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Toward a 100 Year Bridge Coating System: Bridge Topcoats in Japan

FLUOROPOLYMER AND CONVENTIONAL TOPCOAT OVERVIEW

Overview

Conventional Coating Systems

- Zinc rich primer, epoxy, and polyurethane topcoat
- Offer good corrosion protection
- Topcoat begins to chalk and change appearance quickly

Fluoropolymer Coating Systems

- Zinc rich primer, epoxy, and fluorinated urethane topcoat
- FEVE technology
- Developed in the early 1980’s; wide use by the 1990’s

FEVE withstands UV exposure more than 2-3 times longer than conventional coating resins.

FEVE Fluoropolymer Advantages

- Excellent weatherability (30+ year topcoat life)
- Shop or field applied (new construction and maintenance)
- Uses standard painting equipment & application methods
- Formulated to meet all air quality regulations
- Superior gloss and color retention
- Superior resistance to chalking
- Resistant to airborne chemicals and acid rain
- Resistant to cleaning solvents used to remove graffiti

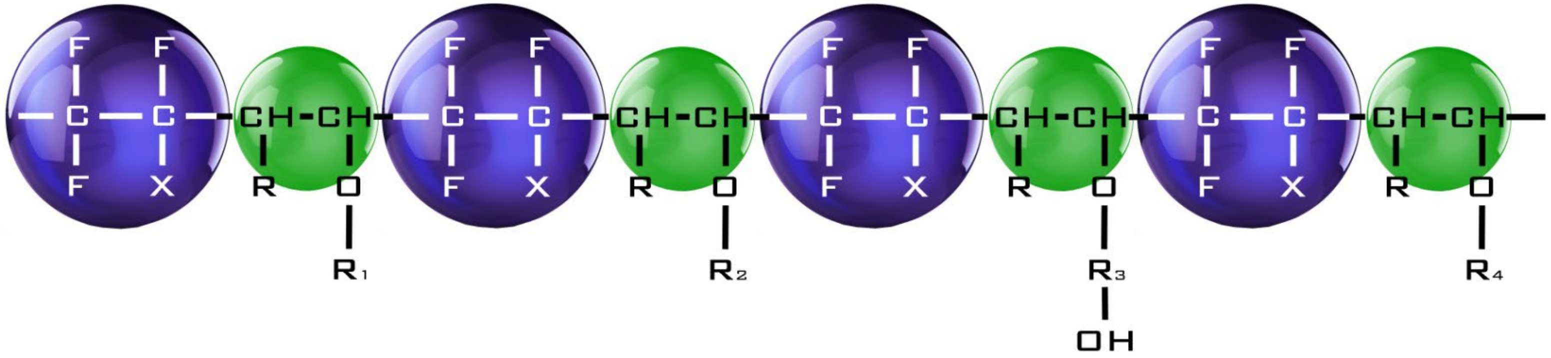
FEVE FLUOROPOLYMER STRUCTURE

Fluoroethylene Vinyl Ether (FEVE) Resin

The fluoroethylene segments impart durability, whereas the vinyl ether gives a range of positive attributes to the FEVE resin including gloss, hardness, flexibility and the ability to crosslink .

