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Invert Abrasion Testing of CSP Coatings

Prepared for:

NATIONAL
CORRUGATED STEEL
PIPE ASSOCIATION

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Objectives

The present study contained three primary objectives:

- Establish a relationship between the simulated abrasion test and the NCSPA Durability Guide (Appendix 1). Modify the test rig to establish abrasion conditions that correspond to a Level 3, Moderate Abrasion.
- Establish the performance of galvanized and coated CSP under test parameters that represent this condition, enhancing our understanding of the abrasion mechanisms (i.e., the influence of abrasive, slope, and flow on the resultant abrasion).
- Qualify innovative coating materials to improve the durability of culvert inverts in the severe and moderate abrasive environments.

Conclusions

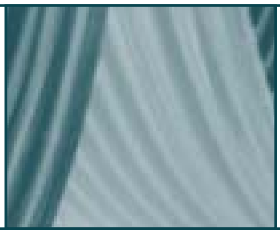
1. The previously developed test method can simulate Abrasion Levels 1–4 as listed in the NCSPA Durability Guide.

2. The test method has been modified to evaluate Level 3 abrasion resistance.

3. A variety of invert coatings have demonstrated good performance under Level 3, Moderate Abrasion. This includes:
   - Polymer Precoat
   - Polymer Modified Asphalt
   - Polymer Modified Asphalt over Polymer Precoat

4. Two coating systems have been qualified for Level 4, Severe Abrasion. Polymer Coated CSP with Polymer Modified Asphalt invert treatment and Asphalt Paved performed well in the Level 4, Severe Abrasion simulation.

5. Changes in either bedload, pipe slope, or both may impact the severity of the abrasive environment.



Background

As a result of continued interest in improving the durability of corrugated steel pipe products, the industry has sponsored extensive research on improved coating materials. The bulk of this research concerns field investigations of CSP. While many of these studies indicated a long life for CSP, the industry continually is searching for improved materials to extend life in general and to provide a suitable service life in the most demanding exposures. In support of this objective, fundamental laboratory studies under controlled circumstances are necessary to understand the underlying mechanism of failure, thus allowing enhanced durability designs.

The track record of CSP is well established, yet the industry would like to excel with new technologies available. The use of tough, abrasion-resistant organic barrier coatings will enhance the protection afforded by the metallic coating by extending its life. Even in "non-abrasive" service environments, abrasion resistant coatings contribute to a robust coating system by providing a barrier that protects the metallic coating from the soil, atmosphere, and water. This will extend service life in any environment.

The primary area of concern in most cases is the CSP invert. NCSPA has developed a test protocol for new CSP coatings[1] to extend invert life. These tests evaluate coating performance under defined conditions. The standardized tests can be used to qualify new and existing materials based on performance comparisons to control materials.

Exposure of candidate coatings to a controlled laboratory representation of service conditions helps yield comparable, repeatable results. The results of such tests, however, can suffer limitations since there is no way to accelerate time. Thus mechanical abrasion can be accelerated yet time-dependent phenomena like corrosion can not usually be accelerated. Such tests can be enhanced by the determination of a time-degradation relationship over the testing period. Using this time-degradation relationship, one may be able to make predictions over service periods significantly longer than laboratory test duration.

A testing protocol provides the ability to single out a characteristic of a particular material for evaluation (e.g., abrasion resistance). This protocol is limited to searching for improved corrugated steel pipe invert protective materials or coatings to obtain superior performance of CSP. It is not the intent to compare types of pipe materials such as reinforced concrete pipe (RCP) or plastic pipe. There has been no attempt to broaden the scope of the test protocol to incorporate applicable test that would be considered prudent if working with RCP (e.g., chloride or sulfate concentrations) or HDPE (e.g., environmental stress cracking).

The original Tier 3[1] 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 developed by the NCSPA, it was desirable to expand the scope of the abrasion test to include alternative, lower levels of abrasion. This will allow the industry to position coating products in the marketplace based on durability and resistance to various levels of abrasion. This report presents the results of testing conducted to characterize various abrasion test parameters.

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[1] *Evaluation Methodology for Corrugated Steel Pipe Coating/Invert Treatments,* National Corrugated Steel Pipe Association, March, 1996.

Procedures

The NCSPA Test Protocol includes three 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 CPS. Coatings properties such as freeze-thaw resistance, water absorption, and abrasion resistance are measured on laboratory test panels. The coatings materials discussed herein have already passed these tiers of testing. This report concentrates on the third tier of testing—the accelerated abrasion test.

Accelerated Abrasion Tests Apparatus

Figures 1A and 1B show a photograph and a design drawing of the accelerated abrasion test apparatus. The apparatus design considers the simulation of water velocities and bedloads established through the experience of others as deleterious to the performance of asphalt coated CSP. In the test rig, seawater is drawn through the pumping manifolds to 4-inch PVC pipe, expanding to 12 inch PVC through a 90° elbow to a 5-foot length of horizontal PVC pipe. The water then flows into a 5-foot length of 12- to 18-inch transition section of galvanized CSP that connects to a second 5-foot length of CSP. This second pipe has an opening in its crown for the entrance of bedload material. In the standard test protocol, the next section is the 10-foot test section of CSP (with the test coating applied). The test section then connects to a 5-foot length of galvanized CSP that empties into a large plastic sump. For the purposes of the present testing, three five-foot “test sections” were used to maximize the amount of data that could be generated with each test run.

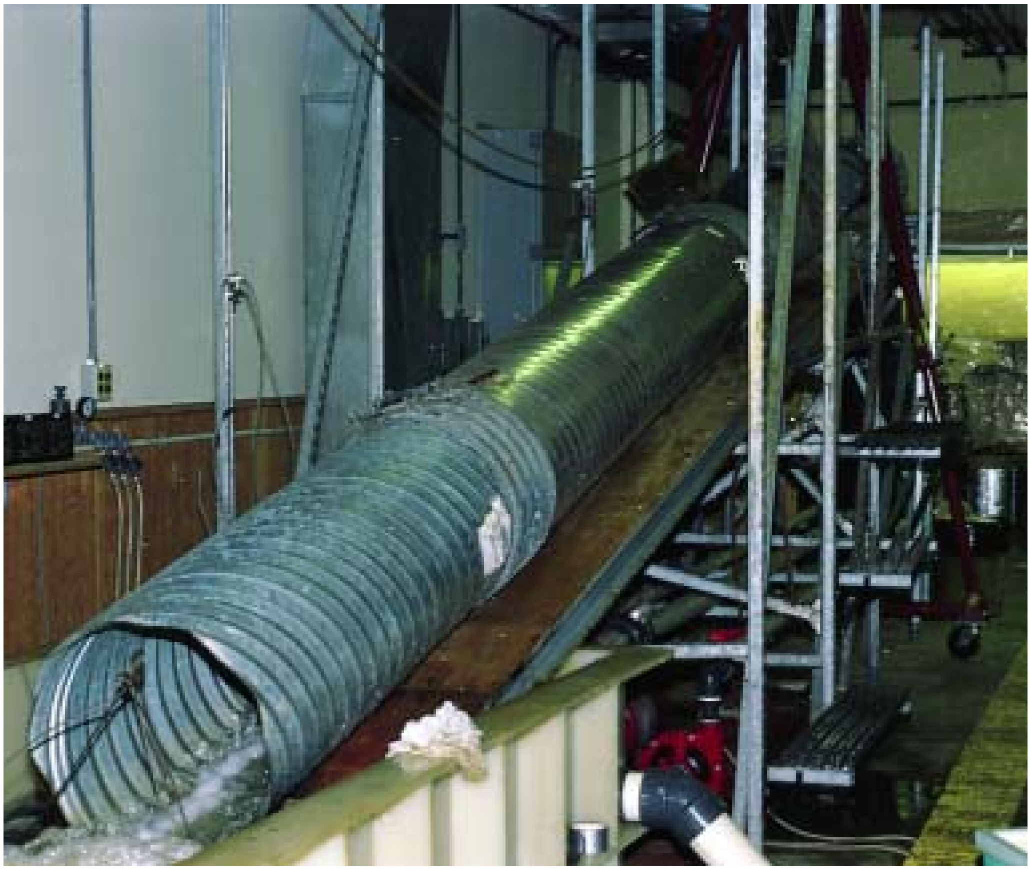
A hopper in the sump retains the discharged bedload material, preventing its entrance into the pumps. This hopper is connected to a hoist that then connects to rail assembly with rollers. The hoist and roller combination allows for the abrasive material to be dropped back through the rig. The pump manifolds are connected to the sump by 4-inch PVC pipe. Plastic lined pumps with plastic impellers and the use of PVC pipe leave the CSP as the only metallic components of the system with which the circulating water contacts. Provision is made, but not shown on the drawing, for continuous refreshment of the circulating water with fresh water, preventing unwanted increases in the circulating water temperature or changes in seawater chemistry. Three pumps circulate the seawater medium.

