COATING CONDITION SURVEYS

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ABSTRACT

A coating maintenance strategy for aging military infrastructure and utilities systems is vital for the long-term performance of the asset. Integrity maintenance plans can enhance risk mitigation and mitigate costly environmental impacts. No well-developed maintenance strategy is complete without the implementation of periodic coating inspection and assessments, collectively referred to as Coating Condition Surveys (CCS), guided by United Facilities Criteria (UFC) and United Facilities Guide Specifications (UFGS).

Regularly scheduled CCSs provide key information that not only helps owners better understand their assets, but also help engineers, specifiers, coatings applicators, and inspectors better perform their roles in corrosion mitigation. Additionally, the information provided by a CCS aids owners in making budgeting decisions for maintenance, helps designers plan for future repairs and inspections, and provides coatings contractors a clear understanding of the repairs necessary to extend the service life of an asset.

This discussion will outline methods involved in performing on-site inspections and highlight the necessity of on-site inspections in corrosion mitigation. While this discussion will focus on inspection and repair strategies for existing coatings on steel substrates, the strategies outlined can be applied to enhance maintenance strategies of all infrastructure subject to corrosion.

Key words: Coatings, Inspection, Maintenance, Protective Coatings, Corrosion Management

INTRODUCTION

Aging military infrastructure and utilities systems, encompassing everything from bridges to tanks and pipelines, are subject to ever-present environmental and operational stressors. Among these stressors is corrosion, a costly risk that threatens structural integrity and operational viability.

Coatings act as the first line of defense in protecting assets from corrosion, acting as a barrier to corrosion risk factors in the environment. To ensure the sustained performance of assets subject to corrosion, a coating maintenance strategy is imperative. This strategy is vital in asset integrity preservation and the mitigation of potentially devastating environmental and financial impacts of corrosion.

The development of a comprehensive maintenance strategy is a multifaceted endeavor, and it hinges on the implementation of periodic coating inspection and assessment protocols known collectively as Coating Condition Surveys (CCS). A well-executed CCS provides owners with the information necessary to make informed budgeting decisions, provides designers and specifiers insights for planning future repairs and inspections, and provides coating contractors clear, precise understanding of repairs required to ensure sustained coating performance.

This paper outlines the conditions and criteria used in evaluating coating condition and explores maintenance approaches, while considering the influence of risk factors in prioritizing a given work plan. While the primary focus of this discussion remains inspection and repair strategies for existing coatings on steel substrates, the discussed strategies can enhance maintenance of other infrastructure subject to corrosion.

CONDITIONS AND CRITERIA

During a CCS, visual observations, non-destructive testing, and destructive testing are performed to assess the existing coating's properties. Standard rating systems can be used to quantify the coating condition of the observed structures. The following criteria can be visually and physically assessed during the CCS:

- Environmental Conditions
- Rust Grade and Distribution
- Substrate Grade/Condition
- Chalking
- Mildew Rating and Growth Pattern
- Blistering
- Coating Thickness
- Adhesion
- Accessibility

Guidelines for assessing each criterion and condition are described in the following pages.

Service Environment Conditions
The environment in which the structure and coating system is exposed will impact the performance and longevity of a protective coating system and the corrosion rate of exposed substrates. There are two general classifications of environmental exposure: Atmospheric and Immersion. Environmental Conditions are assessed based on historical data from the local environment.

Atmospheric Environment Classifications
The International Organization for Standardization (ISO) developed a standard classification system for typical climatic environments in ISO 12944-2:2017, *Paints and varnishes -- Corrosion protection of steel structures by* protective *paint systems. Part 2: Classification of environments*[1]. Environmentally based corrosivity categories range from C1 to C5 (M or I). These classifications are described with example environments below:

Category	Example Environments
C1 – Very Low	Heated buildings, with clean atmospheres, such as schools or offices.
C2 - Low	Atmospheres with low levels of pollution, mostly rural areas. Unheated buildings where condensation may occur such as depots or sports halls.
C3 – Medium	Urban and industrial atmospheres, moderate sulfur dioxide pollution, or coastal areas with low salinity. Production rooms with high humidity and some air pollution, such as food processing plants, laundries, breweries, or dairies.
C4 – High	Industrial areas and coastal areas with moderate salinity. Chemical plants, swimming pools, coastal ships, and boatyards.
C5-I – Very High (Industrial)	Industrial areas with high humidity and aggressive atmospheres. Buildings or areas with almost permanent condensation and with high pollution.
C5-M – Very High (Marine)	Coastal and offshore areas with high salinity. Buildings or areas with almost permanent condensation and with high pollution.

