EVALUATION OF STRUCTURAL STEEL COATINGS USING LABORATORY METHODOLOGY

Final Report
April 1998

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16 . ABSTRACT

Five structural steel coating systems (Wasser, Carboline, Valspar, Watson and Superior) were selected for evaluation and sent to Corrosion Control Consultants & Labs, Incorporated (CCCL) to be tested. In addition to the laboratory tests, three of the coating systems were applied to structural steel in the field. A visual inspection of the coating system was made and the results were recorded. After reviewing and analyzing the results of the CCCL tests and the visual inspection, a cost analysis was performed as well as a survey of the tests and criteria that other transportation agencies use to certify and accept coating systems.

The analysis revealed that four of the seven evaluation procedures, Salt Fog, Envirotest, Taber Abrasion and Fluorescent UV, yielded useful and informative results. By eliminating three of the tests used for evaluation, Relative Humidity, Prohesion testing and visual inspection, and reducing the time that each test was performed from five thousand hours to two thousand hours, the cost of evaluating each coating system was also reduced.

Laboratory testing was recommended to create a performance-based specification for accepting coating systems for use on bridge structural steel. In order to obtain an equitable and balanced evaluation of how each coating system performs, it was recommended that the results of each test be evaluated using a weighted rating system. A weighted rating system using the four tests selected gave the best results that can be obtained in the least amount of time and at the lowest cost. The tests used will be assigned weights as follows: Salt Fog (20%), Envirotest (30%), Taber Abrasion (25%) and Fluorescent UV (25%). Coating systems that receive a total rating of at least 85% will be considered acceptable. In this evaluation, the Carboline and Valspar systems passed these criteria with a rating greater than 85%.

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SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.40	millimeters	mm
ft	feet	0.3048	meters	m
yd	yards	0.9144	meters	m
mi	miles	1.609	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.0929	square meters	m^2
yd^2	square yards	0.8361	square meters	m^2
ac	acres	0.4047	hectacres	ha
mi^2	square miles	2.590	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallon	3.785	liters	L
ft^3	cubic feet	0.0283	cubic meters	m^3
yd^3	cubic yards	0.7645	cubic meters	m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.4536	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.448	Newtons	N
lbf/in^2	poundforce per square inch	6.895	kilopascals	kPa

Approximate Conversions from SI Units

Symbol	When you know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.0394	inches	in
m	meters	3.281	feet	ft
m	meters	1.094	yards	yds
km	kilometers	0.6214	miles	mi
		AREA		
mm^2	square millimeters	0.00155	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.196	square yards	yd^2
ha	hectacres	2.471	acres	ac
km^2	square kilometers	0.3861	square miles	mi^2
		VOLUME		
mL	milliliters	0.0338	fluid ounces	fl oz
L	liters	0.2642	gallon	gal
m^3	cubic meters	35.315	cubic feet	ft^3
m^3	cubic meters	1.308	cubic yards	yd^3
		MASS		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.1023	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	degrees Fahrenheit	9/5(°C)+32	degrees Celsius	°F
		FORCE and PRESSURE or STRESS		
N	Newtons	0.2248	poundforce	lbf
kPa	kilopascals	0.1450	poundforce per square inch	lbf/in^2

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EXECUTIVE SUMMARY

In March of 1994, the Maintenance Division, Bridge Division and Materials & Research Division held meetings to devise a systematic approach of evaluating and approving acceptable coatings systems for the Oklahoma Department of Transportation (ODOT). Five structural steel coating systems (Wasser, Carboline, Valspar, Watson and Superior) were selected for evaluation and sent to Corrosion Control Consultants & Labs, Incorporated (CCCL) to be tested. Each coating system was subjected to a battery of six different tests. The results were recorded then submitted to the Office of Research for analysis.

In addition to the laboratory tests, three of the coating systems were applied to structural steel in the field on four different bridges. A visual inspection of the coating system was made at each location and the results were recorded. After reviewing and analyzing the results of the CCCL tests and the visual inspection, a cost analysis was performed as well as a survey of the tests and criteria that other transportation agencies use to certify and accept coating systems.

The analysis revealed that four of the seven evaluation procedures yielded useful and informative results. These tests included the Salt Fog, Envirotest, Taber Abrasion and Fluorescent UV tests. By eliminating three of the tests used for evaluation and reducing the time that each test was performed from five thousand hours to two thousand hours, the cost of evaluating the coatings was also reduced.

Laboratory testing was recommended to create a performance-based specification for accepting coating systems for use on bridge structural steel. In order to obtain an equitable and balanced evaluation of how each coating system performs, it was recommended that the results of each test be evaluated using a weighted rating system. A weighted rating system using the four tests selected gave the best results that can be obtained in the least amount of time and at the lowest cost.

