"COST EFFECTIVE ALTERNATIVE METHODS FOR STEEL BRIDGE PAINT SYSTEM MAINTENANCE"

CONTRACT NO. DTFH61-97-C-00026

REPORT X:
MAINTENANCE PAINTING MATERIALS: LABORATORY EVALUATION OF FOIL TAPE COATING VERSUS MOISTURE CURED URETHANE COATINGS

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TECHNOLOGY INTRODUCTION AND EXECUTIVE SUMMARY

Corrofoil[1] is a novel coatings concept involving the application of an aluminum-based foil material to the substrate. The foil is supplied with a self-adhesive backing and is recommended for application over primed steel. A topcoat is recommended over the foil to promote aesthetics and UV durability of the system.

The tape coating was tested in a series of accelerated and outdoor exposure tests in comparison to a moisture cured polyurethane coating system. The testing included ASTM B117 salt fog, scratch adhesion, water vapor transmission, and outdoor weathering exposure at a marine exposure location. Analysis of the testing included evaluating the cost of the tape coating in comparison to traditional three-coat wet-applied coating systems in conjunction with the performance data obtained from the various tests.

Key conclusions of this comparison indicate that the tape coating provides a good barrier between the substrate and the environment, but allows more scribe cutback corrosion than the moisture cured polyurethane coating system. None of the tests conducted showed any through film degradation of the tape coating. The tape coating's ability to provide an intact film when folded over edges and crevices resulted in better performance of the tape coating at irregular surfaces than the wet-applied coating system.

The barrier properties of each coating were evaluated via water vapor transmission testing. The barrier properties of the tape coating were confirmed to be better than any of the wet-applied coatings tested.

The tape coating system is a viable option for "targeted" use on highway bridges. Because of the higher cost of the tape coating, widespread use is probably not feasible. However, the better edge coverage and better through film coverage over hand-tool prepared surfaces may make use in difficult-to-prepare areas worth evaluating.

BACKGROUND

The purpose of this testing was to evaluate novel technologies for corrosion control of bridges. The tape coating system is an alternative approach to protective coating systems. The system incorporates a foil-lined tape that is manually applied to the surface. The designers recommend that the tape be applied over an organic coating (e.g., epoxy primer) and that a finish coat be applied over the top of the tape (e.g., aliphatic polyurethane finish coating). It is claimed that this metallic tape provides a far superior barrier to protect the substrate compared to organic coating films.

CONCLUSIONS

- The tape coating system is more expensive than traditional wet-applied coating systems (material cost and labor cost). However, this cost does not appear to be

[1] Corrofoil is the trade name of the Foil Tape Coating that was tested for this report.

significant enough to deter use of the tape coating in limited, target application situations such as bridge expansion joint areas.

- The tape coating systems experienced more scribe cutback than the moisture cured polyurethane coatings tested. This corrosion was evaluated visually by identifying lifting / separation of the film at the intentional scribes.
- The moisture cured polyurethane coating system failed more readily at edges and irregular surfaces than the tape coating systems tested. The solid foil material was able to bend over edges and provide good coverage / protection of these edges.
- The tape coating systems did not show any through-film degradation in any of the tests conducted, even when applied over hand-tool cleaned surfaces.
- The water vapor transmission of the tape coating system is less than that of wet-applied organic coatings.
- The underfilm corrosion that is not visibly detectable through the tape coating was evaluated after two years of marine atmosphere exposure. Over SP-2 prepared surfaces the tape coating allowed corrosion to progress under the film. The performance over SP-6 was similar to the indications from visual examinations prior to removing the tape coating.

EXPERIMENTAL APPROACH

Corrpro performed a series of laboratory test to compare the physical properties and corrosion control performance of a foil lined tape coating to a moisture cured polyurethane coating system. Test beams, designed to simulate actual exposure conditions on rolled girder bridges, were exposed at a beachfront outdoor weathering facility.

Test Panel Design

Samples for evaluation of the tape coating included flat plates, small "T" beams, and structural "I" beams embedded in concrete to simulate a bridge deck. These three different panel shapes were used to generate data based on controlled laboratory samples as well as simulate real-world exposures.

Structural "I-beams" were embedded in concrete and inverted for exposure. These simulated a bridge deck exposure and configuration. Two (2) 36" long W 10X22 beams were pre-exposed at our beachfront weathering facility prior to use. One half of each beam was prepared to SSPC SP-2 and the other half prepared to SSPC SP-6 using Aluminum Oxide Blast media. Chlorides were measured on these surfaces. An example of the concrete embedded beams is

Figure 1. Example bridge simulation beam at the marine weathering facility (looking up at the beam).

shown in Figure 1. This semi-sheltered exposure represents an actual bridge beam with a concrete deck overhead.

