Performance of Polymer Coated Corrugated Steel Pipe

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Abstract: The durability of drainage pipe is a concern to the civil engineer. The National Corrugated Steel Pipe Association (NCSPA) has developed a Test Protocol for the evaluation of new coatings. The protocol includes a laboratory simulation and field service component. Concurrent with the protocol development, the industry has worked with several manufacturers to develop improved coatings to improve corrugated steel pipe (CSP) durability. This paper will discuss the laboratory simulation testing and field service evaluations of one of those coatings – polymer coated corrugated steel pipe. Field inspections document over 20 years of field performance in eight states and a variety of service environments. The combination of simulation test results and field evaluations show the coating is highly resistant to abrasion and delamination and can extend the service life of corrugated steel pipe in excess of 50 years.

INTRODUCTION

The durability of drainage pipe is a concern to the civil engineer. A recent TRB synthesis discusses drainage pipe durability at length. As a result of continued interest in improving the durability of corrugated steel pipe products, the corrugated steel pipe industry has sponsored extensive research on improved coating materials. As part of this research effort, NCSPA has developed a suggested test protocol for new corrugated steel pipe (CSP) coatings to extend invert life. The NCSPA Test Protocol includes four tiers of test procedures for the evaluation of a new coating. Tiers 1 and 2 are intended to confirm the basic suitability of the coating for use on CSP. Tier 1 includes laboratory performance tests while Tier 2 includes laboratory abrasion tests. Tier 3 is a simulated abrasion test while the fourth tier of testing is field exposure. This paper will concentrate on the simulated lab testing (Tier 3) and field exposure (Tier 4) data developed for polymer coated CSP.

Polymer coatings were first introduced for CSP applications in the 1970's. These coatings offered a promising means of increasing the corrosion and abrasion resistance of CSP. At the time several different types of polymer coatings were available. Of these polymer coatings, Dow “Trenchcoat” proved to be the best performing and presently is the only polymer coating remaining in production. The product is a heavy gauge protective film that is laminated to the inside and outside of galvanized sheet metal prior to forming CSP, providing a corrosion and abrasion barrier on the finished product. The film is comprised of two layers that have an overall nominal thickness of 10 mils. The product is fully described in ASTM A742 Polyurethane Precoated Sheet for Sewers and Drains. Numerous laboratory and field studies have been conducted on this product throughout the county. These studies have been conducted by independent engineering firms, DOT's, CSP Fabricators, NCSPA members and the coating supplier. This paper presents the findings of laboratory and field studies of Trenchcoat (hereinafter referred to as “polymer coated”) conducted by Corrpro Companies.

SIMULATED ABRASION TEST (TIER 3)

The original Tier 3 simulated abrasion test contained a very severe level of abrasion that would be outside of the recommended service environment for traditional CSP materials. The Tier 3 test was originally designed to be a short-term destructive test that would quickly provide relative performance results. To extend the usefulness of the full-scale abrasion testing, the scope of the abrasion test was expanded to include alternative, lower levels of abrasion. This allows the industry to position coating products in the marketplace based on their resistance to various levels of abrasion.

To accomplish these goals, various pipe slopes and abrasive materials were used in an attempt to simulate varying exposure environments. The Tier 3 test protocol is designed to test the abrasion resistance of a corrugated steel pipe coating by passing aggregate, accelerated by flowing seawater, through test sections of pipe. The accepted test method is to position the test section at an 11 degree angle from horizontal and pass 3/4” trap rock through the pipe using 550 gpm flowing seawater. As part of an effort to develop a more comprehensive test...
procedure, a different aggregate and different flow geometry were tested. The aggregate examined was a 3/8” local
stone, propelled by 550 gpm, and the new flow angle used was a 2-degree angle from horizontal.

Figure 1 shows both bedload materials. The ¾” trap rock was the more severe of the two bedload materials
because of size, angularity, and hardness of the material. It is commonly used as bed materials for railroads in the
Eastern US. The 3/8” local stone is considered to be less severe because it is smaller, rounded, and softer stone. It
has a variety of common uses including landscaping.