Calculations, based upon the Manning equation indicate that this rate, flowing through 18-inch CSP will attain a velocity of about 11 feet per second with the pipe being half full, if the pipe slope is about

TABLE 1 Summary of Test Conditions

Test Run	Dates	Stone Type High (550 gpm)	Hours Flow Rate Low (50 gpm)	Hours Flow Rate (from horizontal)	Angle of Flow
1	Dec 23 – Jan. 7	Stone	28	254	12°
2	Jan 12 – Jan 25	None	30	229	12°
3	Feb 10 – Feb 19	Rock	20	190	12°
4	Mar 8 – Mar 13	Stone	28	254	12°
5	Jun 24 – Jul 15	Stone	30.5	375.5	2°
6	Sep 13 – Sep 24	Stone	27.5	236.25	2°
7	Jun 12 – Jun 22	Stone	30	233	2°
8	Jun 26 – Jul 7	Stone	34	214.5	12°

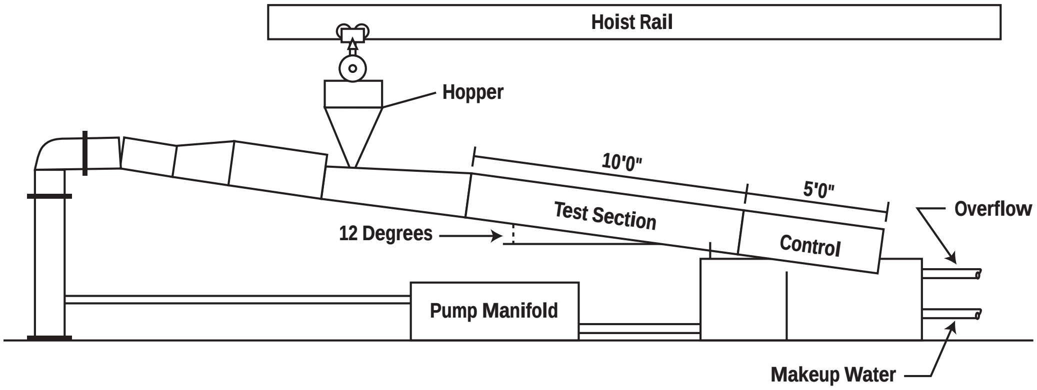
FIGURE 1A. Accelerated Abrasion Test Apparatus.



12°. This rig has been designed to allow for adjustments to be made in the slope if desired. Preliminary testing was performed with the rig aligned with a 12° slope in order to evaluate the acceptability of this slope. These tests determined if the design parameters caused detectable damage to asphalt coating within a reasonable period.

The total test duration is approximately two weeks (10 working days) with a total of about 25 tons of rock being passed through the test and control piping. During the period in which the abrasive is introduced, seawater flow rate through the piping is approximately 550 gpm. An orifice controls the rate of bedload flow into the test stream. Dispatching the bed-

FIGURE 1B. Accelerated Abrasion Test Apparatus Schematic.



load in 25 ton batches allows for cyclic bedload and immersion exposure which may be varied to simulate actual field conditions. Furthermore, assessment of the coating after each "bedload event" allows for accurate measurement of the incremental impact of each event.

FIGURE 2. Bedload Materials (¾" trap rock on left, ⅜" local stone on right)

Alternate Abrasion Conditions

The objective of this effort was to use the National Corrugated Steel Pipe Association (NCSPA) full-scale (Tier 3) test rig to qualify coatings for use in various levels of abrasion and tie those abrasion levels to the NCSPA Durability Guide.

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 ¾" 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 ⅜" local stone, propelled by 550 gpm, and the new flow angle used was a 2-degree angle from horizontal. **TABLE 1** shows the test conditions during test runs with different aggregate or flow geometry.

As can be seen in Table 1, there were two materials used for the bedload—¾" trap rock and a ⅜" local stone. **FIGURE 2** shows both 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 ⅜" 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.

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.

Results & Discussion

The following discussion presents the results of the testing performed during this project. The test results are grouped by coating type.

Galvanized Pipe

Four test were run with standard G210 galvanized CSP meeting ASTM A929 for Zinc Coated Steel Sheet. **TABLE 2** presents a summary of the test conditions and the results.

FIGURE 3 shows the thickness of galvanizing before and after testing under the various abrasion conditions. This figure shows that the wear patterns of the galvanizing are similar for all stone sizes and angles of flow—that is, the wear is concentrated in the invert of the pipe. However, there is decreased wear at a smaller angle of flow than at the standard 12-degree angle. Furthermore, there is a decreased wear using the less severe bedload material even at the higher angle. It is difficult to differentiate between the relative effect of the bedload material and the pipe angle. Each of the changes appears to have a similar magnitude of reduction in the coating wear.

Polymer Precoat

Five test were run with pipe fabricated from ASTM A742 Polymer Precoated Sheet for Sewers and Drains. **TABLE 3** 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.

There was no exposed galvanizing after testing at either slope using the smaller bedload. **FIGURE 4** 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 (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.

Asphalt Paved

One test was run with asphalt paved galvanized CSP. **TABLE 4** summarizes the

TABLE 2 Summary of Test Results for Galvanized Pipe

Test Run	Bedload	Slope	max Thk Loss (mils)	Max Exposed Galv (sq cm)	Notes
	Rock	12°	2.4	N/A	Data from control sections in previous work
1	⅜ Stone	12°	1.6	N/A	Similar to ¾ Rock wear at same slope
5	⅜ Stone	2°	1.2	N/A	Stone collect in the corrugations during the test
6	⅜ Stone	2°	0.7	N/A	
2	None	12°	0.1	N/A	No visible wear

TABLE 3 **Summary of Test Results for Polymer Precoat Pipe**

Test Run	Bedload	Slope	Max Thk Loss (mils)	Max Exposed Galv (sq cm)	Notes
	Rock	12°	10	9.5	Data from original study
1	⅜ Stone	12°	4.7	0	One lockseam beginning to show coating disbondment
4	⅜ Stone	12°	4.2	0	No exposed Galvanized, max loss at invert
5	⅜ Stone	2°	1.6	0	
6	⅜ Stone	2°	1.2	0	
2	None	12°	0.5	0	No visible wear

test conditions and results. **FIGURE 5** shows a photograph of the asphalt pipe after the testing. There was no exposed galvanizing after testing. Signs of wear were observed on the bottom (paved) section of the invert, characterized by a rough texture and extending 2-inches on either side of the paved section. Remainder of asphalt coating is duller than original possibly indicating some wear of the coating. No detectable loss was observed after testing. It is important to note that the test does not consider the effect of aging on asphalt performance.