Structural “T” shapes were used to test these coating systems when applied over mill scale surfaces. These were 6” deep by 12” long each. The surface finish was clean (minimal if any rusting) mill scale. Preparation prior to painting included a solvent wipe only.

Square 6” by 6” flat panels were used as a control surface. These panels were prepared to a SSPC SP-5 cleanliness. These samples represent the “best-case” surface preparation for testing of coating materials and allow for accurate comparison between various coating systems.

Coating Systems and Application

Table 1 shows the coating materials tested under this program. Application of all coatings was done in accordance with the manufacturer’s recommendations. The primer and topcoat for the tape coating systems were discussed with Russell Draper of the Corrofoil Corp. (R.J. Draper Inc.) prior to finalizing the test matrix. The epoxy applied prior to the tape coating was a multi-purpose primer/midcoat epoxy coating. The Polyurethane applied after the tape coating was a high-gloss aliphatic polyurethane commonly used as a finish coating for high-performance coating systems. The moisture cured polyurethane (MCU) system was selected based on the recent popularity, ease of application, and performance of such systems on bridges.

Table 2 outlines the surface preparations, coating systems, sample sizes, and test performed on each sample. Performance testing of the systems included accelerated marine atmosphere exposure and salt fog exposure. Physical properties testing included water vapor transmission and adhesion testing.

Table 1. Coating systems Table

System Description	Primer	Int. Coat	Topcoat
3-coat moisture cured polyurethane, bridge coating system used as a control	MC-Miozinc	MC-Ferrox B	Bridge Finish
Primer / Corrofoil / Topcoat – test of the tape with an epoxy primer and a polyurethane topcoat	BarRust 235	Corrofoil	DevThane 379
Corrofoil / Topcoat – test of the tape without a primer, but with a polyurethane topcoat	none	Corrofoil	DevThane 379
Corrofoil only – test of the tape material with no primer and no topcoat	none	Corrofoil	none

Table 2. Surface Preparations and Tests

Surface Preparation(s)	Coating System(s)	Panel Size	Test(s)
SSPC SP-5	3 coat MCU Epoxy / Foil / Polyurethane Foil / Polyurethane Foil Only	6" X 6"	Salt Fog Marine Exposure Scratch Adhesion
Clean mill scale		"T-beam"	Salt Fog Marine Exposure
SSPC Initial Condition "D" prepared to SSPC SP-2		6" X 12"	Salt Fog
SSPC Initial Condition "D" prepared to SSPC SP-2 and SSPC SP-6		36" X 10" I-beam with simulated bridge deck	Marine Exposure

Accelerated Natural Marine Exposure Testing

Natural marine exposure with daily seawater spray was conducted at a beachfront exposure facility in Sea Isle City, NJ. This site is located approximately 100 ft from mean high tide of the Atlantic Ocean and represents a severe marine exposure location. Depending on specific exposure conditions, mild steel corrodes at a rate between 5 and 20 mils per year in the first year of exposure. The site experiences wide variations in temperature (0 degrees to over 100 degrees Fahrenheit) which also increases the thermal stress to materials and the overall severity of exposure.

The two "I-beams" previously constructed and pre-weathered were prepared for testing. The beams are 32" by 10," cast in a simulated concrete bridge deck, and have stiffener angles, bolt holes, and nuts / bolts. The beams were prepared to SP-2 on one half and SP-6 on the other half. Coating systems were applied lengthwise to each beam. Mill scale covered "T" beams, SP-5 prepared panels and SP-2 prepared panels were also exposed at the marine exposure location.

Salt Fog Testing

This accelerated corrosion screening test was run in accordance with ASTM B117 and was used to gather a relative measure of the scribe cutback resistance of the foil system versus the three-coat moisture cure polyurethane coating system. In addition, the foil system's ability to cover complex shapes was observed. Samples were prepared using 6" by 6" SP-5 prepared steel, 6" by 12" SP-2 prepared steel, and "T" beams of clean mill scale.

Water Vapor Transmission Testing

The "perm cup" test was performed in accordance with ASTM D1653 – "Standard Test Method for Water Vapor Transmission of Organic Coating Films." Test method B was used, the "wet cup" method. This test was run to verify the advertised superior boundary properties of the tape coating. The data was compared to previously obtained epoxy data and data gathered on the moisture cure polyurethane coatings. The following test parameters were followed:

- All organic coating samples were applied and cured for 14 days before testing.
- The mean film thickness of each individual sample was used for the calculations.
- The test temperature averaged 74.4 degrees F.
- The test relative humidity averaged 5%RH within the desiccating chambers.