![Figure 1: Bedload Materials (3/4” trap rock on left, 3/8” local stone on right)](image)

Coating thickness measurements were the primary method of tracking coating deterioration. A series of
measurements were made on the upstream edge of the corrugation. The measurements were made on 1-inch spacing
starting at the bottom of the pipe. Exact locations were marked so that the coating loss could be accurately tracked.

Five test were run on polymer coated CSP. Table 1 presents a summary of the test conditions and the
results. In previous testing under the most severe abrasion conditions, there was exposed galvanizing at the crests of
the corrugation. None of the less-abrasive test scenarios evaluated showed any consistent exposed galvanizing.
Coating loss was limited to less that half of the film thickness in these tests.

### Table 1: Summary of Test Results for Polymer Coated CSP

<table>
<thead>
<tr>
<th>Bedload</th>
<th>Slope</th>
<th>Max Thk Loss (mils)</th>
<th>Max Exposed Galv (sq cm)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>¾ Rock</td>
<td>12 degree</td>
<td>10</td>
<td>9.5</td>
<td>Data from original study</td>
</tr>
<tr>
<td>3/8 Stone</td>
<td>12 degrees</td>
<td>4.7</td>
<td>0</td>
<td>One lockseam beginning to show coating disbondment</td>
</tr>
<tr>
<td>3/8 Stone</td>
<td>12 degrees</td>
<td>4.2</td>
<td>0</td>
<td>No exposed Galvanizing, max loss at invert</td>
</tr>
<tr>
<td>3/8 Stone</td>
<td>2 degrees</td>
<td>1.6</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3/8 Stone</td>
<td>2 degrees</td>
<td>1.2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>12 degrees</td>
<td>0.5</td>
<td>0</td>
<td>No visible wear</td>
</tr>
</tbody>
</table>

There was no exposed galvanizing after testing at either slope using the smaller bedload. Figure 2 shows the
thickness loss around the invert of the pipe for each of the tests. Notice that there is no data for the original test
conditions (i.e., ¾” Rock and 12 degree slope). We can deduce that the maximum coating loss for this condition
was greater than 10 mils since exposed galvanizing was observed. The data suggest that at a lower flow angle the
coating loss was more uniform across the bottom quadrant of the pipe section. However, at a higher flow angle the
coating loss was much greater at the very bottom of the pipe than the loss at a 2-degree flow angle, even with the
same bedload material. The data for the polymer precoat suggests that the impact of bedload material and pipe slope
is similar in relative magnitude.

Coating damage in the most severe abrasive environment (Level 4) was confined to less than 4 square
inches (less than 2.5% of the total surface area) on the upstream crest of the corrugation. The coating was typically
well adhered at the edges of the worn area. None of the less-abrasive test scenarios evaluated (level 3 abrasion and lower) showed any consistent exposed galvanizing. Coating wear was limited to less than half of the film thickness in the most severe of these tests (i.e., Level 3 abrasion conditions).

FIELD INVESTIGATIONS (TIER 4)

During the past five years Corrpro engineers have conducted field investigations of 44 polymer coated CSP pipes in 8 states. Table 2 summarizes the locations of the investigations. The table also includes reference reports for each of the studies. The sites in the Upper Peninsula of Michigan\(^3\) include parallel runs of galvanized, aluminized, and polymer coated pipe. The sites in Mississippi, Arkansas, Florida, California, and Colorado were evaluated as an update to several previous studies evaluating the comparative performance of alternative corrugated metal pipe materials. The complete report\(^5\) provides comparative data on aluminized, galvanized, and other polymer coated substrates. Only the data for polymer coated G210 galvanized is referred to in this paper. The New York and Wisconsin sites include multiple polymer-coated pipes used in construction projects – it is reasonable to assume that no special practices were used in these installations. The Wisconsin site also includes a test installation of four different materials which was jointly sponsored by the FHWA and Wisconsin DOT.\(^4\)