FIGURE 3. Galvanized Thickness Loss Under Different Test Conditions

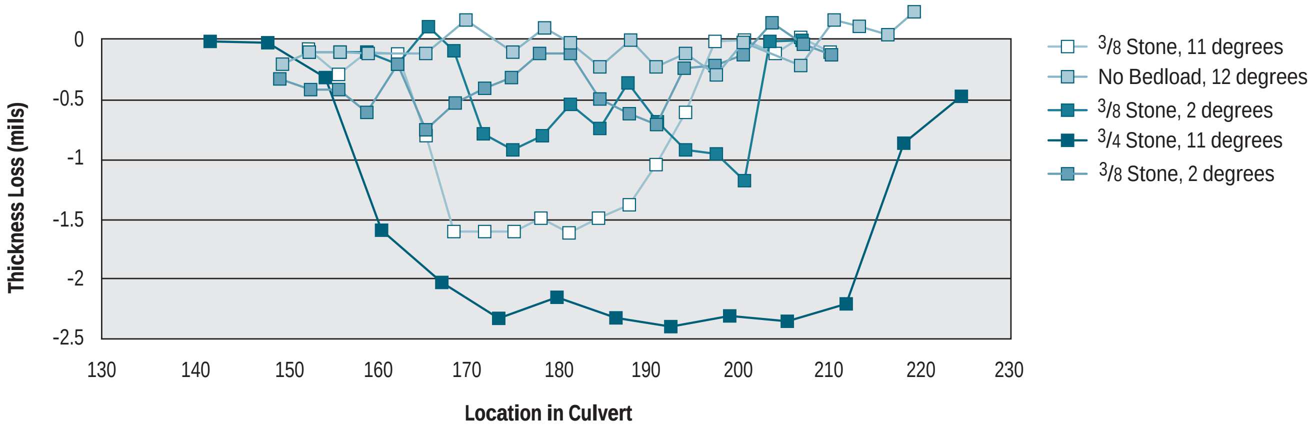


FIGURE 4. Polymer Precoat Thickness Loss Under Different Test Conditions

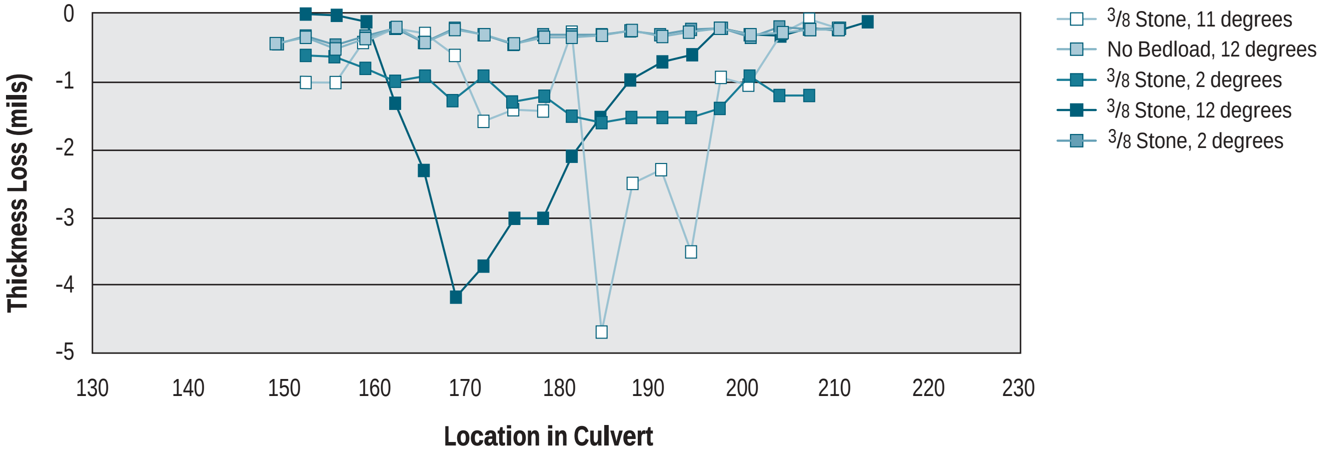


TABLE 4 Summary of Test Results for Asphalt Paved Pipe

Test Run	Bedload	Slope	Max Thk Loss (mils)	Max Exposed Galv (sq cm)	Notes
3	¾" Rock	12°	N/D	0	Too thick and inconsistent to measure loss with any degree of accuracy

TABLE 5 Summary of Test Results for Galvanized with Truflo Polymer Modified Asphalt

Test Run	Bedload	Slope	Max Thk Loss (mils)	Max Exposed Galv (sq cm)	Notes
3	¾ Rock	12°	>50	1.47	Exposed galvanizing at 5 locations
4	⅜ Stone	12°	3	0.2	Exposed galvanizing at one location

TABLE 6 Summary of Test Results for Truflo Polymer Modified Asphalt Invert Treatment over Polymer Precoat Pipe

Test Run	Bedload	Slope	Max Thk Loss (mils)	Max Exposed Galv (sq cm)	Notes
3	¾ Rock	12°	38	0	Dipped invert coating

Galvanized with “Truflo” Polymer Modified Asphalt

Two tests were run on G210 galvanized CSP with “Truflo” polymer modified asphalt. **TABLE 5** presents a summary of the test conditions and the results. **FIGURE 6** shows one of the areas where galvanized has been exposed on a corrugation after Test Run 3. **FIGURE 7** presents the measured thickness losses as a function of location in the invert. The data demonstrated the effect of different abrasive on the abrasion resistance of the material. Clearly the less severe abrasive resulted in less wear as measured both by thickness loss and by exposed galvanizing.

FIGURE 5. Asphalt paved pipe after test.

“Truflo” over Polymer Precoated Galvanized

Three test were run on polymer precoat CSP with “Truflo” polymer modified asphalt invert treatment. The first sample that was tested (Test Run 3) was dipped into the modified asphalt such that the bottom 90-degrees of the pipe had an asphalt coating over the polymer.

FIGURE 6. Polymerized asphalt over galvanizing after test run 3.

TABLE 6 presents a summary of the test conditions and the results. This dipped material did quite well in the most severe abrasion test. There was no exposed galvanized material after the test. This and asphalt coated and paved are the only CSP coating systems that have performed this well at the highest abrasion level. There was substantial thickness loss that exposed some of the polymer precoat in some areas. In those areas there did not appear to be any abrasive damage of the polymer precoat as a result of the test.

FIGURE 8 shows the thickness loss of each of these coatings after the test.

The paved inverts showed the same cold flow phenomenon as was observed on the galvanized pipes. **FIGURE 9** shows an example of the cold flow on the polymer coated pipe from Test Run 8. Note that no galvanizing was exposed during either of these tests

FIGURE 9. Polymer modified asphalt paved invert over Polymer Precoat after Test run 8.

