less than 80 percent of the specified thickness.

Where average spot measurements are less than 80 percent of the specified thickness, additional measurements may be taken to redefine the nonconforming area.

7. Maximum acceptance.
- a. Any number of individual gauge readings may exceed 120 percent of the specified thickness.
- b. No single averaged spot measurement in a 100-square-foot area shall exceed 120 percent of the specified thickness.

Where average spot measurements exceed 120 percent of the specified thickness, additional measurements may be taken to redefine the nonconforming area.

Discontinuity (Holiday) Testing

Reclamation specifies that coatings subject to burial or immersion service exposures be tested for holidays (i.e., pinholes and voids). Holidays provide an avenue for moisture to penetrate through the coating to the substrate, leading to general corrosion, pitting, and underfilm corrosion.

There are two types of holiday testing: (1) low voltage and (2) high voltage. The applied voltage is based on the coating thickness and the coating dielectric strength. Low-voltage testers are used on thin films (20 mils and less), and high-voltage testers are used on high build films (20 mils or greater) or as determined by the manufacturer to prevent coating damage. Using voltages that are too high or leaving the instrument in one place too long may damage the coating by sparking or burning through the coating. Thin coatings are more susceptible to voltage damage. Testing of coatings that contain electrically conductive pigments such as aluminum flakes, graphite, or zinc is not recommended because an electric discharge may spark through the coating at conductive particles, damaging the coating or indicating discontinuities where none exist. Suggested voltages at DFT ranges are provided in table 1 of NACE RP 0188.

Reclamation specifies that testing be in accordance with NACE RP 0188, except that:

- Testing is not required on conductive coatings pigmented with aluminum, graphite, zinc, or other electrically conductive pigments.
- Using a detergent wetting solution is not permitted (detergents may cover over pinholes after testing, leaving the false impression that no pinholes exist).

Previous versions of Reclamation coating specifications reference ASTM D 5162 for holiday testing. ASTM D 5162 and NACE RP 0188 are essentially equivalent, but the NACE version is more complete and easier to follow. (See appendix Q for this procedure.)

DESTRUCTIVE TEST METHODS

Destructive test methods are normally used to evaluate overcoating or aid in determining a coating failure. The following sections are abbreviated descriptions of the destructive testing methods listed in chapter X, “Physical Coating Inspection Survey.”

Adhesion, Tape Method (ASTM D 3359)

This test is considered subjective and should be performed by qualified and experienced personnel. The choice of test method depends on coating thickness.

Method A

This method is used on coatings 5 mils thick or greater. An “X” cut is made in the coating to the substrate. Pressure-sensitive tape is applied over the “X” cut and pulled off. Coating adhesion is assessed by a comparison scale of 0A (lowest) to 5A (highest) as described by written definitions provided in the standard.

Method B

This method is primarily for laboratory use, although it is often employed in the field. The method is not suitable for coatings with a thickness greater than 5 mils. A lattice pattern of 6 to 11 evenly spaced horizontal and vertical lines are cut into the coating to the substrate. Pressure-sensitive tape is applied over the lattice pattern and pulled off. Coating adhesion is assessed by making the best match to a comparison scale of 0B (lowest) to 5B (highest) of narrative and photographic descriptions provided in the standard.

Adhesion, Pulloff Method (ASTM D 4541)

This method is more quantitative, but requires an experienced operator for reproducibility. These testers are recommended for flat horizontal surfaces unless otherwise stated in the appendix. The standard lists the following three types of testers in the annex:

- **Type I, fixed.** Type I testers are restricted to laboratory use.
- **Type II, fixed alignment.** Type II testers were developed for laboratory use, but are employed in the field. Type II is the most common pulloff adhesion testers for field use. (See appendix R for this procedure.)
- **Type III, self-aligning or hydraulic.** Type III testers were developed for laboratory, use but are employed in the field. (See appendix S for procedure.)

Dry Film Thickness by Tooke Gauge (ASTM D 4138)

The Tooke gauge is used for measuring the number of coats applied and DFT if the coating layers can be identified by color difference or by a distinctive line. (See appendix T for this procedure.)

Chapter X: Maintenance Coatings

Reclamation infrastructures may still be coated with the original materials from the initial installation or they may have received full, partial, or spot coating repair in the intervening years. Obviously, any coating material has a finite service life, and maintenance coatings have become an important component in maintaining the structural integrity of high-capital-cost infrastructures.

DEFINITION

A simplified definition of maintenance coatings is “the recoating of any existing coated substrate surface to prevent corrosion or to maintain appearance.”

PURPOSE

The basic purposes of a coating program to maintain Reclamation structures are to:

- Prevent significant loss of metal
- Prevent significant degradation of coating material
- Maintain aesthetics or the appearance of structures exposed to public view
- Identify by color code
- Minimize future repair costs

RISK EVALUATION

Risk evaluation is primarily a project office responsibility. The overriding or ultimate consideration in evaluating risks associated with coatings is whether the coating is maintaining structural integrity or if coating degradation is allowing corrosion to proceed, leading to the possibility of structural failure. There is no standard method to evaluate risks; however, the most basic approach is to compare estimated partial or total metalwork replacement costs with the estimated costs of a maintenance coating program. Safety of the public and workers may

also be a major consideration, and these associated costs may be difficult to assess. To provide a basis for risk evaluation, inspection of the coating and substrate is recommended.

INSPECTION

To determine the corrective action required, structures identified for maintenance coatings work should be inspected before beginning work. Preliminary work should include gathering background information on the structure, including location, original installation date, dimensions, drawings, substrate type, and coating history. The coating history should include the following information if known:

- Service exposure
- Type of substrate
- Surface (anchor) profile
- Age of coating
- Type of existing coating material or brand name
- DFT
- Identification and concentration of toxic metals in the existing coating (cadmium, chromium, lead, etc.)

Inspection Schedule

Ideally, inspection surveys should be conducted every 3 to 5 years, depending on the service exposure and the structure type. The 3- to 5-year interval is reasonable for structures situated in atmospheric service exposure. For structures requiring dewatering, a 5-year inspection interval may not be achievable; however, some designated interval should be initiated.

Inspection Types

The type of inspection survey depends mainly on the time allotted and accessibility. Exterior surfaces in atmospheric exposures are readily accessible

for inspection. Interior inspections of penstocks, piping, scroll cases, and other water-bearing surfaces require a planned outage to dewater. Interior inspections are considered confined spaces, and appropriate safety requirements must be met.

There are four types of inspection—three types are coating related and one is structural. The four types are:

1. General overview survey
2. Detailed visual survey
3. Physical coating inspection survey
4. Structural survey

For most Reclamation structures, the general overview and detailed visual survey methods are sufficient to identify coating and corrosion deterioration trends.

General Overview Survey

This qualitative survey can be accomplished in a few hours and is adequate to ascertain severe corrosion conditions and degraded coatings. Only the major features of the structure or facility are inspected.

1. Visually observe:
 - The general condition of coating; check for defects or deterioration
 - Any evidence of rusting
2. Determine the type of toxic metal-based paint and its concentration, if present
3. Rate the condition of the coating on each major structural feature as good, fair, or poor

Detailed Visual Survey

The time required to conduct this survey varies from a few hours to about 1 day depending on the size of the structure. This semiquantitative survey requires a more detailed description and documentation of the coating condition and corrosion. Major features and structural elements (beams, connections, edges, etc.) of the structure or facility are inspected separately.

Guide to Protective Coatings, Inspection, and Maintenance

1. Observe and document the following coating conditions:
 - **Defects.** Blistering, chalking, cracking, erosion, delamination, pinholes, peeling, undercutting, or other defects
 - **Appearance.** Coating or topcoat loss, abrasion streaks, rust staining, fading color, weathering, or other abnormal appearance
2. By observation, document the following rust conditions:
 - **Type.** Uniform rusted surface or pitting.
 - On flat or curved surfaces
 - At corners or edges
 - Under blisters
 - Estimate the amount of rust by using SSPC-VIS 2. (See appendix U for procedures.)
 - **Metal loss.** Minimal or significant.
3. Determine the type of toxic metal-based paint and its concentration, if present.
4. Rate each structural component separately as good, fair, or poor and combine the results. Using SSPC-VIS 2 to estimate the amount of rust is preferred method. A weighting system or spread sheet can help facilitate by combining individual ratings into an overall assessment, setting priorities, and developing quantities for a preliminary cost estimate.

Physical Coating Inspection Survey

The time required to conduct this survey is from 1 day to several days, depending on structure size and access to the coated surface. The survey incorporates the observations recorded in the Detailed Visual Survey with quantitative measurements. This survey evaluates whether an existing coating can be spot repaired or overcoated or if full removal and recoating is required. For a higher level of confidence, the survey should be conducted by a certified NACE or SSPC coating specialist.

1. Observe and document the following coating conditions:
 - **Defects.** Blistering, chalking, cracking, erosion, delamination, pinholes, peeling, undercutting, or other defects
 - **Appearance.** Coating or topcoat loss, abrasion streaks, rust staining, fading color, weathering, or other abnormal appearance
2. Observe and document the following rust conditions:
 - **Type.** Uniform rusted surface or pitting.
 - On flat or curved surfaces
 - At corners or edges
 - Under blisters
 - Rust rating by SSPC-VIS 2. (See appendix U for procedure.)
 - **Metal loss.** Minimal or significant.
3. Perform the following quantitative measurements:
 - Test adhesion by one or both of the following methods:
 - Pulloff (ASTM D 4541)
 - Tape (ASTM D3359)
 - Determine DFT (SSPC-PA2)
 - Determine the presence and concentration of soluble salts, if present
 - Determine the type and concentration of toxic metal-based paint, if present
 - Determine the depth and frequency of corrosion pits
 - Use a knife to determine the length of undercutting corrosion
 - Use a Tooke gauge to determine the number of coatings
 - Measure the steel wall thickness with an ultrasonic thickness gauge
 - Apply test patches to determine if the coating is compatible for overcoating (ASTM D 5064)

Structural Inspection

The structural inspection can be conducted in conjunction with any of the above surveys. Structural members and components are inspected for severe metal loss, broken joints, defective welds, bent members, or other structural defects. Normally, inspections are by visual observation.

HAZARDOUS BASED PAINTS

During the inspection, samples of the existing coating material should be analyzed to determine the type and concentration of toxic metals. The common toxic metals in pre-1990's paint are cadmium, chromium, cobalt, and lead; however, arsenic, barium, beryllium, mercury, silver, selenium, vanadium, or other heavy metals may be present in very low levels.

The most common heavy metal in paint used on Reclamation projects is red lead primer. It was an excellent corrosion inhibiting primer on metal surfaces. The use of red lead primer has dramatically declined in the coating industry since the late 1980s, and Reclamation no longer specifies red lead primer. There is no problem with red lead primer as long as it remains intact on the structure.

The problem with lead-based paints is contamination of the local environment (soil and water) and exposure to humans. Lead exposure normally occurs during the surface preparation process as old coatings are removed and lead particles become airborne. The environment is contaminated by lead particle fallout. Humans are contaminated by inhaling or ingesting the lead particles. The most serious adverse health effect of lead exposure is permanent damage to the central nervous system.

However, heavy metals are not the only hazards found in old coating systems. Asbestos and polychlorinated biphenyls (PCBs) were also added in coatings to increase tensile strength and to assist in the plasticity of the paint, respectively. The old Reclamation standard coating system VR-M (vinyl resin mastic) called out for a minimum of 19 percent asbestos in its formulation. The VR-M was used in conjunction with vinyl resins systems. The mastic was used as a filler and reinforcement along weld seams, skip welds, sharp edges, mating plates, crevices, gaps, rivets, and other irregularities. Equipment that was known to be coated with VR-3 or the VR-6 should have these areas sampled and analyzed for asbestos using a Tunneling electron microscope or Scanning electron microscope. The EPA has found old coatings that contain PCBs. The EPA has found them in lead-based paint, coal tar enamel, and vinyl resins. These coating systems have been extensively used in Reclamation and may or may not have PCBs in the old coating system, but should be sampled and analyzed for PCBs.

Testing

Testing of existing coating materials should be performed before starting contract or maintenance coating work. The purpose of testing is threefold: (1) to minimize exposure to environment and workers, (2) to reduce surface preparation costs, and (3) to determine the type and concentration of any toxic metals present. The following test methods are recommended:

- **Screen testing.** Screen tests will indicate the presence of toxic metals, but will not indicate the concentration. These tests are not intended to equal or replace laboratory analysis. The following two-common toxic metals can be detected by color change using premixed reagents:
 - Lead at concentrations of 2,000 parts per million (0.2 percent) or more. (See appendix V for manufacturer's information and this procedure.)
 - Chromate (as Cr+6) at concentrations of 3 micrograms or more. (See appendix W for manufacture's information and this procedure.)
- **Laboratory testing.** Paint chip samples should be taken and provided to an accredited laboratory for analysis to verify for asbestos, PCBs, and heavy metal concentration even if screen tests were not positive. The results should be evaluated by a certified industrial hygienist. (See appendix X for sampling, laboratory testing, estimated costs, and Web sites for accredited laboratories and industrial hygienists by city and State).

WORKER PROTECTION FROM TOXIC-BASED PAINTS

Blasting operations are the most likely event in which lead is inhaled or ingested because the particles are too small to be visibly seen. Lead dust on the skin is not hazardous as long as it is not inhaled or ingested. Proper respiratory protection, consisting of supplied air respirators, supplied air helmets, or HEPA filter-cartridge half- or full-faced air purifying respirators, should be worn. The following provides some common sense protection, but does not include all necessary requirements:

- Wear work clothing during removal operations and have clothing industrial washed by contractor or owner
- Wear respiratory protection appropriate to concentration level and exposure time period

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- Wash hands and face before eating or smoking
- After work, shower and change into street clothing to prevent contaminating your vehicle, home, and family

For comprehensive requirements for personal safety, see the following Code of Federal Regulations (CFR):

- 29 CFR 1910.1018, Arsenic
- 29 CFR 1910.1027, Cadmium
- 29 CFR 1926.55, Gases, Vapors, Fumes, Dusts, and Mists
- 29 CFR 1926.62, Lead

LEAD EXPOSURE LEVELS BY REMOVAL METHODS

Engineers, managers, and workers should be aware that surface preparation methods will generate airborne lead particles. The Occupational Safety and Health Administration (OSHA) monitored several types of lead removal operations for typical and maximum exposures. The monitored results indicate high exposure levels, and no surface preparation method will totally eliminate airborne lead particles. Vacuum shrouded equipment will reduce the amount of hazardous coatings of airborne particles, but will not eliminate them. Table X-1 provides OSHA results for typical and maximum lead exposure levels by removal method. The action level is 30 micrograms per square meter ($\mu\text{g}/\text{m}^3$); therefore, respirator protection is required for all the methods of removal.

CORRECTIVE ACTION

After one of the above inspection surveys (see “Inspection Types” above) has been completed and evaluated, the coating may be in some state of deterioration, thus requiring corrective action. Corrective action may range from no painting to full removal and recoating. The following sections provide alternative remedial options based on the inspection assessment.

Table X-1.—Typical and maximum lead exposure levels in $\mu\text{g}/\text{m}^3$ by removal method

Removal Method	Typical Exposure	Maximum Exposure
Open blast cleaning	17,300	59,000
Blast cleaning in containment system	25,700	59,000
Welding, cutting, or burning	600	28,000
Hand-tool cleaning	45	167
Power-tool cleaning	735	20,600
Chemical stripping	11	476
Movement (air, foot traffic, cleanup, etc.) in the containment system (causes particles to become airborne)	500	2,100

No Painting Required

The inspection assessment indicates the following: (1) the coating is in good to excellent condition, (2) the service environment is mild, (3) little corrosion is expected to progress at coating film breaks, (4) minor discoloration is noted, but appearance is not an important factor, and (5) no significant metal loss is noted.

Essentially, this option means “do nothing for “x” number years.” It does not mean “do nothing forever.” It means that the coating maintenance program is delayed until sometime in the foreseeable future when coating deterioration requires attention or until some time when coating maintenance is scheduled with other major maintenance programs. Another reason for not painting is that funding may not be available for “x” number of years.

Spot Repairs

Spot repairs are in order when the inspection assessment indicates the following: (1) the coating is deteriorating in localized areas, (2) the service environment is mild to corrosive, (3) corrosion is expected to progress at coating film breaks, (4) discoloration is noted, but appearance may or may not be an important factor, and (5) minor metal loss is noted.

This option is appropriate for isolated and relatively small areas that do not exceed 1 percent of the total coated surface area and are not in a high appearance area. If color is important, such as in a public area, take color chip samples to the coating manufacturer to match the existing color because the original coating color may have faded.

Spot repairs are a viable option for atmospheric, burial, and immersion service exposures.