Immersion Environment Considerations
The mechanisms of corrosion within a tank are more complex relative to atmospheric exposure because there are at least four different environmental exposure zones within a tank:

- Top of the tank (exposed to fuel vapors)
- Splash zone (border between the gas phase and liquid phase)
- Liquid zone (part of tank permanently in contact with the liquid fuel)
- Bottom of the tank (most exposed to contaminants water, salts, organic and inorganic deposits)

Exposed steel in each zone will have a different corrosion rate due to the different chemical exposures. The rate and type of corrosion will depend on fuel product, solubility of water and oxygen in the fuel, tank capacity, filling/evacuation frequency, and temperature. The lowest corrosion rate will be experienced where the surface is immersed in fuel in the absence of contaminants (with water or other foreign chemicals). The highest corrosion rates are at the top of the tank, which is exposed to humidity and condensation, and the bottom of the tank, where contaminants settle. If the tank is left empty, the local atmospheric corrosion rates can be assumed.

Rust Grade and Distribution
The rust grade can be determined in general accordance with ASTM D610[2], *Standard Test Method for Evaluating Degree of Rusting on Painted Surfaces*. The rating scale is based on the percentage of rust observed, with 10 having no rust and 0 completely rusted. Three different distributions of rusting are described: General, Spot, and Pinpoint rusting.

Rust Grade (ASTM D610[2])	
Grade	Description of Surface Rust
10	No rust, less than 0.01%
9	Minute rusting, less than 0.03%
8	Few isolated rust spots, less than 0.1%
7	Less than 0.3%
6	Excessive rust spots, but less than 1%
5	1% to 3%
4	3% to 10%
3	Approximately 17%
2	Approximately 33%
1	Approximately 50%
0	Approximately 100%

Substrate Condition
The substrate should be assessed prior to coating repairs if significant rust is observed. For Rust Grades between 0 and 5, the substrate condition can be classified with one of the following Substrate Condition Grades. This categorization can inform the prioritization of the repair and maintenance strategies.

Grade	Description
Light Rust	This condition involves a surface condition that does not have any significant metal loss.
Stratified Rust	This condition involves corrosion building into layers, thicker rust that is progressing towards the next phase, significant metal loss.
Pitting	This condition involves isolated or widespread deep spot corrosion (pitting).
Scale	Also known as lamellar or exfoliation corrosion. The edges of the affected area are leaf like and resemble the separated pages of a wetted book.
Section Loss	This condition involves metal loss or failure where components will require mechanical repairs and structural implications.

Chalking
Chalking can be classified in general accordance with ASTM D4214[3], *Standard Test Method for Evaluating the Degree of Chalking of Exterior Coating Films*. Chalking is the unbounded remains of the coating's pigment following degradation of the coating's binder. Degradation is caused by the coating's reaction with the environment, typically ultraviolet light and oxygen. The degree of chalking can provide

guidance on the performance of a coating system and its life cycle projection. Consideration of the degree of chalking is also important when accessing overcoating options. ASTM D4214[3] uses pictorial standards to quantify the amount of chalking present on coating films. The scale ranges from 2 to 8, with the rating 2 having the most chalking (degradation).

Mildew Rating and Growth Pattern
The mildew rating can be determined in general accordance with ASTM D3247[4], *Standard Test Method for Evaluating Degree of Surface Disfigurement of Paint Films by Fungal or Algal Growth, or Soil and Dirt Accumulation*. The rating scale is based on the percentage of fungal growth observed, with 10 having no fungal growth and 0 exhibiting complete coverage. Three different growth patterns are described: Spot Growth (S), Non-Uniform Spread (P), and Complete Coverage (G). A photographic depiction of general and spot corrosion ratings is shown below.