Fluoro Ethylene **(Durability)**

Vinyl Ether **(R1, R2, R3, R4)**



Transparency
Gloss
Hardness

Flexibility

Cross-Linkability

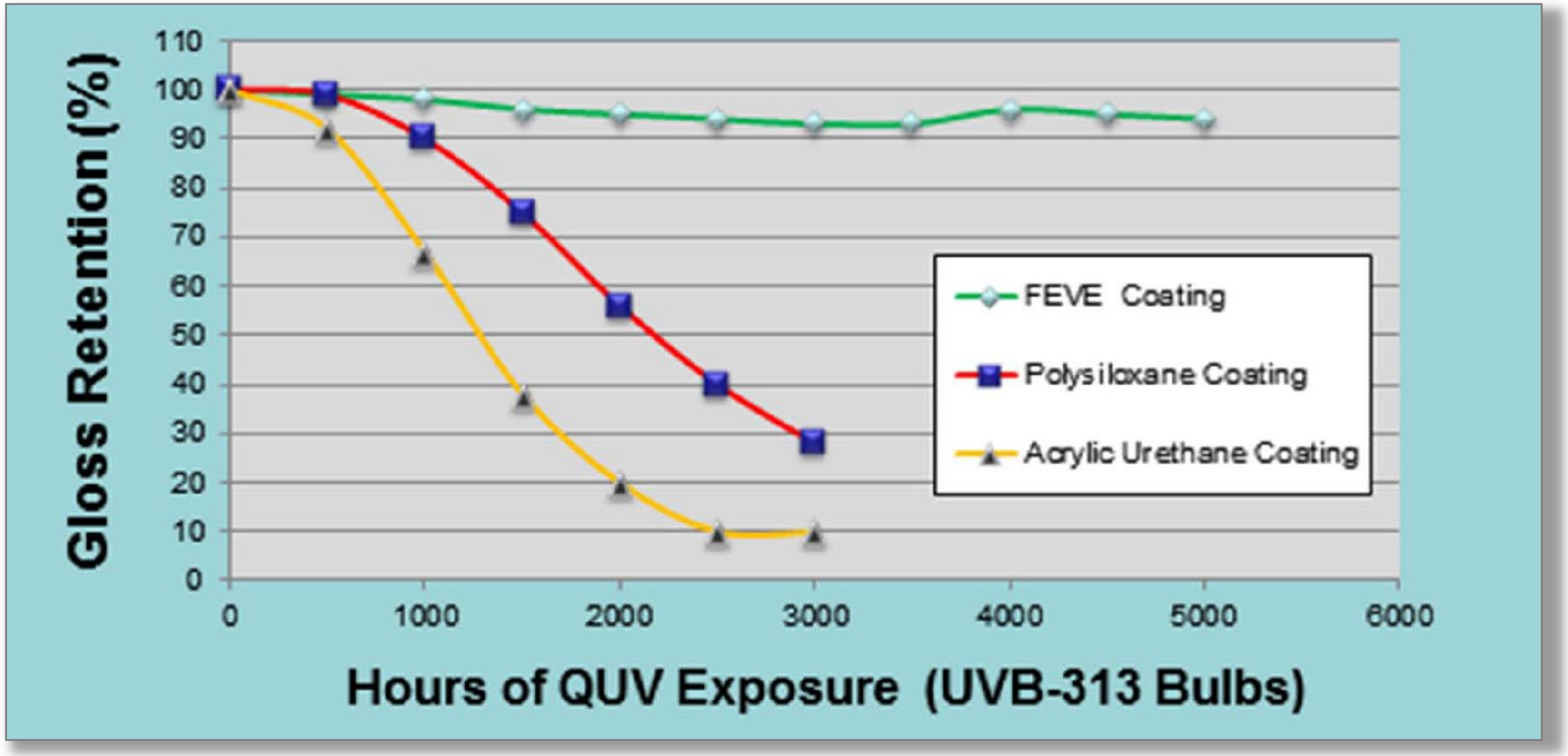
Pigment Compatibility
Adhesion

TEST RESULTS: WEATHERING AND CORROSION

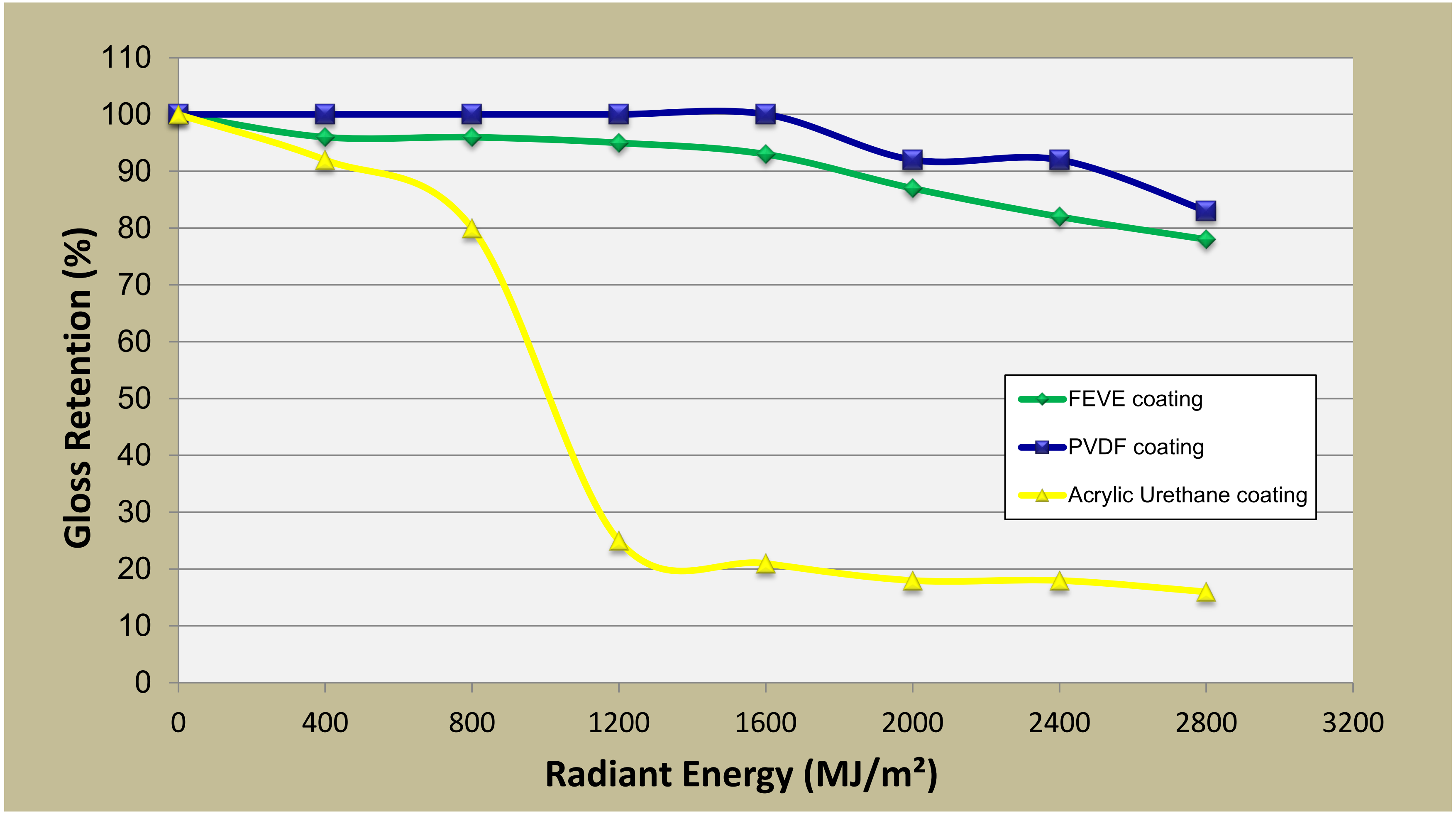
Weather Resistance Tests for Coatings

- Accelerated Weathering Tests
  - Short time frame for results
  - Limitations in accurately simulating real environment
  - Used as screening tool and comparing coatings
- Real Time Weathering Tests
  - Accurate results
