Ultra-Weatherable Fluoropolymer Coatings for Bridges

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ABSTRACT: Fluoropolymer coatings have been used on steel and concrete bridges for over 20 years. As a result of extensive laboratory testing and application success in the field, the Japanese Ministry of Land, Infrastructure, and Transport now requires the use of fluoropolymer topcoats on all bridges in Japan. The use of these topcoats should increase the effective life of bridge coating systems to at least 30 years, and sometimes to 60 years.
This paper will discuss the general characteristics of fluoropolymer coatings, including results of accelerated and natural weathering tests, as well as corrosion resistance. A review of specific bridge projects where long-term performance information is available will be given. Projects will include both steel and concrete bridges. Finally, examples of the use of fluoropolymer topcoats on bridges in the U. S. will be shown, including the Gateway Bridge in Nashville, one of *Roads and Bridges* top 10 bridges in 2005.

1 INTRODUCTION

Coatings have been used on steel and concrete bridges primarily to prevent corrosion. The last 30 years has seen the development and increasing use of zinc rich primers, which offer corrosion protection on steel substrates that approaches 30 years. Typical coating systems include a zinc rich primer, a middle coat, and a topcoat. The middle coat is used to prevent penetration of corrosion initiators in case of mechanical damage to the topcoat. The topcoat is usually a durable coating type used to impart a good appearance and will generally be more resistant to the elements than the middle coat. Examples of topcoats used in bridge coating systems include polyurethanes, acrylics, alkyds, vinyls, and chlorinated rubber.

The use of zinc rich primers has significantly reduced corrosion problems on steel bridges. Many bridges coated up to 30 years ago exhibit no signs of corrosion, even as the use of de-icing salt has increased. However, many of the topcoats used show extensive chalking, fading, loss of gloss and color, and coating loss. These changes are not necessarily significant in topcoats of gray, pale yellow, and other light colors. However, in recent years, a trend toward improving the aesthetics of bridge coatings has been seen. There is more interest in using bridges as a means of architectural expression, including the use of brighter, more vivid colors for topcoats. While polyurethanes and acrylics weather better than earlier coatings, neither can match the long-term performance of the zinc rich primers. As changes in coating requirements occur, there appears to be a requirement for topcoats that can match the long-term performance of zinc rich primers.

2 FLUOROPOLYMER COATINGS

Fluoropolymers have always offered intriguing possibilities in coatings. This has been primarily due to their outstanding UV stability, and their chemical and corrosion resistance. These properties are derived from the extreme stability of the carbon-fluorine bond present in all fluoropolymers. Unfortunately, fluoropolymers have characteristics that make their use in coatings problematic. Most fluoropolymers form films only at high temperatures, either by melting or coalescing, which precludes their use in field-applied coatings. Adhesion to substrates can be difficult with fluoropolymers. Because of their low surface energy, fluoropolymers cannot be readily recoated if damaged.

To address these shortcomings, a group of fluoropolymer resins known as fluoroethylene vinyl ether (FEVE) resins were developed in the early 1980's. As the name implies, these resins are copolymers of a fluoroethylene monomer and a vinyl ether monomer. As in other fluoropolymers, the fluoroethylene segment provides weather resistance, corrosion resistance, and chemical resistance. Incorporation of the vinyl ether segments into the polymer is unique, and provides properties unavailable in traditional fluoropolymers. By changing the type of vinyl ether, the physical properties of the polymer can be modified. Certain groups allow the polymer to be dissolved in solvents commonly used in coatings, or dispersed in water. Coating hardness, flexibility, chemical resistance, and toughness can be modified by changing the vinyl ether. Vinyl ether types that enable formulation of ambient temperature curable coatings can be added. This means that now, fluoropolymer coatings can be applied in the field to structures like bridges. This makes them suitable for both shop application for new construction and field application for existing bridges. Adhesion to substrates such as steel, concrete, composites is excellent, comparable to that achieved by polyurethane coatings. Finally, FEVE based coatings can be recoated, even after weathering, meaning that field repairs can be made.

