For many years now, three-coat zinc-rich/epoxy/polyurethane systems have been identified as the best coating systems for protecting steel bridges from corrosion.1,2,3 These systems are widely used by many states. For humid environments, three-coat zinc-rich moisture-cured urethane (MCU)/MCU/polyurethane systems are used.4 However, application and cure of three coats takes a considerable amount of time. Generally, a highway needs to be closed for at least a day to complete the job of painting a highway overpass.

New systems, two-coat rather than three-coat, are becoming attractive for protecting steel bridges. The two-coat systems consist of one zinc-rich primer matched with one of three types of fast-dry, high-build topcoats: a polyaspartic, a polyurethane, or a polysiloxane. With the epoxy intermediate layer eliminated, a highway overpass can in many instances be coated completely overnight. Two-coat systems can reduce painting labor as well as time, increasing productivity and thereby decreasing the overall cost of a job.

Conventional polyurea is known to cure very rapidly, but it needs special and expensive equipment to apply. Polyaspartics, a type of polyurea, not only dry fast but also can be applied at high thickness by a conventional spray gun, making application less complicated. This so-called breakthrough technology for repainting bridges also minimizes the duration and public impact of work zones, and has been recently used by some states.5,6 To investigate the feasibility of this new technology, the Federal Highway Administration (FHWA) conducted a study to compare the performance of these two-coat, fast-dry systems with the conven-
tional three-coat systems. Both laboratory accelerated test results and outdoor exposure results are presented and compared in this article.

**Experimental Procedure**

All of the coating systems were applied on steel surfaces that were abrasive blast-cleaned to SSPC SP-10 in accordance with the manufacturers’ specifications. The size of all the test panels was 10 cm x 15 cm x 0.48 cm. A 5-cm scribe was made diagonally on all of these coated panels prior to testing.

The solids content was determined using ASTM International’s Method D 2369. The pigment content was ascertained using ASTM Method D 2371. The zinc content was semi-quantitatively determined by a combined scanning electron microscopy/energy dispersive X-ray spectrometry analysis (SEM/EDS) of an isolated pigment fraction, which was pressed into a pellet. The drying times of all of the topcoats, including dry-to-touch times and dry-to-handle times, were tested using ASTM Method D1640. The adhesion strengths were measured with a pneumatic pull-off adhesion tester (ASTM D 4541). The 60° gloss was measured following ASTM Method D 525.

Both laboratory and outdoor tests were used to evaluate the coating performance in this study. Four replicate panels were prepared for each coating system for both laboratory and outdoor tests. In the laboratory test, the panels were cycled through freeze, ultraviolet light (UV)/condensation, and salt-fog/dry-air conditions a total of 10 times over a 5,000-hour duration. The hot salt-fog, generated with a 5 wt% solution of NaCl, was alternated with ambient air at one-hour intervals during the third phase of each cycle.

The test conditions are detailed in Table 1. The panels were examined for any surface failures such as blistering, rusting, or other imperfections, and were measured for scribe creepage at 500-hour laboratory test intervals. The rust creepage developed at the scribe was measured using the FHWA imaging technique, which has been designated as ASTM Method D 7087-05a. The total creepage area was measured by tracing its perimeter onto a transparent plastic sheet with a fine-tipped black permanent marker, scanning the traced image into a computer, and using software to compute the area of the traced region. Scribe creepage was determined by dividing the integrated area by a value twice the selected length of the scribe line. The creepage area at scribe on each exposed panel was traced twice.

Another set of coated panels was
exposed for two years at a marine site in Sea Isle City, New Jersey. All of these test panels were placed at a 45-degree angle on wooden racks, facing directly south, and were sprayed with natural seawater on a daily basis. The outdoor test environment simulates the frequent exposure to road salts on bridges in cold climates and the frequent saltwater exposure of bridges at the splash zone. The environment is the most aggressive type of outdoor test protocol.

**Results and Discussion**

All the coating systems evaluated for their performance in this study are described in Table 2. Three three-coat zinc-rich systems were used as controls. The volatile organic compound (VOC) content of all the coating materials was less than or equal to 340 g/L (2.8 lb/gal). The eight two-coat zinc-rich primer/topcoat systems include four original manufacturer-recommended systems and four product-interchange systems that used a primer from one vendor and a topcoat from another.

The four product-interchange systems were tested to represent bad practice. The use of one vendor’s topcoat with another’s primer is generally not recommended and in fact typically voids both manufacturers’ warranties. Despite the many warnings against this practice, it is not uncommon, especially when a topcoat is being removed and replaced with another topcoat without determining manufacturer information about the primer that remains and its compatibility with the topcoat specified. As will be shown below, the interchange systems performed badly, a fact that should reinforce the importance of not interchanging products from different manufacturers on new or existing steel.