Spot Repairs Plus Full Recoat

Spot repairs are in order when the inspection assessment indicates the following: (1) the coating is deteriorating in localized areas that represent between 1 and 3 percent of the total area and are expected to deteriorate further, (2) the service environment is mild to corrosive, (3) corrosion is expected to proceed at coating film breaks, (4) discoloration is noted and appearance is a factor, and (5) minor to moderate metal loss is noted.

This option is appropriate for coatings that are in relatively good condition but defects and corrosion are noticeable. The coating should still be resilient, it can still have a reduced DFT, and adhesion should be good where the coating has not deteriorated. When overcoating an existing paint, a test patch should be applied to determine compatibility between the coating materials. The test patches should be evaluated between 1 and 3 months after application. The structure's appearance may be of aesthetic importance (such as when in public view), and a full recoat will provide a uniform color and gloss.

This is a viable option for coating structures in atmospheric service exposures, but it is not recommended for burial and immersion service exposures.

Complete Removal and Recoat

Completely removing the old coating and recoating is in order when the inspection assessment indicates the following: (1) the coating is deteriorating in localized and large areas representing greater than 3 percent of the total area, and it is expected to deteriorate further; (2) the service environment is mild to corrosive; (3) corrosion is expected to progress at coating film breaks; (4) discoloration is noted and may or may not be an appearance factor; and (5) moderate to significant metal loss is noted.

This option is conducive to coatings that are in poor condition and are no longer protecting the substrate. This option requires full removal of all the existing coating material and recoating the entire surface.

This is a viable option for atmospheric and immersion service exposures.

MATERIAL SELECTION FACTORS

There are numerous factors to be considered when selecting a coating to meet specific conditions. The most basic factor is the environment the coating will be subjected to (e.g., atmospheric, burial, or immersion surface exposure). (See chapter I, “Service Exposure.”) Coatings should be selected for their intended use (i.e., a coating formulated for atmospheric service exposure is not suitable for immersion). The following are some other factors to be taken into consideration when selecting a coating material:

Coating Properties

- Abrasion or erosion resistance
- Adhesion of primer
- Appearance
- Color and gloss retention
- Recoat window
- Cure or dry time
- Flexibility
- Mildew or fungus resistance

Suitability to Substrate Type

- Ferrous (steel or iron)
- Nonferrous (aluminum, brass, bronze, or copper)
- Concrete or masonry
- Old coatings
- Wood

Environmental

- Temperature and humidity extremes and variations
- Cavitation
- Chemical contact
- Traffic, foot or vehicle

SCHEDULING

Accessible structures are relatively easy to schedule for inspection and maintenance coating work. However, many Reclamation structures such as interior of turbines, pump units, penstocks, draft tubes, discharge lines, and other interior water-bearing surfaces are difficult to access without a scheduled outage,

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and many areas cannot be dewatered in excess of 5 years. Therefore, planned or unplanned outages should be taken advantage of for either inspection or coatings work.

In scheduling a planned outage to perform maintenance coating work, the revenue loss in electricity or water delivery needs to be accounted for since revenue loss will likely become a significant factor.

Chapter XI: Galvanizing

Galvanizing is the application of zinc onto a steel surface. Zinc is anodic to steel (i.e., zinc will sacrifice itself to protect steel from corrosion). Reclamation specifies numerous steel metalwork items to be galvanized. Metalwork items may range from small items, such as bolts and nuts, to large items, such as gates. The following are reasons to coat over galvanizing: (1) to form a barrier coating in burial or immersion service exposures because the zinc will be rapidly consumed, (2) to repair damaged areas, and (3) to improve aesthetics (color appearance). Coating over galvanized surfaces presents unique problems that are characteristic of zinc and the coating material selected.

GALVANIZING METHODS

There are several methods to use when applying zinc. Table XI-1 provides the most common methods for galvanizing and includes manufacturing processes, specification references, zinc coating thicknesses, and typical applications for each method.

Table XI-1.—Galvanizing methods

Method	Process	Specifications	Thickness	Typical application
Electro-galvanizing	Electrolysis	ASTM A 591	Up to 0.14 mil	Interior service exposure: Appliance panels, studs, acoustical ceiling members
Zinc plating	Electrolysis	ASTM B 633	0.2 to 1.0 mil	Interior or exterior service exposure: Fasteners and hardware items
Mechanical plating	Peening	ASTM B 695	0.2 to 4.0 mil	Interior or exterior service exposure: Fasteners and hardware items
Hot-dip galvanizing	Hot-dip	ASTM A 123 ASTM A 153	1.4 to 5.0 mil	Interior or exterior service exposure: Nearly all shapes and sizes, ranging from nails, bolts, and nuts to large structural items
Thermal spraying	Hot zinc spray	AWS C2.2	3.3 to 8.3 mil	Interior or exterior service exposure: Items that cannot be galvanized by other methods because of their size and shape or because galvanizing must be performed onsite
Zinc-rich painting	Brush, roller, airless, or conventional spray	Varies with owner's or manufacturer's specifications	0.6 to 5.0 mil per coat	Interior or exterior service exposure: Items that cannot be galvanized by other methods because of their size and shape or because galvanizing must be performed onsite. Aesthetics (color).

Most Reclamation galvanized metalwork items that require painting are by the hot-dip process. This method requires the metalwork items to be immersed in a bath of molten zinc that clads the metalwork surface in a nearly pure zinc layer.

ZINC CORROSION AND SERVICE LIFE

Zinc, by itself, does not corrode like steel. Corrosion of zinc is achieved by exposing zinc to oxygen and moisture. The result is a white corrosion byproduct. Bare galvanized metalwork immersed in seawater may last for 6 months before being consumed. Bare galvanizing may last 5 to 10 years in fresh water, depending on the water chemistry. However, bare galvanizing in an atmospheric service exposure will form a protective layer between 1 and 2 years after the initial galvanizing process, and this protective layer impedes further corrosion. The service life of atmospheric galvanized metalwork has been known to exceed 50 years.

ZINC CHEMICAL REACTIONS

Zinc is an active metal and will react with other elements to form oxides and compounds. The following zinc compounds are formed on the galvanized surface:

- Zinc oxide is formed about 24 to 48 hours after the galvanizing process by the reaction of zinc with oxygen in the air.
- Zinc hydroxide is formed by the reaction of the zinc with moisture from rain, dew, or high condensation.
- Zinc carbonate is formed by the reaction of zinc oxide and zinc hydroxide with carbon dioxide from free-flowing air.

Zinc oxide (first phase reaction) and zinc hydroxide (secondary phase reaction) are products that are water soluble and not very dense. These products adhere very loosely to the substrate surface. Paint does not adhere well to zinc oxide or zinc hydroxide, and painting over these materials will probably result in premature coating failure. The first and second phase reactions may continue for 1 to 2 years after the galvanized manufacturing process is finished, depending on the local environment. Zinc carbonate (third phase reaction) is a dense, insoluble material that forms the protective layer. The final galvanized surface is a dull matte gray.

Zinc oxide, zinc hydroxide, and zinc carbonate products do not form uniformly over the galvanized surface or to a uniform depth. All three products are a

whitish color and nearly impossible to visually distinguish from each other. Without knowing which zinc compound is present, coating over galvanized surfaces becomes problematic.

CONTAMINANTS

Contaminants on galvanized surfaces are zinc ash residues deposited during the galvanizing process and naturally occurring white oxide stain that forms during storage. The following two sections provide a more detailed description of zinc ash and storage stain contaminants.

Zinc Ash

In the galvanizing process, particles of oxidized zinc float on the surface of the molten bath. When the metalwork is removed from the bath, residue of oxidized zinc particles can remain on the metalwork. A thin layer of residue can form on the surface, and this residue is referred to as “zinc ash.”

Wet Storage Stain

Newly galvanized items are stored and shipped. If the storage area or shipping container prevents the circulation of carbon dioxide in free-flowing air conditions, a white rust will form on the galvanized surface. This is a natural process that is often referred to as “white storage stain.” White storage stain results from a lack of carbon dioxide to convert zinc oxide and zinc hydroxide to the stable zinc carbonate compound. If left unchecked and sufficient moisture is present, all the zinc may be consumed (rare occurrence), the zinc may be consumed in patchy areas, or the result may be reduced zinc thickness.

To prevent white storage stain, manufacturers may perform a post-treatment process. The following are the most common post-treatment methods and their effects on painting:

- ***Apply a coating of oil to form a barrier from moisture.*** Paints will not adhere to oils, and applying oil will result in adhesion failure if the oil is not removed.

To check for the presence of oil, perform a water bead test. Place a drop of water on the surface. If the water beads, it indicates the presence of oil.

- ***Quenching (cooling in a water bath).*** Water may contain grease and oils that float on the water surface and contaminate the galvanized surface, resulting in coating adhesion failure if the grease and oil are not removed.
- ***Chromate quenching.*** Typically, paints will not adhere to galvanized surfaces treated by this method. Chromate quenching is being discontinued because of human safety and environmental concerns.
- ***Phosphate quenching.*** Adhesion of paint is improved by this method.

There is no easy field test to determine the type of quench treatment that was used, if any. The most reliable method is to contact the galvanizing shop.

Deposited Contaminants

Deposited contaminants are foreign substances that accumulate on the galvanized surface. The most common contaminants are dirt, grease, oil, and soluble salts. Chloride salts are aggressively destructive to galvanized metalwork. For protection against chloride contamination, galvanized items should be protected by containers during transport or storage.

SURFACE PREPARATION

The method of surface preparation of galvanized metalwork before painting depends on whether the metalwork is newly galvanized or weathered:

- ***Newly galvanized metalwork.*** The surface is undergoing the active formation of reactive zinc oxide and zinc hydroxide compounds. The chemical reaction may continue for 1 to 2 years, depending on local weather conditions and metalwork geometry.
- ***Weathered galvanized metalwork.*** The surface has completed chemical conversion from zinc oxide and zinc hydroxide compounds to nonreactive zinc carbonate.

Newly Galvanized Metalwork

Zinc is still reactive on newly galvanized metalwork, and several contaminants may exist, such as oil coating or post-treatment applied at the point of galvanizing.

Each specific contaminant may require a specialized surface preparation method. The following steps are surface preparation methods for removal of specific contaminants:

- ***Removal of white storage stain (white rust), if present.*** Apply a 1- to 2-percent ammonia solution by brush or spray. For severe white storage stain, apply 1 part acetic or citric acid to 25 parts of water. Thoroughly rinse the area where the solution was applied with warm potable water and allow the area to air dry.
- ***Removal of dirt, grease, and oil.*** Solvent cleaning in accordance with SSPC-SP1. Water-based emulsifiers and alkaline cleaners have been shown to work best. Ensure that alkaline cleaners have a pH of less than 12 because zinc will dissolve in highly alkaline solutions. Apply cleaning solutions by dipping, spraying, or brushing with soft-bristle brushes. Dipping and spraying works best when the cleaning solution is at about 140 to 185 °F. Thoroughly rinse the area where the solvent was applied with hot potable water and allow the area to air dry.
- ***Removal of zinc ash.*** Apply a 1- to 2-percent ammonia solution by brush or spray. Thoroughly rinse the area where the ammonia solution was applied with warm potable water and allow the area to air dry.
- ***Repair of physical defects (high spots and droplets).*** High spots occur when excess zinc runs down the edges of metalwork as it is removed from the molten tank. The excess zinc forms protrusions or irregular edges. High spots should be ground off with a power tool. Droplets form at metalwork edges where zinc drains when the metalwork is removed from the molten bath. Droplets can be ground down or knocked off by power tools. When using power tools, do not grind off the zinc to less than the required thickness.

If the zinc on metalwork has been removed to bare metal or thinned below the specified thickness during shipping, construction, handling, or installation, the damaged galvanized areas can be repaired by coating with a zinc-rich primer.

- ***Removal of zinc oxide and zinc hydroxide compounds.*** The reactive zinc oxide and zinc hydroxide compounds may not have been completely removed during the initial cleaning process, and there is no simple field detection method. To avoid premature coating failure, the coating industry recommends one of the final surface preparation methods be employed to remove reactive zinc oxide and zinc hydroxide compounds; however, the coating manufacturer should be consulted before applying the primer because some of the methods may not be compatible with the zinc-rich primer:

- **Phosphate treatment.** Apply a phosphate containing solution to form a nonreactive zinc phosphate layer on the surface and inhibit the formation of zinc oxides. The treatment will slightly etch the surface, producing an anchor profile for the coating primer. Application is by immersion, spray, or soft-bristle brush. The solution is left on for about 3 to 6 minutes and rinsed off with potable water. Coloration is returned to the galvanized surface after washing so that any missed areas will be visible and can be retreated. Allow the surface to air dry before coating.

For new construction metalwork items that are specified to be coated, phosphate quenching at the galvanizing plant will produce higher quality and at less cost than application in the field.

Zinc-rich primer should not be applied to phosphate-treated surfaces. The phosphate will form an insulated barrier between the zinc paint particles and the zinc galvanized metal. To be effective, zinc-rich primers require direct contact between the zinc particles in the paint and the zinc metal on the galvanized surface.

- **Wash primers.** Wash primers are coating materials formulated to neutralize surface zinc oxides and zinc hydroxides and to etch the galvanized surface, producing an anchor profile for the coating primer. Typically, the manufacturer recommends a single thin coat be applied by brush or spray at about 0.3 to 0.5 mil. At this thickness, the galvanized surface should shadow or retain a near matte gray appearance. If the galvanized surface becomes hidden, the wash primer was applied too thickly, and it may delaminate because of the wash primer's poor cohesive strength.

A common wash primer is polyvinyl butyral (SSPC Paint Specification No. 27). Other wash primer formulations are commercially available.

- **Acrylic passivation.** Application of an acidic acrylic solution will passivate or neutralize the reactive zinc oxides and zinc hydroxides and roughen the surface, producing an anchor profile for the coating primer. The solution is applied at about 0.04 mil (1 micron). This method is considered applicable only for very thin layers of zinc oxides and zinc hydroxides. The solution must be dry before applying any coating material.
- **Sweep blasting.** This is a light blast cleaning method to remove the reactive zinc oxides and zinc hydroxides and to produce an anchor profile for the coating primer. Soft abrasives should be used to reduce significant zinc metal loss and should have a Mohs' scale hardness of

5 or less and a particle size between 8 to 20 mils. Typical abrasives are aluminum or magnesium silicate, corn cobs, walnut shell, limestone, and some mineral sands.

The blast nozzle should be held at a relatively low angle to remove the reactive zinc oxides and zinc hydroxides. Holding the blast nozzle perpendicular to the surface can quickly remove sound zinc metal. Optimal ambient conditions for sweep blasting are 70 °F and 50 percent or less relative humidity. After sweep blasting, coat the surface within 24 hours.

Weathered Galvanized Metalwork

Fully weathered galvanizing with an outdoor exposure of between 1 and 2 years should have completely converted the zinc oxide and zinc hydroxide compounds to form a stable (nonreactive) protective layer of zinc carbonate. The most common surface preparation method is water power washing at a pressure of about 1,450 psi to remove dirt, grease, and oil. Higher pressures should be avoided to reduce the risk of removing sound zinc. Sweep blasting is another method used, often after water power washing to promote adhesion of the primer.

Aged or Weathered Galvanized Metalwork

Old, aged galvanizing that has been in service for several years and is showing evidence of deterioration presents additional problems and requires remedial surface preparation methods different from those appropriate for newly galvanized metalwork.

Deteriorated areas may show a reddish-brown stain. This color stain may be mistaken for corrosion of the steel base metal. Just above the interface between the steel base metal and the zinc that was applied during the hot-dip galvanizing process, a zinc-iron alloy layer is formed. The zinc-iron alloy layer may be corroding, rather than the steel base metal, and be bleeding through the more pure zinc above, resulting in the reddish-brown stain. Zinc-iron alloy is brownish, and steel corrosion is reddish. It is difficult to visually distinguish the difference between the two metals by color.

A magnetic or electronic DFT gauge can be used to determine if the steel base metal or the zinc-iron alloy is corroding. Since zinc is nonmagnetic, measuring over zinc will produce a thickness reading. A reading showing thickness indicates galvanized material is present (i.e., brownish color) (hot-dip galvanizing is applied at a thickness of about 2 to 5 mils). Readings that show no thickness indicate ferrous rust (i.e., reddish color indicates zinc has been consumed). This

is important because the areas that are brownish may still have sufficient galvanizing material left intact, and this will affect the surface preparation requirements.

