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Evaluation of Flame-Sprayed Polymer Coatings for Civil Works Navigation Structures

by
Timothy D. Race

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This report documents laboratory and field tests to evaluate the performance of flame-sprayed polymer coatings for potential use on Corps of Engineers navigation structures. Laboratory tests included salt and fresh water immersion, water resistance, atmospheric weathering, and ultraviolet (UV) condensation. Exposed test panels were evaluated for blistering, surface rust, adhesion, gloss retention, and rust undercutting. Plastic coatings were also evaluated for impact resistance. Standard Corps of Engineers coating formulations were used as experimental controls.

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Foreword

This study was conducted for Headquarters, U.S. Army Corps of Engineers under "Civil Works Investigations and Studies"; Work Unit 31205, "Developing High Performance Coatings." The technical monitors were Robert Kinsel and John Gilson, CECW-EE.

The work was performed by the Engineering and Materials Division (FM), Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Timothy D. Race. Dr. Paul Howdyshell is Chief, CECER-FM, and Dr. Michael J. O'Connor is Chief, CECER-FL. The USACERL technical editor was Thomas E. Rice, Information Management Office.

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1 Introduction

Background

Approximately 260 Federal lock and dam projects provide safe navigation along more than 21,000 miles of the nation's inland waterways (National Council on Public Works Improvement 1988). The U.S. Army Corps of Engineers (USACE) maintains and operates most of these facilities for the benefit of the public.

Locks and dams are constructed primarily of rock, concrete, and steel. The average age of these facilities exceeds 50 years, so maintenance is extremely important for ensuring their reliability. The prevention of corrosion of steel is an important aspect of the maintenance of these facilities. Materials selection, cathodic protection, and protective coatings are the mainstays of corrosion prevention. The Corps of Engineers protects many millions of square feet of steel surfaces with a number of different coating types. Corps of Engineers guide specifications CWGS-09940, *Painting: Hydraulic Structures and Appurtenant Works* (1993) and CWGS-05036, *Metallizing: Hydraulic Structures* (1992) detail the application of conventional paints and thermal-spray metallic coatings, respectively. The guides include protective coating systems designed for a variety of exposures such as fresh and salt water immersion, atmospheric weathering, and high temperature.

The industrial maintenance painting industry has experienced revolutionary changes over the past 30 years with the introduction of many new resin and pigment technologies. These changes have been driven not only by customer demand but also by environmental regulations. The Clean Air Act of 1970 required the U.S. Environmental Protection Agency (USEPA) to establish national ambient air standards for ozone and other pollutants (McKnight 1987). Atmospheric ozone is a reaction product of nitrogen oxides and volatile organic compounds (VOC). Industrial maintenance coatings are a major source of VOC emissions. The most recent amendment to the Clean Air Act (1990) gives the USEPA additional authority to establish national VOC content requirements for paints and other consumer products. A draft rule has been proposed that will limit most industrial maintenance paints to a maximum VOC content of 350 g/L (2.9 lb/gal) (Maty 1993). This limit, which will be implemented in 1996, will eliminate many of the valuable coating technologies used by the Corps and other coatings users.

In response to existing and planned regulations governing the VOC content of architectural and industrial maintenance paints, the Corps has conducted an active research program in the area of low- and zero-VOC coatings. High-solids and 100-percent solids coatings and thermal-sprayed metal coatings have been evaluated in recent studies (Baker and Beitelman 1992; Race, Hock, and

Beitelman 1990). The subject of this research, flame-spray plastic coatings, is a zero-VOC coating technology. Flame-spray plastic coatings comply with all U.S. air pollution regulations for industrial maintenance coatings. Flame spray does not produce any volatile organic compound emissions and therefore cannot contribute to ozone formation. This is a very important coating attribute, especially with the tightening restrictions on VOC emissions.

Objective

The objective of this research was to evaluate the performance and potential use of flame-spray plastic coatings on Corps of Engineers navigation structures.