**TABLE 2 Inventory of Pipes Inspected**

<table>
<thead>
<tr>
<th>State</th>
<th>Region</th>
<th>No. of Pipes</th>
<th>Age (years)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan</td>
<td>Upper Peninsula</td>
<td>2</td>
<td>23</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Southwest (Berrien County)</td>
<td>8</td>
<td>23</td>
<td>4</td>
</tr>
<tr>
<td>Mississippi</td>
<td>Turkey Fork Road</td>
<td>1</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Arkansas</td>
<td>Sharp County</td>
<td>7</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>Florida</td>
<td>Santa Rosa Cty</td>
<td>1</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>California</td>
<td>Butte County</td>
<td>1</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Colorado</td>
<td>Dolores County</td>
<td>1</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>New York</td>
<td>NYSDOT Region 1 (Capitol Region)</td>
<td>5</td>
<td>10-13</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>NYSDOT Region 2 (Adirondack mountains)</td>
<td>13</td>
<td>9-11</td>
<td>6</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Wood, Adams, Kewaunee and Forest counties</td>
<td>5</td>
<td>17-27</td>
<td>7</td>
</tr>
</tbody>
</table>

During most of the field investigations the culverts were visually inspected along the entire interior length. Where entry was restricted (due to size, slope, or other considerations) the first several feet of the interior was examined.
At most of the locations, water and soil samples were taken for analysis. Water samples were measured in the field for resistivity and pH. These measurements were repeated in the laboratory along with other water chemistry parameters (e.g., hardness). Soil samples were analyzed in accordance with Corpro’s MTCF™ methodology. This includes the determination of moisture content, conductivity, resistivity, pH, sulfide and chloride content of the soil.

All polymer coated corrugated steel pipes were performing well at the time of their inspection. It is evident from the performance of the pipes that the polymer coating will extend the life of the corrugated steel pipe by significantly more than 25 years in severe environments – a service life extension of 50 or more years could probably be expected in most service conditions. Table 3 summarizes the environmental condition ranges for the inspection locations. As can be seen from the data, wide ranges of conditions are represented. A number of the sites involve multiple pipe materials at the same location. In each of those cases, the polymer-coated pipe is performing as well or better than the other corrugated metal pipe products at the same locations.

While the interior of all pipes was relatively accessible and could be visually inspected, soil side performance is less directly assessed. From 1986 through 1988 a detailed inspection and testing program was conducted to evaluate the condition of 122 culverts. The study was followed by a statistical analysis of the data. The analysis showed that 93.2% of plain galvanized CSPs had a soil side service life in excess of 75 years while 81.5% had a soil side service life in excess of 100 years. This study seems to support the conclusion that polymer-coated pipe should have a soil-side service life in excess of 100 years (as was projected for galvanized pipe). Thus the focus on waterside performance as the limiting factor for service life of polymer coated CSP would appear to be technically justified.

### TABLE 3 Summary of Environmental Conditions

<table>
<thead>
<tr>
<th>State</th>
<th>Region</th>
<th>Soil Resistivity</th>
<th>pH</th>
<th>Water Resistivity</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan</td>
<td>Upper Peninsula</td>
<td>2,164 – 4,475</td>
<td>7.8 – 8.0</td>
<td>1,022 – 8,226</td>
<td>6.5 – 7.0</td>
</tr>
<tr>
<td></td>
<td>Southwest (Berrien County)</td>
<td></td>
<td></td>
<td>No Data Taken</td>
<td></td>
</tr>
<tr>
<td>Mississippi</td>
<td>Turkey Fork Road</td>
<td>20500</td>
<td>5.9</td>
<td>Dry</td>
<td></td>
</tr>
<tr>
<td>Arkansas</td>
<td>Sharp County</td>
<td>5,000 – 21,280</td>
<td>5.93 – 6.18</td>
<td>3,200 – 13,500</td>
<td>7.2 – 7.7</td>
</tr>
<tr>
<td>Florida</td>
<td>Santa Rosa Cty</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>California</td>
<td>Butte County</td>
<td>100 – 4,500</td>
<td>2.1 – 3.9</td>
<td>1,150 – 1,220</td>
<td>3.3 – 3.4</td>
</tr>
<tr>
<td>Colorado</td>
<td>Dolores County</td>
<td>6,025 – 7,475</td>
<td>8.6</td>
<td>Dry</td>
<td></td>
</tr>
<tr>
<td>New York</td>
<td>NYSDOT Region 1 (Capitol Region)</td>
<td>2,268 – 11,494</td>
<td>6.9 – 8.1</td>
<td>613 – 5,291</td>
<td>6.7 – 7.6</td>
</tr>
<tr>
<td></td>
<td>NYSDOT Region 2 (Adirondack mountains)</td>
<td>4,310 – 25,641</td>
<td>5.6 – 7.9</td>
<td>455 – 26,316</td>
<td>4.9 – 7.5</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Various throughout state</td>
<td>1,704 – 23,256</td>
<td>6.9 – 8.1</td>
<td>1,612 – 4,000</td>
<td>6.6 – 7.5</td>
</tr>
</tbody>
</table>