The four tests used in this evaluation were assigned the following weights: Salt Fog (20%), Envirotest (30%), Taber Abrasion (25%) and Fluorescent UV (25%). Each test has a specific criterion for passing and assigning a rating. After each individual rating is assessed, the ratings are combined. A combined rating greater than or equal to eighty-five (85%) is considered an acceptable coating system. In this study, the Carboline and Valspar systems had a final rating of greater than 85%.

BACKGROUND

CURRENT PRACTICES

Modifications in regulations regarding the removal, application and composition of coating systems have caused the Oklahoma Department of Transportation (ODOT) to reevaluate some of their policies related to bridge coatings. Currently, ODOT uses five tests designated by the American Society for Testing and Materials (ASTM) and American Association of State Highway and Transportation Officials (AASHTO) to evaluate system performance of paint systems for structural steel. A summary of these tests and their performance criteria is listed in Table 1.

Table 1. Summary of Current ODOT Practices.

Test	Standard	Requirement
Fresh Water Resistance	ASTM D 870	After 30 days, no rust, no blistering, softening or discoloration.
Salt Water Resistance	ASTM D 870	After 30 days, no rust, no blistering, softening or discoloration.
Salt Fog Resistance	AASHTO M 300	As listed in standard except up to 2500 hours
Weathering Resistance & Specular Gloss	ASTM D 4587 (Method D)	After 3,000 hours of continuous exposure, no rust, no blistering, or loss of adhesion.
Elcometer Adhesion	ASTM D 4541	Each trial must have adhesion of 2.76 MPA or more and show no evidence of fracture at the primer-blast surface.

OTHER AGENCY EXPERIENCES WITH COATING CERTIFICATION AND TESTING

Before updating the current program used for assessing system performance, several factors were taken into account. First, the needs of the department were assessed, a preliminary literature search was performed to determine the requirements of other state DOTs, and industry standards were evaluated. Three different organizations were selected to provide a guide in creating a new specification and evaluating the state of the art: California DOT, Michigan DOT and New England Protective Coatings (NEPCOAT).

The California system is largely concerned with the visual distress of the coating system. Their pass/fail criterion is largely based on field performance. Michigan DOT has a balanced approach to their acceptance criteria. Each test used to evaluate a coating system is assigned a different weight. The results are compiled and rated. Coatings with a rating greater than or equal to nine (9) pass.

NEPCOAT has several laboratory tests that they perform to accept a coating system. If a coating fails to meet one requirement, it is rejected. Table 2 shows a comparison of each system and lists the tests that each agency performs.

Table 2. Organization Acceptance Criteria.

	ORGANIZATION ACCEPTANCE CRITERIA		
TEST	**NEPCOAT**	**MICHIGAN**	**CALIFORNIA**
Salt Fog	4000 hours; no blistering, cracks or delaminations; rust creep < 1.5mm, and 2 < 2%	30% of rating	
UV Condensation		10% of rating	No visible color change
Slip Coefficient	Must meet AASHTO Class B; slip coefficient no < 0.5 req.,		
Weathering	4000 hours; no blistering or delamination; rust creep <1.5mm, and rust 2%		
Relative Humidity	4000 hours: no blistering, cracks or delamination; rust creep ,0.8 mm and rust <2%	15% of rating	
Taber Abrasion			
Adhesion Test	Minimum 18 kg/cm² - Inorganic Zinc Minimum - 42 kg/cm² - Organic Zinc		
Infrared ID	Zinc - 2.5 to 1.5 microns 2 Coats - 2.5 to 15 microns		
Weather Cycles		20% of rating	
Cyclic Environment		20% of rating	
Outside Exposure		5% of rating	Visual; >1% rust=fail
Prohesion			
Envirotest			

* Shaded areas highlight tests that ODOT wanted to evaluate.

PROJECT INITIALIZATION

In March of 1994, a systematic approach was developed to evaluate acceptable coatings systems modified to meet new requirements. Initially, the Bridge Division wanted to use fifteen different paint systems on fifteen different bridges, with both repainting and overcoating of existing structures. Eventually, it was decided to establish a research approach that would allow the use of typically selected systems and provide the Department with beneficial information with respect to bridge paint systems. This information was to be used in the development of specifications for accepting coatings. The specifications were to be based on performance testing rather than on long-term field observation. The resultant opinion on how to accomplish this was to run a series of laboratory tests on each paint system, then combine this information with field application and field performance observations over time.

Five coating systems were selected for evaluation. The pertinent information about these systems is listed in Table 3. These coating systems were sent to Corrosion Control Consultants & Labs, Incorporated (CCCL), an independent laboratory, for testing. This text presents the results of the laboratory and field evaluations, a cost analysis, discussion and recommendations for a standard procedure for use of new coating systems.

Table 3. Coating Manufacturer and Product Information.