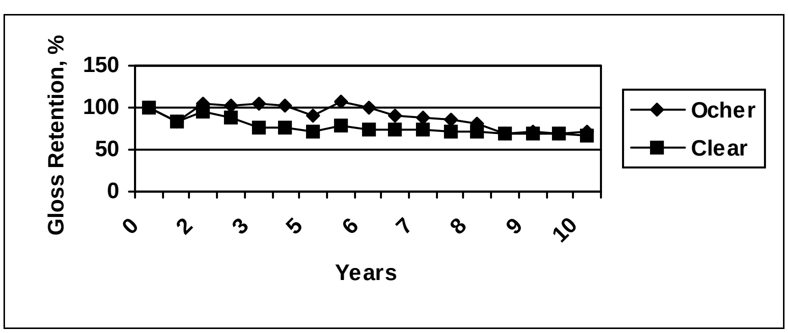
3. FLUOROETHYLENE VINYL ETHER (FEVE) BASED COATINGS

3.1 *Weathering of FEVE Based Coatings*

UV radiation found in sunlight contains enough energy to break chemical bonds in coatings. The results of this degradation include chalking, fading, and loss of color and gloss. In addition, degradation products are more easily removed from the surface of the coating. This leads to loss of coating thickness, and potential subsequent increase in corrosion.

The strength of the carbon-fluorine bond is greater than that found in UV radiation. Therefore, fluorourethane coatings based on FEVE resins offer excellent resistance to UV radiation, as measured by changes in gloss retention after exposure.

Natural weathering tests for coatings are often run in south Florida, due to the intensity of sunlight, humidity, and salt found there. Coated panels are placed on racks at specified angles, then allowed to weather. Physical properties, in this case, gloss retention, are periodically measured. Figure 1 below graphs gloss retention of a clear coating and a pigmented coating made with FEVE resins. In this particular weathering test, gloss retention is required to be greater than 50% after ten years of south Florida weathering. The FEVE based coating easily meets this standard.



Location: Miami, FL
Exposure: Direct, 30 Deg. South, Open Back

Figure 1. Ten-Year South Florida Weathering Test for FEVE Based Coating

In addition to natural weathering tests, there are a number of accelerated weathering tests used to ascertain the durability of coatings. The purpose of these tests is to attempt to reduce the amount of time required to screen coating formulations. There is considerable disagreement on the relationship between results obtained in accelerated weathering tests compared to actual weathering of coatings. Nevertheless, these tests are used extensively in the coatings industry, and may be especially useful to compare the relative performance of coatings.

The first accelerated weathering test is QUV-A exposure (ASTM D 4587). In this test, coated coupons are exposed to QUV-A radiation of 340 nm. UV exposure is typically followed by exposure to moisture by condensation for some period of time to simulate rainfall. The test may be conducted at elevated temperatures to enhance degradation. Results of the test are shown below in Figure 2. QUV testing is typically run for about 5,000 hours. In this test, the FEVE based fluorourethane shows little change in gloss even after 15,000 hours, far outperforming the standard urethane coatings, which are used extensively as topcoats on bridges.

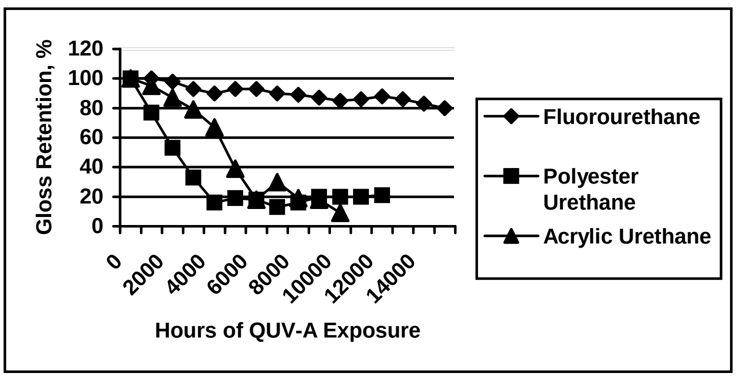


Figure 2. QUV-A Exposure Test: Gloss Retention of White Pigmented Coating Formulations

The second comparative accelerated weathering test is the EMMAQUA (Equatorial Mount with Mirrors for Acceleration with Water) test. In this test, coated coupons are exposed to natural sunlight concentrated with 10 reflective mirrors, exposing the panels to the entire spectrum of radiation found in natural light. The panels are sprayed with deionized water to simulate exposure to rain. Results are expressed as energy exposure per unit area rather than exposure time as in other tests. Figure 3 below shows results from one EMMAQUA test. PVDF is polyvinylidene fluoride, which is a fluoropolymer resin used extensively in the architectural industry for factory applied coatings. It is believed that exposure to 1,000 MJ/m^2 is equivalent to 10 years of natural exposure, so results below correlate to about 25 years of natural exposure.