Mildew Growth (ASTM D3247[4])		
Rating	Percent Coverage	Description
10	0%	No Fungal Growth
9	0.03%	Trace
8	0.1%	Slight
6	0.1%	Moderate
4	10%	Pronounced
2	33%	Severe
1	50%	Complete Coverage

Blistering
Coating blistering can be assessed in general accordance with ASTM D714[5], *Standard Test Method for Evaluating Degree of Blistering of Coatings*. This test uses pictorial standards (reproduced below) to quantify both the size and density of blisters that may develop in linings on a scale of 2 to 10. The scale depicts the largest blister as being 1 inch in width (Blister Size No. 2) and the smallest blister being 1/32 of an inch in width (Blister Size No. 8).

Adhesion
Adhesion can be tested in general accordance with ASTM D3359[6], *Standard Test Method for Evaluating Adhesion by Tape Test*, ASTM D6677[7], *Standard Test Method for Evaluating Adhesion by Knife,* and ASTM D4541[8], *Pull-Off Strength of Coatings Using Portable Adhesion Tester*. Adhesion testing is used to determine the condition of coating systems for life-cycle projections and maintenance strategies. Adhesion ratings will inform work plan recommendations (i.e., overcoating vs. full removal). Adhesion ratings are directly related to the ability of the coating to withstand added stresses (such as an additional coating layer). Adhesion testing is destructive and should only be performed when necessary.

ASTM D3359[6] offers two methods depending on the coating thickness: Method A is recommended for dry film thickness greater than 5 mils and Method B is recommended for dry film thickness less than 5 mils. The test is performed by using a knife to put either an “x” cut (Method A) or a cross-cut (Method B) in the surface. Tape is then placed over the cut and removed at a specified speed and angle. The amount of coating that is removed is rated based on the table below:

ASTM D3359[6]			
Method A		Method B	
Rating	Observation	Rating	Percent Area Removed
5A	No peeling or removal	5B	0%
4A	Trace peeling or removal along incisions or their intersection	4B	< 5%
3A	Jagged removal along incisions up to 1/8” on either side	3B	5 – 15%
2A	Jagged removal along most of incisions up to 1/8” on either side	2B	15 – 35%
1A	Removal from most of the area of the X under the tape	1B	35 – 65%
0A	Removal beyond the area of the X	0B	> 65%

ASTM D6677[7] is performed by using a knife to cut an “x” in the coating surface to the substrate. A knife is then used to attempt to remove fragments of the coating, initiating at the intersection point of the “x”. Adhesion is rated based on the size of the fragments removed during this method as follows:

ASTM D6677[7]	
Rating	Description
10	Fragments no larger than 1/32" x 1/32" can be removed with difficulty
8	Chips up to 1/8" x 1/8" can be removed with difficulty
6	Chips up to 1/4" x 1/4" can be removed with slight difficulty
4	Chips larger than 1/4" x 1/4" can be removed with slight pressure
2	Once coating removal is initiated by knife, it can be peeled at least 1/4"
0	Coating can be peeled easily to length greater than 1/4"

A quantitative measurement of adhesion can be made with ASTM D4541[8]. During this test a “dolly” is glued to the surface of the coating, then pulled off at a specified rate adhesion testing equipment. At failure, the maximum load in pounds per square inch (PSI) is recorded by the machine and is the reported adhesion strength of the coating. In a survey of SSPC member paint manufacturers, minimum tolerable pull-off adhesion values of 50 to 300 psi (340 to 2040 kPa) were cited as necessary for overcoating.[9] Lenhart and El-Naggar have suggested the pull-off adhesion values of 100 to 200 psi (680 kPa to 1360 kPa) are marginal for overcoating, and that adhesion of 250 to 600 psi is acceptable for overcoating.[10] If the failure occurs between two coatings or between the primer and the substrate this is called an "adhesive" failure. If the failure occurs within one coating layer this is called "cohesive" failure. The location of failure exposes the weakest link in the coating system.

Coating Thickness

Coating thickness can be measured using SSPC-PA 2[11], *Procedure for Determining Conformance to Dry Coating Thickness Requirements* as a guide. The average, maximum, minimum, and standard deviation of each measured area should be reported. Calibration of the electronic gauge should be verified before and after each inspection using a calibrated testing block or shim.

Accessibility

The access to the structure is assessed during the CCS and is described as:

Designation	Description
Easily Accessible	Can be reached without scaffolding, a lift, or other equipment.
Moderately Accessible	Can be reached with minimal equipment (ladder).
Not Accessible	Scaffolding, lift, or other equipment may be required for access.
Adjacent to Sensitive Equipment	Precautions must be made to account for sensitive equipment.