Approach

Selected test coatings were applied to steel substrates using a commercially available plastic flame-spray gun. The test coatings were evaluated using laboratory tests designed to simulate a variety of exposures including salt and fresh water immersion, atmospheric weathering, and ultraviolet (UV) condensation. Test panels were evaluated for rusting, blistering, rust undercutting, gloss retention, and adhesion. Test coatings were also evaluated for resistance to impact damage. The most successful laboratory test coating was applied to approximately 150 sq ft of a Mississippi River roller gate at Lock and Dam 17 to assess its resistance to a moderately severe immersion exposure. All laboratory results were compared to the performance of standard Corps of Engineers coating systems.

2 Thermal-Spray Plastic Coatings

Background

Thermal-spray coatings are formed by thermal-induced liquification of solid materials, usually powders, wires, or rods, and subsequent deposition on a substrate where cooling and solidification occur. Materials that melt rather than decompose, including metals, ceramics, cermets, and polymers, may be thermal sprayed. Plastics may be thermal sprayed as powders by either plasma or flame spray (Kremith and Rosenbery 1967). Plasma spray uses a hot ionized gas as a thermal source, and flame spray melts the plastic feed-stock in an oxygen-fuel gas flame. Both methods employ compressed air to propel the liquified plastic to the substrate.

Polymeric powder coatings have been applied by thermal processes for many years. Powder coatings applied by electrostatic spray and fluidized beds have been widely used by equipment manufacturers. Field application of powdered plastics has been used infrequently because of the relative complexity of simultaneous application and thermal fusing of the plastic to form a coating. Improvements in equipment design and polymer feed-stocks have increased the utility of field applied thermal-spray plastic coatings.

Properties of Thermal-Spray Plastic Coatings

Thermal-spray plastic coatings are 100-percent solids materials. Their application does not result in the release of ozone-forming VOCs. Thermal-spray plastics form tough, firmly adherent barrier coatings. They cure virtually instantaneously, unlike most thermoset coatings that may require several hours or even days to be fully cured. They may also be applied at relatively low ambient temperatures, typically below freezing. Other protective coatings such as water-borne materials, epoxies, and urethanes usually require application temperatures above freezing. Because the coatings are thermoplastic they can be repaired easily by remelting or applying additional material. Thermal-spray plastics are quite resistant to damage caused by impact and abrasion. They do not become brittle at ordinary low temperature extremes and therefore may be less prone to impact damage under those conditions than other types of coatings. Thermal-spray plastic coatings can have excellent chemical resistance depending on the polymer type and specific chemical exposure. They may also have superior resistance to ultraviolet degradation.

Corps of Engineers Experience With Thermal-Spray Plastic Coatings

The earliest identified Department of Defense application of flame-sprayed plastics is detailed in MIL-F-15076A, *Flame Spray Coating, Polymer Powder* (1951). The U.S. Navy, Bureau of Ships, was the preparing activity and USACE was a custodian for the specification. The coating was intended for use on shafts, struts, rudders, and other exposed underwater surfaces. The specification details various coating properties including temperature resistance, toughness, adhesion, brittleness, tensile strength, and ultimate elongation. The coating was apparently used for relatively small components where high-performance characteristics were required.

More recently, USACERL conducted a brief evaluation of plasma-spray application equipment to determine the practicality of using Metco's 6P-H Production Thermo Spray Gun for field and laboratory application of powdered plastics (Beitelman 1975). The equipment was designed to apply powdered metals and ceramics rather than thermoplastics. A nylon polymer that was applied during the equipment evaluation was noted to be strong and had excellent adhesion to sandblasted steel. The equipment itself was considered to have limited utility at the time it was evaluated because of relatively low deposition rates. The report recommended that new developments in equipment be evaluated as they became available. Since USACERL's evaluation of the Metco equipment in 1975, new equipment has been introduced into the market. Advances in application equipment allow significantly higher deposition rates. Equipment technology has matured to the point where it is not an exclusionary or limiting factor in the use of flame-sprayed plastics.