FIGURE 7. Polymer Modified Asphalt Thickness Loss Measured After Testing

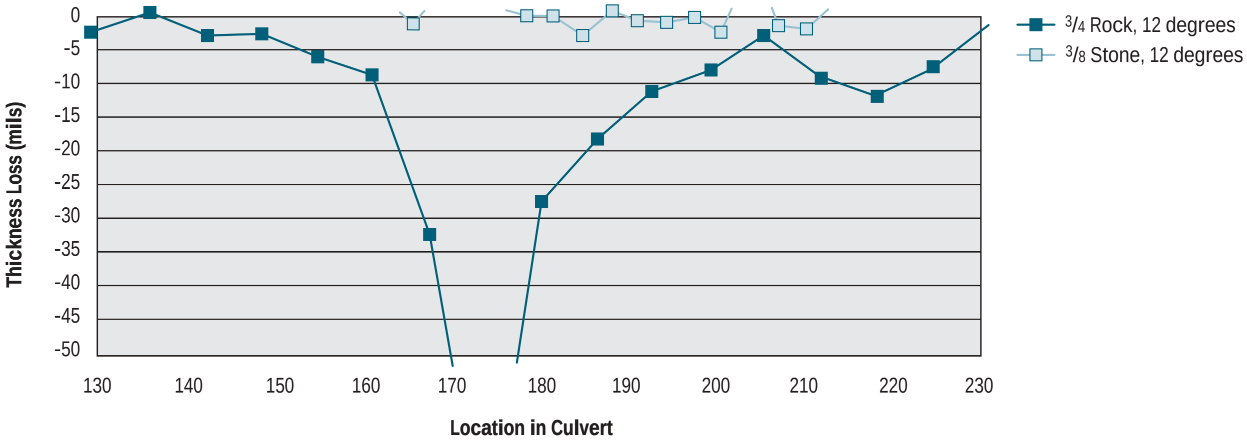
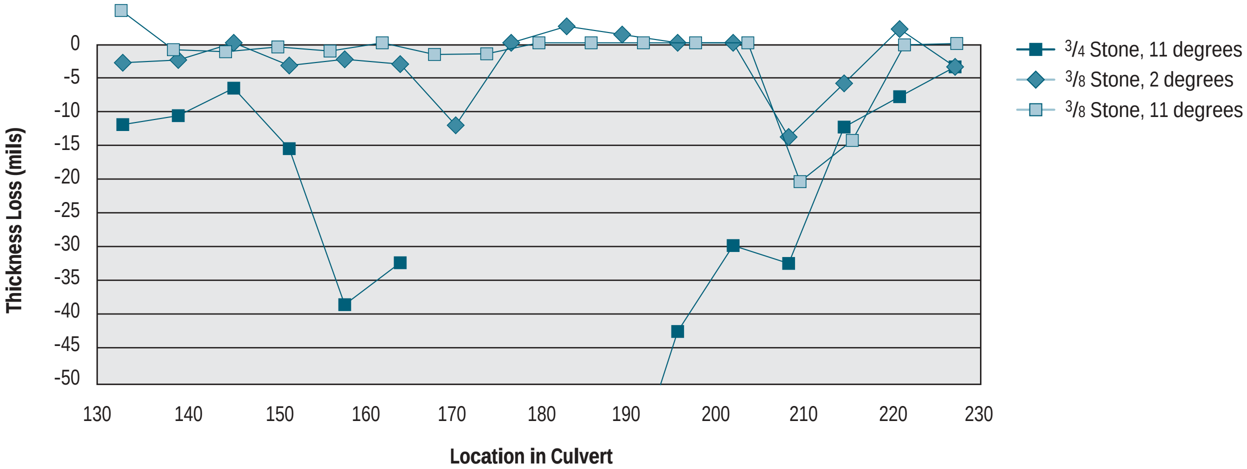


FIGURE 8. Polymer Modified Asphalt Over Polymer Precoat



Appendix A:
CSP Durability Guide

CSP Durability Guide

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■ This Guide provides environmental ranges for CSP products. Service Life of CSP will vary within these ranges. For estimating average invert service life, refer to the Service Life Prediction section in this Guide or the Durability chapters of the AISI publication *Handbook of Steel Drainage & Highway Construction Products* or the *Modern Sewer Design*. ■ This Guide is not a substitute for professional engineering advice and is made without guarantee or representation as to results. Although every reasonable effort has been made to assure its accuracy, neither the National Corrugated Steel Pipe Association nor any of its members or representatives warrants or assumes liability or responsibility for its use or suitability for any given application.

Product Usage Guidelines for Corrugated Steel Pipe

● **Shaded Circles Indicate Applicable Coatings**

* See AISI Chart

	WATERSIDE						
COATING	**Normal Conditions**	**Mildly Corrosive**	**Corrosive**	**Non-Abrasive/Low Abrasion (Lvl. 1 & 2)**	**Moderate Abrasion (Level 3)**	**High Abrasion (Level 4)**	**Provides Additional Soil Side Protection**
Zinc Coated (Galvanized)	●*	●*	○	●	○	○	○
Aluminum Coated Type 2	●	●	○	●	○	○	○
Asphalt Coated	●	●	●	●	○	○	●
Asphalt Coated and Paved	●	●	●	●	●	○	●
Polymerlzed Asphalt Invert Coated†	●	●	○	●	●	○	○
Polymer Precoated	●	●	●	●	●	○	●
Polymer Precoated and Paved	●	●	●	●	●	●	●
Polymer Precoated w/ Polymerlzed Asphalt	●	●	●	●	●	●	●
Aramid Fiber Bonded Asphalt Coated	●	●	●	●	○	○	●
Aramid Fiber Bonded and Asphalt Paved	●	●	●	●	●	○	●
High Strength Concrete Lined	●	●	○	●	●	○	○
Concrete Paved Invert (75mm (3”) Cover)	●	●	○	●	●	●	○

† Use Asphalt Coated Environmental Ranges for Fully Coated Product

Note: Coatings listed under additional soil side protection are generally considered to provide 100 years service life from a soil side perspective within appropriate environmental conditions.[1]

ENVIRONMENTAL RANGES:

- **Normal Conditions:** pH = 5.8 – 8.0 (for R > 2000 ohm-cm)
- **Mildly Corrosive:** pH = 5.0 – 5.8 and/or for R = 1500 to 2000 ohm-cm
- **Corrosive:** pH < 5.0 (for R < 1500 ohm-cm)

ABRASION

Invert Protection/Protective Coatings can be applied in accordance with the following abrasion criteria. Abrasion velocities should be evaluated on the basis of frequency and duration. Consideration should be given to a frequent storm such as a two year event (Q_2) or mean annual discharge ($Q_{2.33}$) or less when velocity determination is necessary.

ABRASION LEVELS

The following qualitative definitions are provided as guidance to evaluate abrasion conditions when necessary.

Non-Abrasive (Level 1): No bedload regardless of velocity; or storm sewer applications.

Low Abrasion (Level 2): Minor bedloads of sand and gravel and velocities of 5 ft./sec. or less.

Moderate Abrasion (Level 3): Bedloads of sand and small stone or gravel with velocities between 5 and 15 ft./sec.

Severe Abrasion (Level 4): Heavy bedloads of gravel and rock with velocities exceeding approximately 15 ft./sec.

Protective Coatings and Pavings

All corrugated steel pipes have a metallic coating for corrosion protection. When the coating selected does not provide the required service life or is outside the appropriate environmental conditions, an alternate coatings system can be selected. Often the required service life can also be achieved by increasing the sheet thickness; this alternative should be weighed against the cost of supplemental coatings. Galvanizing is the most widely used metallic coating and is the basis for the Service Life Chart shown on page 4.

A. METALLIC COATINGS

Zinc-coated (Galvanized) Steel (AASHTO M36, ASTM A929) is produced with a coating weight of 610 g/m^2 (2 oz/ft^2) of surface (total both sides) to provide zinc coating thickness of 86 µm (0.0017 in.) on each surface.

4 Ounce Zinc-coated (Galvanized) Steel (ASTM A929) is a new coating produced with a coating weight of 1220 g/m^2 (4 oz/ft^2) of surface (total both sides) to provide zinc coating thickness of 86 µm (0.0034 in.) on each surface. This coating has been evaluated in the lab and is currently being evaluated in field installations. Initial lab tests have indicated increased corrosion and abrasion protection. Specific performance recommendations will be provided when further data is available.

Aluminum Coated Type 1 (AASHTO M36, ASTM A929) is an aluminum coating with 5 to 11% silicon. It is produced with a coating weight of 305 g/m^2 (1 oz/ft^2) of surface (total both sides) to provide a coating thickness of 48 µm (0.0019 in.) on each surface. Service life will be addressed when sufficient data becomes available.