The surface preparation of old, aged galvanizing requires the following steps:

1. Water power wash the entire surface to remove dirt, oil, and grease at about 1,450 psi
2. Abrasively blast (NACE 3/SSPC-SP6) or power-tool (SSPC-SP3 or SSPC-SP11) clean the rusted reddish areas (little or no galvanizing intact) to bare steel and feather the edges
3. Hand- (SSPC-SP2) or power-tool clean (SSPC-SP3) the brownish-colored areas (galvanizing intact), ensuring no more galvanizing is removed than is necessary
4. Sweep blast the entire galvanized surface to promote the adhesion of the primer coat

COATINGS

Numerous coating materials can be applied over galvanizing; however, it is best to ensure that the material selected is compatible with zinc. The selection depends not only on compatibility but also, in certain cases, on chemical treatments, surface preparation, and service exposure. Consult the coating manufacturer or the specific product data sheets for compatibility with specific chemical treatments and surface preparation methods.

Coating Selection

The following coatings are suitable to overcoat galvanizing under atmospheric, burial, and immersion service conditions:

- Atmospheric service exposure
 - Acrylic or waterborne acrylic
 - Acrylic latex
 - Waterborne latex

- Zinc-rich aerosol spray for repairing damaged areas of bare galvanized surfaces
- Epoxy primer with UV-resistant aliphatic urethane topcoat
- Moisture-cured urethane primer with UV-resistant aliphatic urethane topcoat
- Zinc-rich epoxy or moisture-cured urethane primer with UV-resistant compatible topcoat for damaged areas
- Burial or immersion service exposure
 - Coal tar epoxy
 - Epoxy
 - Moisture-cured urethane zinc-rich epoxy for damaged areas
 - Zinc-rich moisture-cured urethane for damaged areas

Do not use oil-based or alkyd coatings unless they are specifically formulated for galvanizing. Zinc is an alkaline metal. Moisture will eventually permeate through the coating film. The zinc and binders in oil-based or alkyd coatings react in the presence of alkalinity and moisture to form a metallic soap. This process is called saponification. Case histories show that oil-based and alkyd coatings that are adhering well will require about 6 months to 1 year after application in an outdoor environment to begin to fail.

Chapter XII: Coating Failures

Coatings fail for many reasons. These failures can be related to material selection, formulation, adhesion, substrate type, application, structure design, or exterior forces. These related failure types may act independently of each other or in concert with each other. The reader is strongly urged to purchase one of the photographic coating failure books listed in appendix B.

MATERIAL SELECTION

To protect the substrate, coatings are required to resist deterioration from atmospheric, burial, and immersion service exposure. No one type of coating has ever been developed to protect all substrate types in all service exposures. Rather, manufacturers formulate coatings for specific service exposures. Coating material selection is generally based on service exposure suitability, past history performance, recommendations from other facility owners, and accelerated performance tests.

The following are some examples of improper material selection:

- ***Selection of a paint for the wrong service exposure.*** For example, if an atmospheric coating is specified for immersion service exposure, failure will occur in a relatively short time period.
- ***Selection of a paint based solely on costs.*** Not all paints are equal. A manufacturer may produce some excellent products, but other paints from the same manufacturer may not perform well. As a rule-of-thumb, what you pay for is normally what you get, and this, in general, applies to paint materials.
- ***Selection of a paint based solely on an unsubstantiated opinion.*** A person with limited knowledge of industrial coatings can select the wrong or poorly performing materials, resulting in premature failure.
- ***Selection of a paint system that is not compatible with another paint.*** For example, a coating primer manufactured by one coating company should not be topcoated with a material manufactured by a different company, even if the two coating materials are of the same generic type, such as a polyamide epoxy. Incompatibility of solvents between two similar paints is a common cause for premature failure.

ADHESION

Adhesion failures are numerous and can be catastrophic. Failures are caused for a number of reasons. One of the most common reasons for adhesion failure is painting over a contaminated substrate. Contaminated surfaces prevent adhesion. Soluble salts left on the surface promote osmotic blistering where moisture or gaseous vapor is transmitted through the semipermeable coating material, and gases or liquids can form between the coating and the substrate. Table XII-1 provides a description of the types and causes of adhesion failures and the remedies for the failures.

Table XII-1.—Adhesion-related failures (modified from SSPC, Good Painting Practice, volume 1, third edition, 1997)

Failure description	Cause	Remedy
<i>Blistering</i> – Small to large (1/32 to 1 inch plus) hemispherical bubbles in the coating that contain gases or liquids. Bubbles may range from 1 per square foot to several hundred per square foot.	Blisters may be due to poor surface preparation, internal soluble materials (salts), or poor wetting of the substrate. Osmosis causes absorption of gases into substrate or solvent entrapment (also referred to as “solvent blistering”).	Select a coating with very strong adhesion strength and low moisture vapor transfer rate. Ensure clean substrate with proper surface preparation and reduced soluble salt levels to suit service exposure.
<i>Flaking or scaling</i> – Small to large (1/16 inch to 1 inch plus) pieces of coating, curling at edges. Easily removed from surface, leaving substrate exposed.	Normally, coating is brittle, with internal shrinkage characteristics and marginal adhesion strength. Oil type coatings may scale or flake from galvanized surface (never apply an alkyd to a galvanized surface).	Select a coating with very strong adhesion strength and low moisture vapor transfer rate. Ensure clean substrate with proper surface preparation and reduced soluble salt levels to suit service exposure. For galvanized surfaces, use a primer compatible with zinc.
<i>Intercoat delamination</i> – Coatings that do not adhere to the previous coat. Failure is between the primer and the intermediate coat or between the intermediate coat and the topcoat. The substrate is not normally exposed.	Coating material is not compatible with undercoat; undercoat surface may be contaminated with dust, dirt, overspray, or other contaminants; or undercoat may have cured beyond maximum recoat time.	Select a coating with good compatibility and adhesion between coats. Ensure that the undercoat surface is clean before applying the next coat. For epoxies, do not expose to excessive moisture (water and humidity) or excessive sunlight before applying the next coat.

Table XII-1.—Adhesion-related failures (modified from SSPC, Good Painting Practice, volume 1, third edition, 1997)

Failure description	Cause	Remedy
<i>Peeling</i> – Coating may be smooth and lying on the surface or hanging in shreds. Little or no adhesion is evident.	Adhesion is less than the tensile strength of the coating. Coating peelings can easily be pulled from the surface down to bare substrate.	Select a coating with very strong adhesion strength and low moisture vapor transfer rate. Ensure that the substrate is clean and salt has been reduced to levels suited to the service exposure.
<i>Undercutting</i> – Corrosion byproducts from the substrate build up under the coating and will break the coating at edges or pinholes. The corrosion progresses under the coating.	Poor adhesion because of improper surface preparation (dirt, dust, soluble salts, other contaminants); smooth surface (no surface profile); or coating incompatibility with the substrate surface.	Select a coating with very strong adhesion strength. Apply coating over a surface that has been abrasively cleaned or cleaned by water jet blasting. Use of a zinc-rich primer that reduces undercutting.

SUBSTRATE

The type of substrate surface can be a factor related to coating failures. The most common substrates are steel, cast iron, aluminum, zinc, copper, concrete, and wood. These substrates all have different characteristics, such as density, porosity, and chemical reactivity. Steel is very dense (related to surface smoothness), nonporous, and less chemically reactive than other substrate materials. On the other hand, concrete is not a high density (nonuniformed surface) material; it is porous and very chemically reactive. This simplified comparison illustrates the differences between substrate types. Table XII-2 provides a description of the types and causes of substrate failures and the remedies for the failures.

Table XII-2.—Substrate-related failures (modified from SSPC, Good Painting Practice, volume 1, third edition, 1997)

Failure description	Cause	Remedy
<i>Aged steel</i> – The surface includes blisters, rust, pitting, tubercles, or adhesion loss in areas where the substrate was exposed to the environment.	Substrate surface retained minute corrosion byproducts or contaminants even if it was abrasively blasted or water jet blasted to a high degree of cleanliness.	Water jet blast surface with water; dilute phosphoric acid or salt-bonding, chemical-removal solution. Apply an anticorrosion primer or barrier coating with high adhesion strength.

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Table XII-2.—Substrate-related failures (modified from SSPC, Good Painting Practice, volume 1, third edition, 1997)

Failure description	Cause	Remedy
<p><i>Aged cast iron</i> – The surface includes blisters, rust, pitting, tubercles, or adhesion loss in areas where the substrate was exposed to the environment.</p> <p>A silver gray to dark gray color may indicate graphite corrosion. This kind of corrosion can be easily cut or pierced with a knife.</p>	<p>Cast iron has a rough, more porous surface than steel, causing more moisture to be retained.</p> <p>For graphite corrosion, it is the selective leaching of ferrous ions from some cast irons, normally gray cast iron.</p>	<p>Water jet blast surface with water or salt-bonding chemical removal solution. Heat surface to hot-to-touch to drive off moisture. Brush apply primer while surface is warm to allow a maximum wet-coat penetration. Select compatible intermediate coat and/or topcoat.</p>
<p><i>Galvanized or metallic zinc</i> – White zinc corrosion byproduct developing under or breaking through the coating.</p>	<p>Formation of zinc salts (oxide, sulfide, oxychloride, zinc soaps) under the coating.</p>	<p>Brush or low-pressure water jet blast zinc surface or treat with commercial zinc treatment solution. Select an inert, nonoil primer with high adhesion strength.</p>
<p><i>Aluminum</i> – White aluminum corrosion byproduct is causing pinpoint coating failure, adhesion loss from smooth surface, blistering, or pitting.</p>	<p>Environmental pH outside the range of 5 to 8.5. Lack of accessible oxygen. Lack of adhesion to a very smooth aluminum oxide surface (i.e., lack of sufficient surface profile).</p>	<p>Light brush blast, soft abrasive blast, or treat with commercial copper treatment solution. Select a compatible primer with high copper surface adhesion strength.</p>
<p><i>Copper</i> – Blue or gray-green corrosion byproducts, adhesion failure, blistering, or pitting.</p>	<p>Lack of adhesion to a very smooth surface (no surface profile) or the presence of oxides on the surface.</p>	<p>Light brush blast, soft abrasive blast, or treat with commercial copper treatment solution. Select a compatible primer with high copper surface adhesion strength.</p>
<p><i>Concrete</i> – Adhesion loss, blistering, or peeling of coating.</p>	<p>Chemically reactive and high moisture content. Formation of calcium salts under the coating. Pinholes, air, and water pockets in concrete surface. Water vapor transmission through the concrete.</p>	<p>Abrasive blast or water jet blast (acid etching not recommended) to obtain clean and dry surface. Select a low molecular weight, high-penetrating primer with high alkali resistance (coal tar epoxy or modified epoxy).</p>

APPLICATION

Coating failures are most commonly related to the method of application. There are a variety of reasons for application-related failures that have nothing to do with material selection or improper formulation. These failures are mainly caused by humans. There are numerous examples, ranging from failure to understand the consequences of improperly preparing surfaces to improperly applying coatings to rushing the job. Table XII-3 provides a description of application failures, the cause of the failures, and the remedy for the failures.

Table XII-3.—Application-related failures (modified from SSPC, Good Painting Practice, volume 1, third edition, 1997)

Failure description	Cause	Remedy
<i>Improper mixing</i> – Coating is too thin, pigment distribution is nonuniform, or both. Entire or localized areas may have poor adhesion, uneven color, checking, or cracking.	Failure to sufficiently mix material, resulting in improper pigment-to-vehicle ratio; settled pigment remains in bottom of container.	Thoroughly mix the liquid material to an even, smooth, homogeneous consistency, with no color variation. During use, continue mixing as necessary. Mechanical mixing is the preferred method.
<i>Improper thinning</i> – Poor adhesion or pigment flotation, resulting in uneven color. Separation of pigment and vehicle after application, resulting in pinholing or blushing.	Thinner is incompatible with resins or pigments. Improper drying, resulting in surface tension change. Thinner evaporated too rapidly, causing moisture to condense on liquid coating. Excessive thinner, resulting in curdling or flocculation of pigment.	Use only the manufacturer's recommended thinner for selected coating material in the amounts specified. Add thinners slowly and mix thoroughly.
<i>Improper environmental conditions</i> – Blistering and/or poor adhesion caused by damp, humid conditions. Powdery coating where drying occurred too rapidly (overspray). Soft, uncured coating.	Ice, moisture, condensation (above dew point), or standing moisture on surface before application. Lack of proper cure because the temperature and/or humidity were outside restrictive range.	Apply coatings using the manufacturer's environmental (temperature, humidity, dew point, and surface condition) restrictions or more restrictive requirements.

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Table XII-3.—Application-related failures (modified from SSPC, Good Painting Practice, volume 1, third edition, 1997)

Failure description	Cause	Remedy
<i>Improper thickness</i> – Where coating is thin, pinpoint corrosion areas result. Where coating is overly thick, checking, cracking, or flaking results.	Improper applicator technique: Too close or too far away during spraying; incomplete or excessive spray passes. Difficult areas (restrictive accessibility or space).	Use proper application techniques for even passes and overlaps, follow the manufacturer's application instructions, and use the equipment recommended by the manufacture.
<i>Amine blushing</i> – Oily, amber-colored film on coating surface for aliphatic, amine-cured epoxy materials.	Material applied relatively thickly on cold, damp days or in similar environments where amine rises to surface and reacts with carbon dioxide and moisture in the air.	Wait for proper temperature and humidity before application.
<i>Blushing</i> – Milky or whitish appearance of coating film with a dull or flat finish.	Moisture condensation on coating in high humidity because of fast evaporation or unbalanced thinners. Occurs most often on hot, humid days or in similar environments.	Wait for improved humidity, reduce atomizing air pressure to a minimum, or add evaporation retardant to thinner.
<i>Bleeding</i> – Staining of topcoats.	Soluble resins or pigments in undercoat migrate to topcoat.	Seal undercoat with coating in which bleeding components are insoluble.
<i>Cratering</i> – Small, uniform indentations in coating film (also referred to as "pitting").	Surface contaminant or air pockets trapped in wet film during spray application.	Abrasive blast, water jet blast, or roughen affected areas, ensuring removal of contaminants within craters, and reapply coating.
<i>Fisheyes</i> – Separation or pulling apart of wet film to expose underlying coat or substrate.	Coating applied over dirt, oil, silicone, or incompatible coating material.	Remove all material by abrasive blasting or water jet blasting, ensure substrate is contaminant free, and reapply coatings.
<i>Holidays</i> – Bare areas on the substrate that were not coated by the applicator (also referred to as "painter's holiday").	Improper and inconsistent application technique, reflecting a lack of care. Most often occurs in areas difficult to coat.	Apply coating in a careful and professional manner, consistent with industry standards.

Table XII-3.—Application-related failures (modified from SSPC, Good Painting Practice, volume 1, third edition, 1997)

Failure description	Cause	Remedy
<i>Lifting</i> – Wrinkling, swelling, or blistering appearance on the film surface.	Solvents in a coating attack or swell the underlying coating, resulting in film distortion.	Remove all material by abrasive blasting or water jet blasting and reapply coatings.
<i>Orange peel</i> – Overall appearance is bumpy. Film surface is smooth but irregular. Resembles skin of an orange. Note: Orange peeling is not a coating failure, but the appearance may be objectionable.	Inherent with sprayed-on materials and caused by improper application techniques: Gun too far from surface, solvent evaporation too rapid, spray pressure too low for proper atomization, paint particles falling outside of spray pattern, or material too viscous.	Brush out excess paint before material cures. Correct spray technique. After material has cured, sandpaper surface before applying another topcoat that reacts more slowly.
<i>Overspray</i> – Very rough coating surface. Surface may be dry, pebbly, or sandy. Some coated areas may have the appearance of dryness or feel dry (also referred to as “dry spray”).	Improper application techniques: Gun too far from surface, solvent evaporation too rapid, spray pressure too low, atomizing pressure too high, paint particles falling outside of spray pattern, or material too viscous.	Before the material cures, remove the overspray by dry brushing, followed by solvent wiping. After the material has cured, wire screen and sandpaper the surface before applying another topcoat that reacts more slowly.
<i>Pinholes</i> – Small, tiny, deep holes (1/32 inch) in coating, normally through to the substrate. Generally, the distribution of holes appears to be random.	Improper application techniques: Gun too far from surface, solvent evaporation too rapid, spray pressure too low, atomizing pressure too high, paint particles falling outside of spray pattern, or pigment settlement.	Correct any improper application techniques. If pinholes already exist and the material has not cured, apply additional coat by brushing into holes. If material has cured, but it is still within the recoat window, apply an additional coat.