  - Very time consuming: up to 20 years to complete
  - Often done in harsh conditions, e.g. South Florida

Accelerated Weathering: QUV Weatherometer Exposure Testing



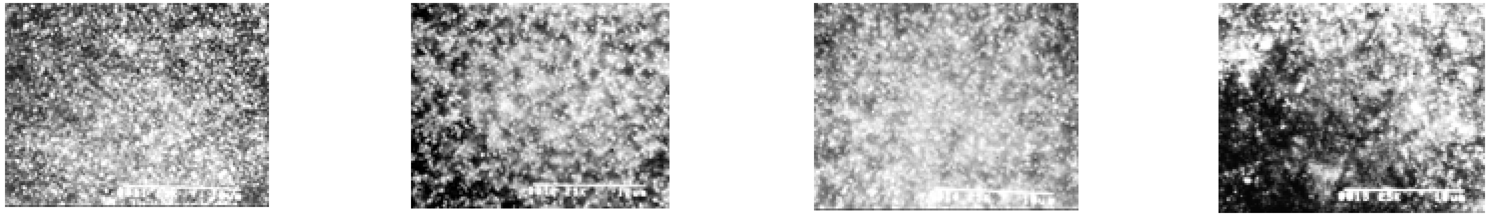
Accelerated Weathering: EMMAQUA



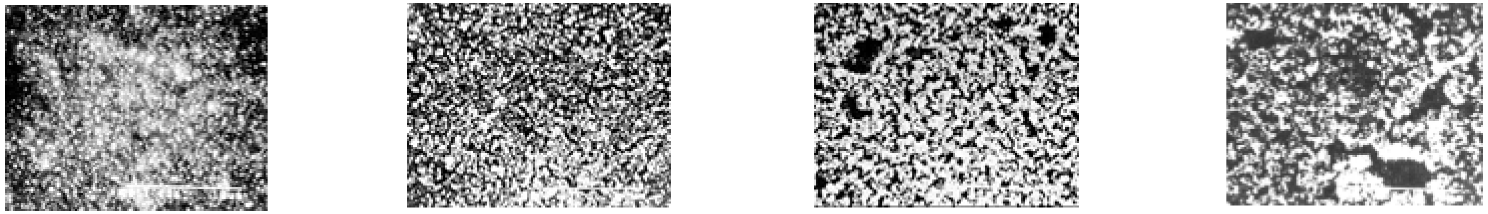
Accelerated Testing: Photomicrographs After Exposure

Hazy white areas: Coating polymer structures
Sharp white areas: White pigment.
Chlorinated rubber and alkyd coatings: polymer degraded; holes evident.
Polyurethane degraded, only pigment remained.
FEVE coating remained intact.