The foil system was tested without a topcoat or primer. Variations of the foil were selected to gauge the effects of "seam overlap" on water vapor transmission results. Tests were conducted with no seam in the foil, an overlap of -inch, and an overlap of ¼-inch. Data included overall water vapor transmission for each sample set and results normalized by film thickness.

Scrape Adhesion Testing

Scrape Adhesion testing was conducted to gauge the resistance of the tape coating to scraping damage compared to the control system. Testing was conducted in accordance with ASTM D2794, "Standard Test Method for Adhesion of Organic Coatings by Scrape Adhesion." The test method incorporates sliding the panel under a hardened wire stylus that exerts a consistent vertical force against the sample. Damage to the sample is correlated with the weight applied to the stylus.

RESULTS AND DISCUSSION

The following discussions are presented based on the results of our testing. Analyses included: ease of application, material and application costs, surface preparation data, marine atmosphere exposure of various samples, accelerated corrosion testing, water vapor transmission testing, and adhesion testing. Data was collected in accordance with ASTM D 610 for corrosion, ASTM D 117 for blistering, and ASTM D 1654 for scribe cutback. Graphs of pertinent data are presented in Appendix A – Graphs.

Tape Coating Application and Cost

Since the application methods for the tape coating system are different from what is normally used for liquid bridge coatings, the following comments and analysis are provided to help readers gauge the ease and cost of application of the tape coating. Analysis will focus on preparation of the smaller "flat" samples and the mock bridge beam/deck samples.

Qualitatively, the application to the small flat samples was significantly more time consuming compared to painting. The major reason for this was that each sample had to be taped individually, where the painted samples could be prepared in groups by simultaneously painting several samples at once.

The "taping" of the beams was also much more time consuming than painting. However, we do see that on an industrial sized structure, the taping speed may be greatly improved.

Some details on the application metrics follow along with a table comparing the various time and cost estimates.

The cost of our tape coating was $50.00 for approximately 30 square feet (equates to $1.67/ft^2). It was supplied in rolls approximately 3 inches wide. For comparison, the material costs for bridge coatings typically range from as low as $0.10/ft^2 for spot repair scenarios to $0.30/ft^2 for complete repainting.

It took almost three hours to tape one of our sample beams. This equates to a unit rate of approximately 3.3 ft^2/hr. This is a very slow production number, however, on an industrial scale, and with improved application equipment (larger tape width, tape dispensing and cutting equipment, back rollers to smooth tape, etc.) the application should proceed much faster. It is estimated that up to 30 ft^2/man-hour may be taped on a bridge. This estimate is based on our limited experience with the tape coating and the production obtained with similar technologies in industry (e.g. pipeline tape wraps).

The following cost analysis was constructed based on this estimated "industrial" application rate and our actual material pricing.

Table 3. Estimated Cost of Corrofoil

Factor	**Actual Result of this Study**	**Estimated for an overpass bridge**	**Comments**
ft^2 to tape	40 ft^2	15,000 ft^2	Estimated square footage for an overpass bridge (100' by 60').
Material Waste	25%	10%	In this study 40 ft^2 was covered using 53 ft^2 of Corrofoil, however, our sample pieces were small. Less waste may be generated on a production scale.
Material Cost / ft^2	$ 2.09 / ft^2	$ 1.83 / ft^2	Equals supplied cost of $ 1.67 / ft^2 considering material waste.
Application Rate	3.64 ft^2 / hour	30 ft^2 / hour	The application rate to a bridge may be an order of magnitude faster than was achieved on small samples.
Labor Hours	11 hours	500 hours	Equals square feet divided by application rate.
Labor Cost / ft^2	$ 13.75 / ft^2	$ 1.67 / ft^2	Used an estimated $ 50.00 / hour labor rate.
Overall Cost / ft^2	$ 15.84 / ft^2	$ 3.50 / ft^2	Equals material Cost / ft^2 plus Labor Cost / ft^2.
A material and labor cost of $3.50 / ft^2 for Corrofoil can be compared to a typical organic coating cost of $0.80 / ft^2 for a single coat of high performance coating.[2]			

Our estimate details a material supply and installation cost of $3.50/ft^2 for the tape coating only. The additional cost of the primer and topcoat must be considered for the complete tape coating system. These costs may make use of the tape coating system prohibitive on a full use scale but possibly within reason for targeted applications. These

[2] Assumed $0.30 / ft^2 for application labor and $0.50 / ft^2 material cost.

targeted applications may include expansion joints or areas that are difficult to clean because of environmental or physical limitations.