**Upper Peninsula, MI**

This inspection included two sites – Hantz Road in Chippewa County and Charles Moran Road in Mackinac County. At each of these locations there are three pipes installed in parallel runs – polymer coated CSP, aluminum pipe, and standard galvanized pipe. The side-by-side installation of these products allows for comparison of their durability in identical environments. The polymer coating was observed to be intact, well adhered, flexible, and did not exhibit any blistering. The galvanizing under the polymer coating is still intact. By comparison, the galvanized pipe had active steel corrosion and metal loss on the lower half of the pipe (though the pipe was still structurally sound). Since the polymer has protected the galvanized substrate thus far, the polymer coating has significantly extended (at least by 23 years) the life of galvanized steel pipe.

**Berrien County, MI**

Several polymer-precoated corrugated steel pipes were installed during the construction of the new US-31, north of US-12 in Berrien County, Michigan. These pipes were installed over 20 years ago. We conducted a visual and physical examination of eight, polymer-coated corrugated steel pipes at four locations. The coated pipe was in excellent condition, with only minor delamination observed at cut edges and coating defects in the invert. Coating
defects could be described as occasional (perhaps one per linear foot of pipe) nicks in the coating from mechanical
damage. The defects are typically small in size (1-inch by 1/16-inch, for example). Typically ¼-inch of
delamination was observed at these defects with no measurable attack on the zinc coating (galvanizing). No steel
corrosion was observed except at the cut edges.

Comparison Study – Various Locations (MS, AR, FL, CA, CO)

The condition of thirty-seven different corrugated steel pipes was evaluated. The pipes were located in six different
environments and ranged in age from six to twenty-one years. At least nine different pipe material/coating
combinations were inspected. Coating deterioration was generally limited to the invert area of the pipes. No steel
corrosion was observed on any of the polymer-coated pipes. The only polymer deterioration noted was in the form
of abrasion and this was limited to the upstream side in the crest of the invert. In the abrasive environments the
coatings were roughened, but no measurable loss of coating was observed. The polymer coating that was not in the
invert of an abrasive environment showed no degradation as determined visually, with optical microscopy, and using
IR spectroscopy.

New York State Department of Transportation

Twenty polymer-coated and asphalt paved corrugated steel pipes were inspected in the state of New York. The
pipes ranged in age from 9 to 13 years. With one exception, the pipes were in very good condition. The polymer
coating was intact, well adhered, pliable and appeared like new. The asphalt paving was intact through most of the
pipe, but beginning to crack at the exposed ends. Where asphalt cracking was observed, the asphalt still exhibited
good adhesion to the polymer. The polymer under the asphalt was still well adhered to the steel. There was minor
damage to some of the polymer that was the result of fabricating and handling. Where the galvanized substrate was
exposed, there was no significant steel corrosion. At the cut ends, there was typically some steel corrosion and
nominally ¼-inch of coating undercutting, typical of 10-year old pipe. The damaged observed affected a very small
surface area of the pipe – certainly less than one percent of the surface area. These imperfections do not show any
signs of impacting the expected service life.

The pipe that was an exception had several locations where blisters in the coating were observed. Beneath
these blisters, the metal appeared to have been mechanically cut from the outside, allowing what appears to be
corrosive groundwater to migrate under the coating.