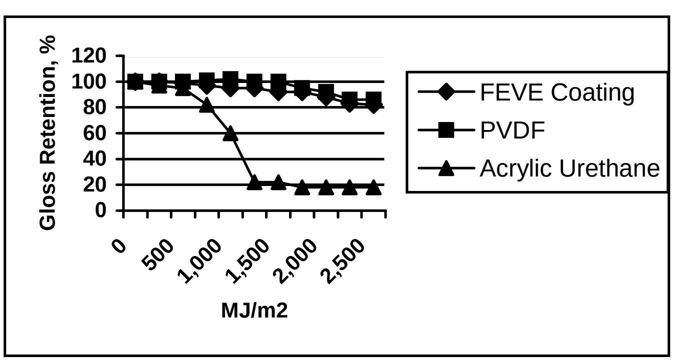


Figure 3. EMMAQUA Exposure Test Results of Pigmented Coating Formulations

3.2. *Corrosion Resistance of FEVE Based Coatings*

While aesthetic considerations in selection of bridge coatings are increasing, the primary reason for coating application is to prevent corrosion or degradation of the substrate, whether it is steel or concrete. Coating systems, not only topcoats, are used to prevent corrosion. On steel, a typical coating system consists of a zinc rich primer, an epoxy or urethane middle coat, and a topcoat. The topcoat and mid coat act to prevent corrosion by excluding contaminants that can initiate corrosion, like chloride or water. The zinc rich primer, while providing some barrier properties, works by setting up an electrical cell where the zinc is sacrificed preferentially to the steel. The primer is meant to be the last resort in preventing corrosion. Some of these primers are estimated to last for 30 years or more.

FEVE fluorourethane coatings assist in corrosion prevention due to their weathering properties. Because decomposition does not occur readily in FEVE coatings, practically the only decrease in coating thickness is due to physical removal by wind, rain, and other mechanical means. This means that even after years of exposure, FEVE coatings will lose less thickness, thus continuing to provide an effective barrier against corrosion initiators. In contrast, other polymeric topcoats degrade over time to lower molecular weight materials which are easily removed by mechanical means. The removal of these materials exposes a fresh surface to UV light, setting up further degradation, and additional coating removal.

The durability of FEVE coatings has been demonstrated in extensive testing. The Ministry of Land, Transportation, and Infrastructure in Japan operates a marine test station 250 meters offshore in Suruga Bay, the deepest bay in Japan. The platform is used to provide a real time test platform for coatings for various types of exposure, including immersion and tidal zone. FEVE based fluorourethane coatings were tested side by side with standard polyurethane coatings over a period of 16 years on this platform. Each coating system consisted of an inorganic zinc rich primer (75μm), an epoxy middle coat (150 μm), and a topcoat (25 μm). Coated panels were evaluated at regular intervals for gloss and color retention, as well as changes in coating thickness.

During the first seven years of the test, the FEVE fluorourethane coating showed no change in thickness. For the next nine years, the FEVE based topcoat showed an average loss of 0.38 μm/year, for a total loss of 3.4 μm over the entire test period. At this rate of change in thickness, the expected life of the fluorourethane topcoat would exceed 60 years. Analysis of the coating system by Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Microanalysis (EDX) indicated that no chloride had penetrated the FEVE based topcoat. No corrosion of the zinc rich primer was found, confirming that corrosion initiators had not reached the primer. The urethane topcoat in contrast, lost about 2 μm/year after the second year of exposure. The urethane topcoat was completely removed from the test coupon after 13 years.