Polymers similar to those evaluated in this study have been used by the Trans Alta Utility in Alberta, Canada, to protect steel light poles along a highway (Glass and DePoy 1992). Other uses included bridge rail panels and irrigation bridge supports, again in Alberta. The light pole application was in good condition after 3 years. The poles were exposed to very low ambient temperatures, road salt, and flying debris such as rocks. The standard epoxy coating used for this application required replacement after 4 years.

Since the initiation of this study, Navy paint specification MIL-P-24441 used in Corps paint systems 21 and 21-A-Z for salt water immersion has been reformulated to comply with the proposed 350 g/L regulated limit for industrial maintenance paints. Research is being conducted by USACERL to establish the performance characteristics of reformulated MIL-P-24441. Other VOC-compliant options for salt water immersion also exist, including paint system 6 of CWGS-09940 and metallizing systems 7-A and 8-A of CWGS-05306. Paint system 6 is a coal tar epoxy coating and 7-A and 8-A are thermal-spray aluminum coatings. For atmospheric exposures, VOC-complaint coating systems based on aluminum epoxy mastic and epoxy primer and urethane topcoat are under development by USACERL and are expected to provide in excess of 10 years of service.

3 Experimental Design

Flame-Spray Application Equipment Description

Flame-spray application unit K-400 was purchased from Plastic Flamecoat Systems, Inc.™ This is a field-portable unit consisting of a powder hopper-feeder, fuel-gas and air hoses, and a spray gun. The plastic powder is air entrained and conveyed to the gun head in a hose. Separate air atomization and fuel-gas hoses also feed to the spray gun. The entrained powder enters a propane flame at the gun head where it melts and is atomized and propelled to the substrate in a stream of compressed air. The gun head is equipped with a fuel-gas supply adjustment and an on-off powder supply control. The powder entrainment air supply is adjustable at the hopper, which also carries an on-off valve for the fuel gas. A minimum air pressure of 60 psi at 15 cu ft per minute is required.

Flame-Spray Test Substrata and Coating Application Description

Flame-spray test coatings were applied to 3 in. (7.5 cm) by 6 in. (15 cm) rectangular A36 steel test panels with a thickness of 1/2 in. (1.25 cm). Standard Corps of Engineers coatings used as experimental controls were applied to cold-rolled steel test panels measuring 3 in. (7.5 cm) by 9 in. (22.5 cm) by 1/16 in. (15 mm). Prior to coating application all test panels were solvent cleaned, dried, and abrasive blast cleaned with aluminum oxide grit in accordance with Steel Structures Painting Council SP-5, *White Metal Blast Cleaning*.

Flame-spray test coatings were applied using the K-400 unit. Substrates were preheated briefly using the gun flame. This procedure is recommended by the equipment manufacturer to assure that any latent moisture is driven from the surface. It probably also prevents the condensation of moisture present in the combustion flame. Control coatings were applied using conventional air atomization paint spray equipment. The edges of all test panels were dip-coated in a vinyl coating to prevent the occurrence of edge degradation during exposure tests.

Flame-Spray and Control Coatings

Three flame-spray plastic coatings were applied for evaluation. These were (1) ethylene-acrylic acid copolymer (EAA I), (2) ethylene-methacrylic acid copolymer (EMAA), and (3) ethylene-methacrylic acid copolymer-partial metal salt (EMAA I). Each of these materials is a copolymerization product of ethylene and a vinyl monomer. The polymers were compounded with carbon black pigment and sized monomer to make the final powdered product. The generic formulas of the

polymers are shown in Table 1. The powder supplier does not disclose the precise resin formula in the product literature; therefore, the ratio of ethylene and acrylic acid are not known. The acrylic or methacrylic acid functionality controls the adhesiveness of the polymer with the active groups forming hydrogen and ionomeric bonds with polar substrates. Particle size and molecular weight distributions are important in determining the suitability of the compounded plastic for flame spraying because they affect the heat input required to melt the powder. A wide disparity in particle size may result in the smaller particles being pyrolized or the larger ones not melting properly. Either will affect the ultimate performance of the coating.