	COATING MANUFACTURER AND PRODUCT NAME				
	Wasser	**Carboline**	**Valspar**	**Watson**	**Superior**
Primer	**MC Miozinc**	**CZ11-HS**	**V13-F-12**	**AS 8100**	**Rust Grip SP-S**
Intermediate	**MC Miomastic**	**Carboline 893**	**V89W9**	**None**	**Rust Grip w/ dye**
Topcoat	**MC Ferrox A**	**Carboline 134**	**V54W7**	**AS8106**	**Rust Grip HS**

LABORATORY TESTS

PROCEDURES

A sample of each coating was sent to CCCL for examination. The coatings were applied as they would be applied in the field for testing purposes. A list of the tests and testing standards is given in Table 4.

Table 4. Laboratory Test and Standards.

Test	Standard
Salt Fog	ASTM B-117
Relative Humidity	ASTM D-2247
Envirotest	Industry Standard
Prohesion	Industry Standard
Taber Abrasion	ASTM D-4060
UV Condensation	ASTM G-53

Standard Salt Spray Test (Salt Fog Test)

This test provides a controlled corrosive environment used to produce relative corrosion resistance information for specimens of coated metals exposed in any particular test chamber. A correlation and extrapolation of corrosion performance can be determined based on environmental conditions simulated in the chamber.

Relative Humidity

Since water can cause degradation of coatings, it is important that this phenomenon be studied. Failure in tests may be caused by a number of factors including deficiency in the coating itself, contamination of the substrate, or inadequate surface preparation. These tests usually result in a pass or fail determination but the degree of failure may also be measured. A coating system is considered satisfactory if there is no evidence of water-related failure after a period.

Envirotest

Envirotest is a test that simulates weathering. The Envirotest rotates coated panels through several different phases. Panels are subjected to detrimental UV radiation, wetting, drying, cooling, heating and dilute acids and/or alkalies during the cycles.

Prohesion Test

Prohesion testing is also a cyclical test that involves wet/dry cycling. A weak solution of the spray used in the Salt Fog test is sprayed onto coated panels then dried and the process is repeated [1].

Both the Envirotest and Prohesion tests were performed with the intention of selecting one for final test specifications. In addition, both are used in the coatings industry to measure performance, but neither has an approved ASTM or AASHTO testing standard. These tests are also used instead of the traditional Salt Fog test by some agencies.

Taber Abrasion Test

The Taber Abrasion test uses a friction wheel to determine the resistance to particle wear.

UV Condensation (Fluorescent UV Test)

The Fluorescent UV-Condensation Type test is intended to simulate the deterioration caused by water as rain or dew and the ultraviolet energy in sunlight.

TEST RESULTS

All of the laboratory tests were done by CCCL. A synopsis of the results is presented in Tables 5 through 8. The double lines on the tables indicate the hour that most agencies suggest their pass/fail criteria (normally after 2000 hours). Test results highlighted in solid colors indicate the coating that showed the most distress; diagonal lines indicate the coating with the least distress at the end of testing.

Table 5. Results of Salt Fog and Relative Humidity Tests.

	Salt Fog					Relative Humidity				
(Hours in 1000's)	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
Wasser	X	S	8Bm	3Bm	C, RS	X	X	X	X	X
Carboline	X	X	8Bf	8Bm	8Bmd	X	X	X	X	X
Valspar	X	RS	8Bf	4Bf	4Bf,C	X	X	X	X	X
Watson	RS	S	50%	75%	100%	X	X	X	X	X
Superior	S	S	4B,S	6B,S	U,S	X	X	X	X	X

L - Paint is Lifted from Panel *RS - Rust Staining* *C - Creepage*

S - Staining at Scribe *U - Undercutting at the Scribe Intersection*

X - No Rust Spots, No Blistering *(%) - Percentage of Rusting on Panel*

B - Type of Blistering (Visual Standard from ASTM D714; d-Dense, md - Medium Dense, m-Medium, f-Few; e.g., 8bm = Number 8 medium blistering; As numbers decrease, blister diameter increases.)

Table 6. Results of Envirotest and Prohesion Tests.

	Envirotest					Prohesion				
(Hours in 1000's)	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
Wasser	8Bd	4Bm	4Bd	2Bd	2B	X	X	8Bf	6Bf	6Bm
Carboline	8Bf	8Bf	6Bm	4B	2B	X	X	X	X	X
Valspar	8Bd	6Bd	6Bd	4Bd	4Bd	X	X	X	X	X
Watson	8Bf	8Bd	4Bd	2Bd	2Bd	X	X	X	X	X
Superior	8Bf	4Bd	2Bd	2Bd	2Bd	8Bf	8Bf	6Bm	4Bm	2Bd

Table 7. Results of Taber Abrasion Test.