Sample Preparation

The tape coating was applied by hand using the manufacturer's published application guides. The most tedious and time consuming efforts were at any irregularities in the samples (stiffeners, rivets, bolts, ends/edges, connections, etc.). These areas required that the tape be cut with scissors and overlapped to allow the tape coating to lay flat on the surface. Many small "patches" of the tape coating were also required to cover these shaped surfaces.

The MCU control system, epoxy primer, and polyurethane finish coatings were all applied via conventional air spray. Graph 1 shows the average thickness of all systems. Notice the relatively large thickness of the tape coating. The tape coating data sheets advertised a thickness of approximately 6 mils, while our micrometer measurements averaged approximately 8.5 mils.

Chloride Data

Chlorides in high amounts have been demonstrated as detrimental to organic coating systems. The effect of applying the foil/barrier system over chloride contaminated steel was part of the overall evaluation. The pre-exposed beam samples were tested for surface chloride levels using the Bresle testing method. These results are in Table 4. All numbers are ranges (in accordance with the test method) and were obtained after surface preparation of the samples (just prior to coating application).

Table 4. Chloride Data Versus Surface Preparation

Surface Preparation	SSPC initial surface condition "D" cleaned to SSPC SP-2 using a wire brush	SSPC initial surface condition "D" cleaned to SSPC SP-6 using virgin Aluminum Oxide	SSPC initial surface condition "A" (clean mill scale / solvent wiped)	SSPC initial surface condition "A" cleaned to SSPC SP-5 using virgin Aluminum Oxide
Detected Chlorides ($\mu g/cm^2$)	60-70 60-70 40-50	20-30 10-20 20-30	<2	<2

Potentially detrimental levels of chloride were detected on the SP-2 prepared surfaces.[3] The SP-2 prepared surfaces with the control coating system later showed rust through the coating and small sized blisters. The SP-6 prepared samples tested in the 10 to 30 $\mu g/cm^2$ range. This is within the threshold range of acceptance for atmospheric exposures of some industrial coatings. Little chloride related failure (blistering, rust bleed, etc.) of the control system was seen upon accelerated marine atmosphere exposure.

[3] "Effect of Surface Contaminants on Coating Life," Federal highway Administration Report No. FHWA-RD-91-0011, November 1991

Marine Atmosphere Exposure

Samples were exposed with daily application of natural seawater to simulate an aggressively corrosive environment (potentially similar to conditions beneath a leaking bridge expansion joint in a geographical area where deicing salts are utilized). Data was collected via visual inspections at one month, three months, six months, and one year's exposure time. The "I-beam" samples remained under exposure for a two-year duration prior to a destructive evaluation. Data included ASTM D610 corrosion ratings, ASTM D714 Blistering ratings, visual scribe undercutting, and percentage of edges corroding. Individual data was collected on both horizontal and vertical surfaces of the test beams.

The ASTM D610 corrosion ratings quantify the degree of visible corrosion over an intact area of the coating (i.e., away from edges scribes, bolts, etc.). The tape coating systems showed zero through film degradation after a 1-year exposure regardless of the use of organic primers and/or topcoats. No pinpoint rusting or blistering was observed on the undisturbed foil coatings. The control system showed through film defects over the SP-2 prepared surfaces starting with the 3-month inspection. After one year of exposure, there was some visible rusting on all beam sections with the MCU control system (SP-2 and SP-6 preparations).

The tape/foil material controlled corrosion at and near irregular surfaces much better than the organic control system. Graph 2 shows the time degradation relation between corrosion at bolts, edges, seams, and holes in the test beams for each coating system. Notice that the tape coating systems are all grouped together, showing approximately 10% of the irregular surfaces with corrosion.

The scribe cutback resistance of the various coating system and surface preparation combinations are graphed by surface preparation in Graph 3. This plot shows better resistance to scribe cutback for the abrasive blasted surface preparations compared to the hand-tool cleaning and the mill scale preparations. When the scribe cutback resistance of the individual coating systems are compared with each other, the control coating shows better performance than the tape coating systems over an SP-6 surface. Graphs 4 and 5 show these comparisons over the SP-2 and the SP-6 surfaces respectively.

Figure 2. End of test beam showing MCU system on left and Corrofoil on right.

Figure 2 shows the end portion of the test beam prepared to SSPC SP-6. The tape coating system with a primer and topcoat is on the right side of the beam and the 3-coat MCU system is on the left side of the beam. There is staining at the seams in the tape coating system and rusting at the edge of the beam for the MCU system. The tape coating's ability to cover irregular surfaces is demonstrated by the condition of the bolt head on the MCU side and the nut/washer on the tape coating side.