Aluminum Coated Type 2 (AASHTO M274, ASTM A929) is a pure aluminum coating (no more than 0.35% silicon). It is produced with a coating weight of 305 g/m^2 (1 oz/ft^2) of surface (total both sides) to provide a coating thickness of 48 µm (0.0019 in.) on each surface.

B. NON-METALLIC COATING & PAVINGS

Asphalt Coated (AASHTO M190, ASTM A849). An asphalt coating is applied to the interior and exterior surface of the pipe with a minimum thickness of 1.3 mm (0.05 in.) in both fully coated and half coated.

Invert Paved with Asphalt Material (AASHTO M190, ASTM A849). An asphalt material is used to fill the corrugations and provide a minimum thickness of 3.2 mm (1/8 in.) above the crest of the corrugations for at least 25% of the circumference of round pipe and 40% of the circumference for pipe arch.

Invert Paved with Concrete Material (ASTM A849, ASTM A979). A 75 mm (3 in.) thick concrete layer is placed in the installed pipe for at least 25% of the circumference of round pipe and 40% of the circumference for pipe arch.

Fully Lined with Asphalt Material (ASTM A849). An asphalt material is used to fill the corrugations and provide a minimum thickness of 3.2 mm (1/8 in.) above the crest of the corrugations providing a smooth surface over the entire pipe interior.

Fully Lined with Concrete Material (ASTM A849, ASTM A979). A high strength concrete material is used to fill the corrugations and provide a minimum thickness of 3.2 mm (1/8 in.) above the crest of the corrugations providing a smooth surface over the entire pipe interior.

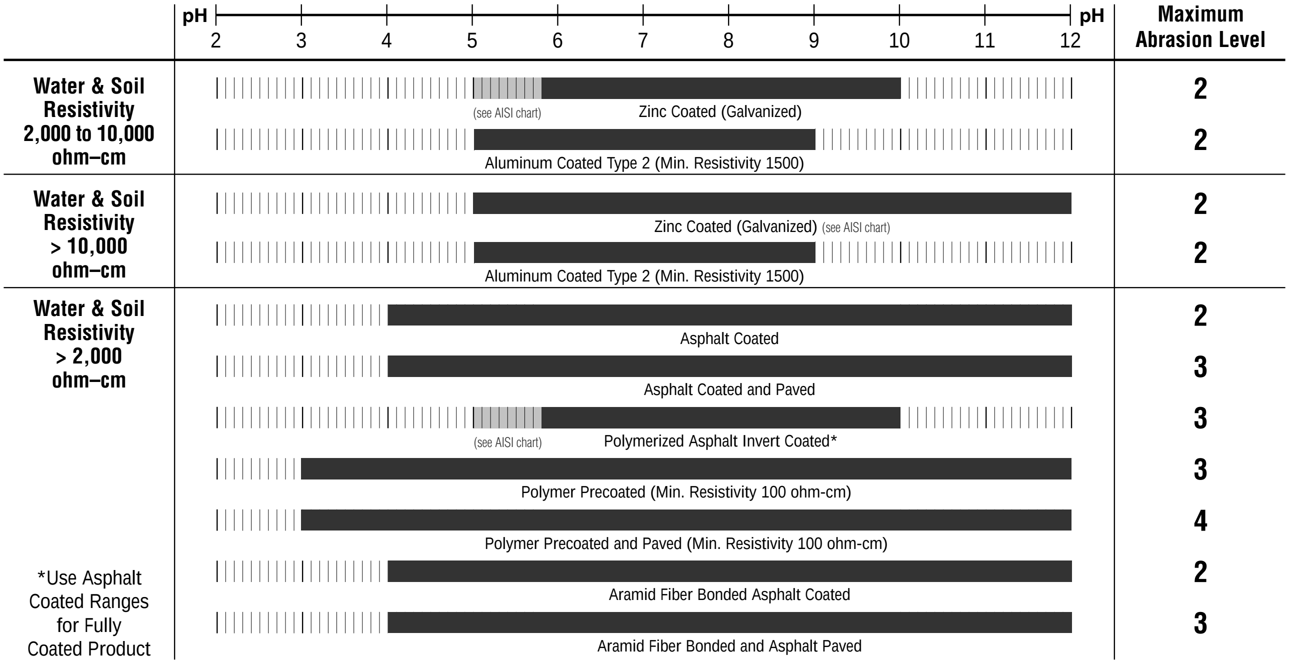
Invert Coated with Polymerized Asphalt Material (ASTM A849). A polymer modified asphalt material is used to provide a minimum thickness of 1.3 mm (0.05 in.) for at least 25% of the circumference of round pipe and 40% of the circumference for pipe arch. Generally used for invert treatments only.

Invert Paved with Polymerized Asphalt Material (ASTM A849). An asphalt material is used to fill the corrugations and provide a minimum thickness of 1.3 mm (0.05 in.) above the crest of the corrugations for at least 25% of the circumference of round pipe and 40% of the circumference for pipe arch.

Polymer Precoated (AASHTO M245, ASTM A742). A laminate film is applied over protective metallic coatings. The 10/10 grade (10 mils thickness, each side) is the primary product used.

Aramid Fiber Bonded Asphalt Coated (ASTM A885). An aramid fiberfabric is embedded in the zinc coating while it is still molten, which improves bonding to the asphalt coating.

Environmental Guidelines for Corrugated Steel Pipe



Service Life for Corrugated Steel Pipe

A. METALLIC COATINGS

As discussed above, CSP coatings can be classified into two broad categories, metallic and non-metallic coatings and pavings. Metallic coatings commercially available include zinc (galvanized) and aluminum coated (Type 2). Several non-metallic coatings are available as shown in this document. The following discussion explains the differences and similarities of the two metallic coatings.

All metals form some type of corrosion product when they corrode, regardless of whether they are protective metallic coatings such as aluminum or zinc, or the base steel. Typically the corrosion product, such as an oxide, is more stable and its buildup will result in a decreasing corrosion rate. In practice, corrosion products formed through the galvanic cell (pit) may be deposited in small discontinuities in the coating and serve to stifle further corrosion just as films of corrosion products protect solid surfaces. Thus, the development of scales on metal surfaces is an important consideration when using metals in waters.[1]

Zinc-Coated (Galvanized)[2]

Zinc corrodes much more slowly then steel in natural environments and it galvanically protects steel at small discontinuities in the coating. Its excellent resistance to corrosion is due to the formation of protective films on zinc during exposure. On the average, the rate of attack of zinc is approximately 1/25 that of steel in most atmospheres and various waters.

High corrosion rates in strongly acidic and strongly alkaline solutions can be attributed to the absence of film on the metal surface (stable films are present on the surface when the corrosion rates are low). Lab test indicated stable films in the pH range from about 6 to 12.5.

Aluminum Coated Type 2

"Aluminum is a reactive metal, but it develops a passive aluminum oxide coating or film that protects it from corrosion in many environments."[3] This film is quite stable in neutral and many acid solutions but is attacked by alkalies greater than a pH of 9. From a corrosion standpoint, aluminum has an advantage over galvanized in lower pH and in soft water due to the formation of the oxide film. (Soft waters are generally classified as waters with a hardness of 50 parts per million CaCo3 or less.) The coatings are essentially equal under abrasion[8] and in waters where the zinc oxide film forms rapidly.

Service Life

The service life of zinc coated galvanized is determined using the AISI Chart on page 4. This chart predicts a variable service life based on pH and resistivity of water and soil and has been an industry standard for many years. Many specifying agencies view service life of aluminum coated type 2 as having additional service life over galvanized.[4,5,6,7]This advantage varies throughout the country from minimal to significant depending on the environment and the geographic location. Users are encouraged to review the practices in their area.