Taber Abrasion									
	Panel Number	*Beginning DFT* (mils)*	*Ending DFT (mils)*	*Beginning Wt. (grams)*	*Ending Wt. (grams)*	*Difference (grams)*	*Average (grams)*	*Difference (percent)*	*Average (percent)*
Wasser	**1**	9.5	8.0	219.03	218.75	0.28	0.30	0.13	0.14
	2	9.9	8.3	218.83	218.53	0.30		0.14	
	3	9.8	7.9	219.54	219.23	0.31		0.14	
Carboline	**1**	10.5	9.8	218.46	218.11	0.35	0.23	0.16	0.11
	2	10.9	9.8	217.95	217.72	0.23		0.11	
	3	10.8	9.9	218.33	218.23	0.10		0.05	
Valspar	**1**	10.1	9.9	265.57	265.33	0.24	0.23	0.09	**0.10**
	2	11.1	10.2	221.62	221.45	0.17		0.08	
	3	10.9	9.8	224.25	223.99	0.26		0.12	
Watson	**1**	8.9	4.4	215.98	215.33	0.65	0.75	0.30	**0.35**
	2	9.4	4.8	211.28	210.55	0.73		0.35	
	3	9.7	4.7	214.31	213.43	0.88		0.41	
Superior	**1**	5.6	4.8	212.64	212.43	0.21	0.24	0.10	**0.10**
	2	5.4	4.9	215.72	215.51	0.21		0.10	
	3	5.9	5.4	212.87	212.63	0.24		0.11	

NOTE: DFT is Dry Film Thickness

Table 8. Results of Fluorescent UV Tests.

Fluorescent UV Test												
	Beginning Gloss	***1000 hours***		***2000 hours***		***3000 hours***		***4000 hours***		***5000 hours***		***% lost***
Wasser	3.0	3.1, X	103%	3.0, X	100%	2.7, X	90%	2.7, X	90%	2.6, X	87%	13
Carboline	77.1	66.3, X	86%	65.4, X	85%	64.9, X	84%	62.0, 1B	80%	*59.5, L*	77%	23
Valspar	90.2	83.0, X	92%	78.4, X	87%	65.7, X	73%	50.9, X	56%	46.2, X	51%	49
Watson	9.4	2.2, X	23%	2.1, X	22%	2.0, X	21%	1.8, X	19%	1.3, X	14%	86
Superior	11.1	6.5, X	59%	6.2, X	56%	6.1, X	55%	6.0, X	54%	6.0, X	54%	46

ANALYSIS

ANALYSIS OF CCCL RESULTS

Salt Fog

The Salt Fog Test is designed to provide information on how coatings perform in a corrosive environment. Results from this test indicate the degree of rust, stain and blistering on each panel. There were several changes to note for each coating. The coating with the least amount of distress at the end of testing was the Carboline System. Carboline showed no visual distress after 2000 hours of testing and only medium dense blistering after 5000 hours of testing. Watson coating system showed the most visual distress. This coating showed both rust and staining at the end of 1000 hours where most of the other coatings showed no signs of distress. At the end of 5000 hours, the panel was completely rusted.

Relative Humidity

No coating showed any signs of distress at the end of 5000 hours.

Prohesion and Envirotest

Valspar performed better than any other coating systems in both the Envirotest and Prohesion tests. Superior performed the worst in each test. In the Prohesion test, Superior was the only coating system that showed any changes to the coating after the first 1000 hours.

Results from the Prohesion test were unchanged for three out of the five coating systems. Wasser and Superior (the remaining two systems) showed evidence of blisters at the end of 5000 hours.

The Envirotest results were more varied than results from the Prohesion test. Each system had blisters at the end of 1000 hours. At the end of 3000 hours, the blisters increased in diameter for each coating and, with the exception of the Carboline system, were dense.

Taber Abrasion

Taber Abrasion test results were reported by recording the dry film thickness (DFT) of each coating. The coating with the greatest average decrease in coating thickness was the Watson system with 0.35 percent. Both Valspar and Superior had the least average decrease in DFT after testing was complete, 0.10 percent

Fluorescent UV Test

Results from this test were recorded in the percentage of gloss retained by the coating system. The Wasser system had the highest percentage of gloss retained with a 13 percent loss; Watson had the lowest percentage of gloss retention with 86 percent.

Summary of Results

Table 9 summarizes the coating systems with the most and least distress for each test.

Table 9. Summary of Coating Performance.

Summary of Coating Performance					
	Wasser	**Carboline**	**Valspar**	**Watson**	**Superior**
Salt Fog	High			Low	
Relative Humidity					
Envirotest			High	Low	Low
Prohesion Test		High	High	High	Low
Taber Abrasion			High	Low	High
Fluorescent UV	High			Low	

Note:

"High Performance" indicates that the coating system had the least distress of the five coating systems being tested at the end of the evaluation period.

"Low Performance" indicates that the coating system had the most distress of the five coating systems being tested at the end of the evaluation period.

PROJECT SITE VISUAL ANALYSIS

Three of the five coating systems were applied in the field; project information, location and additional information are listed in Table 10.