Wisconsin

On August 8 and 9, 2001 several polymer coated corrugated steel pipe installations were inspected in the state of
Wisconsin. The installations included test sites previously inspected and documented by the Wisconsin Department
of Transportation. Of particular significance is the age of the pipes – from 17 to 27 years old. The polymer coated
CSP has performed very well at all 5 of the sites inspected, providing excellent corrosion protection in these
aggressive environments for up to 27 years. The coating was intact, well adhered and pliable. There was minor
damage in the form of scratches in the polymer coating that was likely due to handling damage. Where the
galvanized substrate was exposed as a result of this damage, no steel corrosion was evident. At the cut ends of the
pipe, there was typically some steel corrosion and nominally ¼-inch of coating undercutting. These imperfections
do not show any signs of impacting the expected service life. One installation had coating delamination on
approximately 2 square feet of the surface area limited to the inside crown of one exposed end. There was no steel
corrosion underneath the delaminated film and the zinc coating was intact. The polymer film was tightly adhered at
the edges of the delaminated area.

Also significant are pipes installed in 1981 as part of a joint Wisconsin/FHWA test. This location included
four pipe materials – Aluminum, Polymer coated, Epoxy coated, and Aluminum coated Type 2. Each pipe was 30
inches in diameter and carried runoff between woodland areas on wither side of State Highway 80, a two lane road.
After 20 years, the polymer pipe is performing as well as or better than each of the other materials. Only the epoxy
coated pipe has active corrosion occurring. The coating had delaminated at one end.

Service Life Model

Based on the material composition of polymer coated CSP, it is reasonable to describe a service life model that
includes four distinct phases – an initiation period, a polymer degradation phase, a zinc corrosion phase, and a steel
corrosion phase. It would be expected that the phases would overlap, but one mechanism would dominate a phase
of the pipe life. For simplicity, figure 3 depicts these phases as distinct. During the initiation period, random events
such as mechanical impact will weaken the coating, creating weak points in the coating. Since the polymer is
relatively inert in the service environment, the polymer degradation phase would be dominated by delamination of
the polymer coating from the substrate. Even loosely bonded polymer will provide some protection to the
galvanized coating both by reducing oxygen access to the surface (and therefore corrosion rate) and by protrecting
the zinc from abrasive forces. As the polymer is removed, the zinc corrosion will dominate the pipe aging. Finally,
steel corrosion will be the dominant failure mechanism for the final years of the pipe life. While it is not possible to
put time frames to each of these phases of the pipe life, the field studies to-date show pipes between 6 and 27 years
old which are still in the polymer degradation phase.

CONCLUSIONS
1. The polymer precoat significantly extends the life of corrugated steel pipe by offering protection to the pipe
invert. None of the 44 pipes we inspected showed any invert deterioration.
2. Several mechanisms of degradation had initiated on the pipes. However, there was negligible difference in
the extent of damage observed on the pipes investigated. Given that the pipes range in age from 6 to 27
years, it would seem that the damage does not progress significantly with age in the first 25 years of
service.
   • Mechanical damage can cause very small, isolated areas of film to be removed from the pipe.
     Typically, the extent of such damage isn’t noticed except under scrutiny. Where mechanical damage
     or disbonded coating was observed, the galvanized steel is less corroded than bare galvanized pipe
     when such a comparison was possible. It is possible that the coating provides limited protection to
corrosion mechanisms (e.g., limits abrasion, limits oxygen access at the surface) in a loosely bonded
state or when small area of zinc are exposed.
   • Minor undercutting (less than ½-inch) at cut edges is sometimes observed in isolated locations after 5
     or more years of service. The coating is usually tightly adhered beyond the extent of the undercutting.
3. All of the accelerated abrasion tests incorporate conditions more severe that what was observed in the field.
   In no cases was abrasion damage in the invert observed that was comparable to that observed in the
   accelerated simulation test rig with any of the three abrasive/slope configurations. Where abrasion was
   apparent, it has only resulted in roughening of the coating at the upstream of the corrugation – not
   measurable coating loss.

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