Four coating systems were applied as controls; each is a standard system for immersion in either fresh or salt water. Their description and use are detailed in CWGS-09940, *Painting: Hydraulic Structures and Appurtenant Works*. The paint systems and specifications are identified in Table 2. Vinyl paint systems 4 and 5-E-Z are used primarily in fresh water. Both systems are very resistant to impact and abrasion, with system 5-E-Z being more corrosion resistant because of the zinc-rich primer. Epoxy-polyamide paint systems 21 and 21-A-Z are standard systems for salt water immersion but may also be used in fresh water. The epoxy paints are somewhat less impact resistant than the vinyl systems.

Table 1. Flame-spray plastics.

Product Name	Chemical Name	Formula
EAA I	Ethylene-Acrylic Acid Copolymer	$[(CH_2\text{-}CH_2)_X\text{-}\ (CH\text{-}CH\text{-}C00H)_Y]_N$
EMAA	Ethylene-Methacrylic Acid Copolymer	$[(CH_2\text{-}CH_2)_X\text{-}\ (CH_2\text{-}CCH_3\text{-}C00H)_Y]_N$
EMAA I	Ethylene-Methacrylic Acid Copolymer - Partial Metal Salt	$[(CH_2\text{-}CH_2)_X\text{-}\ (CH_2\text{-}CCH_3\text{-}C00^-M^+)_Y]_N$

Table 2. Control paint systems.

Paint System Number	Primer Specification	Topcoat Specification
4	V-766e	V-766e
5-E-Z	VZ-108d	V-766e
21	MIL-P-24441/150	MIL-P-24441/152
21-A-Z	E-303d	MIL-P-24441/152

System 21-A-Z is more corrosion resistant than system 21, again because of the inclusion of the zinc-rich primer.

Coating thicknesses were measured in accordance with ASTM D 1186, *Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base* (1987). The average dry film thicknesses of plastic coatings EAA I, EMAA, and EMAA I were 20.3 mils (508 µm), 22.3 mils (558 µm), and 17.7 mils (443 µm), respectively. Dry film thicknesses of control systems 4, 5-E-Z, 21, and 21-A-Z were 6 mils (150 µm), 4.5 mils (112 µm), 11 mils (275 µm), and 8 mils (200 µm), respectively.

Test Exposures and Evaluation Factors

Two test panels of each flame-spray plastic coating and one panel of each epoxy control system were exposed for 63 months in synthetic sea water. The synthetic sea water solution was prepared by dissolving 5 parts, by weight, of low nickel sodium chloride in 95 parts of water conforming to Type IV water in ASTM Specification D 1193, *Standard Specification for Reagent Water* (1991). The salt water solution was continuously aerated using an aquarium pump and the temperature was maintained between 70 and 80 °F (21 and 26.4 °C). Each test panel was diagonally scribed through the coating to the substrate. Panels were removed from testing and evaluated after 1, 3, 6, 12, and 63 months. Test panels were rated in accordance with ASTM Standard Method D 1654, *Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments* (1992). Panels were rated for rust undercutting at the scribe as described in Procedure A, Method 2 (Scraping) of ASTM D 1654, blistering as described in ASTM Standard Test Method D 714, *Evaluating Degree of Blistering of Paints* (1987), and adhesion as described in section 2.3.2 (b) of CWGS-09940.