**Properties of Paint Materials**

The drying times of all of the topcoats were examined (Table 3). The dry-to-touch times for all of the topcoats ranged from 0.5 to 1.6 hours and the dry-to-handle times ranged from 3.0 to 5.0 hours. The drying times were very similar for the topcoats in the two-coat systems and in the three-coat systems. The polyaspartic topcoats were applied at thicknesses of 7 or 8 mils, yet had dry times similar to the two- and three-mil thicknesses of the T3 and T4 aliphatic polyurethane topcoat (Table 2). It should be noted here that all the zinc-rich primers dried in two hours.

The primers and topcoats were analyzed in terms of solids content, pigment content, and zinc content. The solids content of all the primers represented about 90 wt% of wet paint. The zinc content in the applied primer films ranged from 81 to 83 wt%, meeting class level 2 of SSPC Paint Specification No. 12. The zinc content determined by the SEM/EDS method agreed very well with the manufacturers’ data. In addition, analysis of the
topcoats showed that all had high-solids content (>70 wt%).

Laboratory Tests
None of the coating systems showed any surface failures except System 6, which exhibited an extensive topcoat-wrinkling failure. After the 5,000-hour laboratory test, the topcoat gloss was reduced for the two-coat systems (T1, T2, T5, and T6), but the topcoat gloss of three-coat systems (T3 and T4) remained the same (Fig. 1).

System 6, with the polyaspartic topcoat (T1), lost the most of gloss (21%), but this behavior would be affected by the surface wrinkling. In general, the adhesion strength remained nearly constant. Figure 2 shows the overall adhesion losses at the weakest point before and after exposure to the test environment. Among all the coating systems, those coated with inorganic zinc alkyl silicate primer (Systems 5, 8, 9) displayed the lowest adhesion strength (~ 5.0 MPa), due to the well-known low cohesive strength of the inorganic zinc primer. Adhesion of the other systems was found to be at least two or three times as strong.

All of the coating systems developed rust creepage at the scribe after the 5,000-hour test, and the mean creepage distance grew linearly with test time after rust creepage became visible in all cases. Mean creepage was obtained by averaging the creepage of four replicates, i.e., eight measured values. Using a statistical linear regression analysis, relatively high correlation factors ($R^2$) were obtained indicating a good linear fit. From slopes of the lines, the corrosion rate for each coating system can be estimated. In addition, from the incubation time when scribe creepage starts to appear initially, the coating performance can be differentiated.

Three-coat systems — The three-coat zinc-rich systems (Systems 3, 4, and 5)
developed scribe creepage of 1.7, 1.4, and 2.8 mm, respectively, after the 5,000-hour cyclic freeze/UV-condensation/salt fog dry air test. The extent of the scribe creepage was found to be small, indicating good coating performance on the SSPC SP 10 steel surfaces. The creepage criterion for a zinc-rich coating system is no more than 2 mm after the 5,000-hour cyclic test (ASTM Method D 5894) in the AASHTO/NTPEP program. Even though the FHWA-developed test for evaluating bridge coatings\(^5\) is somewhat different, particularly in the inclusion of a freeze cycle, the creepage produced in this more severe environment is considered to be relatively small. The inorganic zinc system (System 5) did not perform as well as not just rust alone.

**Two-coat systems** — The two-coat rapid deployment systems (Systems 1, 2, 10, and 11) exhibited scribe creepage of 3.1, 3.3, 1.6, and 1.6 mm, respectively after the 5,000-hour test. The first two systems with polyaspartic topcoats performed as well as or slightly worse than the three-coat systems with the epoxy intermediate coat. On the other hand, the latter two systems (Systems 10 and 11), using a different type of zinc-rich primer and the topcoats with slightly longer drying times than polyaspartics, performed as well as the three-coat systems (Systems 3 and 4) in terms of the small amount of scribe creepage (< 2 mm). These low failure results suggest that the use of the two-coat systems may have promise for painting steel bridges, particularly since two-coat systems can reduce labor cost and traffic congestion.

**Interchange of products from different manufacturers** — Coating systems with organic zinc epoxy primer and inorganic zinc alkyl silicate primer have been applied over many steel bridges in the U.S., and many of these primers have been re-topcoated when the original topcoat no longer served its protective function. As noted above, new topcoats applied over existing primers are not always from the same manufacturer and are not always even tested for compatibility with the original topcoat, despite the fact that the interchange of products from different manufacturers is not considered good practice. Our findings below reinforce recommendations against this practice.