Research personnel made a visual inspection of the coated bridge steel beginning April 7, 1997. The Watson coating system in McCurtain County was inspected first. There were some areas of rust on the beams (less than 5 percent). Most of the rust can be seen near the ends of the beam on the web. There is also evidence of paint deterioration along the ends of the bottom flanges coupled with blistering and some peeling. No signs of major cracking or other anomalies were evident in the coating system. Some findings are illustrated in Figures 1 through 3.

On April 10, 1997, the inspection party went to Ellis County to view the bridge steel there. There were minor rust stains were observed near the pier caps in the center span. No evidence of peeling, blistering, or cracking was noted.

The final inspection was performed on May 2, 1997 in Wagoner County on the bridge over the Verdigris River. It was obvious that steel was recently painted. There we no signs of any anomalies or degradation of the coating system (refer to Figures 4 and 5).

Table 10. Coating Project Information.

Coating	Project Number	County	No. of Bridges	Location	Completed
Wasser	MC-173C (001)	Wagoner	1	SH-16 (1.8 mi. N. of Wagoner/ Muskogee County line)	March 1997
Valspar	MC-23(128) (129)	Ellis	2	US-283 (0.5 mi. N. of Jct. SH-15)	October 1994
Watson	MC-45(301)	McCurtain	1	US-70 (5.8 mis. E & N of Jct. US-259)	March 1995

Figure 1: Rust at ends of Beams - *McCurtain County.*

Figure 2: Erosion of Coating System and Flange Edges- *McCurtain County.*

Figure 3: Rust along Bottom of Web - *McCurtain County.*

Figure 4: Newly Painted Beams - *Wagoner County.*

Figure 5: Bridge over Verdigris River - *Wagoner County.*

COST ANALYSIS

Any specification and acceptance criterion that ODOT plans to adopt should also be cost effective. Table 11 lists the costs of laboratory testing performed on the five coating systems. These figures do not represent costs to perform visual testing and inspection. CCCL prepared three test panels for each coating and this cost is reflected in the information given.

Table 11. Cost of Performing Laboratory Tests.

Test	No. of Hours	Cost	Average Total Cost
Salt Fog	5000	0.10 per panel per hour	$500.00 per panel
Relative Humidity	5000	0.05 per panel per hour	$250.00 per panel
Envirotest	5000	0.10 per panel per hour	$500.00 per panel
Prohesion	5000	0.10 per panel per hour	$500.00 per panel
Taber Abrasion	N/A	$250 per coating w/ 3 replicates	$2,250.00 per coating system*
Fluorescent UV	5000	0.05 per panel per hour	$250.00 per panel
Average Total Cost per Coating System (w/ 3 panels)			**$8,250.00**

* The average coating system consisted three coats: primer, intermediate coat and top coats.

DISCUSSION

SELECTION AND ANALYSIS OF TEST RESULTS

ODOT needs a coating system evaluation and acceptance process that is equitable, reliable and cost-effective. If laboratory testing is to be the chief criterion for coating acceptance, the test results should be informative. The original seven criteria (Salt Fog, UV Condensation, Relative Humidity, Taber Abrasion, Envirotest, Prohesion and Visual) used for this evaluation to develop a performance-based specification were selected based on the industry standards, recommendations made by CCCL and other agency experiences.

After reviewing the data, it can be inferred that not all of the test results were informative.

- No coating system showed signs of distress after 5000 hours of testing for the Relative Humidity Test.
- It is widely held that the Salt Fog Test is not an accurate predictor of the effect corrosive elements in the field [2, 3], particularly for bridges that are not in a marine environment.
- The Envirotest and Prohesion tests were selected with the intention of selecting only one test to evaluate the coating system
- Three of five coating systems showed no signs of distress after 5000 hours for the Prohesion test.

Based on the limited information that both the Relative Humidity and Prohesion tests give, eliminating these tests from a coating evaluation process would be prudent. The Envirotest, like the Prohesion test is cyclical in nature and seemed to provide more information about the failure of a coating system. In addition, the Envirotest is more comprehensive than the Prohesion test since it incorporates a greater number of elements in each cycle.

Since the Salt Fog Test is generally thought to be an obsolete and imprecise measuring tool for determining the effects of corrosive elements on coatings, it may also seem like a poor choice for evaluating the behavior of a coating system in the field. However, there was some valuable and useful information found in the test results such as blistering, creep and rust staining data.

The Taber Abrasion test simulates the windy conditions in Oklahoma and provided information that was not contained in any other test.

The Fluorescent UV Test measures the effect of harmful ultraviolet energy and moisture on the coating system and provided more useful information than the results given in the Relative Humidity test.

A visual survey can be a time-consuming method of evaluating a coating system. In order for a visual survey to be revealing, a coating would have to be monitored for a minimum of 12 months to offer a true representation of how coatings hold up from season to season. While a visual survey is probably the most accurate way to evaluate the effectiveness of a coating system, it is not the most practical option available when time is of the essence.

Given the test results listed in Tables 5 through 8, it is apparent that most of the significant changes that occurred in the coating systems after the 2000 hour period mark (approximately three months). This testing time is also the benchmark that many other agencies use when creating their specifications.