Two test panels of each flame-spray plastic coating and one of each vinyl control system were exposed for 63 months in municipal tap water maintained at 55 to 65 °F (12.7 to 18.7 °C). Test panels were scribed diagonally through the coating to the substrate. Panels were evaluated after 1/2, 3, 6, 12, and 63 months. Evaluation factors were as described for salt water immersed coatings. An additional test panel for each flame-spray plastic system was impacted with a falling weight in accordance with ASTM Standard Test Method G 14, *Impact Resistance of Pipeline Coatings (Falling Weight Test)* [1988]. Each panel was impacted in four locations using four different forces. The impact forces were 10, 20, 30, and 40 in.-lb (1.13, 2.26, 4.07, and 5.42 J) The impacted plastic coatings were placed in fresh water immersion and evaluated for degradation at the impacted locations after 12 and 63 months.

One panel of each flame-spray plastic system and control systems 4 and 21 were exposed in accordance with ASTM Standard Practices D 4587, *Conducting Tests on Paint and Related Coatings and Materials Using a Fluorescent UV-Condensation Light- and Water-Exposure Apparatus* (1991) and G 53, *Operating*

Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials (1991). The test cabinet was run at 60 °C under UV conditions and at 50 °C under condensing conditions. Each cycle was 4 hours in duration. Initial 60° specular gloss and gloss after 7, 14, 28, and 56 days was measured in accordance with ASTM Standard Test Method D 523, *Specular Gloss* (1989).

Two panels of each flame-spray system were exposed in an atmospheric test rack facing 45° south at Champaign, Illinois. Specular gloss of 60° was measured prior to exposure and after 6, 12, and 63 months. Rusting and coating adhesion were determined after 63 months of exposure.

The impact resistance of each flame-spray plastic system was evaluated using a falling weight. Degree of deformation was measured at 4, 80, and 140 °F (-15.6, 4.4, and 60 °C) using a force of 20 in.-lb (2.26 J). The diameters of the deformed plastic and bare steel caused by the dropped weight were measured in millimeters.

4 Experimental Results

Salt Water Immersion

Table 3 depicts the blistering/rust, rust undercutting, and adhesion test results and composite scores for the salt water immersion exposure. Blistering and surface rusting are summed as a percentage and converted to a numerical rating as illustrated in Table 2, Rating of Unscribed Areas (Procedure B) of ASTM D 1654. Rust undercutting measurements in millimeters are converted to numerical ratings per Table 1, Rating Failure at Scribe (Procedure A) of ASTM D 1654. Qualitative adhesion results are also converted to a numerical scale of 0 to 10 (poor = 0, fair = 6, good = 8, very good = 9, excellent = 10). Intermediate adhesion values are possible and represent the numerical average of multiple measurements. The composite scores are the average of the sum of the numerical ratings for each test material at each time interval.

Fresh Water Immersion

Table 4 shows the results for the fresh water immersion tests. The numerical rating scheme used for the salt water immersion test is repeated. Table 5 summarizes the results of the impacted immersion panels. Panels were rated for adhesion near the impacted areas and for maximum rust undercutting adjacent to the impact areas. The composite score is the average of the adhesion and undercutting ratings. The numerical 0 to 10 scale is used.

Table 3. Salt water immersion: numerical ratings for rusting, undercutting, and adhesion, and composite score.

Exposure Duration	Coating Systems				
	Sys. 21	Sys. 21-A-Z	EAA I	EMAA	EMAA I
1 mo	10/10/10/10	10/10/10/10	10/10/10/10	10/10/10/10	10/10/10/10
3 mo	10/10/10/10	10/10/10/10	10/7/8.5/8.5	10/7/8/8.33	10/7/3/6.67
6 mo	10/8/10/9.33	10/10/10/10	10/7/8.5/8.5	3/7/0/3.33	9/7/3/6.33
12 mo	9/8/10/9	10/10/10/10	10/7/0/5.67	1/2/0/1	7/6/0/4.33
63 mo	7/5.5/9/7.17	10/10/9.5/9.83	4/5/0/3	4/4/0/2.67	2/1/0/1

Table 4. Fresh water immersion: numerical ratings for rusting, undercutting, and adhesion, and composite score.

