he history of coating system types used on steel bridges has always paralleled the evolution of coatings technology as a whole. When breakthroughs have occurred, the bridge coating market has paid attention and embraced these advancements. Sometimes, regulations have played a significant part in altering this course of evolution, but the goal of the stewards responsible for bridge maintenance and preservation has never changed. The ideal coating system will always be the one that offers the best protection of the substrate at a reasonable cost, with due respect for compliance with regulations.

The most popular long-life coating system in place at this time for bridges with challenging applications and environments is a three-coat system consisting of a zinc-rich primer, an epoxy midcoat and a polyurethane topcoat. Other less expensive coating systems still exist, but many provide lesser protection and have a shorter lifetime. Depending on the available funding for any specific bridge project, these options may be the only choice. However, if the goal of the bridge steward is the ultimate protection of the bridge against structural degradation for the longest period of time, the standard three-coat system is the preferred choice.

Fluoroethylene vinyl ether (FEVE) fluoropolymer technology has proven to be a successful addition to the global bridge coating market (Fig. 1). In the U.S., there is a growing interest from state DOTs, local municipalities and the private sector (Fig. 2). The discussion of the life cycle of a coating system has paved the way for this growing interest, as the cost of coating a bridge decreases dramatically when it is based on the lifetime of the coating system. When the life cycle costs of bridge painting and maintenance are taken into account, then the use of fluoropolymer coatings becomes cost effective.

This article will discuss the chemistry behind FEVE technology, coating types that can be formulated with FEVE resins, and the performance of FEVE-based coatings used as topcoats on steel bridges.

**FEVE Resin Structure**
FEVE technology is most effective when incorporated into the aforementioned three-coat system. The FEVE polyol resins play an integral part in the topcoat layer, replacing the standard acrylic or polyester polyols as the principle binder. This technology has been commercial since 1982 and has been used on bridge coating systems across the globe since its introduction. The key performance improvements of the FEVE polyol resins over traditional polyesters are their resistance against UV degradation and their resistance to moisture permeation. The structure of the resin’s backbone is illustrated in Figure 3.

The uniqueness of this resin lies in the combination of fluoropolymer chemistry with vinyl ether chemistry, allowing both chemistries to bring their respective strengths to the polymer’s performance. Without the presence of fluorine, the polyol would lack its superior weatherability and resistance properties. Without the vinyl ether, the common properties of most organic resins — solubility in solvents, available functional groups, and adjustability of the glass transition temperature (Tg) — would be absent and the resin could not function in liquid coatings.

**Coating Formulations with FEVE Resins**
As with any coating, the performance of the finished product is dependent on many factors. Each raw material plays a part in either improving or weakening the coating’s performance. When an FEVE polyol is part of a formulation, it can only benefit from the careful choice of other components in the formulation. The
whole concept of creating a coating that will endure for many years necessitates consideration of every ingredient in the coating to be the best choice for weatherability and resistance properties. There can be no weak link in the chain.

Several types of coatings can be produced with FEVE resin technology. The original coating in 1982 was a solvent-based, two-component finish that used an aliphatic polyisocyanate as the cross-linker. It strongly resembled conventional polyurethane finishes in curing behavior and methods of application. This system cures and applies just like a conventional polyurethane finish, but with far superior exterior durability. This coating type is still the fluorinated topcoat of choice on bridges. VOC regulations in certain regions of the U.S. have made reformulation necessary, but the availability of solid FEVE resins and their ability to dissolve in VOC-exempt solvents have preserved the presence of this technology to date.

In 2012, a water-based FEVE polyol dispersion entered the coatings market. This resin utilizes water-emulsifiable aliphatic polyisocyanates as its cross-linking partner. Up to now, water-based, two-component polyurethane technology has not been widely accepted in the bridge coating market, due to the increased sensitivity to atmospheric conditions like temperature and humidity when these coatings are applied. Consequently, this resin has only been tested in laboratory trials. To date, the advantages of FEVE water-based resin chemistry are only being realized in factory-applied finishes for prefabricated bridge components, where the reduction in VOCs will improve the air quality of the interior working space.

A third FEVE resin type, a water-based emulsion synthesized to a high molecular weight, is available for use in one-component coatings for bridges. Several DOTs across the country have incorporated one-
component, water-based coatings, which are predominantly acrylic-based. Extensive lab work has been completed in the testing of topcoats that contain FEVE emulsions. Due to the strict limitations in cost dictated by the current price range of the acrylic-based coatings that have penetrated this market, most of the FEVE emulsion-containing formulations use both FEVE emulsions and acrylic emulsions as the binder portion. Performance improvement has been evident in formulations utilizing 20 to 50 percent FEVE emulsion as the binder, depending on the particular color.