By eliminating the tests that do not provide adequate and sufficient information and reducing the number of hours needed for the remaining test, the cost of testing is decreased. The associated costs to perform these tests is $3,750 as illustrated in Table 12.

Table 12. Cost of Proposed Tests.

Test	No. of Hours	Cost	Average Total Cost
Salt Fog	2000	0.10 per panel per hour	$200.00 per panel
Envirotest	2000	0.10 per panel per hour	$200.00 per panel
Taber Abrasion	N/A	$250 per coating w/ 3 replicates	$2,250.00 per coating system
Fluorescent UV	2000	0.05 per panel per hour	$100.00 per panel
Average Total Cost per Coating System (w/ 3 panels)			**$3,750.00**

COATING SYSTEMS PERFORMANCE

Table 13 summarizes the high and low results from the Salt Fog, Envirotest, Taber Abrasion and Florescent UV tests after 5000 hours. Based on the information presented in Table 13, it is evident that the Watson coating system consistently had the lowest performance rating when compared with the other coating systems. Both the Wasser and Valspar systems rated highest on 50 percent of selected tests while Carboline rated neither highest nor lowest for any given test.

Table 13. Summary of Coating Performance.

Summary of Coating Performance					
	Wasser	**Carboline**	**Valspar**	**Watson**	**Superior**
Salt Fog	Highest			Lowest	
Envirotest			Highest	Lowest	Lowest
Taber Abrasion			Highest	Lowest	Highest
Fluorescent UV	Highest			Lowest	

PROPOSED RATING SYSTEM AND SELECTION CRITERIA

Based on the test results given in Tables 5 through 8, it is possible to have a coating system that can meet the following criteria:

- Salt Fog Test
  - ■ No rust at 1000 hours
  - ■ No blistering at 2000 hours
- Envirotest
  - ■ Blisters no larger than number 8 at 1000 hours
  - ■ No rust or blistering at 2000 hours
- Taber Abrasion
  - ■ Less than 0.12 percent loss of DFT
- Fluorescent UV
  - ■ No blistering or rust at 2000 hours
  - ■ Less than 15 percent loss of gloss at 2000 hours

A proposed rating system is listed in Table 14.

Table 14. Proposed Weighted System.

Test	Weight for Rating
Salt Fog	20%
Envirotest	30%
Taber Abrasion	25%
Fluorescent UV	25%
Passing Criteria	*85%*

The weight of each test was assigned based on the relative importance, i.e., the most useful and necessary information required, of the test. A passing criterion of 85 percent was assigned for a better weighted system; it is possible for a coating to perform flawlessly in 3 of 4 tests and still not meet the criteria if it fails the remaining test. Using the bulleted information, the weights can be calculated as shown in Table 15.

Table 15. Proposed Criteria and Rating System.

Test	Criterion	Assigning a Rating
Salt Fog	No rust at 1000 hours.•	For S at 2000 hrs., rating= 17
	No blistering at 2000 hours. •	For RS at 2000 hrs., rating=15
Envirotest	Blisters no larger than number 8 at 1000 hours.•	For blisters larger than no. 8* at 2000 hrs., rating = (blister no. ÷ 8) x 30
Taber Abrasion	Average %Remaining of DFT less than 60%.	Rating = $\%Remaining_{Average}$ x 25
Fluorescent UV	No blistering or rust at 2000 hours.•	For loss greater than 15%,
	Less than 15% loss of gloss at 2000 hours.	rating = (15 ÷ % loss) x 25

•Failure to meet this criterion would result in a rating of 0.

*Blister size increases as blister number decreases (eg., no. 8 blister is smaller than no. 4 blister).

Using this rating system, the coatings used in this study were evaluated and the results are listed in Table 16.

Table 16. Rating of Coating Performance Using Proposed System.

Rating of Coating Performance					
	Salt Fog	**Envirotest**	**Taber Abrasion**	**Fluorescent UV**	**Rating**
Wasser	17	15	21	25	**78**
Carboline	20	30	23	25	**98**
Valspar	15	23	23	25	**86**
Watson	0	30	12	5	**47**
Superior	17	15	22	8	**62**

Carboline and Valspar met the 85 percent passing criteria listed in Table 14. This system gives an overall picture of the behavior of each coating. The performance results summary in Table 13 listed the high and low ratings at the end of each test. The only information that was easily discernible was that Watson showed more signs of distress than any other coating at the end of 5000 hours.

With this rating system, it is apparent that Watson's coating system had the lowest overall rating in this system however, it is also apparent that Carboline, while not the highest performer for each test, is overall, a "good" coating system. Valspar was an acceptable system although it did not perform flawlessly on the Salt Fog and Envirotest.