Exposure Duration	Coating Systems				
	Sys. 4	Sys. 5-E-Z	EAA I	EMAA	EMAA I
1/2 mo	N/A	N/A	10/10/9/9.67	10/10/8/9.33	10/10/8/9.33
3 mo	10/10/8/9.33	10/10/10/10	10/10/9/9.67	10/9/7.5/8.83	10/10/3/7.67
6 mo	10/6/8/8	10/10/10/10	10/10/9/9.67	10/9/8.5/9.17	10/10/0/6.67
12 mo	10/6/9/8.33	10/10/10/10	10/10/9/9.67	9/9/8/8.67	9/9/7/8.33
63 mo	2/6/9/5.67	10/9/10/9.67	10/9/8.5/9.17	6.5/6/7/6.5	8/9/5.5/7.5

UV Resistance

Table 6 shows the results of the UV resistance analysis. Gloss measurements at 0, 7, 14, 28, and 56 days are recorded for each coating. The percent gloss retained for the entire 56-day exposure is shown in the last column.

Atmospheric Weathering

The results of the periodic gloss measurements on naturally exposed atmospheric test panels are shown in Table 7. The final column is the percent gloss retained after 63 months of exposure. Table 8 presents a numerical rating analysis of adhesion and rusting/blistering and the composite score after 63 months.

Impact Resistance of Flame-Spray Plastics

Table 9 shows the results of the temperature dependent impact tests on the thermal-spray plastic coatings. The results show the degree of deformation caused by a 20 in.-lb (2.26 J) impact at three temperatures. The diameter of the deformed plastic and the diameter of the exposed substrate are given in millimeters. The latter value is enclosed in parentheses.

Table 5. Impacted fresh water immersion: numerical ratings for undercutting and adhesion, and composite score.

Flame-Spray Plastic Systems		
EAA I	EMAA	EMAA I
10/8/9	7/6/6.5	10/7/8.5

Table 6. UV resistance: retained gloss.

Coating System	Days in Test					Percent Gloss Retained
	0	7	14	28	56	
EAA I	43.0	35.7	27.7	18.6	13.5	31 %
EMAA	38.7	14.2	8.5	6.1	3.0	8 %
EMAA I	44.0	30.8	23.0	17.2	10.5	24 %
4	34.5	N/A	40.9	43.0	19.1	55 %
21	31.4	N/A	11.1	2.8	2.3	7 %

Table 7. Atmospheric weathering: retained gloss.

Coating System	Months in Test				Percent Gloss Retained
	0	6	12	63	
EAA I	49.2	19.0	9.0	2.5	5 %
EMAA	37.3	5.0	3.4	0.6	2 %
EMAA I	41.0	15.6	13.5	4.2	10 %

Table 8. Atmospheric weathering: adhesion and rusting, and composite score.

Coating System	Adhesion	Rusting	Composite Score
EAA I	8.5	9	8.75
EMAA	6	9	7.5
EMAA I	7	9	8

Table 9. Impact resistance: temperature dependence.

Coating System	4°F (-15.6°C)	80°F (26.7°C)	140°F (60°C)
	Diameter of Deformation (mm)		
EAA I	5.1 (0)	6.8 (1.1)	6.9 (1.7)
EMAA	6.0 (0)	7.2 (1.5)	7.5 (1.7)
EMAA I	5.3 (0)	6.0 (1.3)	6.7 (2.6)

5 Discussion of Results

Salt Water Resistance

Flame-spray plastic systems were evaluated in a side-by-side comparison with two standard Corps of Engineers paint systems used for salt water immersion exposures. System 21 is a two coat epoxy-polyamide system developed by the U.S. Navy for use on ships. System 21-A-Z is identical to system 21 except that an epoxy zinc-rich primer is used in addition to the epoxy topcoats. The zinc-rich primer greatly improves the corrosion resistance of this coating system.