When the "I-beam" samples were destructively evaluated after two-year's exposure, the results were best correlated with the original surface preparation. Beams sections prepared to SP-6 displayed destructive cutback results very similar in extent to the visual indications of scribe cutback. Once the tape coating was removed from the SP-2 prepared beam sections, the surface appeared completely corroded. Taking into consideration that an SP-2 prepared surface is partially corroded to start, the extent of the corrosion was difficult to gauge, but nevertheless had progressed to a certain degree. This observation seems logical considering that the organic coating system applied over SP-2 was showing pinpoint corrosion. The corrosion beneath the tape coating remained undetectable until the destructive evaluation.

Figures 3 and 4 show photographs of an MCU coated beam section and a beam section with the tape coating system. The bolt holes and edges of the MCU beam are showing some rusting, but the scribe cutback for this coating was less than that of the tape coating system (also see Graphs 4 and 5). The tape coating did, however provide a more aesthetically acceptable surface by hindering the appearance of corrosion at many edges and irregular surfaces. Corrosion products were limited to staining that originated from the seams in the tape coating.

Figure 3. Test beam section coated with a 3-coat MCU system.

Figure 4. Test beam section coated with epoxy primer, Corrofoil, and a polyurethane topcoat.

Salt Fog Exposure

The accelerated exposures simulated by the salt fog test provided a comparison of the scribe cutback resistance between coating systems. The tape coating systems and the MCU control system allowed zero blistering (unrelated to the scribe) and zero through-film rusting. The results presented in Graphs 6, 7, and 8 are for visual scribe cutback of the coating systems.

In all cases, the resistance to scribe cutback of the MCU system was better than any of the tape coating systems. Adding a primer and/or topcoat to the tape coating system did little to affect the cutback results. The surface preparation also did not affect the cutback results for the tape coating systems.

Water Vapor Transmission

This testing was conducted to compare the barrier properties of the various coatings. The data clearly shows that intact tape coating is a superior vapor barrier compared to the organic coatings tested.

Graph 9 shows the results plotted on a logarithmic scale. All of the individual coatings are compared by the actual water vapor transmission for each sample. The results are also normalized based on sample thickness. The first three groups of data attempt to differentiate the effects of "overlap" distance on the vapor transmission performance of the tape coating system. Overlaps of the tape seams included none, -inch, and ¼-inch. The manufacturer of the tape coating recommends a ¼-inch overlap. These results indicate that as long as the seal is visually acceptable, the water vapor transmission properties are minimally effected by overlap distance. This indicates that the practical aspects of choosing the seam overlap may outweigh the performance attributes.

The water vapor transmission data is grouped according to film chemistries. The MCU and acrylic show the highest water vapor transmission. The epoxy and polyurethane coatings were in the middle and the tape coating showed the lowest water vapor transmission of the films tested.

Adhesion Testing

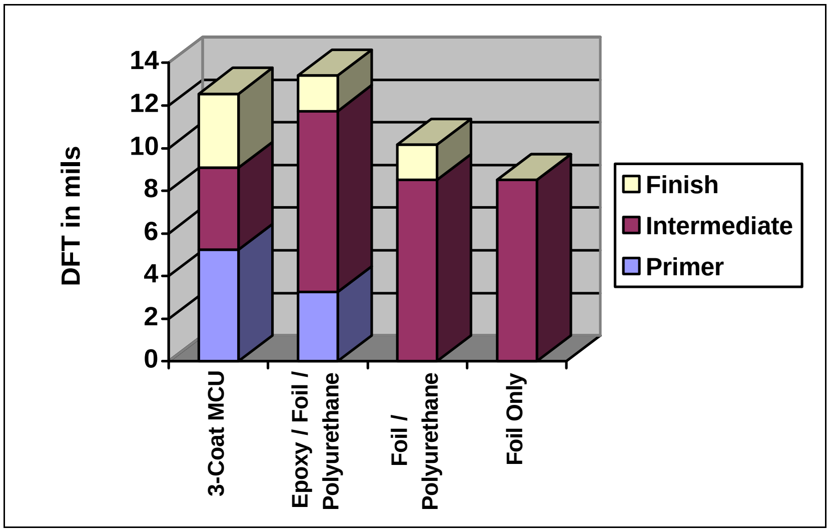
The peel adhesion and tensile adhesion of the tape coating material is qualitatively minimal compared to organic coatings. The tape coating's adhesion properties are also highly dependent upon the surface the tape is applied over. To attempt a quantification of the tape coating's toughness, the scratch adhesion test was performed.