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Table XII-3.—Application-related failures (modified from SSPC, Good Painting Practice, volume 1, third edition, 1997)

Failure description	Cause	Remedy
<i>Runs or sags</i> – Downward movement of coating material on vertical or curved surfaces in the form of droplets or streams. Runs are the result of excess material continuing to flow after the surrounding surface has set. Sags are the result of differences between application and setting times. Sags have the appearance of a curtain	Excessive application of coating material, spray gun too close, too much thinner, surface too hard or glossy to hold material, or temperature too cold for proper drying.	Correct any improper techniques. Apply thinner coats. If material has not cured, brush out excess material. If material has cured and is still within the recoat window, apply an additional coat. If outside the recoat window, abrade the surface and apply an additional coat.
<i>Spatter coat</i> – Areas of thin coating (less than specified coating thickness), normally at end of the spray pass or around complex sections of structure. Under good lighting conditions, coating appears continuous; under poor lighting, coating appears discontinuous. May develop into pinpoint corrosion at a later date.	Improper application techniques, causing a noncontinuous coating over the surface: Inconsistent spray passes not overlapping by 50 percent, spray gun flipped at end of spray pass, or spray gun not held perpendicular to the surface.	Correct any improper application techniques. If material has not cured, apply additional coat. If material has cured but it is still within the recoat window, apply an additional coat. If outside the recoat window, abrasive blast or water jet blast all material off and recoat.

DESIGN

Numerous coating failures occur not because of misformulated materials, deficient surface preparation, or application errors but because of the inherently difficult problems presented by the design of the structure. Most designers do not have corrosion mechanisms and coating operations in mind when they design structures. However, with the proper selection of coating materials and application techniques, many design inadequacies can be overcome. Table XII-4 describes design failures, the cause of the failures, and the remedy for the failures.

Table XII-4.—Design-related failures (modified from SSPC, Good Painting Practice, volume 1, third edition, 1997)

Failure description	Cause	Remedy
<i>Back-to-back angles and plates</i> – Corrosion between back-to-back angles and plates is resulting in undercutting of coating.	Impossible to apply coating in crevice between angles and plates.	Design: Use T bar of pipe in construction. Precoat: Coat angles and plates prior to construction assembly. Stopgap Measure: Fill crevice with resinous chalking and topcoat with compatible material.
<i>Edges</i> – Linear corrosion along edge and undercutting coating away from the edge.	Surface tension causing coating to pull away from edges.	Brush or stripe coat surfaces before full coating. Overlap full coating on both sides of edges. Spray directly at edge to build up thickness and reduce surface tension.
<i>Interior corners</i> – A void or blister is developing under coating.	Excessive coating thickness, resulting in coating shrinkage during or after curing.	Apply multiple thin coats and allow coating to thoroughly dry between coats, but within recoat window.
<i>Skip welds</i> – Corrosion in weld gaps and between overlapping metal is causing undercutting of coating.	Impossible to apply coating in crevices in weld gaps and between metal surfaces.	Provide continuous weld in gaps and overlap areas before applying coating in any corrosive environment.
<i>Small discontinuous areas</i> – Corrosion is developing on edges of bolt heads, bolt threads, nuts, washers, rivets, and other small-edged or cornered surfaces.	Small surfaces with high ratio of edges and corners to plain, flat area will increase coating surface tension and cause coating to pull away from edges and corner points.	The best method is to use a filler of caulk material to bridge the larger gaps. Smaller gaps can receive brush or stripe coat surfaces prior to full coating. Overlap brush or stripe coat with each full coat applied. Applying multiple thin coats is more beneficial than one thick coat.
<i>Storage tank roofs</i> (Interior of umbrella type for center post and rafters) – Corrosion is developing between roof and rafter and between lapped roof plates.	Impossible to apply coating in crevices between roof and rafter and between lapped roof plates.	Butt weld or double weld roof plates. Precoat rafters and underside of roof.

Table XII-4.—Design-related failures (modified from SSPC, Good Painting Practice, volume 1, third edition, 1997)

Failure description	Cause	Remedy
<i>Welds</i> – Corrosion along welds, particularly hand welds, is undercutting coating away from weld. Corrosion along weld may be continuous or discontinuous.	Welding flux in undercuts along weld. Rough weld surfaces. Soap remaining after pressure testing of welds. Blue scale (similar to mill scale) remaining on weld surface.	Remove all soap solution and blue scale. Grind rough welds smooth or nearly smooth. For interior of hydraulic structures, such as pipelines, grind welds down to 1/8 inch, minimum. Abrasive blast weld and apply brush or stripe coat 2 to 3 inches on each side of weld, working coating into all rough areas before applying full coating.

EXTERIOR FORCES

The environment the coating is subject to can be a primary cause of failure. Corrosive environments normally encountered on Reclamation projects are freshwater environments that contain various concentrations of dissolved salts and flowing water that contains abrasive material such as sand particles. In this section, ordinary atmospheric exposures are not considered. Table XII-5 provides a description of failures related to exterior forces that cause of the failures and the remedy for the failures.

Table XII-5.—Failures related to exterior forces

Failure Description	Cause	Remedy
<i>Abrasion or erosion</i> – Thinning or wearing away of coating is resulting in a bare substrate subject to corrosion.	Wear caused by wheeled traffic, wind, or liquid-borne abrasives.	Select coating with strong adhesive properties and specific abrasion and erosion resistance. Thoroughly prepare surface (near-white blast minimum) and apply new coating.
<i>Cavitation</i> – Loss of coating and metal material. Appears as tiny craters overlain by multiple craters in metal surface, accompanied by significant metal loss.	Drop in water vapor pressure, forming air bubbles that repeatedly collapse at high pressure.	Select coating with strong adhesive properties and high cavitation resistance.

Table XII-5.—Failures related to exterior forces

Failure Description	Cause	Remedy
<i>Chemical</i> – Dissolution of coating; undercutting or underfilm corrosion.	Selection of unsuitable coating material. Improper coating application.	The prime requirement is to select a coating for the specific chemical service exposure.
<i>Faying surfaces</i> – Coating failure and corrosion in joint area.	Concentration (or crevice) corrosion caused by oxygen differences between closely spaced or joined coated surfaces, subject to friction-producing movement (e.g., steel plates and high strength bolts).	Precoat metal surfaces before assembly with inorganic zinc coating or a suitable coating with a high coefficient of friction.
<i>Graffiti</i> – Painted words or graphics over coated surface.	Vandals painting coated surfaces, especially with spray cans.	Select the manufacturer's graffiti remover and anti-graffiti coating.

Chapter XIII: Coatings for Quagga and Zebra Mussel Control

INTRODUCTION

Zebra and Quagga mussel infestation presents a serious problem for Reclamation infrastructure. Zebra and Quagga mussels, which are native to parts of eastern Europe and Asia, were initially introduced to the United States via the ballast water in cargo ships. Infestation first occurred in the Great lakes region during the 1980s. In 2007, mussels were observed in Lake Mead and have since been observed in several other Reclamation reservoirs in Colorado, Utah, California, and Arizona. Due to their high rates of reproduction, they tend to out-compete native aquatic species for food, posing a serious threat to freshwater ecosystems. In addition, the mussels colonize on hydraulic infrastructure such as piping and trashracks and thereby have the potential to create blockages, threatening the continued reliable operation of facilities and equipment. Reclamation has been aggressively pursuing methods to mitigate the impacts of invasive mussel infestation. This chapter details potential impacts to Reclamation facilities as well as potential mitigation strategies, with specific emphasis on foul-release coating systems.

Each facility at Reclamation is unique in nature and may present specific challenges and requirements for Zebra and Quagga mussel mitigation. This chapter provides general information on what are considered to be typical points of vulnerability, as well as potential mitigation strategies, with emphasis on protective coating systems.

BACKGROUND ON POTENTIAL INVASIVE MUSSEL IMPACTS

Quagga and Zebra mussels (adult lengths average 2.5 centimeters or 1 inch) are unique in that they can firmly attach to the underwater surfaces using byssal threads. They begin spawning by emitting eggs and sperm into the water column when water temperature reaches around 10–12 °C (50–54 °F). On a population-wide basis, egg production occurs in astronomical levels (on the order of 30,000 eggs/female/ reproductive cycle). Depending on temperature and environmental suitability, multiple reproductive cycles may occur in a single year. Fertilized eggs develop into freely swimming larvae or veligers (ranging in sizes from 60 to 250 micrometers), which may be transported by water currents for many miles. Within a few weeks, and if water conditions are suitable, the veligers will settle (i.e., attach to hard surfaces) and continue growth to adulthood.

Successful settlement is dependent on a number of environmental conditions inherent in the natural water system. These include calcium, alkalinity and hardness, pH, nutrients, dissolved oxygen, temperature, and conductivity. It should be noted that some of these parameters are indirect measures of others (e.g., alkalinity and hardness are presumptive for calcium and magnesium). All parameters are typically listed since data for many are not always available. Dissolved calcium appears to be the most important parameter. It is generally accepted that highly successful mussel colonization occurs when calcium levels exceed 24 milligrams per liter (mg/L). Successful establishment is more in question when calcium values fall below 10 mg/L. With the possible exception of nutrients (which are implied indicators of food supply) in high mountain lakes, available data have shown levels of the remaining parameters to be adequate for mussel propagation. Table XIII-1 provides water quality parameter suitability criteria for invasive mussels. It should be noted that this information was obtained from various sources involving Zebra mussel specific studies in Europe and eastern portions of North America and may not be entirely applicable to water bodies in the Western United States. Even so, it provides an approximate indication of suitability requirements.

Table XIII-1.—Presumptive infestation-level suitability criteria for invasive mussels

Parameter	Infestation Levels			
	Low Probability of Establishment	Low	Moderate	High
Calcium (mg/L)	<8–10	10–15	15–24	>24
Alkalinity (mg CaCO ₃ /L)	<30	30–45	45–90	>90
Total hardness (mg CaCO ₃ /L)	<30	30–45	45–90	>90
pH	<7.0 >9.5	7.0–7.5 9.0–9.5	7.5–8.0 8.8–9.0	8.2–8.8
Mean summer temperature (°F)	<64 >86	64–68 83–86	68–72 77–83	72–75
Dissolved oxygen (mg/L)	<3	5–7	7–8	>8
Dissolved oxygen (% saturation)	<25%	25–50%	50–75%	>75%
Conductivity (µS/cm) ¹	<30	30–60	60–110	>110
Salinity (mg/L)	>10	8–10	5–8	<5
Secchi depth (meters)	<0.1 >8	0.1–0.2 2.5–8	0.2–0.4	0.4–2.5
Chlorophyll a (µg/L) ²	<2.5 >25	2.0–2.5 20–25	8–20	2.5–8
Total phosphorous (µg/L)	<5 >50	5–10 30–50	15–25	25–35

Source: Renata Claudi, RNT Consulting, Inc..

¹ Microsiemens per centimeter.

² Milligrams per liter.

Environmental and operational conditions of the structures themselves may also influence veliger settlement and subsequent colonization. Within a facility, veliger settlement is prohibited or greatly reduced in pipes where water velocities continuously exceed 6 feet per second (ft/s). However, intermittent operations or slower velocities may lead to successful settlement. Once attached, mussels can sustain attachment even when flow velocities exceed 6 ft/s. Ideal areas for mussel colonization are those areas with continuous flows of moderate velocities (<6 ft/s) and ample supplies of food and oxygen. Piped systems, which are seldom utilized or idle for prolonged periods and which have depleted oxygen, are not generally supportive of successful colonization. A major exception is when leaking valves allow constant flows and replenishment to the seldom used systems.

Invasive mussels pose serious threats to Reclamation's infrastructure and operations. Of major importance to Reclamation facilities is the ability of mussels to rapidly colonize hard surfaces at densities of tens of thousands per square meter. This heavy accumulation can lead to costly operations and maintenance problems. Flow restriction is the foremost concern because mussels can clog water intake structures such as trashracks, pipes and screens, thereby threatening water delivery to critical systems at hydropower plants and reducing pumping and conveyance capacities of water distribution systems.

Major structural impacts caused by Quagga and Zebra mussels at Reclamation facilities fall into the following categories:

- ***Flow restriction or blockage.*** Light infestations can roughen water conveyance surfaces, reducing the ability to deliver water in desired quantities and in a timely manner. If accumulation is allowed to progress to extremes, pipes as large as 1 foot in diameter have been blocked. Accumulations of shells from dead mussels are also problematic in screens, filters and small-diameter pipes, fittings, and valves.
- ***Mechanical damage.*** Mussel shells can cause abrasive damage to soft materials such as seals, and over time, finely machined surfaces. Removal of attached mussels can cause damage to surfaces by lifting of coatings.
- ***Chemical degradation of structures.*** The accumulation of mussel fecal material, digestive byproducts, and sediments next to uncoated or damaged coatings on metallic (ferrous) substrates under large colonies is highly supportive of bacterial colonies that accelerate corrosion processes.

One promising method to control mussel infestations on Reclamation infrastructure is to use coatings that prevent fouling by mussels on trashracks, intakes, and piping that are at high risk for blockage from mussels. Currently,

chemical treatment (chlorine) is the most widely used method for control. However, chemicals require discharge permits to release into open waters, and it is not practical in all situations. Ontario Hydro has reduced the amount of chemicals it uses by applying antifouling or foul-release coatings to critical infrastructure. There are two basic types of coatings that can be used for control of mussels: (1) antifouling coatings and (2) foul-release coatings. Antifouling coatings are toxic to the fouling organism and leach biocides into the water. Cuprous oxides and chemical biocides are normally the biocides used in antifouling coatings. Biocide leach rates are dependent on water chemistry, pH, water temperature, and flow rates. Foul-release coatings rely on unique surface properties (chemistry) to deter the attachment of fouling organisms without releasing toxins into the water. These types of coatings do not depend on water chemistry, pH, temperature, or flow rates. The majority of foul-release coatings is formulated with silicone elastomers such as poly(dimethyl siloxane) (PDMS). Unfortunately, the majority of these coatings are soft and not very durable. Therefore, the service life will depend on the amount of mechanical damage induced on the coating.

ANTIFOULING COATINGS

There are many types of antifouling coatings that use different binders and biocides. The paint binders can be insoluble or soluble in water. Soluble binder system will wear away over time and are known as ablative coatings. Nonablative antifouling paints contain insoluble binders which remain intact while the biocides leach out slowly, eventually creating a honeycomb like structure.

Biocides could be heavy metals such as copper, organic biocides, or natural biocides. The development of antifouling coatings is a complex process involving many different factors and ingredients to make a successful coating system. The most successful antifouling coating was a self-polishing tributyl tin system. However, due to the environmental impacts of the tin, the International Maritime Organization banned the use of tin in antifouling coatings in 2003. Today, the most common antifouling coating contains cuprous oxide as the biocide. These coatings are also receiving a lot of attention and review of their toxicity to marine organisms. Some European nations and U.S. cities (San Diego) have also banned the use of copper antifouling coatings in their harbors on smaller ships. Concerns over the environmental toxicity are driving the technology towards organic biocides that do not have a long-term effect on the environment and degrade relatively quickly. There is a broad spectrum of organic biocides that can be used in antifouling coatings. Each organic biocide has different toxicity and degradability (Hellio, 2009).

Natural biocides are another category of biocides that have the potential to be used in antifouling coatings. However, due to the complexity and number of different types of fouling organisms, there is not a commercial product that uses natural biocides.

Antifouling coatings can be classified into three different categories: (1) contact leaching, (2) controlled depletion, and (3) self polishing. Contact leaching means that the binder matrix is water insoluble (such as epoxy), where the biocides leach out exponentially and the coating matrix left behind is a honeycomb structure. The biocides at or near the surface are consumed rather quickly, resulting in a coating life of 2–3 years. Eventually, there is not enough biocide leaching out to keep the mussels off the surface. At this point the mussels attach quite firmly to the surface because they inject their adhesives into the honeycomb structure. Controlled depletion is where the coating matrix erodes at a different rate than the biocide. These types of systems leach out exponentially, but may reach up to 5 years of service before coming ineffective. Rosin is a typical binder for the controlled depletion systems. Self-polishing systems are where the coating matrix and the biocides leach at approximately the same rate. This allows for a fresh supply of biocide at the surface to prevent the fouling organisms from attaching. Self-polishing systems provide the longest service life of 7 years or more; the service life is dependent upon the number of coats and thickness of the coating system. The binder is normally a hydrolysable acrylic polymer.

The environmental exposure conditions also affect the effectiveness of the antifouling coatings. The leach rate and matrix solubility are dependent on the water chemistry, pH, temperature, and flow rates. Just because a product works well in sea water does not necessarily mean it will work in fresh water. Another factor is hard water versus soft water. Each coating system needs to be evaluated for different water bodies if antifouling coatings are used.