All three plastic coatings suffered severe degradation over the 63-month testing period. EAA I was marginally better than EMAA and EMAA I at each testing interval. Note in Table 3 that for the intermediate evaluations conducted at 1, 3, 6, and 12 months the rust rating is the sum of the blistering and surface rust. The final inspection is much more precise than the intermediate rust values because the value is determined after stripping away any coating that is not firmly adherent to expose the subfilm corrosion. This also provides a more accurate picture of rust undercutting at the scribe. Of the control systems, the zinc-rich primed system was in excellent condition after 63 months and the epoxy without the zinc-rich primer was in good condition.

Fresh Water Resistance

The flame-spray plastic coatings were evaluated against the performance of two Corps of Engineers vinyl paint systems. System 4 is a conventionally pigmented three-coat system and system 5-E-Z is a three-coat system that includes a zinc-rich primer.

Again, EAA I was superior to EMAA and EMAA I at each inspection interval. EMAA I was marginally better than EMAA. The condition of EAA I was very good after 63 months of testing while EMAA I and EMAA were good and fair, respectively. It is interesting to note that the adhesion of vinyl system 4, EMAA, and EMAA I declined initially and then improved somewhat. This phenomenon has been noted for nonzinc-rich vinyls in the past, although the large change noted for EMAA I between 6 and 12 months is unusual.

After 63 months of testing the condition of vinyl control system 4 was poor. Dense black subfilm corrosion and small dense blisters were observed over the entire surface. This is somewhat unusual but not unheard of for this vinyl paint system, occurring in perhaps 1 of 50 manufactured lots. Failures of this nature may be caused by solvent acidification that may occur during prolonged storage of vinyl

paints prior to application. System 5-E-Z was in excellent condition and marginally better than EAA I at the conclusion of testing.

Flame-spray plastic coatings were damaged using a falling weight and then immersed for a 63-month period in fresh water. At the conclusion of testing, the panels were examined for rust undercutting and adhesion adjacent to the impact areas. No undercutting was observed for EAA I or EMAA I although the adhesion of EAA I was better. EAA I would appear to be the least likely to experience impact-related coating failures.

UV Resistance

Exposure in a UV-condensation test cabinet is often used to predict the appearance properties and surface degradation of coatings in a controlled exposure. UV degradation can lead to coating failure in atmospheric exposures. Coatings exposed to high intensity UV for relatively short periods will begin to degrade. This degradation can be measured by monitoring the specular gloss of the coating.

Of the three flame-spray plastics, EAA I was the most resistant to UV degradation. EMAA had very poor gloss retention in this experiment and may be expected to have somewhat poor long-term resistance to atmospheric weathering.

Control systems 4 and 21 are not specifically designed to be resistant to UV-induced degradation. Epoxies coatings generally have quite poor UV resistance and experience rapid declines in gloss. They may also chalk and erode faster than other generic coating types. Not surprisingly the epoxy coating in this evaluation exhibited a rapid and extensive loss of gloss. The vinyl control exhibited the highest degree of UV resistance in terms of absolute and retained specular gloss.

Atmospheric Weathering

Flame-spray test coatings were evaluated for resistance to degradation under natural weather conditions at Champaign, Illinois. Atmospheric conditions are not severe at this location and are best classified as nonindustrial or rural. Degradation and performance were measured in terms of gloss retention, adhesion, and rusting. The gloss retention for EAA I was superior to both EMAA and EMAA I for the first 6 months of the evaluation. These results are similar in terms of retained gloss and ranking for the artificial 56-day UV-condensation exposure. EMAA I surpasses EAA I in gloss retention after 12-months exposure. All of the plastic coatings were significantly degraded after 63-months exposure. Degradation was not limited to poor gloss retention. EMAA I experienced visible surface erosion. EAA I and EMAA both experienced severe checking. EAA I was better than the other plastic coatings in terms of adhesion and rusting. Overall

EAA I was in fair to good condition at the completion of the 63-month atmospheric exposure.