Initial appearance before exposure in SWOM



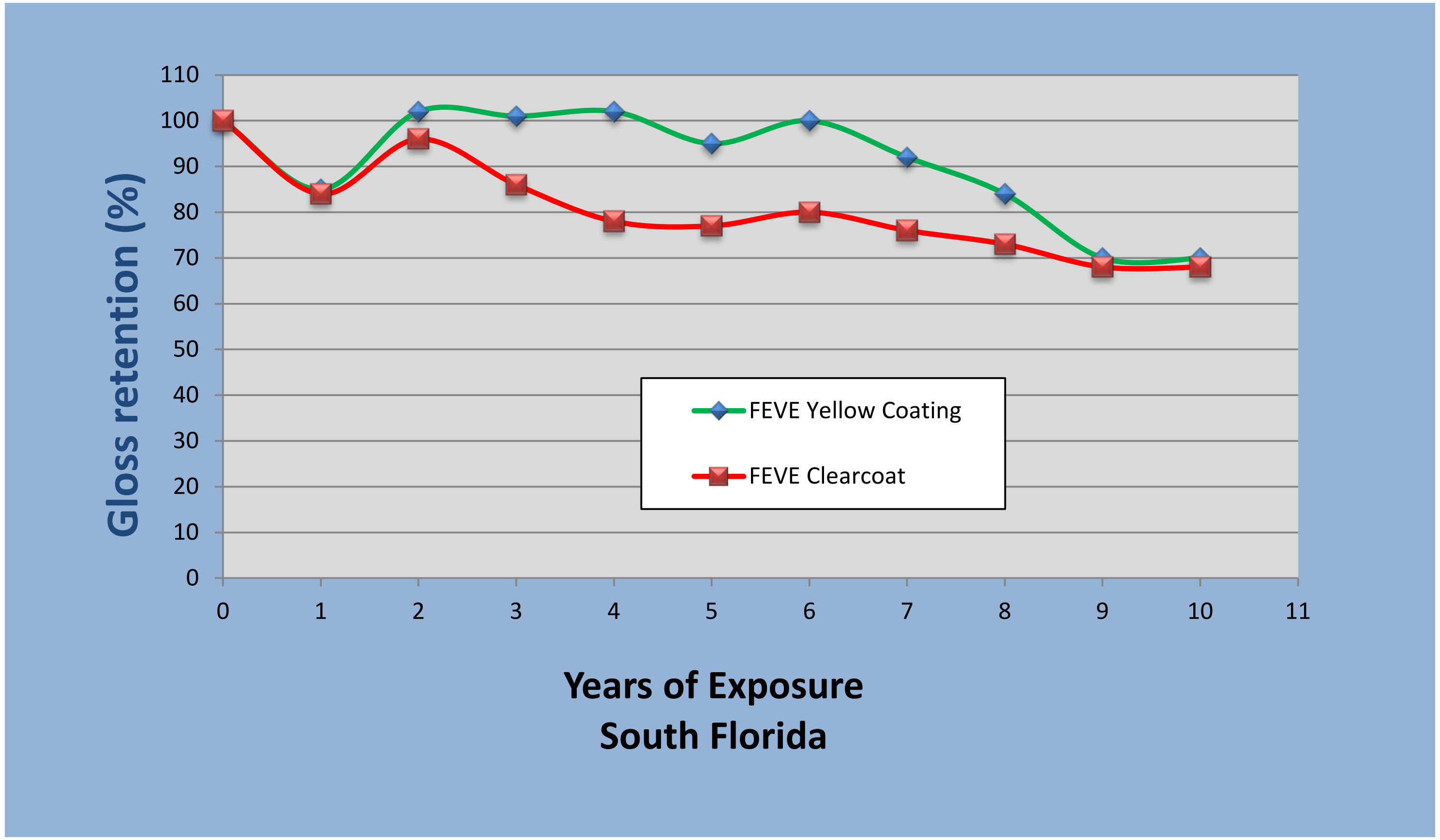
SEM photomicrographs after 2,000 hours of exposure in SWOM chamber



Fluorourethane | Polyurethane | Chlorinated Rubber | Alkyd

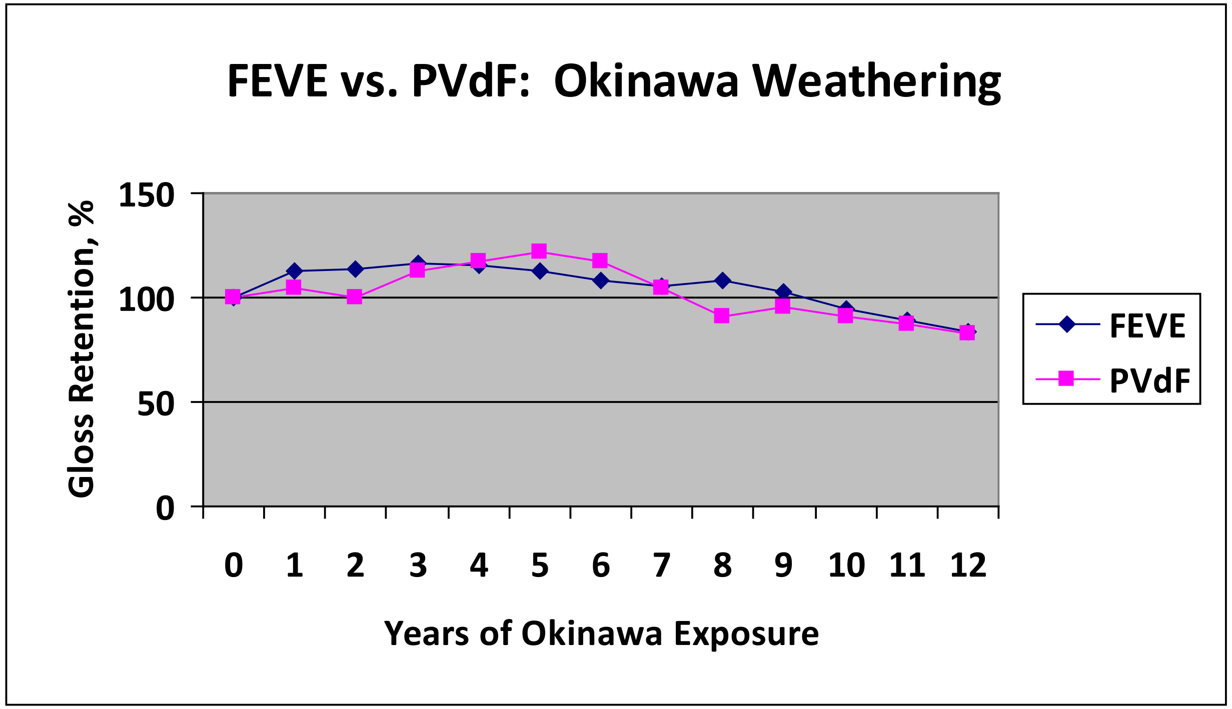
Real Time Weathering: South Florida Exposure

The graph below shows gloss retention results for pigmented and clear FEVE coatings after 10 years in South Florida.



Real Time Weathering: Okinawa Exposure

The graph below compares the performance of PVDF fluoropolymer and FEVE coatings after 12 years of weathering on Okinawa.