REGULATORY AND ENVIRONMENTAL CONSIDERATIONS

All antifouling coatings must be registered through the EPA for use in marine environments. Recently it was found that these coatings may not necessarily be registered to be used in fresh water or irrigation water. Reclamation maintains 476 dams, produces 17 percent of the Nations hydroelectric power, supplies irrigation water for 10 million acres of farmland (25 percent of fruits and 60 percent of vegetables produced in the U.S.), and serves 31 million people for municipal, residential, and industrial water use. It is unlikely that Reclamation could use some of these biocides due to the unknown chemical byproducts and health risks after the biocides decompose.

FOUL-RELEASE COATINGS

The most common foul-release binders are based on PDMS, commonly known as silicone. Many of these coatings rely on a combination of low surface energy and low elastic modulus to achieve their nonstick properties. Reclamation has conducted field testing at Parker Dam, and the results have shown that silicones are effective at deterring mussel attachment. Eventually the silicone FRCs do foul with algae and a few mussels; however, they have shown effective self-cleaning properties once a critical drag (or shear) force is obtained. The algae and mussels can be cleaned with minimal force to remove the fouling.

Reclamation's Materials Engineering and Research Laboratory (MERL) has conducted laboratory evaluations of foul-release coatings to determine the expected durability in service for each product compared to traditional epoxy and polyurethane based coatings. These tests included brush abrasion, erosion, and high flow water immersion testing. While silicone systems have performed well in field testing, remaining relatively foul free, laboratory testing has shown that these coatings have a diminished resistance to brush abrasion testing in comparison to a conventional epoxy-type coating. However, these coatings appear to hold up well in erosion testing, outperforming the epoxy controls, and some hold up better than ceramic epoxies, which were designed for erosion and abrasion resistance. These coatings may lend themselves well to an application such as a penstock where risk of abrasion and scraping is expected to be minimal but where high flow rates and erosion resistance is desirable.

In 2011, MERL tested various foul-release coatings overcoated on top of coal tar enamel. Coal tar enamel is the protective coating found in most outlet works, penstocks, and piping in Reclamation's infrastructure. The idea was to overcoat the coal tar enamel with the foul-release coatings to reduce the drag and head loss due to Zebra or Quagga mussels. However, the results were disappointing. All of the samples had stress cracking and delaminated the coal tar from the steel surface in the high flow water immersion. It is not recommended to overcoat coal tar enamel with foul-release coatings. Foul-release coatings can only be used if the steel is prepared correctly and blasted to bare metal.

Durable foul-release coatings are another type of coating, and their chemistry can be based on different binders. As of September 2011, field test results show that all of the durable coating systems allow the Quagga mussels to attach to the surface with varying degrees of force required for removing a mussel. Furthermore, abrasion resistance is greatly increased over silicone FRC. However, some of durable foul release coatings are not as abrasion resistant as traditional epoxy coatings. The erosion resistance was worse than the silicone FRC, but better than a traditional epoxy coating. At this time, periodic cleaning would still be required if the durable foul-release coatings were used. MERL is still evaluating durable foul-release coatings for fresh water fouling control. As technology advances, there may eventually be a durable foul-release coating that

performs well.

The durable foul-release coatings may still have a role on Reclamation infrastructure. Since the durable foul-release coatings still foul, periodic cleaning will be required. It does not take as much force or effort to remove mussels from the durable foul-release coatings as a traditional epoxy, stainless steel, or galvanized steel. Some may question this decision because corrosion protective coatings could be allowed to foul and then be cleaned off periodically. The timeframe between cleanings should be as long as possible. Currently, at some reservoirs, cleaning is required twice a year with the existing coatings. Foul-release coatings could be expected to extend the interval between cleanings up to 2 years or more, potentially minimizing downtime and maintenance costs. Most cleaning methods would require the use of divers to do the work. It is well known that any underwater construction costs more than the same task being performed on the ground. Another problem is that many Reclamation dams are a few hundred feet tall, making the dives quite challenging and dangerous. Therefore, the ease of cleaning is very important to increase the productivity of the divers to keep the maintenance costs as low as possible.

Current service life expectations for silicone foul release is about 7–10 years before the coatings would have to be replaced. Reclamation typically wants as long a service life as possible and is currently applying coatings with an expected service life of 20 years. It is desirable to have a foul-release coating with increased durability because this could increase the expected service life to 20 years.

PRACTICAL ISSUES ASSOCIATED WITH FOUL-RELEASE COATINGS

Increased Cost

In addition to performance and service life, product cost and application requirements are two important factors to consider when choosing a coatings system. In general, foul-release coating systems are more expensive to purchase and apply compared to a conventional epoxy- or polyurethane-type system. The typical product costs for a conventional epoxy system are around \$75 per gallon and \$125 per gallon for a polyurethane-type coating. For comparison, foul-release coatings cost \$300–450 per gallon.

Application Issues

The foul-release coatings that contain a polysiloxane binder system will have special application requirements. A special tie coat is required to tie the epoxy primers to the polysiloxane topcoat. These systems typically require that the last

coat of epoxy be slightly tacky when the tie coat is applied. This is known as a wet on wet application and is necessary for the topcoat to achieve adequate adhesion to the epoxy primers. The result is that the tie coat must be applied within a narrow window of time, which can create logistical difficulties and increase the probability of a coating failure due to incorrect application. Consequently, the use of a skilled applicator is highly recommended to ensure a successful coating job. Also, a qualified coatings inspector is a must in order to catch errors in application. Not all foul-release coating systems will have the same application requirements, and it is important to consider these when choosing a coating system. Also, some foul-release coating systems require a minimum of 40 percent relative humidity in order to cure properly. This could be problematic in the arid Western United States.

Handling Issues

Silicone foul-release coatings are very delicate and cannot withstand impact, gouging, abrasion, or scraping. This means that coating infrastructure at a shop is not very practical since the coating will be severely damaged before it is placed in the final position. Shipping and handling will damage the coating.

Touchups and Repair

Many of the silicone foul-release coatings will require a special repair method or technique. Epoxy coatings will not bond to the silicone coating. The silicone coating will not bond to steel or epoxy without the special tie coat. Follow the manufacturer's recommendations for repairs.

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- The Society of Protective Coatings, C-2: Specifying and Managing Protective Coating Projects, two volumes, version 7, Pittsburgh, Pennsylvania, 2000.
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- The Society of Protective Coatings, SSPC-SP 15: Commercial Grade Power Tool Cleaning, Pittsburgh, Pennsylvania, 2002.

Organizational Sources for Standards and References

American Society of Testing and Materials (ASTM)
1916 Race Street
Philadelphia PA 19103
Telephone: (610) 832-9500
Fax: (610) 832-9555
Website Address: www.astm.org

NACE International (NACE)
PO Box 218340
Houston TX 77218
Telephone: (281) 228-6223
Fax: (281) 228-6329
Website Address: www.nace.org

Society for Protective Coatings (SSPC)
40 24th Street, 6th Floor
Pittsburgh PA 15222
Telephone: (412) 281-2331 ext 16
Fax: (412) 281-992
Website Address: www.sspc.org

Bureau of Reclamation
Guide Specifications
Website Address: <http://intra.usbr.gov/guidespecs>

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Steel Penstock Coating and Lining Rehabilitation, A Hydropower Technology Roundup Report, Volume 3, Technical Report TR-113584-V3, August 2000.

Available from Electric Power Research Institute (EPRI), 3412 Hillview Avenue, Palo Alto CA 94304; telephone: (650) 855-2000; Customer Service: (800) 313-3774; Website Address: www.epri.com

Visual Comparison Manual, Application and Coatings Defects, Brendan Fitzimons, Robinson Irwin Technical Support Ltd., England 1997-1998, (SSPC Publication No. 00-8)

Inspection Checklist

- ☐ Delivered materials
- ☐ Approved materials, record batch numbers
 - ☐ Stored properly
 - ☐ Containers secured
 - ☐ Shelf life not exceeded
- ☐ Abrasive material
 - ☐ Complies with SSPC-AB1, Class A, Type I or II
 - ☐ Contaminants
 - ☐ Check for presence of oil, ASTM D 4940
 - ☐ Check for chloride ion, if suspected with Chlor*Rid A test kit
 - ☐ Retain sample
- ☐ Air compressor equipment
 - ☐ Compressed air lines
 - ☐ Check for oil and water contaminants, ASTM D 4285
 - ☐ Blast nozzle pressure
 - ☐ Check pressure at blast nozzle with hypodermic needle gauge
- ☐ Surface preparation
 - ☐ Do not proceed with surface preparation if the substrate surface temperature is less than 5 degrees F above the dew point
 - ☐ Determine the rust grade by one of the following prior to cleaning:
 - ☐ SSPC-VIS 1, for abrasive blast cleaning
 - ☐ SSPC-VIS 3, for hand and power tool cleaning
 - ☐ SSPC-VIS 4(I), for water jetting
 - ☐ Check for chloride ion contaminant in wash water or water used in water jetting, if suspected
 - ☐ Use Chlor*Rid W test kit
 - ☐ Preparation complies with specification method (i.e., NACE No. 2/ SSPC-SP10, NACE No. 3/ SSPC-SP6, etc.)
 - ☐ Check for chloride ion contaminant after cleaning with Chlor*Rid test kit
 - ☐ Determine degree of surface cleanliness by one of the following after cleaning:
 - ☐ SSPC-VIS 1, for abrasive blast cleaning
 - ☐ SSPC-VIS 3, for hand and power tool cleaning
 - ☐ NACE No. 7/ SSPC-VIS 4(I), for water jetting

- ☐ Surface profile
 - ☐ Determine surface profile by NACE RP 0287
- ☐ Environmental conditions
 - ☐ Ambient (air) temperature
 - ☐ Substrate surface temperature
 - ☐ Relative humidity
 - ☐ Dew point
 - ☐ Wind velocity, if applicable
- ☐ Coating application
 - ☐ Coating material complies with specifications
 - ☐ Mixed in accordance with manufacturer's instructions
 - ☐ Type of application method used
 - ☐ Ensure stripe coats are applied before overall application proceeds
 - ☐ Temperature and humidity restrictions
 - ☐ Air and substrate temperatures are 50 degrees F or greater or complies with the manufacturer's instructions
 - ☐ Surfaces are a minimum of 5 degrees F above dew point
 - ☐ Relative humidity within manufacturer's instructions
 - ☐ Surfaces free of moisture, frost, and ice
- ☐ Curing
 - ☐ Coated items are not moved or allowed foot traffic before dry
 - ☐ Complies with manufacturer's instructions for temperature and humidity during curing period
- ☐ Post application inspection
 - ☐ Dry film thickness by SSPC-PA2
 - ☐ Holiday testing by NACE RP 0188

Reference Standards Cited in Guide

American Society for Testing and Materials (ASTM)

ASTM A 123	Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Productions
ASTM A 153	Zinc (Hot-Dip) Coatings on Iron and Steel Hardware
ASTM A 591	Steel Sheet, Electrolytic Zinc-Cated, Light Coating Weight [Mass] Applications
ASTM A 653	Steel Sheet Zinc-Coated (Galvanized or Zinc-Iron Alloy-Coated (Galvanized) by the Hot-Dip Method
ASTM B 633	Electrodeposited Coatings of Zinc on Iron and Steel
ASTM B 695	Coatings of Zinc Mechanically Deposited on Iron and Steel
ASTM D 3359	Measuring Adhesion by Tape Test
ASTM D 4138	Field Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means
ASTM D 4285	Indicating Oil and Water in Compressed Air
ASTM D 4414	Measurement of Wet Film Thickness by Notch Gages
ASTM D 4417	Field Measurement of Surface Profile of Blast Cleaned Steel
ASTM D 4541	Pull-Off Strength of Coatings Using Portable Adhesion Testers
ASTM D 4940	Conductimetric Analysis of Water Soluble Ionic Contamination of Blasting Abrasives
ASTM D 5064	Conducting a Patch Test to Assess Coating Compatibility
ASTM D 5162	Discontinuity (Holidays) Testing of Nonconductive Protective Coating on Metallic Substrates
ASTM E 337	Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)
ASTM E 832	Laboratory Filter Papers

American Welding Society (AWS)

AWS C2.2	Recommended Practices for Metallizing with Aluminum and Zinc for Protection of Iron and Steel
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NACE International (NACE)/Society of Protective Coatings (SSPC)

NACE RP 0188	Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates
NACE RP 0287	Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape
SSPC-AB1	Mineral and Slag Abrasives
SSPC-PA2	Measurement of Dry Paint Thickness with Magnetic Gages
SSPC-SP1	Solvent Cleaning
SSPC-SP2	Hand Tool Cleaning
SSPC-SP3	Power Tool Cleaning
SSPC-SP8	Pickling
SSPC-SP15	Commercial Grade Power Tool Cleaning
SSPC-SP11	Power Tool Cleaning to Bare Metal
NACE No. 1/ SSPC-SP5	White Metal Blast Cleaning
NACE No. 2/ SSPC-SP10	Near-White Metal Blast Cleaning
NACE No. 3/ SSPC- SP6	Commercial Blast Cleaning
NACE No. 4/ SSPC-SP7	Brush-Off Blast Cleaning
NACE No.5/ SSPC-SP-12	Surface Preparation and Cleaning by High- and Ultrahigh-Pressure Water Jetting Prior to Coating
NACE No. 8/ SSPC-SP-14	Industrial Blast Cleaning
SSPC-VIS 1	Abrasive Blast Cleaned Steel (Standard Reference Photographs)
SSPC-VIS 2	Evaluating Degree of Rusting on Painted Steel Surfaces
SSPC-VIS 3	Power- and Hand-Tool Cleaned Steel (Standard Reference Photographs)
NACE No. 7/ SSPC-VIS 4	Guide and Visual Reference Photographs for Steel Cleaned by Water Jetting
NACE-VIS 9/ SSPC-VIS 5	Guide and Reference Photographs for Steel Surfaces Prepared by Wet Abrasive Blast Cleaning

Inspection Equipment

Inspection Gauges, Instruments, and Kits:

- Adhesion tester (Elcometer), destructive testing (optional)
- Blast nozzle analyzer gauge (optional)
- Calibrated shims
- Conductivity meter
- Dry film thickness gauge
- Pull-off
- Fixed or constant pressure probe
- Environmental meter for ambient and surface temperature, humidity, and dew point
- Holiday detector (optional):
 - Low voltage
 - High voltage
- Micrometer and replica tape
- Nozzle orifice gauge (optional)
- Pit gauge (optional)
- Pressure needle gauge (optional)
- Sling psychrometer
- Swab checks for lead and chromate
- Test kits, chloride ion specific (Chlor*Rid International)
- Thermometer with magnetic backing
- Tooke gauge, destructive dry film thickness instrument (optional)
- Wet film thickness gauge

Inspection Tools:

- Flashlight
- 1 to 1-1/2 inch wide stiff putty knife with sharpened edge
- Knife
- Latex gloves
- Plastic booties
- Magnet

Appendix F

Example of Inspection Daily Check Sheet

COATING DAILY INSPECTION REPORT						1 of 2
Project:				Date:		
Feature:				Report By:		
Contract No:			Paint Contractor:			
SPECIFICATIONS		Tabulation No: _____		Item to be Coated: _____		
Coating Category: _____		Total DFT (min.): _____ mils		Tab Surface Prep. Method: _____		
Coat No. _____		Material Manufacturer _____		Product Name _____		DFT Range _____
Primer:						
Intermediate:						
Topcoat:						
WEATHER		Reading Time:				
1. Substrate Temperature (degrees F):						
2. Ambient (Dry Bulb) Temp. (degrees F):						
3. Wet Bulb Temperature (degrees F):						
4. Relative Humidity (percentage):						
5. Dew Point Temperature (degrees F):						
6. Item (1) minus (2) (in degrees F):						
7. Wind (mph) and Direction:						
Comments:						
SURFACE PREPARATION		Surface Preparation Method _____ SSPC-SP _____ / NACE No. _____ Used:				
Abrasives: Manufacturer: _____ Product Name: _____ Class A, Type _____						
Contaminants (ASTM D 4940): Fines __ yes / __ no; Oil __ yes / __ no; pH _____; Conductivity _____						
Chloride Specific Ion: Test Method Used _____; Results _____						
Compressor Air: Type: _____ CFM Passes ASTM D 4285: __ yes / __ no						
Surface Profile (NACE RP 0287): No. Measurements Taken _____; Averaged Measured _____ mils						
Cleanliness: Chloride Specific Ion: Test Method Used _____; Results _____						
Visual Standards (SSPC/NACE): VIS 1 __ yes / __ no; VIS 2 __ yes / __ no; VIS 4 (I) __ yes / __ no						

COATING DAILY INSPECTION REPORT						2 of 2	
APPLICATION AND MATERIALS							
<u>Manufacturer</u>	<u>Product Name</u>	<u>Batch Number</u>	<u>Gal</u>	<u>Color</u>	<u>Thinner</u>	<u>Product</u>	<u>Gal/Oz %</u>
Environmental Control: Heaters ___ yes / ___ no; Dehumidification ___ yes / ___ no, Unit Size _____							
Material Mixing: Power Mixing Time _____ minutes; Induction Time ___ yes / ___ no, _____ minutes							
Stripe Coats Applied: ___ yes / ___ no; Method: ___ Bush/Roller ___ Spray							
Application Method: ___ Brush; ___ Roller; ___ Airless; ___ Conventional; ___ Plural; ___ Electrostatic							
Applied Within Recoat Window: Primer ___ yes / ___ no; Intermediate ___ yes / ___ no; Topcoat ___ yes / ___ no							
Wet Film Thickness (WFT): Primer _____ mils; Intermediate _____ mils; Topcoat _____ mils							
Comments:							
TESTING OF HARDENED COATING							
Dry Film Thickness (DFT) by SSPC-SP PA2:							
Area Inspected: ___ less than 300 ft ² ; ___ less than 1,000 ft ² ; ___ equal to or greater than 1,000 ft ²							
Number of 5 Spot Measurement Groups Taken Within Above Inspected Area: _____ at _____ 100 ft ² areas							
Average of 5 Spot Measurement Groups _____ mils; Conform to Specifications ___ yes / ___ no							
Discontinuity (Holiday) Testing by NACE RP 0188							
Tester Used: _____ Low Voltage (Sponge) _____ High Voltage							
Set at _____ volts; Number of Defects Found _____; Defects Repaired ___ yes / ___ no							
Comments:							

Procedure for Detecting Moisture and Oil in Compressed Air (ASTM D 4285)

A. Purpose

This test detects the presence of moisture and oil contaminants in compressed air for abrasive blasting, air blast cleaning, and coating application operations. The contaminants are detected visually.