To investigate the viability of using a polyaspartics topcoat together with the zinc-rich primers from different manufacturers, we evaluated the performance of topcoats (T1 and T2) using both an organic zinc primer (P3) and an inorganic zinc primer (P4). At the scribe, the organic zinc primer topcoated with a polyaspartic (Systems 6 and 7) performed better than Systems 1 and 2 that used zinc-rich moisture-cured urethane primers. The creepage developed at the scribe was found to be very small: 0.8 and 1.6 mm for the

### Table 3: Drying Time for Different Topcoats

<table>
<thead>
<tr>
<th>Topcoat</th>
<th>System Used</th>
<th>Dry Film Thickness(^a) µm (mil)</th>
<th>Dry Time, Hours Dry-to-Touch Time</th>
<th>Dry-to-Handle Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>2-coat</td>
<td>200 (8)</td>
<td>0.5</td>
<td>3.0</td>
</tr>
<tr>
<td>T2</td>
<td>2-coat</td>
<td>175 (7)</td>
<td>1.0</td>
<td>3.5</td>
</tr>
<tr>
<td>T3</td>
<td>3-coat</td>
<td>75 (3)</td>
<td>1.0</td>
<td>5.0</td>
</tr>
<tr>
<td>T4</td>
<td>3-coat</td>
<td>50 (2)</td>
<td>1.0</td>
<td>3.0</td>
</tr>
<tr>
<td>T5</td>
<td>2-coat</td>
<td>100 (4)</td>
<td>0.5</td>
<td>4.5</td>
</tr>
<tr>
<td>T6</td>
<td>2-coat</td>
<td>150 (6)</td>
<td>1.6</td>
<td>5.0</td>
</tr>
</tbody>
</table>

\(a\): Targeted dry film thickness in the dry time test

### Table 4: Comparison of Scribe Creepage Developed by Laboratory and Outdoor Tests

<table>
<thead>
<tr>
<th>Test Coating System</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Scribe Creepage, mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A 5,000-hour laboratory test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 2-year outdoor exposure in marine environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>3.1</td>
<td>3.3</td>
<td>1.7</td>
<td>1.4</td>
<td>2.8</td>
<td>0.8</td>
<td>1.6</td>
<td>4.0</td>
<td>5.4</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>1.5</td>
<td>1.0</td>
<td>0</td>
<td>1.7</td>
<td>0</td>
<td>1.3</td>
<td>2.6</td>
<td>1.8</td>
<td>0.9</td>
<td>0.8</td>
</tr>
</tbody>
</table>

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developed both rust creepage and topcoat delamination at the scribe, suggesting low compatibility of the topcoat T2 to the inorganic primer.

Among the four interchange systems, only one system performed well (System 7). Therefore, to ensure good coating performance, both the organic zinc primer and the inorganic zinc primer should only be used with their manufacturer’s recommended product for topcoating.

Outdoor Exposure
After two years of outdoor exposure, two of the interchanged two-coat systems (System 6 and System 7) showed cracking all over the coating surfaces. This failure mode is worse than the wrinkling observed in the laboratory test for System 6. The conditions of System 6 and System 7 after the exposure are shown in Figs. 4 and 5, respectively. The aggressive environment and intense ultraviolet light present at Sea Isle, New Jersey, probably caused the failure because such failure for System 7 was not observed in the laboratory test.

Only the polysiloxane topcoat (T6) showed no gloss reduction. All of the other topcoats showed gloss reduction in the range of 60 to 90% (Fig. 6). This large gloss reduction was attributed to the high UV light intensity at the outdoor exposure site. Among six topcoats, polysiloxane has illustrated the highest ability to retain gloss under the intense UV condition. Adhesion strength before and after the two-year outdoor exposure is shown in Fig. 7. The pattern of adhesion strength is very similar to that in the laboratory test. Essentially, these results demonstrate the retention of the mechanical strength of all the coating systems throughout the test period.

Three coat systems — The three-coat zinc-rich systems exhibited scribe creepage of 1.0, 0, and 1.7 mm, respectively, after a 2-year outdoor exposure (Table 4). The amounts are smaller than those obtained by the 5,000-hour accelerated laboratory test, but the relative performances are similar.

Two-coat systems — Systems 1, 2, 10, and 11 exhibited scribe creepage of 0, 1.5, 0.9, and 0.8 mm respectively after two years of outdoor exposure (Table 4). These results suggest that System 1 was the best performer among these four systems after the two-year outdoor exposure; the different performance behavior of System 1 found in the laboratory test and in the outdoor test must be caused by the different environment conditions in these two tests. The laboratory environment is well-controlled, but the outdoor environment is variable (e.g., the number of rainy days, amount and frequency of rainfall, sunny days and sun intensity, and temperatures).