One measure of corrosion is indicated by Electrochemical Impedance Spectroscopy (EIS). EIS involves sending alternating current between two electrodes, one a 3% salt water solution, the other the metal panel. The coated side of the panel is exposed to the salt solution. The change in impedance at a constant frequency of 1 kHz is then measured. The smaller the change in impedance, the better the corrosion protection offered by the coating system. In essence, the change in impedance can be related to the movement of corrosion initiators like chloride through the coating system. In the particular test, results of which are shown below in Figure 4, four coating systems were exposed for 1,000 hours in an accelerated weathering test. Then, the unscribed panels were subjected to 500 and 1,000 hours in the ASTM B-117 salt fog test, which is an accelerated test for corrosion. Results indicate that the FEVE based coating system far outperforms competitive systems. Because the coatings were subjected to accelerated weathering and corrosion tests prior to use in the EIS test, the results indicate that the competitive topcoats suffered some degradation, and therefore were permeable to corrosion initiators.

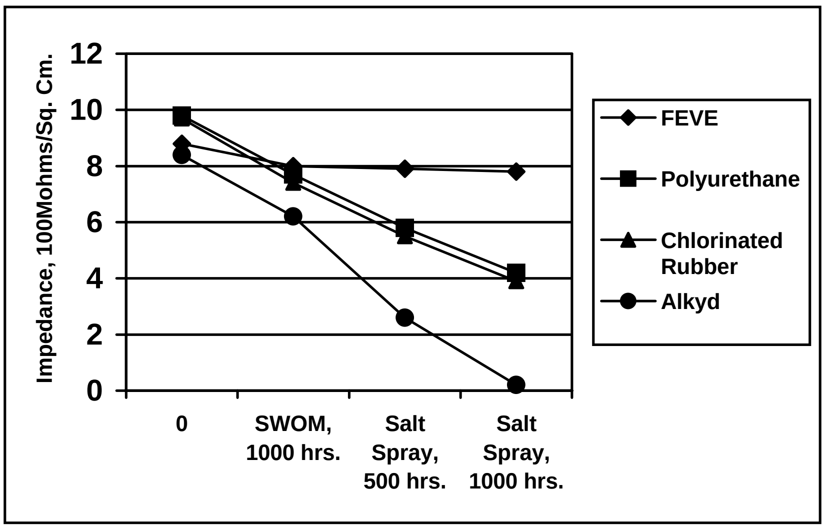


Figure 4. Electrochemical Impedance Spectroscopy Test Results for FEVE Based Coatings

4. BRIDGE PROJECTS USING FEVE BASED COATINGS

4.1 *Projects Demonstrating Long Term Performance*

Since FEVE resins were developed in Japan, the great majority of bridge applications demonstrating long-term performance were done there. In the mid 1980's a number of bridges were coated with FEVE based topcoats on half, and half with conventional topcoats. The performance of each topcoat was then observed over time.

The Tokiwa Bridge in Hiroshima was recoated in 1986; half with an FEVE based topcoat and half with a chlorinated rubber topcoat. Photos were taken over the next 20 years, examining the weathering of each coating system. Photos in Figure 5 below show weathering of the FEVE based fluorourethane topcoat through 2005. The consistency of gloss over that 19-year period is clear from the photos.

October, 1988 April, 1993 July, 2005

Figure 5. Tokiwa Bridge, Hiroshima, Japan, Repainted 1986

The portion of the bridge topcoated with chlorinated rubber showed a decrease in gloss almost immediately. Signs of rust and corrosion appeared after five years.

The Katsushika Harp Bridge was completed in 1986, although coating of metal components had begun as early as 1982. The coating system consisted of a zinc rich primer, epoxy middle coat, and FEVE based fluorourethane topcoat. In addition to steel, the concrete feet of the bridge were also coated with an FEVE based topcoat. In the case of concrete, primer coats of an elastomeric material were used to address flexibility requirements on concrete. In 2007, about 80% of the concrete piers were encased in steel to reduce potential damage from earthquakes. The side-by-side photos of the newly painted steel panels and the concrete feet painted in 1987 show the gloss retention of the FEVE topcoat.