B. Equipment

White absorbent material, filter paper, blotter paper, or cloth with a rigid backing.

C. Procedure

1. Allow the air compressor to reach operating conditions.
2. Shut off the abrasive flow.
3. Place the absorbent material within 24 inches of the discharge-point-centered air stream and downstream from the in-line oil and moisture separators.
4. Allow air to flow for 1 minute.
5. Visually check absorbent material for the presence of moisture or oil.

Any observed contaminants on the cloth or in the air flow will require corrective action. Tests should be performed at the beginning of the shift or after the air compressor has been shut off. Testing is recommended every 4 hours during blasting operations or more frequently if humidity is high.

Procedure for Detecting Chlorides and Soluble Salts in Abrasives by Conductivity Method

A. Purpose

To detect and determine the level of soluble salts in abrasives to prevent substrate deterioration and subsequent coating failure.

B. Conductivity Method

1. Equipment

- a. Electronic conductivity meter

2. Procedure

- a. Calibrate the conductivity meter according to the manufacturer's instructions.
- b. Place equal volumes of abrasive material and distilled or de-ionized water in a glass and stir for 1 minute. Let stand for 8 minutes and stir again for 1 minute. Allow the abrasive material to settle.
- c. Insert the conductivity meter probe in the water without contacting abrasive material.
- d. Allow the conductivity meter to stabilize in accordance with the manufacturer's instructions.
- e. Read and record the direct reading in microsiemens.

C. Chloride-Specific Ion Method

1. Purpose

To determine the concentration of chlorides in abrasive materials and prevent substrate contamination and subsequent coating failure.

2. Equipment

CHLOR*TEST A, Chloride Ion Test For Abrasives titration kit

3. Procedure

- a. Overfill the small container with abrasive blast material and level-off with the metal snapper included with the kit or with a straight edge.
- b. Remove the lid from the CHLOR*EXTRACT solution container and pour the leveled-off blast abrasive material into the solution.
- c. Replace the lid of the CHLOR*EXTRACT solution container and vigorously shake for 2 minutes. Allow the abrasive material to settle for about 5 minutes before proceeding. Clear solution should be visible about a ½ inch from the top surface.
- d. Hold the titration tube along the middle. Do not handle or touch the narrow ends before or after snapping them off. Handling of the titration tube narrow ends can contaminate the solution with bodily perspiration, i.e., salts, and affect the results. Snap off both ends of the titration tube and hold the tube in the solution with the blue arrowhead pointing up. Do not insert the titration tube into the abrasive material because this may plug the tube.
- e. Allow the titration tube to remain in the extracted solution until the solution has wicked-up to the top of the cotton wicket. Saturation of the wicket is complete when the cotton tip changes to an amber color.
- f. Immediately after the cotton tip has changed to an amber color, remove the titration tube from the test sleeve and read the chloride level at the interface of the pink-white color change. White indicates the presence of chloride. If no color change occurs (remains all pink), the chloride level is below the threshold detection limit of the titration kit. The chloride concentration level is read directly from the titration tube in micrograms per square centimeter or ppm.

Procedures for Detecting Chloride Ion in Water

A. Purpose

To determine the concentration of chloride ions in water used with water jetting blast cleaning or for water evaluation to prevent substrate contamination and subsequent coating failure.

B. Equipment

CHLOR*TEST W, Chloride Ion Test For Water/ Liquids titration kit

C. Procedure

1. Remove dropper assembly cap from bottle.
2. Use the dropper assembly in the bottle to transfer the water to be tested. Add about a ½ inch of water to the bottle.
3. Hold the titration tube along the middle. Do not handle or touch the narrow ends before or after snapping them off. Handling of the titration tube narrow ends can contaminate the solution with bodily perspiration (i.e.), salts, and affect the results. Snap off both ends of the titration tube and hold the tube in the solution with the blue arrowhead pointing up.
4. Allow the titration tube to remain in the extracted solution until the solution has wicked-up to the top of cotton wicket. Saturation of the wicket is complete when the cotton tip changes to an amber color.
5. Immediately after the cotton tip has changed to an amber color, remove the titration tube from the test sleeve and read the chloride level at the interface of the pink-white color change. White indicates the presence of chloride. If no color change occurs (remains all pink), the chloride level is below the threshold detection limit of the titration kit. The chloride concentration level is read directly from the titration tube in micrograms per square centimeter or ppm.

Procedures for Determining Blast Cleaning Air Pressure

A. Purpose

To measure the blast hose air pressure for assessing abrasive blast cleaning efficiency.

B. Equipment

Hypodermic needle pressure gauge, 0 to 120 pounds per square inch (psi) or more.

C. Procedure

1. Blast cleaning equipment is to be operational at the time of testing. If more than one blast hose is to be used, operate all blast hoses.
2. Insert hypodermic needle pressure gauge into the interior of the blast hose immediately in front of the blast nozzle and slant the needle at a 45 degree angle so that it is pointed in the direction the abrasives are flowing to minimize needle clogging and damage.
3. Read the blast cleaning air pressure directly from the dial gauge. Normal blast pressure is between 90 and 100 psi.
4. Pressure readings should be taken periodically or when blast cleaning efficiency decreases.

NOTE:

1. Use this test method only for abrasive blast hoses. Do not use this method on coating application hoses.
2. There is no current standard reference to determine blast pressure; ASTM D 4264 was withdrawn.

Determination of Environmental Factors

Environmental factors are determined by various instruments, and some instruments can perform multiple functions. Electronic and digital instruments are becoming increasingly more accurate, faster, more affordable, and acceptable. The instruments are not detailed below because of wide variation among instrument types and because of the variation in the way instruments are used. But, as with any instrument, always follow the manufacturer's instructions. The following sections describe the instrument and the procedures to be used to determine each environmental factor:

A. Ambient Temperature by Thermometer

1. Description of the Procedure
 - a. Determining the ambient temperature by a single direct reading with a thermometer.
2. Equipment
 - a. A thermometer or the dry bulb thermometer of a psychrometer.
3. Procedure
 - a. Ambient temperature should be taken near the surface to be coated. Locate all thermometers and instruments where they are not subject to direct sunlight, wind, construction lighting, heating or ventilation ducts, and where they are not subject to other conditions that would affect true temperature readings.
 - b. Let temperature equipment stabilize for 1 to 2 minutes if it was brought from a place where the temperature was different from the area where the equipment will be used (e.g., an air conditioned or heated room or next to someone's body).
 - c. All instruments are direct read. For electronic instruments, follow instructions and ensure that the correct mode is being used and the reading is on the desired scale, degrees F or Celsius.

B. Substrate Surface Temperature

1. Description
 - a. Determining the surface temperature of the substrate to be coated
2. Equipment
 - a. Dial thermometer with a magnetic base

3. Procedure

- a. Place the dial thermometer on the steel substrate and allow the temperature to stabilize for about 2 to 3 minutes.

C. Relative Humidity and Dew Point (ASTM E 337)

1. Description

- a. Determining relative humidity and dew point to ascertain if evaporation will occur. The substrate surface is to be at least 5 degrees F above the dew point.

2. Equipment

- a. Psychrometer, either sling or battery, and psychrometric table and charts.
- b. Electronic or digital meter (provides direct readings).

3. Procedure for Psychrometer

- a. The wick of a wet bulb psychrometer (cotton sock) should be relatively clean. Dirty wicks need to be cleaned or replaced.
- b. Saturate the wick on the wet bulb, but keep the dry bulb thermometer dry.
- c. Whirl (sling type) or operate fan (battery type) until the thermometers stabilize, about 20 to 30 seconds, and note the temperature.
- d. Repeat steps 2 and 3 without re-wetting the wick until two or more wet bulb readings are equal to the lowest temperature obtained.
- e. Record the dry (air) and wet bulb temperatures.
- f. The relative humidity is determined from the intersect of the dry and wet bulb readings on psychrometric tables or charts. Psychrometric tables and charts normally are included with the instrument.

4. Dew Point

- a. Using the psychrometric tables:
 - (1) Determine the atmospheric (barometric) pressure for your geographical location from U.S. Department of Commerce or U.S. Weather Bureau tables. The average barometric pressure at sea level is about 30 inches of mercury, and it will average less than 30 inches at higher elevations.

- (2) Determine the difference between the dry and wet bulb temperatures. The wet bulb temperature is always less than the dry bulb. The difference is commonly called the “depression of the wet bulb.”
- (3) From the tables, locate your geographic atmospheric pressure (located in table header), dry bulb temperature (row header), and depression of wet bulb (column header) and determine the corresponding dew point value. Dew point is given in degrees Fahrenheit or Celsius.

D. Wind

1. Description

- a. Determining when the wind velocity can cause in dry spray, over spray, or damage to nearby equipment, metalwork, or property.

2. Equipment

- a. Rotating vane anemometers, direct dial, or electronic (digital)

3. Procedure

- a. Place or hold the instrument in the direction of the wind and read the wind (air) velocity. Digital anemometers may require holding down a switch or button for a fixed period of time to determine the average air velocity. Follow the manufacturer's instructions.

Procedures for Detecting Chloride Salts on Prepared or Existing Surfaces

A. Purpose

To detect chloride ions and their concentration level on prepared surfaces or existing surfaces for precoating evaluation to prevent substrate contamination and subsequent coating failure.

B. Equipment

CHLOR*TEST titration kit

C. Procedure

1. Test a spot where the surface is relatively smooth. Do not pick irregular surfaces such as corrosion pits and weld spatter, and do not pick areas between depressed and raised surfaces because these surfaces may allow the solution to leak out.
2. Pour the entire contents from the solution bottle into the test sleeve.
3. Peel off the blue backing from the adhesive strip on the open end of the test sleeve and discard the backing. Remove air from the test sleeve by squeezing between fingers and thumb. Do not spill any of the solution. If solution is lost, discard the test sleeve and the remaining solution and begin with a new kit.
4. Apply the adhesive strip of the test sleeve to the test surface and firmly press the adhesive strip to ensure a proper seal. For applying the adhesive strip to horizontal surfaces, allow the solution to fill the closed end of the test sleeve and squeeze the test sleeve in the middle with index and middle fingers to prevent solution loss.
5. Massage the solution against the test surface for 2 minutes. All the solution should be exposed to the test surface during massaging to extract any chloride salts. The following procedures are recommended for the various test surface positions, so that the solution will flow towards the test surface without solution loss.
 - a. Horizontal and vertical - Lift the closed end of the test sleeve up, allowing the solution to flow towards the test surface.
 - b. Overhead - Lift the closed end of the test sleeve up, allowing the solution to flow towards the middle of the test sleeve. Then squeeze the empty portion of the test sleeve with the index and middle fingers and slide the fingers along the test sleeve, forcing the solution to the test surface.

If the solution is leaking out from the test sleeve, discard the test sleeve and the remaining solution and begin with a new kit.

6. After massaging the solution for 2 minutes, remove the test sleeve and solution from the test surface. To remove the test sleeve and retain the solution from the test surface, the following procedures are recommended for the various test surface positions:
 - a. Vertical and overhead - Lower the test sleeve, allowing the solution to flow toward the closed end of the test sleeve.
 - b. Horizontal - With the test sleeve laying flat, squeeze the solution towards the closed end of the test sleeve. Then, pinch off and lift up the test sleeve near the test surface, allowing the solution to flow towards the closed end of the test sleeve.
7. Punch out the perforated hole on the lid of the original box container lid, close the box lid, and insert the test sleeve with the solution into the hole.
8. Hold the titration tube along the middle. Do not handle or touch the narrow ends before or after snapping them off. Handling the titration tube narrow ends can contaminate the solution with bodily perspiration (i.e.), salts, and affect the results. Snap off both ends of the titration tube and hold the tube in the solution with the blue arrowhead pointing up.
9. Allow the titration tube to remain in the extracted solution until the solution has wicked-up to the top of cotton wicket. Saturation of the wicket is complete when the cotton tip changes to an amber color.
10. Immediately after the cotton tip has changed to an amber color, remove the titration tube from the test sleeve and read the chloride level at the interface of the pink-white color change. White indicates the presence of chloride. If no color change occurs (remains all pink), the chloride level is below the threshold detection limit of the titration kit. The chloride concentration level is read directly from the titration tube in micrograms per square centimeter or ppm.
11. After completing the test, clean the test surface (substrate) with acetone or alcohol to remove all adhesive strip residue.

NOTE: The presence of some salt ions and certain pH ranges can adversely affect the above chloride test results in the following ways:

- The presence of bromide, iodide, or cyanide ions can yield a higher concentration level than the actual chloride ions extracted from the test surface.
- The presence of sulphide ions can turn the cotton wick in the titration tube a brownish color rather than white and can yield a higher concentration level than the actual chloride ions extracted from the test surface.
- pH values of less than 3.5 and higher than 11 can yield a higher concentration level than the actual chloride ions extracted from the test surface.

Determining Surface Profile of Blast-Cleaned Steel Using Replica Tape (NACE RP0287 or ASTM D 4417, Method C)

A. Description

To determine the anchor pattern depth of abrasive blasted surfaces by use of a spring micrometer and replica impression tape.

B. Equipment

1. Spring micrometer
2. Replica impression tape, coarse or extra coarse

C. Procedure

1. Measurements are to be taken on a smooth, flat or curved plate that is free of surface dirt, dust, and abrasive particles that will distort results. An accurate profile cannot be made on pitted or partially coated areas.
2. Select the correct replica tape range for the specified profile depth
 - a. 0 to 2 mils, use coarse
 - b. 1.5 to 4.5 mils, use extra coarse

The replica tape has a thickness of 2 mils but will vary slightly.

3. Prepare the spring micrometer by cleaning the anvils, setting the gauge to zero, and calibrating with a shim between 1 and 4 mils. The spring micrometer should be precise to 0.3 mil.
4. Remove a single piece of replica impression tape from container and pull off the adhesive backing. The release paper (nonadhesive piece) with the circle can be discarded. The measuring paper strip has a 0.4 inch square white plastic film at the center of the adhesive back.
5. Before applying the film to the blasted surface, the thickness of the film must be subtracted from the final reading. Subtraction of the film thickness can be accomplished by one of the following methods:

- a. Measure the replica tape with the spring micrometer at the round cutout portion opposite the 0.4 inch square white plastic film and subtract the replica film thickness by one the following methods:
 - (1) Subtract the thickness from the final reading.
 - (2) Turn the dial indicator arm on the spring micrometer counter clockwise from zero the measured replica film thickness (e.g., for a measured 2.2 mils film thickness, set the dial indicator arm at 7.8). This method compensates for the replica film thickness and provides a direct reading.
- b. Nominal thickness of the replica tape is 2 mils. Instead of measuring the replica tape, it is acceptable practice to use the 2 mil nominal thickness and subtract the replica film thickness by one the following:
 - (1) Subtract the thickness from the final reading.
 - (2) Set the dial indicator arm at 8.0 (turning it counter clockwise from zero) on the spring micrometer to provide a direct reading.
6. Apply the film to the blasted surface. The adhesive backing will hold the film in place.
7. With a rounded tool (a bar plastic swizzle stick has been found to work well), rub over the round cutout portion of the replica tape with moderate pressure. The circular area of the replica tape will become darker or grayish, indicating the blasted profile has been replicated. Ensure the entire circular area has uniformly darkened.
8. Remove the replica tape and place it between the anvils of the spring micrometer (with circular area centered between the anvils). Gently release the trigger of the micrometer and take reading. Depending on the gauge setting, either zero or the measured replica tape thickness, ensure original replica tape thickness is subtracted from reading.
9. Three readings should taken in one location within about 3 inches of each other and averaged. Location readings (three averaged readings) should be taken on every 100 square feet of surface, or portion thereof, to establish consistency of the profile.
10. Retain replicated tape samples for future reference.