Impact Resistance

Impact resistance of the three flame-sprayed plastic coatings was measured with a force of 20 in.-lb (2.26 J) at below ambient, normal, and elevated temperatures. This test was conducted to determine the degree of softening and brittleness for normal temperature extremes. At low temperatures the coatings were not brittle and were less susceptible to damage than at normal and elevated temperatures. The higher the temperature, the more the damage caused by the falling weight. EMAA I may be more prone to impact damage than EAA I and EMAA.

6 Field Application and Evaluation of Thermal-Spray Plastic Coating

After 1 year of laboratory testing, flame-spray plastic coating EAA I was noted to be superior to EMAA and EMAA I, and a field test of the coating was scheduled for Lock and Dam 17 on the Mississippi River. Approximately 22 mils (550 µm) dry film thickness of coating was applied using the same K-400 spray unit used to apply the laboratory test coatings. The test surface was a 10 by 15 ft (3 by 4.5 m) area on the downstream face of roller gate number 1. This exposure spans from just above to several feet below the normal water line. At certain times of the year the entire surface may be completely in or out of the water. The downstream face experiences moderate impact and abrasion from ice and floating debris. For this type of exposure, vinyl paint system 5-E-Z will provide adequate protection for approximately 15 to 20 years.

As was noted in laboratory tests, the performance of EAA I was only marginally inferior to vinyl paint system 5-E-Z after 12 and 63 months of fresh water immersion. From the laboratory test results, EAA I was expected to have good impact resistance in actual field exposures. Corrosion resistance and resistance to undercutting in fresh water immersion were expected to be acceptable.

EAA I flame-spray coating was inspected after 2 years of exposure at Lock and Dam 17. Rivet heads were mostly bare and moderate levels of surface rust were evident. Rivet heads are usually where the first signs of failure occur because they are difficult to coat properly and are more prone to abrasion damage in service. The condition of the flame-spray coating after 2 years was roughly equivalent to the condition of vinyl zinc-rich paint systems at similar locations after 10 to 12 years of exposure.

7 Conclusions and Recommendations

Because of their relatively poor performance in laboratory and field tests compared to standard Corps of Engineers coating systems, plastic flame-sprayed coatings are not recommended at this time.

Of the three plastic-spray plastic coatings evaluated, ethylene-acrylic acid copolymer (EAA I) was superior. It had the best performance in fresh and salt water immersion and in atmospheric weathering. However, the salt water immersion performance of EAA I was generally poor in comparison to standard Corps systems and is not recommended.

For fresh water immersion flame-spray coating EAA I performed nearly as well as the standard Corps vinyl system 5-E-Z in laboratory tests. A 2-year exposure in the field resulted in poorer results for EAA I. The projected maintenance cycle for EAA I at the field test site is estimated to be 5 years and vinyl paint system 5-E-Z would require repainting every 15 to 20 years. Vinyls have very high VOC contents, but their use on locks and dams in fresh water immersion is exempted under the proposed National Rule on VOCs in architectural and industrial maintenance coatings. If this exemption is nullified, there are other low- and zero-VOC options that could be used, including paint systems 6 and 21 and metallizing systems 5-Z-A and 6-Z-A. Neither of the paint systems is as abrasion resistant as the vinyl paint systems; however, metallizing system 6-Z-A is very resistant to impact and abrasion damage. Better VOC-compliant options exist; therefore, EAA I is not recommended for use in fresh water on Corps structures.

For atmospheric weathering, the performance of EAA I was good for the 5-year test period. The estimated maintenance cycle for this exposure is 8 to 10 years. Corps epoxy and vinyl systems will provide up to 20 to 30 years of protection in rural atmospheric exposures. Although EAA I performs adequately in atmospheric weathering, there are better low-VOC options available, and its use is not recommended.

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