MAINTENANCE RECOMMENDATIONS

Repair recommendations include surface preparation recommendations, coating system proposals, mechanical repair suggestions, square foot approximations, and other repair notes.

The surface preparation for maintenance coating can vary depending on a variety of factors, such as the degree of corrosion, the size of the repair needed, the substrate material, and access to the repair area.

The typical surface preparation standards may include one or more of the following methods:

- SSPC-SP 3[12]
  - *Power Tool Cleaning*
  - Power tools used to remove loose rust and coatings in localized areas on carbon steel
- SSPC-SP 10/NACE 2[13]
  - *Near-White Metal Blast Cleaning*
  - Abrasive blasting used to remove all coatings to bare carbon steel
- SSPC-SP 11[14]
  - *Power-Tool Cleaning to Bare Metal*
  - Power tools used to remove coatings from localized areas to bare carbon steel
- SSPC-SP 16[15]
  - *Brush-Off Blast Cleaning of Coated and Uncoated Galvanized Steel, Stainless Steels, and Non-Ferrous Metals*
  - Abrasive blasting used to remove non-adherent coatings from non-carbon steel substrates
- SSPC-SP 17[16]
  - *Thorough Abrasive Blast Cleaning of Non-Ferrous Metals*
  - Abrasive blasting used to remove all coatings from non-carbon steel substrates

- SSPC-SP 18[17]
  - *Thorough Spot and Sweep Blast Cleaning for Industrial Coating Maintenance*
  - Abrasive blasting used to remove non-adherent coatings from carbon steel prior to overcoating
- SSPC-SP WJ4[18]
  - *Joint Surface Preparation Standard Waterjet Cleaning of Metals – Light Cleaning*
  - Water jetting used to remove non-adherent rust and other corrosion product prior to overcoating

The general maintenance strategies for coating systems can be broken into six (6) work plan categories:

Work Plan	Typical Surface Preparation
Full Removal and Replacement	SSPC-SP 10[13], SSPC-SP 11[14]
Spot Repairs and Full Overcoat	SSPC-SP 11[14], SSPC-SP WJ4[18], SSPC-SP 18[18]
Spot Repairs	SSPC-SP 11[14]
Mildew and Fungal Growth Removal	Pressure washing or hand washing
Mechanical Repairs	NA
Monitor and Reinspect	NA

All surface preparation procedures and maintenance strategies should be developed to be specific to the coating system that is being applied. Additional surface preparation standards and techniques can be used, if recommended by the coatings manufacturer.

Full Removal and Replacement

Complete removal and replacement of the existing coating system provides the longest time interval before the next maintenance coating repair requirement. However, the extra cost of the coating removal (especially if hazardous materials are present) and surface preparation may be excessive compared to the cost of maintenance overcoating (where the existing coating system is in fair-to-good condition and the risk for overcoating is low). For this reason, the condition of the existing coating and the presence of potentially hazardous substances (i.e., lead, cadmium, and chromium), may impact the coating maintenance strategy. The corrosion morphology in failed locations (i.e., localized or uniform corrosion) must also be considered when developing a repair recommendation because spot repairs in many localized areas across the entire structure may be less cost effective than a full removal and replacement of the coating system.

The surface preparation for full removal and replacement will typically involve SSPC-SP 10[13] for carbon steel or SSPC-SP 17[16] for stainless and non-ferrous metals.

The coating procedure should utilize current manufacturer recommendations and/or applicable specifications, including the current, relevant sections of United Facilities Guide Specifications (UFGS).

Overcoating

Overcoating is often recommended when the existing coating is sound and well adhered to the surface but needs an additional layer due to thickness loss, chalking, abrasion, or other degradation. This recommendation would only be considered if the existing coating can withstand the stresses of an additional coating. The combination of poor adhesion and thick coatings will limit the existing coating’s ability to withstand the added stress of additional coat(s). If a coating is applied over weakly adhered, brittle, checked, and/or cracked coatings, the entire system will fail prematurely. On coating systems with excessive thickness, the additional stress from additional weight of overcoats can contribute to delamination. When thick existing coatings with poor adhesion are encountered, overcoating will not be a practical maintenance strategy.