Procedures for Measuring Wet Film Thickness (ASTM D 4414)

A. Purpose

To determine the wet coating thickness being applied and to estimate the dry film thickness.

B. Equipment

A notch gauge is a rectangular or square-shaped plate. Each edge has two outer projections of equal height. Between the outer projections is a series of graduated notches marked in mils. Each edge of the notch gauge is calibrated for a specific mil thickness range. Typical notch gauge materials are aluminum, plastic, polished steel, and stainless steel.

NOTE: The plastic gauges are disposable and are intended for a limited number of readings. The aluminum and plastic gauges will wear down and become inaccurate with extended use.

C. Procedure

1. If possible, test a flat area. For curved surfaces, test along the longitudinal axis, not the curved axis. Test smooth areas that are free from surface irregularities such as seams or welds.
2. Select the mil thickness range along the edge of the gauge for the anticipated film thickness.
3. Test immediately after the coating is applied.
4. Firmly press the gauge into the wet coating, holding the gauge perpendicular to the substrate with the two equal outer projections resting on the substrate. Do not tilt or scrape the gauge through the wet coating.
5. Remove the gauge from the wet coating and note the shortest coated step between the notches. The wet film thickness lies between this value and the adjacent uncoated step.
6. Clean the gauge before taking the next measurement.

Wet Film Thickness Formulas and Example Calculations

A. Description

Determining the wet film thickness (WFT) to achieve a desired dry film thickness (DFT)

B. Formulas

Without Thinning the Coating Material

$$\text{WFT} = \frac{\text{DFT}}{\% \text{ Solids by Volume}}$$

Note: Percent of solids by volume is expressed in decimal form.

Example: The desired DFT is 8 mils. The coating material contains 83 percent solids by volume. Determine the WFT to achieve an 8-mil DFT.

$$\text{WFT} = \frac{8}{0.83} = 9.64 \text{ mils}$$

With Thinning the Coating Material

$$\text{WFT} = \frac{\text{DFT}}{(\% \text{ Solids by Volume}) (1 + \% \text{ by Volume of Thinners Added})}$$

Note: The percent of solids and thinners added by volume is expressed in decimal form.

Example: The specified DFT is 6 mils. The surface areas requires 5 gallons of thinned paint. The coating material contains 86 percent solids, by volume. The manufacturer's instructions state 1½ pints of thinner is added to each gallon of coating material (16 pints = 1 gallon). Determine the WFT to achieve a 6-mil DFT.

$$\text{Percent thinner added} = \frac{1.5 \text{ pints per gallon}}{16 \text{ pints per gallon}} (100) = 9.38\%$$

$$\text{expressed as decimal} = \frac{9.38}{100} = 0.09$$

$$\text{WFT} = \frac{6}{0.86} (1.09) = 7.60 \text{ mils}$$

Procedures for Dry Film Thickness Gauges (SSPC-PA2) and Example

I. Purpose

Determining the thickness of a hardened coating.

II. Equipment

The nondestructive gauges described in SSPS-PA2 are grouped into two general categories:

Type I, magnetic pull off gauge.

Type II, fixed probe or constant pressure probe gauges.

III. Type I, Magnetic Pulloff Gauge

A. Description

Type I, magnetic pull off gauges, commonly referred to as “banana” gauges, measure the coating thickness of a non-magnetic coating over a ferrous metal substrate. The gauge has an exposed magnet attached to a spring. The amount of tension applied on the spring to lift the magnet from the coated surface is directly proportional to the distance of the magnet from the ferrous surface.

B. Calibration

1. Use nonmagnetic, standard calibrated shims, commonly chrome. Plastic and mylar shims are not acceptable for calibrating pull off gauges because plastic or mylar is nonadherent and may cause the magnet within the gauge to lift prematurely.
2. Select a shim that will be in the range of the expected dry film thickness to be measured.
3. Place the shim on the prepared substrate or any clean bare steel and place the gauge on the shim.
4. Rotate the dial forward until the magnet contacts the shim.
5. Rotate the dial backward slowly and evenly until the magnet breaks contact and lifts up. A clicking sound may be heard.
6. If the reading does not agree with the shim thickness, check the magnet for cleanliness.
7. If the reading is still not in agreement with the shim thickness, the gauge is out of calibration and should be re-calibrated by the manufacturer or replaced. Follow the manufacturer’s instructions for adjustment or return the gauge to the manufacturer for factory adjustment. Do not adjust the gauge yourself.

8. The gauge is to be calibrated before use, during use, and after use to verify accuracy of readings.

C. Procedure

1. Ensure the magnet is clean.
2. Hold the calibrated gauge firmly to the coated steel surface and rotate the dial forward until the magnet contacts the coated surface.
3. Rotate the dial backward slowly and evenly until the magnet breaks contact and lifts up. A clicking sound may be heard. The following may influence readings:
 - a. Vibrations may prematurely break the magnetic contact.
 - b. Soft or tacky coatings may inhibit the lifting of the magnet.
4. Read the coating thickness on the dial that aligns with the marked line on the gauge and record the reading.

IV. Type II, Fixed Probe or Constant Pressure Probe Gauges

A. Description

The type II, fixed or constant pressure probe gauge, measures the magnetic flux associated with non-magnetic coatings applied to ferrous substrates. For reliable readings, the gauges must remain in direct contact with the coated surface until a reading is obtained. These gauges are normally faster and more accurate than the magnetic pull off gauges.

B. Calibration

1. Use nonmagnetic or plastic calibrated shim standards.
2. Select a shim that will be in the expected range of the dry film thickness to be measured.
3. Place the shim on the prepared substrate or any clean bare steel and place the gauge on the shim.
4. Place the gauge firmly against the shim and obtain a reading.
5. If the reading does not agree with the shim thickness, adjust the gauge in accordance with the manufacturer's instructions. Adjustment is normally conducted by pressing keys to adjust upward or downward until the gauge reading and the shim thickness are in agreement.

C. Procedure

1. Ensure the probe is clean.
2. Set gauge to read in desired scale, either mils or micrometers.
3. Hold the calibrated gauge firmly to the coated steel surface.

4. Read the coating thickness on the digital display. Some gauges will store several readings for downloading into printer and may be capable of averaging readings.

Example:

Specifications require the upstream face of a radial gate be coated. The gate has the dimensions of 26 feet in height along the radius curvature and is 10 feet in width. The coating tabulation specifies 2 coats of epoxy at 8 mils per coat and 1 topcoat of polyurethane at 3 mils for 19-mil DFT, minimum, for the total system.

Step 1: Determine the number of spot measurements required on an area basis.

Surface area of structure: 26 feet x 10 feet = 260 square feet

Surface area is less than 300 square feet; therefore, 5 spot measurements are required in each of two 100 square foot areas (total of 30 individual gauge readings).

Step 2: The DFT instrument is calibrated with a 20-mil shim.

Step 3: An imaginary line is drawn horizontally across the gate at the mid elevation, effectively dividing the gate into equal lower and upper areas. Five spot measurements are randomly taken in each area, consisting of three individual gauge readings within a 1.5-inch-diameter circle per spot measurement. The following are the results:

Lower Gate Area					
Gauge reading	Spot measurement (DFT in mils)				
	A	B	C	D	E
1	18.2	20.6	21.0	16.7	26.4
2	18.6	19.1	21.8	17.1	29.8
3	17.8	20.4	20.8	16.8	29.0
Average	18.2	20.0	21.2	16.9	28.4

Upper Gate Area					
Gauge reading	Spot measurement (DFT in mils)				
	A	B	C	D	E
1	22.6	20.4	18.6	19.5	29.3
2	22.1	21.7	18.3	19.9	31.0
3	21.9	21.3	19.4	19.2	30.4
Average	22.2	21.1	18.8	19.5	30.2

Step 4: Determine minimum and maximum acceptance thickness criteria.

a. The specified coating thickness is 19 mils. The allowable criteria are:

Minimum - 90 percent of specified thickness ($0.9 \times 19 \text{ mils}$) = 17.1 mils

Maximum - 150 percent of specified thickness ($1.5 \times 19 \text{ mils}$) = 28.5 mils

b. The following evaluates the results for thickness acceptance:

(1) Average spot measurements that are between the minimum specified thickness of 17.1 mils and the maximum specified thickness of 28.5 mils

(aa) Spot measurements A, B, C, and E on the lower gate area (18.2, 20.0, 21.2, and 28.4, respectively) are acceptable.

(bb) Spot measurements A, B, C, and D on the upper gate area (22.2, 21.1, 18.8, and 19.5, respectively) are acceptable.

(2) Average spot measurements that are less than the 90 percent minimum of the specified thickness of 17.1 mils at spot measurement D on the lower gate area (16.9) are not acceptable.

(3) Average spot measurements that are greater than the 150 percent maximum specified thickness of 28.5 mils at spot measurement E on the upper gate area (30.2) are not acceptable.

Step 5: From the above evaluation, the following can be concluded:

One average single spot measurement (D) on the lower gate area was less than the 90 percent minimum, and one average single spot measurement (E) on the upper gate area was greater than the 150 percent maximum. Therefore, the coating thickness does not conform to the minimum and maximum thickness requirements and is not acceptable.

However, additional gauge readings are allowed to be taken to verify previous results. Several factors could have affected the gauge readings. Possible factors include calibration, dirty surface, soft or tacky coating surface, proximity to edges or other steel masses, curvature of steel, tilting of probe, possible other nearby magnetic sources, temperature extremes, and vibrations.

Procedures for Discontinuity (Holiday) Testing (NACE RP 0188)

I. Purpose

To locate pinholes and other defects in hardened coating using low or high voltage instruments.

II. Using a Low Voltage Instrument for Coating Thicknesses of 20 Mils and Less

A. Description

A low voltage, normally between 5 and 90 volts DC, battery powered device with a wet sponge electric probe is dragged across the coated surface to locate discontinuities (pinholes) in the coating film. Should discontinuities be encountered, an electric current will flow to the steel substrate. This process will close an electrical circuit within the instrument and set off an audible or visual alarm.

B. Equipment

1. The following are two general types of low voltage holiday testers. Each uses a wet sponge probe, but they are based on different electrical principles.
 - a. Electromagnetic-sensitive or a solid state electronic relay circuit that, when discontinuity is detected, closes the circuit and produces an audible or visual alarm. Generally, this instrument can be field adjusted.
 - b. An electronic relaxation oscillator circuit measures the drop in electrical resistance between the coating and the steel substrate and produces an audible alarm when discontinuity is detected. Generally, this instrument type cannot be field adjusted.

C. Procedure

1. Ensure the coating is sufficiently dry (see chapter VIII, subsection 36, "Drying, Recoating, and Curing") before testing.
2. Test the instrument's power supply batteries for sufficient power with the battery check switch. If the batteries are low, replace or recharge the batteries.
3. Test the instrument for operational use and calibrate it in accordance with the manufacturer's instructions or NACE RP0188, sections 3.3 and 3.4, before its initial use.
4. Attach the electrical ground (negative) wire from the instrument to the steel substrate.
5. Wet the sponge probe with potable water

Note:

- a. A low-sudsing wetting agent such as that used in photographic development can be added to the potable water at a ratio of ½ fluid ounce to 1 gallon of water to increase sensitivity.
 - b. The use of detergent wetting solutions is not permitted because a bubble may form over a defect, rendering it undetectable.
6. Turn the instrument switch to the “on” position.
 7. The sponge is to be moved over the coating surface at about 1 foot per second, using a double pass over each area and applying sufficient pressure to keep the surface wet.
 8. The sponge should be kept saturated, but not dripping wet, while moving over the coating.
 9. When a discontinuity is detected, the sponge is to be turned on edge to determine the exact spot of the defect, and the spot is to be marked for repair. Use a greaseless marker that can be easily cleaned off.
 10. If wetting solutions are used, the solutions must be completely rinsed off before applying the repair coating.

III. Using High Voltage Instrument for Coating Thickness of Greater Than 20 Mils

A. Description

A high-voltage device, normally in excess of 800 volts DC, with wet sponge electric probe is passed over the coated surface to locate discontinuities (pinholes) in the coating film. Should discontinuities be encountered, the electric device will spark through the air gap at the discontinuity and produce an audible or visual alarm. A general rule-of-thumb for determining the required voltage is 100 to 125 volts per mil; however, it is best to consult the manufacturer to prevent damaging the coating.

B. Equipment

1. The following are two general types of high voltage holiday testers:
 - a. Pulse type—discharges a cycling, high-voltage pulse
 - b. Direct current—discharges continuous voltage
2. The following are general types of electrodes and probes:
 - a. Half- or full-circle spring electrodes used for pipes
 - b. Phosphor bronze brush probes
 - c. Conductive rubber strip probes

C. Procedure

1. Ensure the coating is sufficiently dry before testing. (See chapter VIII, subsection 36, “Drying, Recoating, and Curing.”)
2. If moisture is present on the coated surface, dry the surface before testing because moisture will indicate invalid discontinuities.
3. Test the instrument for operational use and calibrate it in accordance with the manufacturer’s instructions or NACE RP 0188, sections 4.5 and 4.6, before its initial use.
4. Adjust the instrument to the proper voltage setting for the coating thickness.
5. Attach the electrical ground (negative) wire from instrument to the steel substrate.
6. Turn the instrument switch to the on position.
7. Touch the probe to a bare conductive (steel) substrate to verify that it is properly grounded. Electric sparks should be seen, or an alarm signal should be activated.
8. Using a single pass, move the probe over the coated surface at a rate of about 1 foot per second.
9. When a discontinuity is detected, mark the spot for repair. Use a greaseless marker that be easily cleaned off.

Procedure for Mechanical (Pulloff) Adhesion Testing (ASTM D 4541; Annex A2)

A. Purpose

To determine the adhesive strength between a fully cured coating and the substrate.

B. Description

The adhesion tester mechanically measures the relative strength of adhesion between a coating and the substrate or between coating layers. An aluminum pull off stub (dolly) is adhesively bonded to the coating and allowed to cure. A pulling force on the bonded dolly is continuously increased until the dolly detaches or a specific force is achieved.

C. Equipment

There are several different types of pulloff adhesion testers. The type II tester, cited in ASTM D 4541, annex A.2, is the Elcometer Model 106. This model is the most commonly used. Elcometer Model 106 is available in six scale ranges. The scale most commonly used is 0 to 1,000 pounds per square inch (psi), and it is discussed below. A standard 3/4-inch-diameter aluminum dolly is used with the Elcometer Model 106.

D. Procedure

1. Select the spot where the dolly will be bonded to the coating. The selected area must be large enough to accommodate the feet of the instrument. Dollies should be located at least 2 inches from any surface obstructions and have at least 1 foot of vertical clearance to accommodate inserting the instrument in the dolly.
2. Use a suitable solvent wipe to remove surface contaminants such as dirt, dust, grease, and oil from the test spot. Wipe all moisture from surface and then solvent wipe.
3. The manufacturer recommends testing only on flat surfaces; however, curved surfaces of 24-inch radius and greater can be tested. For curved surfaces with a radius of less than 24 inches, the dolly needs to be ground down to match the existing metalwork radius. The following matches the dolly type with the surface:
 - Flat surfaces - Use standard dollies
 - Curved surfaces - Use dollies with a radius that matches the surface radius to be tested. The manufacturer will fabricate dollies for a specified radius and the following curvatures:

- Concave - outer radius (example: pipe exterior)
 - Convex - inner radius (example: pipe interior)
4. To promote adhesion of the dolly to the following surfaces, roughen the test spot area using:
 - Light sandpaper on glossy surfaces
 - Coarser sandpaper on uneven surfaces
 5. Wipe clean any grit and repeatedly solvent wipe on the test spot.
 6. Solvent clean and roughen the dolly surface using 40-60 grit sandpaper on the dolly's flat surface (tapered end).
 7. Mix the adhesive according to the instructions. The adhesive is normally an epoxy. Apply a thin, smooth layer of adhesive to the prepared test dolly surface.
 8. Place the dolly on the prepared test spot and press firmly to squeeze out excess epoxy. Do not twist the dolly.
 9. Remove any excess epoxy around the periphery of the dolly without disturbing the dolly.
 10. Allow the epoxy to fully cure. Depending on the temperature, curing time may take up to 24 hours. Follow the adhesive manufacturer's instructions.
 11. For vertical, overhead, or other surfaces, secure the dolly by taping or using the magnetic clamp that is supplied with the tester kit. Ensure that the magnetic clamp disc keeper is removed before use.