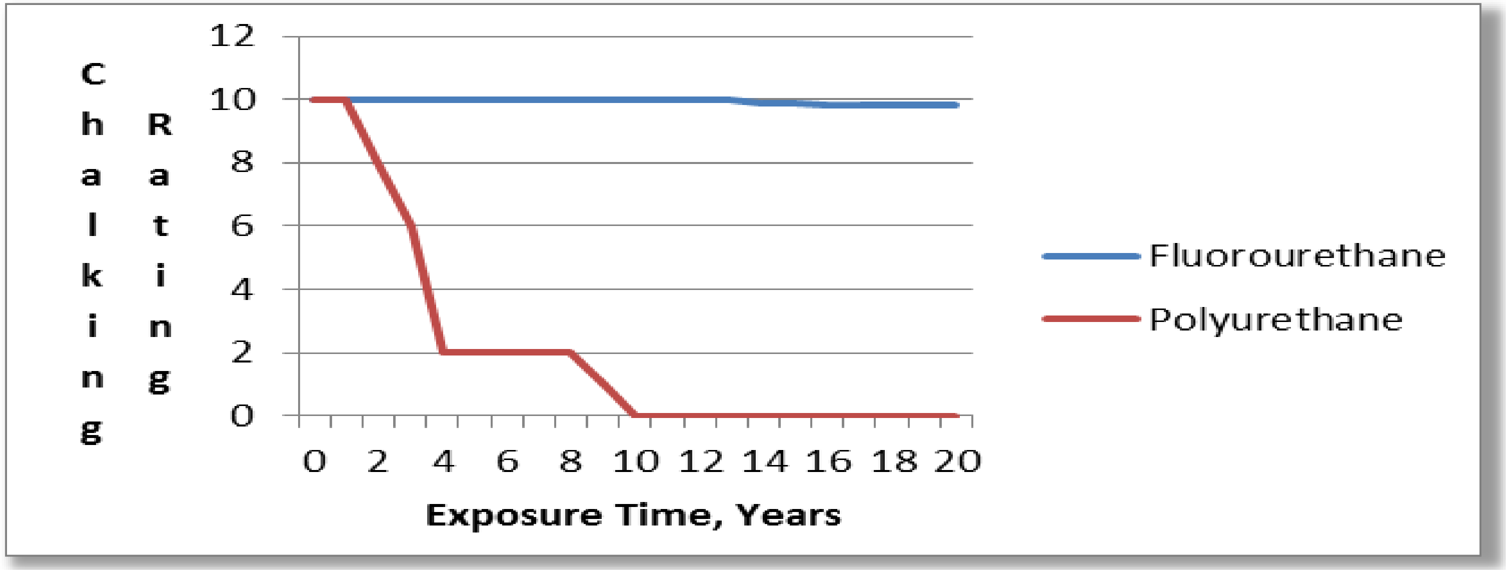


Real-Time Weathering: Testing on Offshore Platform

At Suruga Bay Marine Test Station (offshore), two samples were tested for 16 years. Both samples had 3 mils zinc-rich primer, 6 mils midcoat, and a 25 micron (1 mil) topcoat. After 13 years, the acrylic urethane topcoat was gone; at 16 years, the FEVE topcoat still measured 21 microns thickness.

	ACRYLIC URETHANE TOPCOAT	FLUOROURETHANE TOPCOAT
INITIAL MEASUREMENT (microns)	25	25
FINAL MEASUREMENT (microns)	0 (after 13 years)	21

Real-Time Weathering: Offshore Platform Chalking Test



In the chalking test, topcoat properties are monitored over time. Chalking (coating degradation by UV light and corrosives) is rated from 0-10, with 10 being no chalking and 0 being severe chalking over the entire coating surface. The performance of FEVE fluoropolymer compared to polyurethane is striking.

Corrosion Resistance of Steel Bridges

Corrosion resistance is the primary reason for using coatings

1) Primary corrosion resistance is provided by zinc primer which corrodes before steel if coating is damaged.
2) The topcoat serves to keep corrosion initiators like chloride, water and oxygen from reaching the metal surface.
3) Because of their long term durability, FEVE topcoats offer superior corrosion protection.

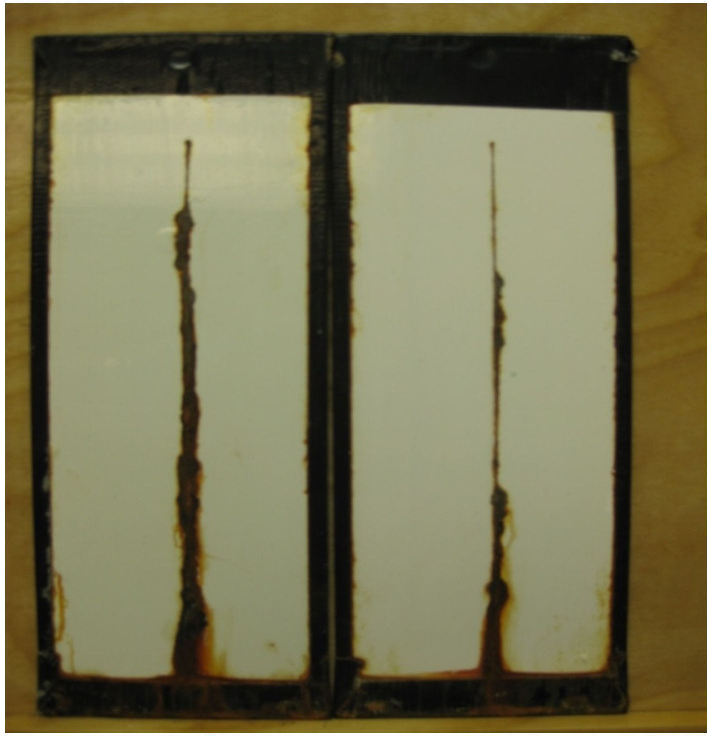
Corrosion Resistance of FEVE Coatings: ASTM B-117 Salt Fog Test