Figure 5. Example test results – Corrofoil after scratch adhesion testing.

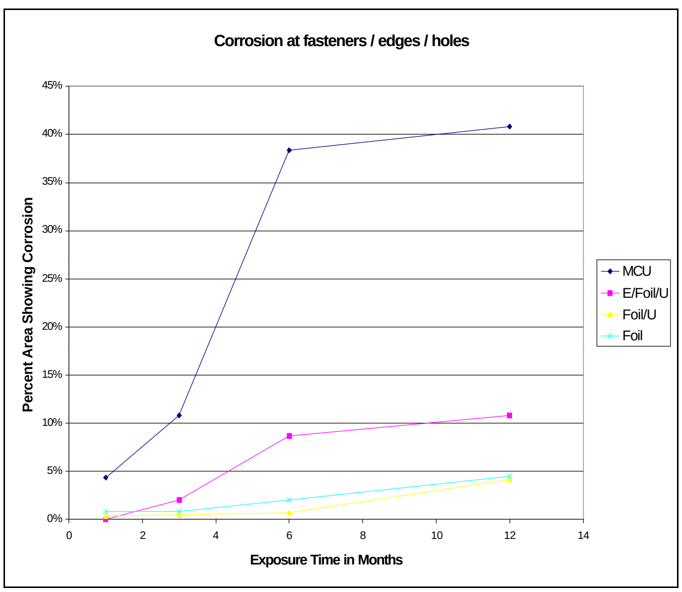
The failure mode of the tape system in the scratch adhesion test was not amenable to reliable data interpretation. The foil tended to tear and cause the stylus to skip along the panel during this test. Figure 5 shows an example panel with the tape coating system.

When evaluating organic coatings the stylus gouges the coating film allowing more consistent interpretation of the results. Qualitatively, the physical toughness of the tape coating is best away from edges and/or seams in the material and superior to that of organic barrier coatings. However, the susceptibility of seams and/or edges in the tape coating to tearing and damage must be considered.

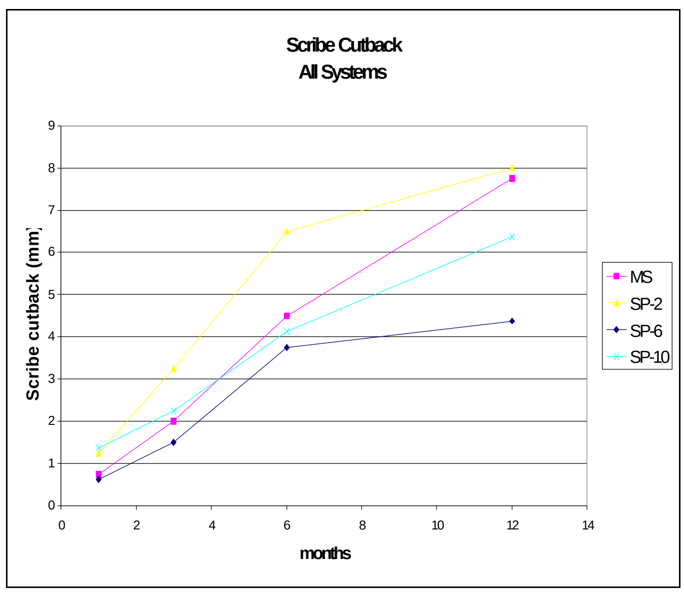
APPENDIX A
GRAPHS



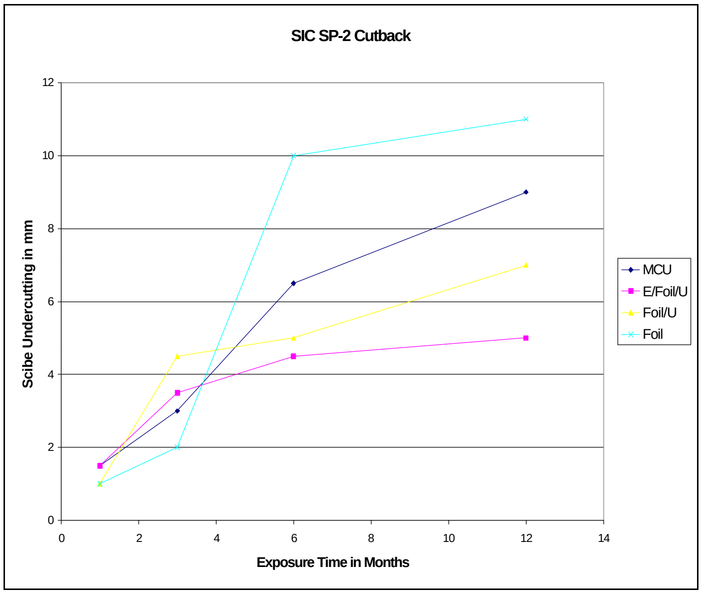
GRAPH 1. FILM THICKNESS AVERAGES OF THE COATING SYSTEMS TESTED.