Note: Dollies applied with insufficient adhesive or not perpendicularly positioned are not acceptable and will provide erroneous results.

After the epoxy has cured, make a circular cut through the coating to the substrate around the dolly with the cutting tool that is provided with the tester kit. The cutting tool fits over the dolly. Kits are provided with a small diameter bar to assist in this operation.

12. If testing a flexible coating or substrate, place the support ring over the test dolly. Set the drag indicator (steel pin projecting through a slit on the shaft at the scale range) to zero.
13. Slip the tester support ring (claw at the bottom center of the tester) in the groove of the dolly. Ensure that the tester is perpendicular and that the 3 feet of the tester bear equally on the coated surface.

Note: Should the tester be tilted, one of the feet not be secure, or the bearing of the instrument be unequal, a shearing force may be imparted to the coating, resulting in an erroneous reading.

14. Slowly and continuously rotate the tester handwheel in a clockwise direction until the dolly is pulled free or a specified maximum tension is achieved.

15. Read the highest value attained at the bottom of the drag indicator in psi. If the dolly did not pull free, report the result as greater than the maximum capacity of the instrument (i.e., 1,000 psi for the Elcometer Model 106).
16. Always reset the drag indicator to zero after testing. Failure to reset will result in a distorted or permanently damaged helical spring.
17. Report one or a combination of the following types of failure:
 - Adhesive
 - Failure between the substrate and the first (prime) coat
 - Failure between any two coats
 - Cohesive
 - Failure or a break within any one coating layer
 - Glue
 - Adhesive failure of the adhesive glue between the dolly and the coating (coating remains intact and glue remains on either the coating or dolly)
 - Cohesive failure of the adhesive glue (glue remains on the coating and dolly)

Procedure for Hydraulic Adhesion Testing (ASTM D 4541; Annex A3)

A. Purpose

To determine the adhesive strength between a fully cured coating and the substrate.

B. Description

The adhesion tester uses a hydraulic system to measure the relative strength of adhesion between a coating and the substrate or between coating layers. A uniform tensile load is applied through a hole in the center of a pull stub using a hydraulic piston and pin. An aluminum pull off stub (dolly) is adhesively bonded to the coating and allowed to cure. A pulling force on the bonded dolly is continuously increased until the dolly detaches or a specific force is achieved. Reproducible results are achieved because the applied tensile load is consistent.

C. Equipment

The self-aligning type III tester cited in ASTM D 4541, annex A3, is the Hate Mark VII. Testers are available in the following three ranges: (1) 0 to 1,500 psi, (2) 0 to 2,250 psi, and (3) 0 to 3,000 psi.

D. Procedure

1. Select the spot where the dolly will be bonded to the coating. The selected area must be large enough to accommodate the feet of the instrument. Dollies should be located at least 2 inches from any surface obstructions and provided at least 1 foot of vertical clearance to accommodate inserting the instrument in the dolly.
2. Using a suitable solvent wipe, remove surface contaminants such as dirt, dust, grease, and oil from the test spot. Wipe all moisture from surface and then solvent wipe.
3. The manufacturer recommends testing only on flat surfaces; however, curved surfaces of 24-inch radius and greater can be tested. For curved surfaces with a radius of less than 24 inches, the dolly needs to be ground down to match the existing metalwork radius. The following matches the dolly type with the surface:
 - Flat surfaces - Use standard dollies
 - Curved surfaces - Use dollies with a radius that matches the surface radius to be tested. The manufacturer will fabricate dollies for a specified radius and the following curvatures:
 - Concave - outer radius (example: pipe exterior)
 - Convex - inner radius (example: pipe interior)

4. Clean the bonding surface of the load fixture, the Teflon plug, and the coating area to be tested with solvent.
5. Lightly sand the test area to achieve an even, smooth surface and wipe clean. Repeat the solvent wipe.
6. Insert the teflon plug into the loading fixture until the plug tip protrudes from the surface.
7. Apply a thin coat of adhesive epoxy to the bonding surface of the fixture, taking care not to get epoxy on the plug.
8. Press the loading fixture onto the coating and wipe the excess adhesive epoxy from around the periphery of the fixture.
9. Remove the teflon plug and allow the adhesive epoxy to cure in accordance with the manufacturer's instructions.
10. Connect the tester to the load fixture.
11. Ensure the gauge is set at zero.
12. Increase the pressure slowly by turning the handle clockwise until the fixture pulls free or until a specified pressure is achieved.
13. Directly read the gauge value attained in psi. If the dolly did not pull free, report the result as greater than the maximum capacity of the instrument.
14. Report one or a combination of the following types of failure:
 - Adhesive
 - Failure between the substrate and the first (prime) coat
 - Failure between any two coats
 - Cohesive
 - Failure or a break within any one coating layer
 - Glue
 - Adhesive failure of the adhesive glue between the dolly and the coating (coating remains intact and glue remains on either the coating or dolly)
 - Cohesive failure of the adhesive glue (glue remains on the coating and dolly)

Procedure for Measuring Dry Film Thickness by Destructive Means With Tooke Gauge (ASTM D 4138)

A. Purpose

To determine the dry film thickness and the number of individual coats of a coating system

B. Description

The Tooke gauge is used to cut through the hardened coating to the substrate. One side of the cut is made at a specific angle through the coating. A microscope with a graduated (reticle) scale, attached to the gauge, is used to measure the exposed coating perpendicular to the specific cut angle to determine the dry film thickness. The number of applied coats and the individual thicknesses can also be determined, provided that coating layers can be identified by color difference or by a distinctive line. This method is considered destructive because the cut made in the coating is an intentional defect, unless repaired. The Tooke gauge is most often used in evaluation of coating failures.

C. Equipment

A Tooke gauge, either aluminum or plastic body, with an illuminated 50X microscope and reticle (calibrated) scale. It includes three cutting tips and a marker pen.

D. Procedure

1. Select an area of the coating to test and draw about a 1-inch straight line with the marker pen. The mark serves as a reference line.
2. Select the proper cutting tip for the existing coating thickness to be measured. The following are the three types of cutting tips and their associated thickness ranges:
 - 10X tip: 0 to 3 mils coating thickness
 - 2X tip: 3 to 20 mils coating thickness
 - 1X tip: 20 to 50 mils coating thickness
3. After selecting the proper cutting tip, place the cutting tip and two guide studs against the coating surface, with the cutting tip just above the marked line. Align the forearm to cut across (perpendicular to) the marked line. Draw the forearm straight back with sufficient pressure to cut continuously through the coating into the substrate. Maintain the three point surface contact (cutter and 2 guide studs) to ensure a straight and vertical cut. The length of cut into the substrate needs to extend slightly beyond the marked line.

4. View the cut through the lighted 50X microscope and focus on the coating on either side of the exposed substrate. Focus and align the reticle scale perpendicular to the cut. The coating on one side of the cut will be smoother than on the opposite side of the cut. If the cutting tip was correctly positioned, the smoother side will be on the left. Always measure on the smoother side.
5. Line up the reticle scale across the cut on the smoother side and count the number of divisions for each coating layer in the total system. Begin at the exposed substrate and work towards the marker line.
6. The coating thickness is determined by the number of counted divisions on the reticle scale. The following provides the thickness for each division for each cutting tip:

Cutting tip	1 - Division represented on reticle scale
10X	0.1 mil
2X	0.5 mil
1X	1.0 mil

7. Helpful hints:
 - Where the primer is an inorganic zinc or galvanized zinc, it is difficult to distinguish the zinc from the substrate. To differentiate between steel substrate and zinc, use a 5 percent solution of copper sulfate and distilled water. The steel substrate will turn a copper color, and the zinc will turn black.
 - For dark-colored coatings, use a liquid eraser white-out instead of the felt tip marker.
 - The thickness of coating chips can be measured by viewing the cross section of the coating chip through the Tooke gauge. (Each division is equal to 1 mil.)

Procedures for SSPC-VIS 2 (2000 Revision)

A. Purpose

To evaluate the amount and distribution of rust on coated surfaces.

B. Description

This appendix provide a standard method of evaluating and qualifying the degree of rust on painted ferrous (steel or iron) surfaces using pictorial images (color and black and white photographs) with a given rust percentage and distribution. The results are reported in a rust grade scale from 10 (least rusted) to 0 (most rusted), and rust distribution is noted by S (spot rust), G (general rust), and P (pinpoint rust).

C. Procedure

1. Select an area or areas for evaluation. Area size may range from very small to very large, but should be representative of the structure type being evaluated. For complex structures, such as I-beams or channels, the entire structure can be evaluated, or the evaluation can be limited to certain portions of the structure such as flange tops, I-beam web, or edges.
2. Determine the rust distribution and the percentage of rust by the following.
 - a. Choose the rust distribution (spot, general, or pinpoint) for the selected area that most closely matches the corresponding color or black and white photograph.
 - b. Select the percentage of rust for the evaluated area that most closely matches the corresponding photograph. Rust staining or dirt with the appearance of rust is not to be included. Rust under the coating and broken blisters with apparent rust are to be included. Nonbroken blisters are to be defined by the following and included in the percentage of rust:
 - (1) Rust filled blister (determined by opening blister) is to be incorporated in the percentage of rust.
 - (2) Fluid filled blister (determined by opening blister) is not to be incorporated in the percentage of rust, but it is to be recorded separately.
 - c. Select one corresponding color photograph that best represents both the rust distribution and the percentage of rust for the evaluated area.
3. Determine the rust grade according to table 1 of the standard. For example, the rust distribution area was determined to be "spot," and the percentage of rust was "greater than 0.3 percent to 1 percent;" therefore, the rust grade is "6-S."

Procedure to Determine the Presence of Soluble Lead and Insoluble Lead Chromate in Coatings

A. Purpose

To determine whether the coating contains lead.

B. Description

The presence of lead and lead chromate pigmented coatings can be determined by a color indicator using reagents to swab over exposed coating layers. The swab test will verify only the presence of lead and chromate and will not provide quantitative results. The swab test may also detect the presence of lead chromate.

C. Equipment

Lead Check Swabs manufactured by Hybrivet Systems, Inc., PO Box 1210 Framingham, Massachusetts 01701; telephone: 800-262-5323.

D. Procedure for Detecting Water Soluble Lead Pigments (Lead Oxide or Lead Carbonate)

1. Clean and remove all dust and dirt from the test area.
2. Cut about a 1/4 inch notch through all coating layers and expose the substrate.
3. Activate the swab by crushing the glass ampules marked "A" and "B" on the swab tube.
4. With the porous fiber facing down, shake and gently squeeze the swab tube until a yellow liquid is visible on the swab tip.
5. Rub the yellowish swab tip in the exposed coating notch for 30 seconds.
6. Results
 - a. If the swab tip or the test surface turns pink or red, lead is present.
 - b. If the swab tip or the test surface does not turn pink or red, lead is not present or is below the detection range of the indicator reagent.
 - c. Lead chromate is nearly insoluble in water and will not immediately turn color. Place the swab in a plastic bag and re-examine the swab and the test area in about 18 hours. If the swab tip or the test area turned pink or red, chromate is present.

7. Negative test results should be confirmed by using the “Test Confirmation Card” that is included with the kit. The card has individual circles on one face, and each circle contains a small amount of lead.
 - a. With the used swab, squeeze a drop onto reagent within the test circle.
 - b. If pink or red appears on the circle, the negative test result is valid.
 - c. If pink or red does not appear on the circle, the negative test result is invalid, and a retest is required using a new swab and test area.
8. The swab’s reagents have a 2-minute life from the time the glass ampules are broken, and all testing should be completed within the time limit. The swab is to be used for one test area only.
9. Red bleeding versus pink- or red-colored swab
 - A red “bleeding” may occur for coatings with red pigments (the color red), which includes red lead primers, when testing. This red bleeding can mask the pink or red test results and can be misinterpreted. The manufacturer recommends that one of the following methods be used to determine if red pigments, not lead, are bleeding from the coating:
 - Crush the colorless solution in glass ampule “B” only and squeeze a drop onto the swab tip. Swab the test area. If red appears, it indicates bleeding is occurring and the presence of lead cannot be confirmed.
 - Take a cotton tip dipped in vinegar and swab the test area. If red appears, it indicates bleeding is occurring.
 - If the coating is bleeding red and lead is suspected but cannot be confirmed, the manufacturer recommends one of the following methods to confirm the presence of lead:
 - Use the solutions from ampules “A” and “B” and squeeze a couple of drops onto a new test area. Do not swab. The friction of swabbing may induce bleeding. If the solution turns pink or red, lead is present.
 - Use a sodium sulfide solution supplied separately by the manufacturer at a new test area. If the test area turns black, lead is present.

Procedure to Determine the Presence of Chromate in Coatings

A. Purpose

To determine whether the coating contains chromate.

B. Description

The presence of chromate pigmented coatings can be determined by a color indicator using reagents to swab over exposed coating layers. The swab test will verify only the presence of chromate and will not provide quantitative results.

C. Equipment

Chromate Check Swabs manufactured by Hybrivet Systems, Inc., PO Box 1210 Framingham, Massachusetts 01701; telephone: 800-262-5323.

D. Procedure for Detecting Water Soluble Lead Priments (lead or lead carbonate)

1. Clean and remove all dust and dirt from test area.
2. Cut about a 1/4 inch notch through all coating layers and expose the substrate.
3. Activate the swab by crushing the glass ampules marked "A" and "B" on the swab tube.
4. With the porous fiber facing down, shake and gently squeeze the swab tube until a clear liquid is visible on the swab tip.
5. Rub the clear solution on the tip in the exposed coating notch for 30 seconds.
6. Results
 - a. If the swab tip or the test surface turns pink or purple, chromate is present.
 - b. If the swab tip or the detection test surface does not turn pink or purple, chromate is not present or is below the range of the indicator reagent.
7. Negative test results should be confirmed by using the "Test Confirmation Card" that is included with the kit. The card has individual circles on one face, and each circle contains a small amount of chromate.
 - a. With the used swab, rub reagent within the test circle.
 - b. If pink or purple appears on the circle, the negative test result is valid.

- c. If pink or purple does not appear on the circle, the negative test result is invalid and a retest is required using a new swab and test area.
- 8. The swab's reagents have a 1-minute life from the time the glass ampules are broken, and all testing should be completed within the time limit. The swab is to be used for one test area only.

Determination of Toxic Metals in Hardened Paint

A. Objectives

1. Identify type of toxic metals that may be in the paint on existing infrastructures.
2. Determine concentration of toxic metal in the paint.
3. The results of the analysis of the existing paint are required before the paint can be removed for:
 - Predesign specification data gathering
 - Premaintenance work
 - Worker protection
 - Protection of the environment
 - Proper disposal of the old paint

B. Sampling

1. Take paint sample in about a 2- to 3-inch square
2. Make sure the sample includes the primer (primer contains most toxic metals)
3. Sample in at least three locations to verify results
4. Place the samples in separate bags and label each bag for identification
5. A suitable tool for sampling is a sharpened $\frac{1}{2}$ - to 1-inch wood chisel

C. Laboratory Testing

1. The primary metals to test for:
 - Cobalt, associated with blueish and greenish colors
 - Cadmium, associated with safety colors
 - Chromium, associated with lead chromate, zinc chromate, and safety colors lead
 - Lead
 - Zinc (defined as a toxic metal only in the State of California)
2. The secondary metals to test for:
 - Arsenic
 - Barium
 - Beryllium
 - Selenium
 - Silver
 - Vanadium

3. Request results in percent, by weight of metal, and to at least three significant digits.
4. Typical test methods are EPA 6010B, EPA 7420 (lead specific), OSHA 125G metal scan, ICP, or portable XRF instrument for lead only (requires certified operator).

D. Costs

About \$20 to \$25 for each metal tested—reduced cost for several metals.

E. Test Laboratories

- Bureau of Reclamation, Ecological Research and Investigation (D-8220); contact: Chris Holdren; telephone: (303) 445-2178
- Accredited Laboratories
 1. Association: American Industrial Hygiene Association (AIHA)
 2. Accreditation Programs:
 - Environmental Lead Laboratory Accreditation Program (ELLAP)
 - National Lead Laboratory Accreditation Program (NLLAP)
 3. Website Address: www.aiha.org (accredited laboratories are listed by city and State in table format)

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to tribes.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally sound manner in the interest of the American Public.