Scribed coated panels exposed to 5% salt solution for 2,000 hours.

Corrosion is measured by the amount of rust in the scribe and under the coating adjacent to the scribe as well as by blisters formed by corrosion products. In the test below, both topcoats were applied over a 3 mil epoxy primer.

Left Panel: Polysiloxane Topcoat

Right Panel: FEVE Topcoat



Corrosion Resistance of FEVE Coatings: ASTM B-117 Salt Fog Test

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Left Panel: Polyurethane Topcoat

Right Panel: FEVE Topcoat

Corrosion Resistance of FEVE Coatings: ASTM D-5894: Cyclic Prohesion Test

Coated scribed panels exposed to alternating UV/condensation and salt fog/dry exposure cabinet.

Salt solution is 0.05% sodium chloride and 0.35% ammonium sulfate.

5,040 hours of total exposure.

2 Coat System

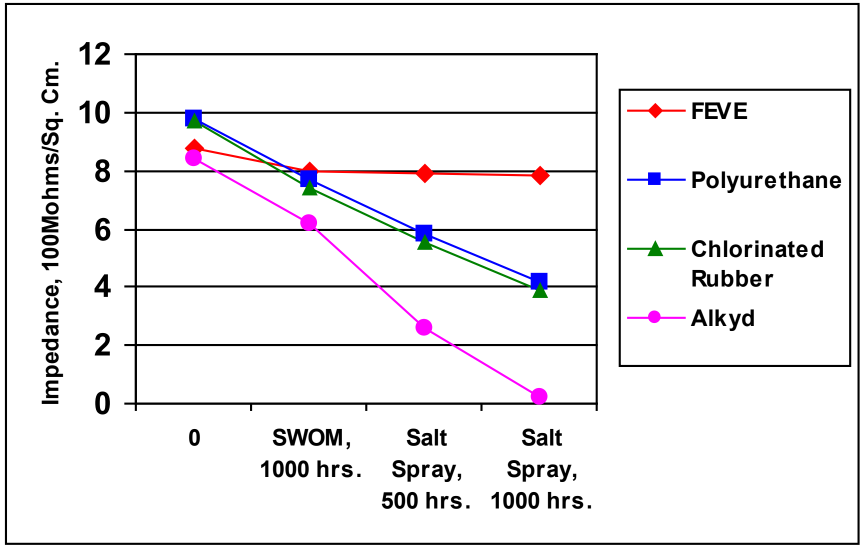
	Coating Type	60^o Gloss Retention (%)	Max. Scribe Creep (mm)
Primer	Organic Zinc Epoxy	NA	NA
Topcoats	Polyurethane	35.6	10
	Epoxy Polysiloxane	52.2	12
	Fluorourethane	73.2	8

3 Coat System

	Coating Type	60^o Gloss Retention (%)	Scribe Creep (mm)
Primer	Organic Zinc Epoxy	NA	NA
Midcoat	Polyamide Epoxy II	NA	NA
Topcoats	Polyurethane	54.3	8
	Epoxy Polysiloxane	72.0	12
	Fluorourethane	91.0	8

Corrosion Resistance of FEVE Coatings: Electrochemical Impedance Spectroscopy

Electrochemical impedance spectroscopy (EIS) involves setting up a corrosion cell, measuring the movement of corrosion initiator chloride through coating systems. In this version of the test, the coatings are first weathered in the SWOM test, then placed in the salt fog corrosion test. The change in impedance in 100 ohms/cm^2 is measured for each coating system. The smaller the change in initial impedance, the better the corrosion resistance of the coating system.



SPECIFICATIONS

Bridge Topcoat Specification

This was the 1990 Japanese National Specification for Bridge Topcoats. FEVE topcoats were required for use only in the most severe environments

		General Environment	Slightly Severe Environment	Severe Environments
Coating Type		No salt or corrosives Non-industrial areas Little smog Easy to recoat	Salt in environment Slight pollution Moderate smog Difficult to recoat	High salt levels Severe pollution Heavy smog Difficult to recoat
	General Purpose Coating	A-1, A-2	B-1	C-1, C-2
	High Durability Coating	A-3, A-4	C-3, C-4	

A-1, A-2: Long Oil Alkyd Coating **B-1: Chlorinated Rubber**
A-3, A-4: Silicone Alkyd Coating **C-1, C-2: Polyurethane Coating**

C-3: Fluoropolymer Coating, Shop Applied **C-4: Fluoropolymer Coating Field Applied**

Bridge Topcoat Specification

Japanese National Specification for Bridge Topcoats (Version 2), 2005

The Japanese National Specification was changed to focus on preventive maintenance and to yield lower life-cycle cost. Fluoropolymer topcoats are now required for all environments.