CONCLUSIONS

It is possible to create a good performance-based specification using laboratory tests. Of the seven tests originally suggested for this evaluation, five (Salt Fog, Envirotest, Fluorescent UV and Taber Abrasion and a Visual Survey) produced the most comprehensible and informative results. A visual survey is an extremely useful tool to measure coating performance, but to get a true representation of how a coating will perform as Oklahoma seasons change, it would be necessary to leave a system on for twelve months. This is not a very efficient practice when information is needed quickly. Accelerated seasonal test results can be simulated using laboratory testing with the Envirotest thus eliminating the need for visual surveys in the field for coating certification.

Laboratory testing for the Salt Fog, Envirotest and Fluorescent UV tests is billed by the hour. Generally, the most useful results from these tests can be obtained after the 2000 hour mark. By testing coatings only until the 2000 hour mark instead of for 5000 hours, the cost to perform these tests is reduced by more than 50 percent and is therefore more cost effective.

RECOMMENDATIONS

Results should be evaluated using a weighted rating system. A weighted rating system gives a balanced and comprehensive picture of the overall performance of a coating system instead of some simple pass/fail criteria based solely on one property of a coating.

Laboratory testing is recommended for creating a performance-based specification. The Salt Fog, Envirotest, Fluorescent UV and Taber Abrasion tests results should be used to qualify a coating system for acceptance. For the best results that can be obtained in the least amount of time and with the expenditure of the least amount of money, test results, except the Taber Abrasion test, should be evaluated after 2000 hours.

Using the proposed weighted system for coating acceptance, both the Carboline and Valspar systems are recommended for use. These were the only two coating systems out of the five evaluated that meets the eighty-five percent pass requirement.

REFERENCES

1. Cremer, N.D., Prohesion Compared to Salt Spray and Outdoors Cyclic Methods of Accelerated Corrosion Testing, C. & W. Specialist Equipment Ltd., Shropshire, England, 1989

2. Skerry, B.S., Alavi A., and K. I. Lindgren, "Environmental and Electrochemical Tests Methods for the Evaluation of Protective Organic Coatings," Journal of Coatings Technology Vol. 60 No. 765, October 1988, pp. 97-106.

3. Simpson, C.H., Ray, C.J. Ray and Skerry, B.S., "Accelerated Corrosion Testing of Industrial Maintenance Paints Using a Cyclic Corrosion Weathering Method," Journal of Protective Coatings & Linings, Vol. 8 No. 5, May 1991, pp. 28-36.

APPENDIX A

SECTION 730
PAINT FOR STRUCTURAL STEEL

730.01 GENERAL REQUIREMENTS.

(c) **System Performance**. To qualify for acceptance a manufacturer of a coating system must CERTIFIED TEST RESULTS verifying that the proposed system meets the minimum specified requirements for the following performance criteria:

Tests must be administered or performed by an authorized independent testing facility identified on the approved list. The principal facility evaluating a specific coating system or any laboratory performing testing for the principal facility must obtain prior approval from the Bridge Engineer before initializing any testing.

Prior to any testing, the "Principal Laboratory" selected by a manufacturer to evaluate a specific coating system shall provide the Bridge Engineer, in writing, with the following information:

1. Name of the manufacturer of the coating system.
2. Names of the designated coatings that will be tested.
3. Product data sheets for each coating system that will be tested.
4. Indicate the application order and conditions under which each system should be applied.
5. Indicate the dry mil thickness for each system and system component tested.
6. Identify the name and address of the manufacturer and the contact person for the organization.

Performance Test Procedures

The performance of the coating system, consisting of all required paint coats applied as specified shall be tested as follows: Three test panels shall be made for each of the specified tests; the test panel shall be prepared as described in AASHTO M 300; and where applicable, blistering shall be rated by ASTM D 714.

1. ***Salt Fog.***
   ASTM B 117, with scribed panels. Panels are evaluated every 1000 hours up to 2000 hours.
2. ***Envirotest.***
   The Envirotest is an industry standard using an experimental piece of equipment; therefore, there is no ASTM standard procedure. The chamber has a paddle wheel configuration that makes one revolution every four hours. The top of the chamber is heated to 49 °C (120 °F) and contains an ultraviolet light source. The bottom contains enough 3 percent (3%) NaCl solution to cover the panels for eighty (80) minutes each rotation. Panels are evaluated every 1000 hours up to 2000 hours. A copy of the Envirotest can be obtained from KTA-Tator, Inc.
3. ***Taber Abrasion.***
   ASTM D 4060. Panels are evaluated at the end of 1000 cycles.
4. ***Fluorescent UV.***
   ASTM G 53, with scribed panels. Panels are evaluated every 1000 hours up to 2000 hours.

System Performance

Each coating system will be evaluated using Salt Fog, Envirotest, Taber Abrasion and Fluorescent UV testing conducted at the "Principal Laboratory." Each test will be evaluated using the weighted rating system outlined in this section.