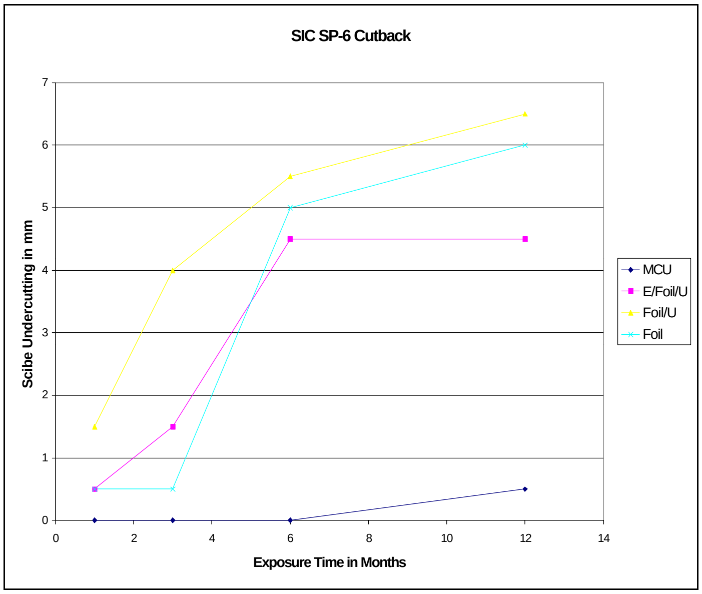
GRAPH 2. COMPARISON OF CORROSION AT IRREGULAR SURFACES FOR THE TEST BEAMS UNDER MARINE ATMOSPHERE EXPOSURE.



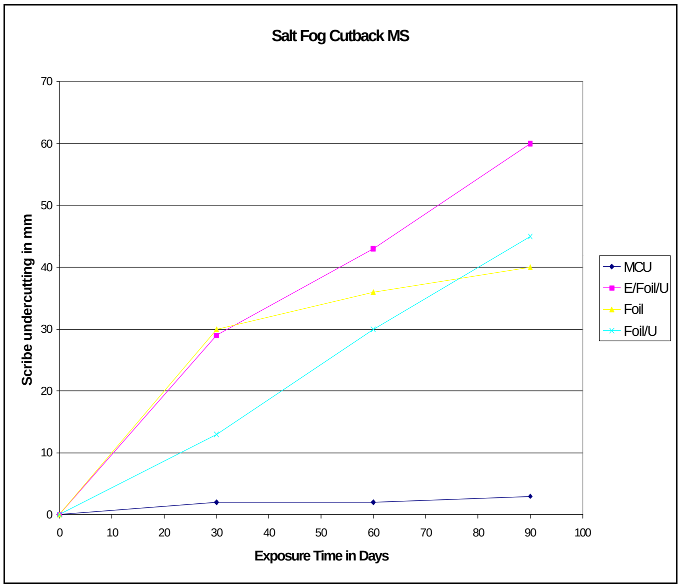
GRAPH 3. COMPARISON OF SCRIBE CUTBACK RESULTS SORTED BY COATING SYSTEM FOR THE TEST BEAMS UNDER MARINE ATMOSPHERE EXPOSURE.



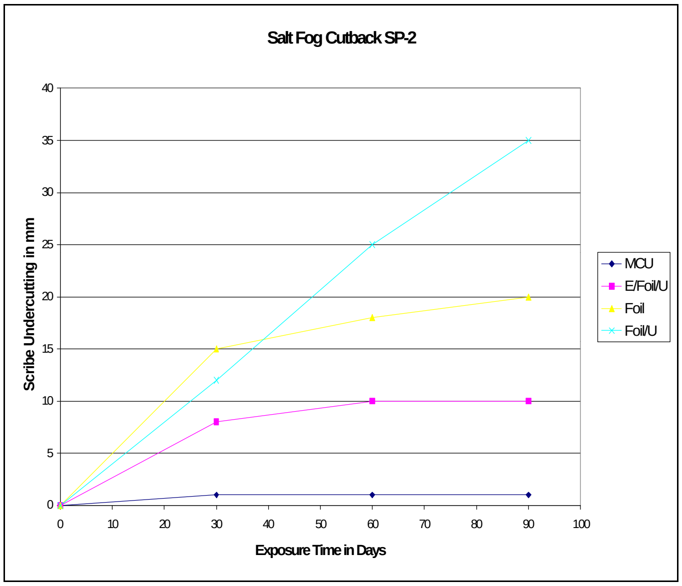
GRAPH 4. COMPARISON OF SCRIBE CUTBACK RESULTS OVER AN SP-2 SURFACE FOR THE TEST BEAMS UNDER MARINE ATMOSPHERE EXPOSURE.



