Steel Market Development Institute

2014

DURABILITY OF ALUMINIZED TYPE 2 COATED CORRUGATED STEEL PIPE EXPOSED THROUGHOUT THE UNITED STATES

WRITTEN BY -

Elzly Technology Corporation

Prepared for:

NATIONAL CORRUGATED STEEL PIPE ASSOCIATION

August 2014

THIS RESEARCH WAS PERFORMED IN PARTNERSHIP WITH:

Steel Market Development Institute: Construction Market Council

A Business Unit of the American Iron and Steel Institute

25 Massachusetts Ave, NW

Suite 800

Washington, DC 20001

THIS REPORT WAS WRITTEN BY:

J. PETER AULT, P.E

ELZLY TECHNOLOGY CORPORATION
1610 WASHINGTON PLAZA NORTH
RESTON, VA 20190

THIS REPORT WAS PREPARED FOR AND PUBLISHED BY:

NATIONAL CORRUGATED STEEL PIPE ASSOCIATION
14070 Proton Road
Suite 100, LB 9
Dallas, TX 75244

August 2014

Durability of Aluminized Type 2 Coated Corrugated Steel Pipe Exposed Throughout the United States

Written By –

J. Peter Ault, P.E. – Elzly Technology Corporation

Co-Author –

Michael McGough, P.E. – National Corrugated Steel Pipe Association

Special Thanks To–

James Evans – AK Steel Corporation

August 2014

Durability of

Aluminized Type 2 Corrugated Steel Pipe

Exposed throughout the United States

Prepared for:

National Corrugated Steel Pipe Association

Prepared by:

Elzly Technology Corporation

August 2014

Executive Summary

The durability of a drainage system is an important consideration for a civil engineer. As a result of continued interest in improving the durability of corrugated steel pipe (CSP) products, the CSP industry has sponsored extensive research over the past several decades on improved coating materials.

Aluminized Type 2 CSP was developed in 1952 to be a more durable coating than zinc in many of the common installation environments. In the early 1950's, over 125 Aluminized Type 2 corrugated steel pipes were installed through a collaborative effort of Armco, now AK, Steel and over 20 county and state highway departments. Starting at the anniversary of 30 years of service, an inspection was conducted approximately every 10 years thereafter to track the performance of specific installations. Since that time, the material performance of sites in Maine, Maryland, Michigan, Ohio, Iowa, Illinois, Missouri, Mississippi, Alabama, Georgia, South Carolina, Louisiana, Texas, Kansas, Oklahoma, Colorado, Oregon, Utah, New Mexico, California and Washington have been documented. These studies, in addition to the work conducted by the Federal Highway Administration (FHWA) and multiple state DOT's have continued to demonstrate the durability of Aluminized Type 2 CSP .

The present study was focused on documenting performance of Aluminized Type 2 CSP in long term installations as well as determining the viability of current technologies for measuring steel and coating thicknesses. Sites in this study were selected from AK Steel's 50-year report, FHWA's report titled "Durability Analysis of Aluminized Type 2 Corrugated Metal Pipe.", and manufacturer records. In total, 26 core samples were removed and analyzed for coating thickness, pit depth, and alloy layer. These samples of both helical and riveted pipe ranged between 30 and 60 years in service. Soil and water samples were gathered from the site and analyzed for resistivity, pH and chlorides when available.

The data confirms current service life guidance for Aluminized Type 2 CSP, where 16 gage steel provides a minimum of 75 years of service life when the FHWA abrasion level is 2 or less, the pH range is from 5 to 9 and the resistivity is greater than 1500 ohm-cm or greater than 5000 ohm-cm with a pH of 4.5 to 5. The soil side of all but six of the samples has 100 percent coating remaining with only one of the six having been exposed for less than 60 years. The water side of the samples exhibit varying degrees of degradation due to water corrosivity, wet and dry cycling, bedload and water flow. Of the few sites with pitting, it was found mainly on the upstream side of the corrugation in the invert. All pipes are currently functioning as intended at this point in their life and would be expected to meet the design service life of 75 or 100 years.

For future inspections, it is recommended that advantage be taken of newer technologies for measurement of both coating thickness and overall pipe thickness. The use of Dry Film Thickness (DFT) gages and Ultrasonic Thickness (UT) gages allow for a larger sampling size for each pipe. The larger sample size can be produced in less time than it normally takes to drill out a core and analyze a single sample. A larger performance database will continue to increase the level of confidence in the durability of Aluminized Type 2 CSP.