Adhesion assessment is typically performed on surfaces that are candidates for overcoating, as adhesion tests can provide valuable information on the condition of the existing coating. All loose, peeling, or poorly adhered coatings should be removed prior to adhesion testing. Only the sound underlying systems should be tested to assess its ability to withstand the added stress of additional coating layers.

The surface preparation for overcoating will typically involve either SSPC-SP WJ4[18] or SSPC-SP 18[17] for carbon steel or SSPC-SP 16[15] for galvanized, stainless, and non-ferrous metals. The objective of the surface preparation is to remove all unserviceable coatings, clean any exposed steel to a near-white metal cleanliness, and uniformly roughen the remaining serviceable coating.

In some cases, rust may be present and spot repairs to bare metal may be necessary. In these cases, SSPC-SP 11[14] may be used to prepare the spot repairs, followed by SSPC-SP WJ4[18] or SSPC-SP 18[17], then the full overcoat procedure can be applied when repairs are complete. Areas adjacent to spot repair areas should be feathered as required to leave three (3) inches of each succeeding coat feathered and abraded.

After surface preparation is completed and spot repairs are made, the topcoat is applied to the entire structure. The coating repair procedure should utilize current manufacturer recommendations and/or applicable specifications, including the current, relevant sections of United Facilities Guide Specifications (UFGS).

Spot Repairs

Where economically feasible, spot repairs will extend the life of a coating by preventing small coating defects from becoming larger (undercutting). Depending on the asset size, structural complexity, containment restraints, and distribution of rusting, the cost of cleaning and coating the individual defect areas may approach (or exceed) the total cost of removal and replacement. Spot repair areas should not exceed 10 SF.

The surface preparation for spot repairs will typically require power-tooling the repair location down to bare metal in accordance with SSPC-SP 11[14]. The surrounding area should be feathered three (3) inches beyond the succeeding coat so a smooth transition can be made for each subsequent coating.
Coatings should be applied using requirements from current manufacturer recommendations and/or applicable specifications.

Mildew and Fungal Growth Removal

If mildew or fungal growth is present on the coated surface, it can lead to premature coating failure. Mildew and fungal growth must be removed prior to overcoating or other repairs. Pressure washing in combination with chemical washes can be used to remove fungal growth. Care must be taken to avoid coating damage if overcoating will not be performed. Both United Facilities Criteria (UFC) 3-190-06[19] and ASTM D3274[4] provide guidance regarding fungal growth removal.

Mechanical Repair

If damage to the substrate is observed or occurs prior to coating application, substrate repairs must be made to the substrate before coating repairs can be made.

Monitor and Reinspect

If the coating is in good or excellent condition, repair may not be necessary. In this case, the recommendation is to monitor the condition of the coating and reinspect the facility in 1 to 3 years.

PRIORITY LEVELS

Defining priority levels helps prepare a timeline for the maintenance strategy. Four typical priority levels are defined as:

Priority 1	Work required as soon as possible (less than 1 year)
Priority 2	Work required in 1-2 years
Priority 3	Work required in 2-5 years
Priority 4	Work required in 5+ years

Priorities are developed based on the expected time period that maintenance work will be required on the facilities based on the as-inspected condition of the facility. Factors that affect priority ratings include:

- Date of original application and historical repairs
- Percentage of coating breakdown
- Section loss or pitting of exposed steel substrate
- Dry film thickness
- Degree of chalking
- Adhesion
- Atmospheric environment
- Safety issues
- Underlying function of the asset to be protected
- Facility outage schedules
- Site specific issues
- Repairs being performed and nearby or adjacent components

The priorities for each facility will be owner specific, site specific, and project specific. There are many factors involved with maintenance decisions, some that are not technical. Priorities included in a CCS should be developed based on the historical and technical information to the best of the inspector's ability. All assumptions and understandings that are used to assess these priorities should be clearly stated in the CCS. Assumptions that are not described and explicitly stated can contribute to poorly established priorities and costly repair decisions.

CONCLUSION

A well-developed coating maintenance strategy, including regular CCSs and on-site inspections, is vital for preserving the integrity and longevity of military infrastructure and utilities systems. These strategies not only reduce environmental impacts and mitigate risks but also optimize maintenance budgets and ensure the continued functionality of critical assets. By implementing the principles discussed in this paper, asset owners, engineers, coatings applicators, and inspectors can contribute to the sustainability and reliability of military infrastructure and utilities systems in the face of corrosion challenges.

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