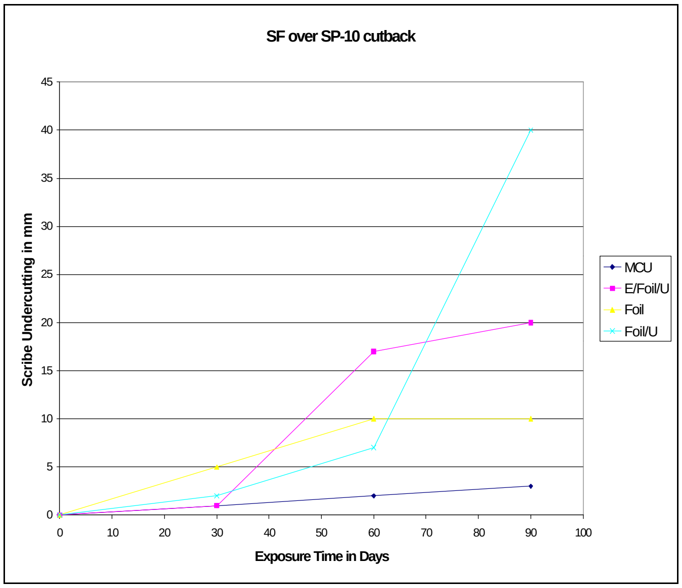
GRAPH 5. COMPARISON OF SCRIBE CUTBACK RESULTS OVER AN SP-6 SURFACE FOR THE TEST BEAMS UNDER MARINE ATMOSPHERE EXPOSURE.



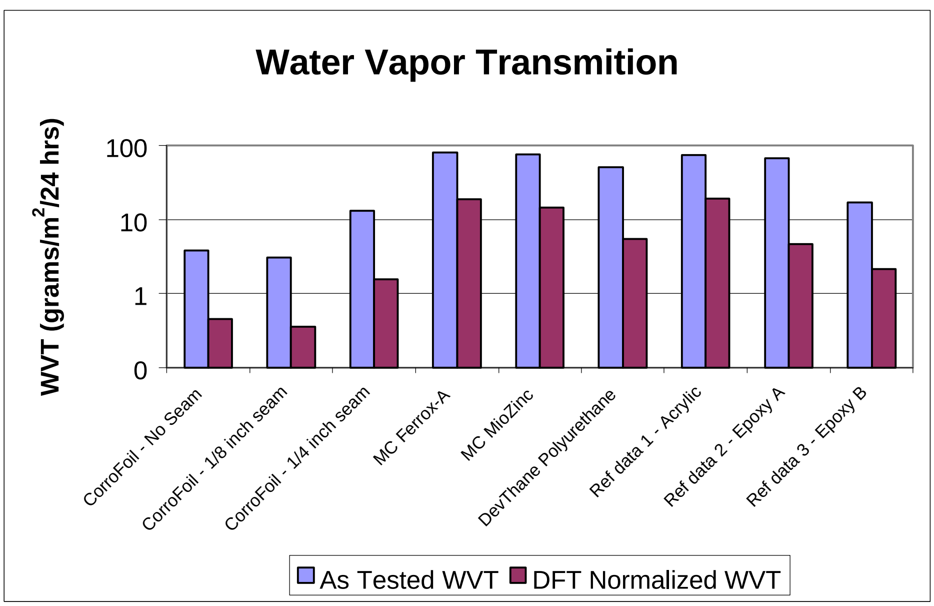
GRAPH 6. COMPARISON OF SCRIBE CUTBACK RESULTS OVER A MILL SCALE SURFACE FOR THE SALT FOG TEST.



GRAPH 7. COMPARISON OF SCRIBE CUTBACK RESULTS OVER AN SP-2 SURFACE FOR THE SALT FOG TEST.



GRAPH 8. COMPARISON OF SCRIBE CUTBACK RESULTS OVER AN SP-10 SURFACE FOR THE SALT FOG TEST.



GRAPH 9. COMPARISON OF WATER VAPOR TRANSMISSION RESULTS FOR VARIOUS COATING FILMS.