For the purposes of this Guide, aluminum coated type 2 can provide a service life range of a minimum 1.3 times the AISI chart for galvanized (roughly 1 gage) and up to to 75 years (possibly more) in the appropriate environmental conditions. This is consistent with the range of practice by state and federal specifying agencies. The specific multiplier used for design purposes should be based on comparable experience under similar environmental conditions. There may be conditions where the actual performance is more than or less than this range. The significant advantage appears to be either for more corrosive effluent or soft waters where the protective scale forms rapidly for aluminum. In benign environments or where protective scales form rapidly on zinc, there may be little advantage.

AISI Method for Service Life Prediction

The service life of CSP can be reasonably predicted based on the environmental conditions, the thickness of the steel, and life of the coating. The most practical method of predicting the service life of the invert is with the AISI (American Iron and Steel Institute) chart shown on page 4.[9] This chart is based on 16 gage galvanized CSP with a 610 g/m^2 (2 oz/ft^2) coating and can be applied to other thicknesses with the appropriate factor. See discussion above for estimating the service life of aluminum coated type 2.

The AISI chart, which gives service life in terms of resistivity and pH, was developed from a chart originally prepared by the California Department of Transportation(Caltrans).[10] The Caltrans study of durability was based on life to first perforation in culverts that had not received any special maintenance treatment. The results included the combined effects of soil-side and interior corrosion, as well as the average effects of abrasion. For pipes where the pH was greater than 7.3, soil-side corrosion controlled and life could be predicted by resistivity. For pipes where the pH was less than 7.3, the interior invert corrosion generally controlled and both resistivity and pH were important. In the field inspection of 7000 culverts in California for Caltrans, Richard Stratfull, Lead Project Investigator, states he "has no memory of a corrosion perforation being initially found other than in the invert." At least 70 percent of the pipes were expected to last longer than the chart prediction.

The consequences of small perforations are minimal in a gravity flow pipe such as most storm sewers and culverts and do not accurately reflect the actual service life. Because of this fact, the original curves were converted by Stratfull to average service life curves using data on weight loss and pitting in bare steel developed by the National Institute of Standards and Technology. Since storm sewers and culverts are usually designed with a structural safety factor of at least 2.0, a significant safety factor of 1.5 remains at the end of the service life predicted by the chart. Thus, use of the chart is considered reasonably conservative. The Caltrans Method may be appropriate for use under pressure applications. Where service life is controlled by invert performance, rehabilitation of the invert at the end of the predicted life can extend service life significantly

Soil-Side Durability

A study performed by Corrpro Companies in 1986 found that soil-side durability is generally not the limiting factor in designing CSP systems. "Survey results indicate that 93.2 percent of the plain galvanized installations have a soil-side service life in excess of 75 years, while 81.5 percent have a soil-side service life in excess of 100 years."[11]

The study also found that soil moisture contents below 17.5 percent did not exhibit any accelerated corrosion. "Under most circumstances, corrosion rates are directly related to soil moisture content. However, for galvanized steel storm sewer and culvert pipe, the soil moisture content primarily affects the activity of any chloride ions present and the chloride's acceleration of the corrosion. Where the soil moisture content was below 17.5 percent, the chloride ion concentration did not have a significant affect on the corrosion rate of the zinc coating."

A computer program to estimate soil-side service life is included in "Final Report, Condition and Corrosion Survey of Corrugated Steel Storm Sewers and Culvert Pipe," and is available from NCSPA.

Steps in Using the AISI Chart

The durability design chart can be used to predict the service life of galvanized CSP and to select the minimum thickness for any desired service life. Add-on service life values are provided in the table on page 5 for additional coatings.

1) Locate on the horizontal axis the soil resistivity (R) representative of the site.
2) Move vertically to the intersection of the sloping line for the soil pH. If pH exceeds 7.3 use the dashed line instead.
3) Move horizontally to the vertical axis and read the service life years for a pipe with 1.6 mm (0.064 in.) wall thickness.
4) Repeat the procedure using the resistivity and pH of the water; then use whichever service life is lower.
5) To determine the service life for a greater wall thickness, multiply the service life by the factor given in the inset on the chart.

Additional Service Life

Additional service life can be provided by increasing the thickness of the base steel in accordance with the factors shown in the Chart for Estimating Average Invert Service Life or with the use of additional coating systems. Add-on service life values are provided in the Tables on page 5.

B. NON-METALLIC COATING & PAVINGS

Non-metallic coatings offer advantages over metallic coatings in the form of increased abrasion resistance, wider environmental ranges and longer service life. Inherent in these coatings is less variability in performance which is why specific add-on service life values are recommended under various abrasion levels.

Asphalt Coated – Asphalt coatings are generally used for soil-side protection but also provide additional waterside protection. Numerous studies have concluded that asphalt coating typically provides 10 years additional service life to the inside of the pipe.[12,13,14,15,16] Asphalt coatings provide much higher service life on the soil-side and inherently extend the environmental ranges for soil conditions. According to Corrpro[11], "study results indicate that the addition of an asphalt coating may have provided a soil side service life in excess of 100 years."

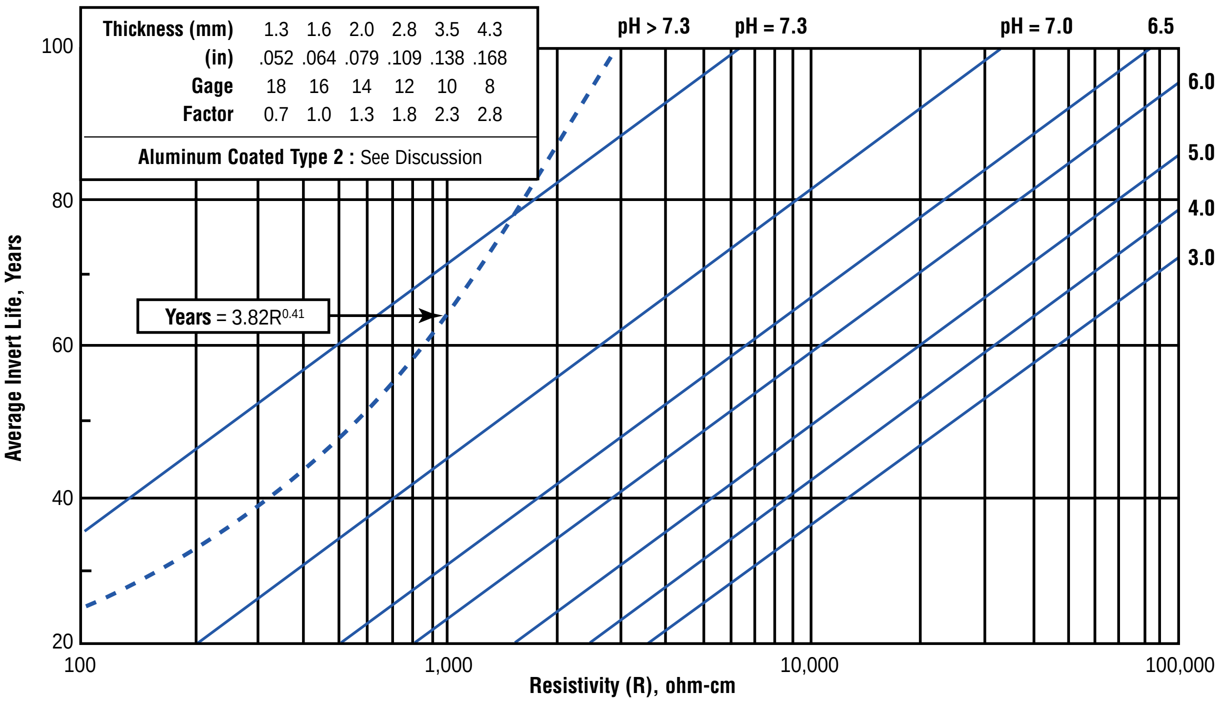
Asphalt Coated and Paved – Asphalt coated and paved provide both additional service life and added abrasion protection on the water side of the pipe. Based on several studies, coated and paved is considered to provide an additional 30 years service life under most abrasion levels.[12,13,15,16,17,18] This is considered a very conservative estimate for non abrasive and low abrasion (level 1 and 2).