		General Environment	Slightly Severe Environment	Severe Environment
Application		No salt or corrosives Non-industrial areas Little smog Easy to recoat	Salt in environment Slight pollution Moderate smog Difficult to recoat	High salt levels Severe pollution Heavy smog Difficult to recoat
	New Construction, Shop Application	C-5 Coating System, Fluoropolymer Topcoat		
	Repair Coatings, Field Application	Rc-I, RC-III, Fluoropolymer Topcoat		

Bridge Coating Specification

- State Bridge Coating Specification
- PWB180A (Dark Green) and PWB181A (Light Green) are 40% FEVE/60% acrylic water based coatings
- Extend painting cycle from once/5 years to once/10-15 years
- Reduce repainting cost and bridge downtime
- Improved properties
  - Corrosion creepage PWB180A=2.96
  - Corrosion creepage PWB181A=3.45
  - Color change PWB180A=3.29 (4,000 hrs. QUV)
  - Color change PWB181A=6.21 (4,000 hrs. QUV)

Bridge Coating Specification

SP-150172
(New)

IOWA DOT

SPECIAL PROVISIONS
FOR
FLUOROPOLYMER PAINT FOR STRUCTURAL STEEL

Scott County
IM-NHS-074-1(197)5--03-82
IM-NHS-074-1(198)5--03-82
IM-NHS-074-1(199)5--03-82

Effective Date
April 25, 2017

THE STANDARD SPECIFICATIONS, SERIES 2015, ARE AMENDED BY THE FOLLOWING MODIFICATIONS AND ADDITIONS. THESE ARE SPECIAL PROVISIONS AND THEY SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

150172.01 DESCRIPTION.
These Special Provisions describe surface preparation and shop painting of structural steel and incidental parts for the I-74 Mississippi River Crossing and Corridor project using a three coat fluoropolymer paint system.

150172.02 MATERIALS.
Approved fluoropolymer paint systems for this project are listed in Materials I.M. 482.09.

150172.03 CONSTRUCTION.
The work includes the following items: preparation of all surfaces to be painted, application of paint, protection, drying of paint coatings, and repairing and repainting of coating damaged in the shop or after erection, or both.

ISO 12944, 2018 Update

- **6.2.5 Paints for polyurethane coatings (PUR)**

- Single pack polyurethane paints dry initially by solvent evaporation (where solvent is present) and by a chemical reaction with moisture from the air. The process is irreversible, meaning that the coating cannot be dissolved in the original solvent. Aromatic as well as aliphatic types of polyurethane coatings are available. Aromatic types are not recommended for top coats, as they tend to chalk.

- Two pack paints for polyurethane coatings dry by evaporation of solvents, if present, and cure by a chemical reaction between a base and a curing agent component. The mixture of base and curing agent has a limited pot-life.

- The binders of the base component are polymers with free hydroxyl groups e.g. polyester, acrylic, epoxy, polyether, fluoro resin, which react with suitable isocyanate curing agents. They can be combined with non-reactive binders, e.g. hydrocarbon resins.

- The curing agent component contains an aromatic or aliphatic polyisocyanate.

- **A special type of PUR is based on fluoropolymers.**

- **Paints for fluoropolymer/vinyl ether co-polymer (FEVE) coatings are two pack coating materials, and both water-borne and solvent-borne types are available. Solvent-borne paints dry by solvent evaporation and cure by a chemical reaction between a base resin and a curing component. Paints for FEVE coatings are ambient curable coating materials cross-linked with isocyanate hardener.**