Salt Fog

Each coating system will be evaluated after 1000 hours and 2000 hours. For a coating system to be accepted, each coating system will be assigned one of the following ratings that best describes the condition of the coating system listed below:

- For no distress at 2000 hours, assign a rating of 20.
- For staining at the scribe at 2000 hours, assign a rating of 17.
- For slight lifting at 2000 hours, assign a rating of 17.
- For rust staining at 2000 hours on the panel, assign a rating of 15.
- For evidence of blistering at 2000 hours, assign a rating of 0.
- For evidence of rust at 1000 hours, assign a rating of 0.
- For all other anomalies at the end of 2000 hours not listed here, assign a rating of 10.

In the event that two or more of the above instances occur in one testing period, assign the lower rating.

Envirotest

Each coating system will be evaluated after 1000 and 2000 hours. Each coating system will be assigned one of the following ratings that best describes the condition of the coating system listed below:

- For no distress at 2000 hours, assign a rating of 30.
- For blister number 6, 4 or 2 as defined in ASTM D 714 at 1000 hours, assign a rating of 0.
- For blisters at 2000 hours, sized as defined in ASTM D 714 at 2000 hours, assign ratings accordingly:

Blister size 2, rating = 8
Blister size 4, rating = 15
Blister size 6, rating = 23
Blister size 8, rating = 30

- For coating distress other than blistering (rust, staining, etc.) at 2000 hours, assign a rating of 0.

Taber Abrasion

Each coating system will be evaluated at the end of the test.

Step 1:

Calculate the percent change in the beginning dry film thickness (BDFT) and the ending dry film thickness (EDFT) for each panel as indicated:

$$[\text{EDFT}_{\text{Panel(X)}} \div \text{BDFT}_{\text{Panel(X)}}] = \%\text{Remaining}_{\text{Panel(X)}}$$

Round $\%\text{Remaining}_{\text{Panel(X)}}$ value up to the nearest hundredth.

Step 2:

Calculate the Average %Remaining for the three panels:

$$(\%\text{Remaining}_{\text{Panel(1)}} + \%\text{Remaining}_{\text{Panel(2)}} + \%\text{Remaining}_{\text{Panel(3)}}) \div 3 = \%\text{Remaining}_{\text{Average}}$$

Round $\%\text{Remaining}_{\text{Average}}$ value up to the nearest hundredth.

Step 3:

Multiply the $\%Remaining_{Average}$ by 25 to obtain the rating.

$$\%Remaining_{Average} \times 25 = Rating$$

Round rating up to the nearest whole number.

Fluorescent UV

Each coating system will be evaluated after 2000 hours. For a coating system to be accepted, each trial will be rated as follows:

For blistering or rust at 2000 hours, rating = 0.

Calculate the loss of gloss at the end of 2000 hours:

$$(1 - [\text{End Gloss} \div \text{Beginning Gloss}]) \times 100 = \text{Loss of Gloss.}$$

Round Loss of Glass value up to the nearest whole number.
For loss less than or equal to 15, rating = 25.
For loss greater than 15, rating = $(15 \div \text{loss}) \times 25$.
Round Rating up to the nearest whole number.

Coating Performance Rating

The coating performance rating is the sum of the individual performance test ratings for the Salt Fog, Envirotest, Taber Abrasion and Fluorescent UV Tests.

Salt Fog Rating + Envirotest Rating + Taber Abrasion Rating + Fluorescent UV Rating = Performance Rating.

For a paint to be acceptable, each coating system must have a coating performance rating greater than or equal to eighty-five (85).

Test	Reference	Criterion	Weight of Rating
Salt Fog	ASTM B117	No rust at 1000 hours.●	**20%**
		No blistering at 2000 hours. ●	
Envirotest	Industry Test	Blisters no larger than number 8 at 1000 hours.●	**30%**
Taber Abrasion	ASTM D 4060	Average %Remaining DFT less than 60%.	**25%**
Fluorescent UV	ASTM G53	No blistering or rust at 2000 hours.●	**25%**
		Less than 15% loss of gloss at 2000 hours.	
Acceptance Criteria Rating ≥ 85%			

●Failure to meet this criterion would result in a rating of 0.

*Blister size increases as blister number decreases (e.g., no. 8 blister is smaller than no. 4 blister).

Approved Testing Laboratories

Corrosion Control Consultants & Labs, Inc.
4403 Donker Ct., S.E.
Kentwood, MI 49512
(616) 940-3112
(616) 940-8139 Fax

KTA-Tator, Inc.
115 Technology Drive
Pittsburgh, PA 15275
(412) 788-1300
(412) 788 1306 Fax

KTA-Tator, Inc.
6430 Variel Avenue
Suite 101
Woodland Hills, CA 91367
(818) 713-9172

KTA-Tator, Inc.
Deerbrook Plaza
9810 FM 1960 BYPASS Suite 140
Humble, TX 77338
(713) 540-1177

The Coatings Laboratory, Inc.
8605 Rayson Road
Houston, TX 77080
(713) 939-8553
(713) 939-8841 Fax