Polymerized Asphalt Invert Coated – Polymerized asphalt provides improved adhesion and abrasion resistance over standard asphalt products.[8] Full scale abrasion tests conducted by Ocean City Research indicate no deterioration of the coating under moderate abrasion (level 3)[19].

Based on independent test lab results using test method ASTM A926, results indicate that the commercially available polymerized asphalt coating lasts at least 10 times longer than standard asphalt coating and at least three times longer than standard culvert coated and paved. [5]

Polymer Precoat – Polymer precoat provides excellent adhesion to the base steel and extended corrosion and abrasion resistance. The service life recommendation are based on extensive lab and field tests.[8,19,20,21,22] According to PSG[22], "No corrosion was observed on any of the coated (polymer coated) pipes. We can not find any data to suggest the pipe coating would not provide at least one hundred years service." Sites contained environmental conditions with Resistivity as low as 100 ohm-cm and pH as low as 2.1. In addition, PSG conducted current requirement testing that is designed to determine corrosion activity of a given

AISI Chart for Estimating Average Invert Life for Galvanized CSP



$\text{Years} = 35.85\ (\text{Log}_{10}\ \text{R} - \text{Log}_{10}\ (2160 - 2490\ \text{Log}_{10}\ \text{pH}))$

structure. The current requirement data shows polymer coated structures have up to 10,000 times less corrosion versus bare G210 galvanized. Recent tests conducted by Ocean City Research indicate polymer coated withstanding abrasion level three conditions.[19](Note: Corrosion conditions at the extreme limits of the environmental ranges may require adjusting add-on service life values).

Polymer Precoat and Asphalt Paved – Polymer precoat and asphalt paved benefits from the excellent adhesion of the polymer precoat to the base steel and the subsequent adhesion of the paving to the precoat. According to laboratory and field tests, [22,23] the combination of the three coatings results in a pipe which is highly resistant to acidic effluent. The bituminous material has much better adhesion to the polymeric coating than it does to the galvanizing.

Polymer Precoat with Polymerized Asphalt Invert Coated – Full scale abrasion tests conducted by OCR show equal performance of the polymerized asphalt over polymer precoat as standard asphalt paved.[19] This system has the same bonding characteristics as the polymer precoat and paved. Field sites also indicate improved adhesion.[22]

Aramid Fiber Asphalt Coated/ Aramid Fiber Asphalt Paved – The fibers embedded in zinc provide an anchor for the asphalt coating or paving to improve adhesion.

High Strength Concrete Lined – Concrete linings are typically used for improved hydraulic performance but also provide additional abrasion protection and extended service life. The use of high strength concrete and metallic coated steel provide the high service life values.

Concrete Invert Paved – Concrete inverts provide extreme abrasion protection and extended service life. According to Stratfull[10], "metal pipe with an invert paved with concrete should provide an indefinite service life if it is of sufficient width, thickness and quality. By calculation, a 4-inch thick coating over the invert steel could be expected to postpone its initial time to corrosion by approximately 7.7 times greater than a 3/4 inch coating."

Estimated Service Life

Add-On Service Life for Non-Metallic Coatings (in years)

COATING	WATER SIDE			References
	Level 1 & 2	Level 3	Level 4	
Asphalt Coated	10	N/R	N/R	12, 13, 14, 15, 16
Asphalt Coated and Paved	30	30	30	12, 13, 15, 16, 17, 18, 19
Polymerized Asphalt Invert Coated*	45	35	N/R	5, 8, 19
Polymer Precoat	80+	70	N/R	8, 19, 20, 21, 22
Polymer Precoat and Paved	80+	80+	30	22, 23
Polymer Precoat with Polymerized Asphalt Invert Coated	80+	80+	30	19, 22
Aramid Fiber Asphalt Coated	40	N/R	N/R	20
Aramid Fiber Asphalt Paved	50	40	N/R	20
High Strength Concrete Lined	75	50	N/R	10,24
Concrete Invert Paved (75mm (3 in.) cover)	80+	80+	50	10, 24

N/R Not recommended

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Appendix B: Coating Test Protocol

The National Corrugated Steel Pipe Association (NCSPA) encourages the development of coating and invert treatments to improve the service life of their products in certain aggressive environments. These are primarily abrasive environments but can also include highly acidic, alkaline, and low resistivity environments. To help guide the development of candidate materials that would protect and extend the life of the invert of corrugated steel pipe (CSP), the NCSPA, along with AISI, has funded a program to develop and qualify a comprehensive testing protocol. This Protocol is not a standard or specification. The existence of the Protocol does not preclude anyone from manufacturing, marketing or purchasing products, nor from using products, processes or procedures whether or not tested in accordance with the Protocol and, if tested, regardless of test results.

In addition to evaluating the candidate materials improved properties, there are a number of qualities exhibited by existing CSP coatings that must be retained by the new materials. Most prominent among these qualities is the ability to be cost-effectively applied to CSP. Other qualities include impact resistance, freeze-thaw resistance, resistance to microbial attack, and resistance to ultraviolet deterioration. Finally, the candidate material is not expected to be an environmental or worker health risk. In today's regulatory climate it is difficult to predict the types of materials which will pose problems in the future. However, the new candidate materials will be screened for compliance with existing regulations (e.g. heavy metal content, VOC content) and potential future risks identified.

Screening Evaluation

The purpose of this initial screening is to provide a mechanism by which unsuitable materials can be screened out prior to testing. Because of the wide variety of possible coating material technologies that may be tested in accordance with this protocol, it is difficult to set specific criteria for initial screening. The screening process is intended as an initial step to eliminate unreasonable candidates. The flowchart at the end of this appendix addresses three key issues; performance, environmental/ worker health, and feasibility of application. There is a final checkpoint for "other concerns."

Evidence of Possible Performance (Block 1). Before evaluating any candidate material, there must be some evidence that it may be appropriate for the CSP service environment. This could be limited laboratory testing or documented service in a similar environment (e.g. pipelines). The purpose of this block is merely to ensure that testing is not blindly conducted on materials that are not applicable to CSP service environments. If no information on the material performance is available it should not be evaluated.

Environmental/Worker Health Compliance (Block 2). Compliance issues include EPA, OSHA and other state and/or federal compliance regulations. This evaluation protocol can not purport to address all issues of regulatory compliance, if only because of the changing regulations. Environmental and worker health issues must be the responsibility of the manufacturer and end user. However, it is important to identify possible problems prior to embarking on an extensive series of tests.

Application/Manufacturing Concerns (Block 3). Prior to evaluating a candidate material, consideration must be given to how it will be applied to CSP. There are two options for CSP coating application: application to coil steel prior to corrugating or application to the CSP after fabrication. There are special issues associated with either application method which should be considered prior to testing.

For materials applied after the manufacture of the CSP, the effects of surface contamination on coating adhesion must be considered. During corrugation and cutting, machining oils are left on the pipe that will affect adhesion. Cleaning steps required for their removal must be identified. The dry time of the coating material is also important as it may affect industrial engineering concerns such as production schedules and work flow. Tendency of the coating to sag must be considered to determine if spinning is required to coat around the pipe circumference. Any concerns with the material's adaptability to spraying, brushing, and pour/dip application should also be addressed at this stage.

For coatings applied to coil steel, manufacturing concerns center around the effects of production operations on the coating quality. Specifically, the ability of the coating to adhere to the lock seam and to rerolled ends should be considered. Shipping, handling, and installation will cause some damage to any coating; however more susceptible coatings should be identified.