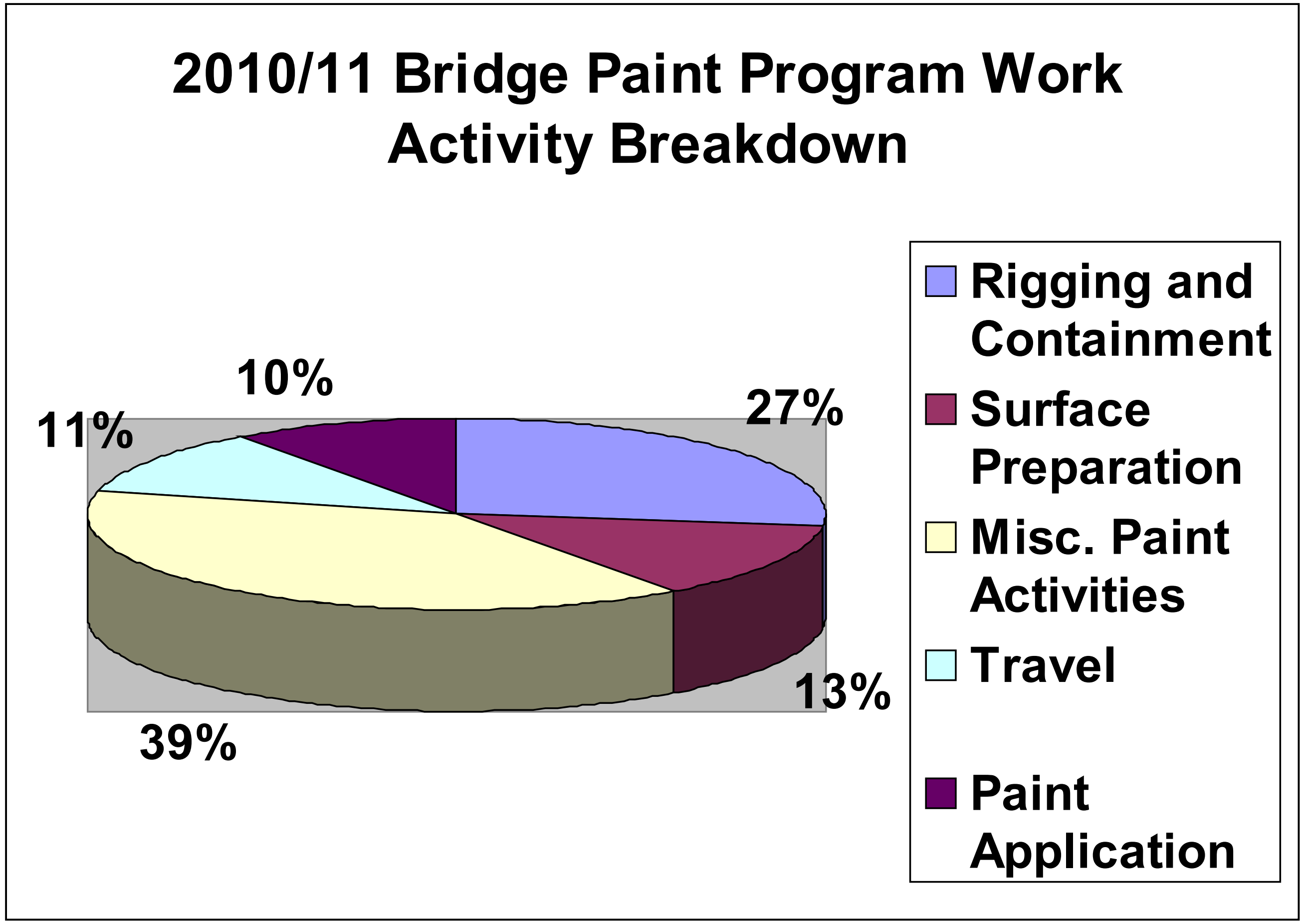
- **The resin of the base component is fluoropolymer with free hydroxyl groups which reacts with suitable isocyanate curing agents.**

LIFE CYCLE COST ANALYSIS

Topcoat Cost Analysis

Topcoat Type	Topcoat Thickness, µm	Coating Cost, $/m2
Alkyd	50	1.47
Polyurethane	55	4.08
Fluorourethane	55	24.02

Bridge Paint Program Activity



Life-Cycle Cost Comparison

Coating System	Alkyd	Polyurethane	Fluorourethane	
Total Repainting Cost, $/m2	69.48	85.65	105.88	
Estimated Coating Life, Years	7	18	30	60
Total Applied Coating System Cost, $/m2/Year	9.93	4.76	3.53	1.76
Cost Index	100	48	35	18

CASE STUDIES

Tokiwa Bridge

In 1986, the bridge surface was prepared to SSPC SP2/SP3 and repainted with two coats of epoxy primer and two coats of FEVE fluoropolymer.

Tokiwa Bridge (cont'd.)

- 19

1993

2008

2016 (30 Years)

Gloss and Color Change		Initial Gloss	2008 Gloss	2016 Gloss	2008 Color Change
Before Wiping	Gloss	75.2	66.2	52.7	ΔE=3.5
	Gloss Retention	N/A	88.0%	70.1%	
After Wiping	Gloss	75.2	77.6	73.2	ΔE=2.3
	Gloss Retention	N/A	103.2%	97.3%	

Daiichi Mukoyama Bridge

30 years
No corrosion or degradation of topcoat

Gloss and Color Change		Initial Gloss	2008 Gloss	2016 Gloss
Before Wiping	Gloss	52.4	46.5	28.3
	Gloss Retention	N/A	88.7%	54.0%
After Wiping	Gloss	52.4	49.9	38.7
	Gloss Retention	N/A	95.2%	73.8%

U. S. Bridges with Fluoropolymer Topcoats

Shelby Street Bridge, Nashville, TN
Gateway Bridge, Nashville, TN
Woodland St. Bridge, Nashville, TN
Victory Memorial Bridge, Nashville, TN
Topeka Blvd. Bridge, Topeka, KS
I-235 Pedestrian Bridge, Des Moines, IA
I-17 Pedestrian Bridge, Phoenix, AZ
Boynton Inlet Bridge, Boynton Beach, FL
Skydance Pedestrian Bridge, Oklahoma City, OK
Blue Bridge, Grand Rapids, MI
Salmon Creek Bridge, Albion, CA, Test patch
Duquesne University Skywalk, Pittsburgh, PA
Georgetown Pedestrian Bridges, Washington, DC
I-65 Arch Bridge, Columbus, IN, IN DOT
Tucson Historic Depot Pedestrian Bridge, Tucson, AZ
Navy Pier Pedestrian Bridge, Chicago, IL

Conclusions

- Based on accelerated and real time testing, fluoropolymer topcoats offer outstanding weathering and corrosion resistance
- Expected topcoat life in Japan is 30-60 years, as close as possible to 100 year coating
- Shop and field application
- Substantial life cycle cost advantages
- Environmental advantages

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