Interchange of products from different manufacturers — After the two-year outdoor exposure, the performance at the scribe for the organic zinc primer/polyaspartic systems (Systems 6 and 7) was similar to that of Systems 1 and 2, which had zinc-rich moisture-cured urethane primers. The rust creepage developed at the scribe was found to be none or very small: 0 and 1.3 mm for the two systems, respectively (Table 4). These creepage values are similar to those obtained with the
three-coat zinc-rich systems. However, the organic zinc primer topcoated with either T1 or T2 developed severe surface cracking (Figs. 4 and 5). Again, it appears that these coating systems do not have proper primer/topcoat combinations. On the other hand, the inorganic zinc primer appears to be even more incompatible with polyaspartics, because both Systems 8 and 9 exhibited a large amount of scribe creepage—2.6 and 1.8 mm, respectively. System 9 panels were found to develop both rust creepage and topcoat delamination at the scribe, suggesting low compatibility of the topcoat T2 with the inorganic primer. Again, these results indicate that both the organic zinc epoxy primer and the inorganic zinc primer should only be used with topcoats that the manufacturers recommend.

**Summary and Conclusions**

**Rust Creepage at Scribe**

The current commercial two-coat zinc-rich primer/fast-dry topcoat systems all performed very well, without any surface failures, but with no rust creepage or a small amount developed at the scribe after both the 5,000-hour accelerated laboratory test and the two-year outdoor exposure in a salt-rich environment. These systems included moisture-cured, zinc-rich primers topcoated with polyaspartics, and organic zinc epoxy primers topcoated with either fast-dry polyurethane or polysiloxane. The performance of these coating systems was similar to or slightly poorer than the conventional three-coat zinc-rich/epoxy/polyurethane systems. These good performance results suggest that the new two-coat zinc-rich coating systems can replace the three-coat systems to protect steel structures without sacrificing much corrosion resistance. At the same time, painting costs and traffic congestion will be greatly reduced.

In addition, it was found that the organic zinc epoxy primer topcoated with two different polyaspartics (Systems 6 and 7) performed as well at the scribe as those topcoated with the matched intermediate coat and topcoat designed by the same manufacturers. Unfortunately, one of the two systems (System 6) developed topcoat wrinkling...
failures after the 5,000-hour laboratory test, and both systems displayed cracking after the two-year outdoor exposure. The organic epoxy zinc primer as well as the inorganic zinc alkyl silicate primer can only be used with their own matched topcoats; otherwise, performance is dramatically reduced at the scribe when they are topcoated with polyaspartics. These results indicate that the new polyaspartics topcoats should be used with the moisture-cured urethane primers as designed by their manufacturers. Their use for topcoating other manufacturers’ organic zinc epoxy primers and inorganic zinc alkyl silicate primers is not recommended.

In summary, almost all of the systems showed no surface blistering and rust after exposure, and all of the manufacturer-recommended two-coat systems had generally good resistance to creepage at the scribe. The two-coat organic zinc epoxy primer with the fast-dry polyurethane or polysiloxane topcoat and the three-coat conventional organic zinc epoxy/epoxy/polyurethane systems performed slightly better than the two-coat moisture-cured zinc primer with fast-dry polyaspartics topcoat.

**Physical and Chemical Properties**

All the zinc-rich primers in the candidate coating systems contained at least 80 wt% of zinc dust, and the topcoats used for the two-coat systems dried very fast compared to the three-coat systems. All the paint materials have high-solids contents.

The gloss of the topcoats in the two-coat zinc-rich coating systems was reduced after the 5,000-hour laboratory test, but it stayed the same for the topcoats of the three-coat zinc-rich coating systems. The conventional aliphatic polyurethane overall performed slightly better than the fast-dry polyaspartics, polyurethane, and polysiloxane after the laboratory test using a UVA 340 lamp. However, only polysiloxane retained much of its gloss under the intense UV condition existing in the outdoor exposure site at Sea Isle, NJ.

The adhesion strength showed little variations before and after both the 5,000-hour cyclic laboratory test and the two-year outdoor exposure.

**References**


Dr. Shuang-Ling Chong began working at the Federal Highway Administration in 1989. She has worked on all generic types of bridge coatings, (e.g., low-VOC coatings, moisture-cured urethanes, water-borne coatings, and two-coat systems); leaching of blasted paint residues; chloride testing methods; and failure analysis. Dr. Chong is a research chemist as well as manager of TFHRC Coatings and Corrosion Laboratory and has more than 30 years of experience in various fields of chemical research. She is a member of numerous industry and standards organizations, including SSPC, ASTM, TRB, and ACS.

Ms. Yuan Yao joined SaLUT, Inc. in 1994, working on performance evaluations of various coating types and a wide range of testings. She also has worked on analytical techniques in the TFHRC Coatings and Corrosion Laboratory as an on-site contractor. She is a senior chemist and has worked on many chemistry and coating projects for 15 years.

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