It is prudent to mention the mechanism by which FEVE resins resist degradation by UV radiation. FEVE resins do not absorb the sun’s UV radiation. Without absorption, no excitation of the FEVE chemical bonds can occur, and the resin basically remains unchanged. This is the key to the superior durability of FEVE resins. Accordingly, since they do not absorb the light, they cannot block it either. This is an important point to consider when formulating a FEVE-based coating. UV absorbing and light stabilizing additives must be formulated into FEVE resin-based clear coatings to protect any base coating to which it is applied. The most popular additives are the organic UV absorbers and hindered amine light stabilizers available on the market. To expand on this any pigmented FEVE resin-based formulation will also be improved with the use of UV light-stabilizing additives. These additives can extend the lightfastness of pigments, which allows coatings systems to remain robust against UV degradation.

Fig. 4: This graph compares two different FEVE resin-based coatings against two other popular bridge topcoats. The coatings were tested inside of a QUV weatherometer for 3,000 hours, and the two FEVE-based coatings showed significantly better gloss retention percentages than the other coatings tested.
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Performance Properties

Both accelerated exposure testing and real-life exposure testing have been performed on coatings using FEVE technology. Figures 4 (p. 40) and 5 show comparisons of FEVE resin-based coatings with different coatings also used as topcoats for bridge coating systems.

The graph in Figure 4 shows two different FEVE resin-based coatings — a 100% FEVE polyol, and a 78% FEVE polyol blended with 22% polyester polyol. FEVE solvent-based resins, like the FEVE emulsions, have a wide range of compatibility with other polyols. Laboratory work is being done to measure the performance capabilities of these blended formulations. Some physical properties of the paint film, such as flexibility, can be improved when non-FEVE polyols become part of the formulation. As this graph shows little change with the 60-degree gloss at 3,000 hours, the exposure is still in progress.

The second test exposure was done at the Equatorial Mount with Mirrors for Acceleration with Water (EMMAQUA) test site in Arizona (Fig. 5). The measurement of UV exposure is in megajoules per square meter (MJ/m²). Again, the FEVE coating showed the best gloss retention percentage of all the coatings tested.

Certain bridge applications are being monitored for their performance. The Tokiwa bridge is located in Japan (Fig. 6). This bridge was recoated in 1986, using two coats of an epoxy primer and two coats of a FEVE-based topcoat. The changes in 60-degree gloss and color over 25 years of exposure are shown in Table 1 (p. 44).

Fig. 5: This graph compares the gloss retention of a FEVE resin-based coating against a PVDF polyurethane coating and a standard acrylic-urethane bridge topcoat. As the exposure to UV light increased, the FEVE coating again displayed the best gloss retention percentage.
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the procedure for coating a bridge so that the critical components of the bridge get the best protection from the coating system. Conversely, the remaining components, which are not prone to early coating failure, can be given a lesser degree of protection. This idea is explained in detail in a JPCL article written in 1984 by Clive Hare, entitled “Specific Utility In the Design of Coating Systems for Steel Bridges.” Hare states that, “The ever-increasing demands on bridge paint systems (fed by increasing traffic loadings, salt usage, and years of neglect) must be met by the use of heavier duty coating systems applied with great exactitude over better surfaces.”

The article goes into detail about specific areas of bridges that have historically experienced premature coating failure resulting in...

Table 1: Results of FEVE Topcoat Application on Tokiwa Bridge

<table>
<thead>
<tr>
<th>Initial 60° Gloss</th>
<th>Final 60° Gloss</th>
<th>Gloss Retention (%)</th>
<th>Color Change ($\Delta E$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>69</td>
<td>91</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Fig. 6: These photos show the Tokiwa Bridge in Japan, which was coated with a FEVE-based topcoat in 1986. The photo on the left was taken in 1988, the middle photo in 1993, and the photo on the right in 2014. Clearly, there has been very little change in the coating’s gloss and appearance over the years.
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damaging corrosion of the steel. The seams, edges, bolts and rivets of bridges are most susceptible (Fig. 7). These are the areas that need coating systems that are more functional for corrosion resistance. In many instances, these areas do not receive the level of UV radiation experienced by other parts of the bridge, but the need for recoating is still critical.

FEVE Coatings Systems on Bridges

The use of a FEVE resin-based topcoat has demonstrated the ability to resist the penetration of chloride ions through energy-dispersive X-ray microanalysis testing. However, the difficulty of attaining success lies in the morphology of certain bridge components and the challenge of coating application on these components. Although FEVE technology can offer greater longevity of the topcoat on a bridge, the protection of every steel surface, for up to thirty years, is still a significant challenge.

Conclusion

Although FEVE technology has shown itself as a viable alternative to standard topcoats for the three-coat system for bridges, research is continuing on the utilization of this technology in combination with zinc-rich primers or epoxy primers to create an effective two-coat system. The elimination of an entire coat will significantly lower the final cost of the coating project.

As the evolution of coatings for bridges continues, the ultimate goal will always be the most efficient protection of the steel substrate at the most reasonable cost. If we can succeed in prolonging the life of an important part of our nation’s infrastructure, much will be gained from this success.

About the Author

Bob Parker is a technical service chemist for AGC Chemicals Americas in Exton, Pa. He has been involved in formulating paints and coatings for over 30 years. He received his Bachelor of Science degree in chemistry from Alvernia College. He is currently responsible for technical service for LUMIFLON fluoropolymer resins in the U.S.
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