Steel Panels Encasing Concrete, Painted In 2007

Original Concrete, Painted 1987

Figure 6. Katsushika Harp Bridge, Comparison of FEVE Coating from 1987 and 2007

4.2 *Bridge Projects in the U. S. Using FEVE Topcoats*

FEVE coatings have been used in the U. S. since the mid-1980's. Many of the applications for these coatings to date have been in the architectural market, mainly for commercial applications. Examples include coatings for aluminum canopies for gas stations, rehabilitation of monumental buildings, and corporate identity programs. In the last several years, FEVE based coatings have been finding more application in the U.S. in industrial maintenance coatings, for example, those used on water towers and bridges. Traditionally, the winners of contracts for these type of projects were the low bidders. Because FEVE based topcoats are 5-10 times the cost of traditional topcoats, it was rare that they could be used in a low bid situation. However, the use of life cycle costing, discussed in section 5 below, has allowed FEVE based coatings and other more expensive materials to be specified in these projects.

A series of bridges in Nashville, TN have been coated using FEVE based topcoats. FEVE based coatings were chosen for these projects due to the limitations in performance of a more conventional coating on a nearby structure. Components of this structure, painted red, had changed color to pink within three years. This led to fears that similar coatings used on these bridges would change color in similar manner.

The Shelby Street Bridge was the first bridge coated, using an inorganic zinc rich primer, an epoxy middle coat, and a fluorourethane topcoat. This bridge was to have been demolished in 1998; however, its historic nature led to efforts for its preservation. Eventually, the Shelby Street Bridge was converted to a pedestrian bridge linking the downtown entertainment area to the stadium on the east bank of the Cumberland River. The bridge was recoated in 2003. At 960 meters, it is one of the longest pedestrian bridges in the world. Figure 7 shows a photograph of the Shelby Street Bridge, three years after completion of the coating process.

Figure 7. Shelby Street Bridge, Nashville, TN, Photographed in 2006

The Gateway Bridge in Nashville won top honors in the National Steel Bridge Association 2005 Major Span category. The bridge also won a place in the Top Ten Bridges of 2005 list for Roads and Bridges Magazine. The bridge is 506 meters in length, and is Tennessee's first fixed, through-arch structure. The box structure, which is painted red, is topcoated with an FEVE resin based fluorourethane coating over an inorganic zinc rich primer and epoxy middle coat. A photo of the bridge is shown in Figure 8 below.

Figure 8. Gateway Bridge, Nashville, TN, Completed in 2004, Photo Taken 2006

There are two other bridges in Nashville that have been partially topcoated with an FEVE based fluorourethane topcoat, the Woodland Street Bridge and the Victory Memorial Bridge. Both are coated in the same manner as the Gateway Bridge, the red box color being the signature for all of the bridges.

5. LIFE CYCLE COST OF FEVE BASED TOPCOATS

As mentioned earlier, life cycle costs are being considered more in bridge markets. Usually, these costs are expressed in the applied cost of a coating, with labor making up 80 to 90% of the cost of field application. Material costs are therefore only about 10-20% of the total applied cost of the coating system. In a typical bridge coating system, three coats are used. Since the FEVE resin is used only in the topcoat, it has been determined that the initial applied cost of such a coating system is only about 10-15% higher than that of a standard polyurethane coating system.

Assuming that after ten years, the polyurethane topcoat will require replacement, the life cycle cost advantage swings to the FEVE based coating, yielding a cost advantage of about 18%. Assuming replacement of all coating layers after 18 years, the life cycle cost advantage of the FEVE coating rises to about 25%.

This life cycle analysis doesn't include other costs incurred during bridge repainting. The cost of closing lanes during painting operations, the use of maintenance dollars for painting, and liability costs can be substantially reduced by using FEVE based coatings.

Based on their analysis of life cycle costs, and on the field performance of FEVE topcoats over the last 20 years, the Japanese Ministry of Land, Infrastructure, and Transport has now required the use of fluoropolymer topcoats on all bridges in Japan, including new construction and repair. The Ministry expects a minimum of 30 years of topcoat life, and hopes to extend repainting cycles to 100 years in some cases.

5. CONCLUSIONS

FEVE topcoats have now been in use for over 25 years. Based on field experience over this time, it has been proven that the use of FEVE topcoats can substantially reduce life cycle costs for bridges and other structures, especially when costs like traffic diversion are factored in. The use of FEVE topcoats in combination with zinc rich primers should offer bridge coating systems that provide corrosion protection exceeding 30 years.

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