Other Concerns (Block 4). This step allows for the consideration of unforeseen issues that may be encountered with new technology coating materials. It is important that all potential issues be addressed prior to embarking on the three tier test program.

Tier 1 – Qualification Tests

Qualification testing consists of an array of physical tests conducted to evaluate the relative performance between coating materials. These tests are conducted as a preliminary evaluation of coating performance. These test results will allow poor performers to be eliminated without further, more elaborate testing. All issues involved in coating deterioration are not considered in these tests. Passing these tests qualifies the coating for the more realistic abrasion, simulation, and field tests in Tier 2 and 3. Six standard tests are described, others may be added depending on the intended application of the coating. Manufacturers data may be considered acceptable for certain of these tests at this stage.

Freeze/Thaw Resistance (Column 5). Freeze/Thaw testing shall be conducted in accordance with ASTM A742/A742M, "Specification for Steel Sheet, Metallic-Coated, and Polymer Precoated for Corrugated Steel Pipe." If any coating damage occurs due to this cycling, the coating is unacceptable for application where freeze/thaw is a major concern.

UV/Weathering (Column 6). UV accelerated weathering tests will be conducted in general accordance with ASTM 4587, "Practice for Conducting Tests on Paint and Related Coatings and Materials Using a Fluorescent UV-Condensation Light- and Water-Exposure Apparatus." Types of damage recorded are observations of color change, cracking, blistering, chalking and any other damage the UV exposure may have caused.

Chemical Resistance (Column 7). It is not within the scope of this protocol to test for all combinations of chemical resistance. However, it is expected that all candidate materials will pass the chemical resistance (imperviousness) testing conducted in accordance with paragraph 9.6 of ASTM A742/A742M, "Specification for Steel Sheet, Metallic-Coated, and Polymer Precoated for Corrugated Steel Pipe" or ASTM G20, "Test Method for Chemical Resistance of Pipeline Coatings." Additionally, if the coating is being designed for improved resistance to specific, harsh conditions (e.g., high acidity or alkalinity), similar testing shall be conducted in an appropriate environment. If the coating shows any softening, thinning, disbondment, etc. it will not be considered for further testing.

For characterizing metallic coating resistance without an organic topcoat in different electrolyte chemistries, it may be desirable to run additional screening tests. Two suggestions include a corrosion rate test (e.g., polarization resistance) and a porosity test.

Coating Adhesion (Column 8). Coating adhesion tests are conducted to quantify the resistance of a coating to disbond from the substrate it is protecting. There are a variety of adhesion tests provided by ASTM.

Some tests for metallic coatings involve bending the coated material around small diameter rods and evaluating adhesion. All metallic and organic coatings applied to coil will be tested in accordance with ASTM D 4145 "Standard Test Method for

Coating Flexibility of Prepainted Sheet." The coating should show negligible failure at the 1-T bend which is representative of a lockseam bend radius.

Organic coating adhesion is often measured by applying tensile forces with calibrated apparatus or adhesive tape. Organic coating adhesion will be evaluated before and after a 30-day exposure to cathodic disbondment current in accordance with ASTM G8 "Test Method for the Cathodic Disbondment of Pipeline Coatings." The coating is expected to show less than 4 in^2 disbondment after this test.

Impact Resistance (Column 9). Impact resistance will be tested on organic coatings. Mechanical damage to the coating system from impact can occur on CSP during shipping, handling, and installation. Impact resistance is evaluated using the falling weight method in general accordance with ASTM A742/A742M "Specification for Steel Sheet, Metallic-Coated, and Polymer Precoated for Corrugated Steel Pipe." This method uses an apparatus with a vertical appendage and fixed weight. The weight is dropped from varying heights. The height at which the dropped weight causes coating damage that exposes the substrate is used to calculate the impact energy. There shall be no observed damage when subject to 35 in. lb. force from a 0.625-inch diameter punch.

Microbial Activity (Column 10). If it is determined that microorganisms may have an effect on the coating in its application environment, tests will be conducted in accordance with ASTM G22, "Practice for Determining Resistance of Plastics to Bacteria." Biodegradation effects will be evaluated in a laboratory environment. This involves subjecting test coating specimens to prepared cultures of various organisms that affect the adhesive qualities of a coating. These effects are monitored and documented over the length of the exposure period. There shall be no effect of microbial attack on the coating.

Other Concerns (Block 11). Tests will also be conducted for any other qualities expected to be of concern. If the candidate material is acceptable to the level required for the particular application, then the material may proceed to Tier 2 - Abrasion Testing.

Tier 2 - Abrasion Testing

Blocks 12 and 13. If the candidate material is not intended for use in an abrasive environment then this portion of the testing is not performed. If the candidate material is intended for an abrasive environment then the level of its abrasion resistance necessary for the application must be determined. The abrasion resistance will be characterized relative to a control material such as galvanized or asphalt coated CSP.

Block 14. The bedload abrasion test consists of a rotating drum apparatus. The test simulates an abrasive bedload by passing water and abrasive material over the test pipe specimen at tangents to the circumference of the pipe. In this test while the drum is rotating the test specimens pass through a slurry of water and abrasive material. The test apparatus is a 2-foot in diameter and 8 inch thick drum rotated by an electric motor. A 10-inch x 5-inch size curved piece of coated coil steel is bolted to the inside circumference of the drum. Water and abrasive material are also placed in the drum. At various intervals the specimens are removed and weighed. Coating damage is quantified by weight loss of the coating per cycle.

Block 15. The rotary disk test is conducted by rotating a flat coated disk in a round test chamber that holds the specimen, water, and abrasive material. Flat pieces of coated coil steel are cut and backed on a flat steel plate which is rotated within the chamber. As the disk with the test coating rotates it passes through the slurry of water and abrasive material which wear at the coating material. Coating damage is quantified by intermediate thickness measurements along the radius of the disk. The diameter (and thus relative velocity) of observed coating damage is recorded.

Block 16. When the necessary number of cycles of the above tests have been completed, the samples are removed and analyzed. An evaluation process now takes place to verify if the coating meets the established criteria for performance in the application environment. Acceptable coatings proceed to Tier 3 – Simulation

Testing. Unacceptable coatings should not be considered for the particular application.

Tier 3 – Accelerated Abrasion Simulation Testing

The purpose of this test is to subject a full size pipe coated with the test material to a variable abrasive bedload under controlled conditions. The abrasion resistance necessary can be quantified by characterizing the abrasive nature of the intended range of applications. Factors that should be considered in the application environment are flow velocity, size and amount of abrasive, and the slope of installation. Once these characteristics are determined, standards of performance for the simulation testing may be defined.

It is expected that some candidate materials will be designed to have an abrasion threshold lower than that used for preliminary testing. The test apparatus is designed to accommodate various flow and abrasion levels. Currently there are three potential levels for the testing:

- Level “L” (Low) – non-abrasive conditions of no bedload and very low velocities (< 5 fps).
- Level “I” (Intermediate) – abrasive conditions with bedloads and velocities representing the predominate expected field conditions. (TBD per test objectives)
- Level “H” (High) – highly abrasive bedload designed to accelerate field abrasion conditions. The test conditions shall mimic those used in the development of the protocol: >10fps velocity of a seawater medium and 3/4-inch trap rock bedload, 25 tons in ten days.

The physical properties of the candidate material will be closely monitored through the test. For organic, barrier-type coatings damage is quantified by measuring the electrical resistance between the corrugated pipe and an internal electrode. In addition the % coating loss is determined. For metallic coatings, the electrochemical potential and the coating thickness are measured to indicate coating loss.

Field Testing

Field performance data is an excellent means of giving confirmation to results of laboratory testing and at the same time presenting an opportunity for improvement of the candidate material.

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