Table of Contents

Background

The durability of a drainage system is an important consideration for a civil engineer. As a result of continued interest in improving the durability of corrugated steel pipe (CSP) products, the CSP industry has sponsored extensive research over the past several decades on improved coating materials. A synthesis study funded through the Transportation Research Board (TRB) discusses drainage pipe durability at length.[1]

Aluminized Type 2 (Aluminized) steel was first introduced as a corrugated steel pipe material in 1952-53. This type of corrugated steel pipe is fabricated from high strength steel coils that have been hot dip coated in a bath of commercially pure aluminum, creating a metallurgical bond to the base metal. The aluminum material protects the steel by first forming a passive aluminum oxide layer, which provides longer protection over a broader range of environments than comparable zinc coatings. The second layer of defense is the hard aluminum-iron alloy layer itself. Several independent studies have demonstrated excellent performance of aluminized steel in the most common types of culvert installations. The material manufacturer has also conducted long-term studies of Aluminized culvert performance for over half a century. Following is a brief discussion of studies conducted by the manufacturer and the Federal Highway Administration (FHWA) which include the pipes that make up the majority of this study.

The sites that were selected for this study are taken from previous manufacturer reports, the FHWA study referenced and the addition of several new sites identified through industry. The reduction in the numbers of sites inspected over the course of these studies has been attributable to many factors including: urbanization or other changes in land use, abandonment, submergence or the inability to locate. Several sites were either removed from service or not included due to exposure to severe abrasion conditions, while other sites were removed or rehabilitated due to deterioration in the adjacent galvanized sections.

Armco / AK Steel Corporation Studies

In 1952-53, 137 Aluminized Type 2 corrugated steel pipes were installed through a collaborative effort of the manufacturer and several state departments of transportation. Since that time, performance at sites in Iowa, Illinois, Missouri, Mississippi, Texas, Kansas, Oklahoma, Colorado, New Mexico, California and Washington have been documented. The reports for these locations document the backfill material, water quality and the soil side and water side corrosion.

Three primary published reports resulted from the 1952-53 study of Aluminized Steel Type 2 corrugated steel pipes. These reports included a 30-year, 42-43-year and 50-year evaluation. The 30-year report investigated 58 sites in 14 states. The report focuses on water side corrosion, noting that "no sites had

[1] Gabriel, Lester H., *Service Life of Drainage Pipe, NCHRP Synthesis 254*, Transportation Research Board Washington, DC, 1998.

severe soil side influences." Based on the data in this report, usage guidelines were developed which reflected the ability of Aluminized Type 2 to tolerate more severe environmental conditions than traditional CSP materials.

The report titled *Aluminized Steel Type 2 Corrugated Steel Pipe Durability Update: 1995; Field Performance of Pipes in Service for 42-43 Years* documents the performance of 34 of the original sites in 11 states as well as an additional 24 younger sites in 7 states. The study concluded that the data was "indicative of projected service life of 75 years minimum at 16 gage in normal environments." The 50-year evaluation included 22 of the original sites in 9 states. The data in this report was consistent with the present design guidance for 75 and 100-year service life.

FHWA-FLP-91-006

An FHWA sponsored study, *Durability of Special Coatings for Corrugated Steel Pipe* was conducted in 1991. This study included a comprehensive literature review and field study of the service life of different CSP coating systems, using galvanized as a performance baseline. The study reviewed both metallic (galvalume and Aluminized Type 2) and non-metallic (bituminous, polymer, concrete etc.) coatings that could potentially produce a service a life in excess of 50 years. The study concluded that CSP life cycle can be extended past 50 years if the proper coating was used under proper environmental conditions. The study was favorable to the Aluminized coating.

FHWA-RD-97-140

Another FHWA sponsored study, *Durability Analysis of Aluminized Type 2 Corrugated Metal Pipe* was conducted as a follow up to FHWA-FLP-91-006. In this study, a focus was made on Aluminized Type 2 pipes, including those inspected in the 1991 FHWA study. At the time of inspection most of these sections of pipe had 14-16 years of service.

This study attempted to incorporate the effects of bed load abrasion into service life potential. Previous studies neglected this factor, which contributes to variability in the observed durability. This study concluded that Aluminized CSP has the potential to last up to eight times longer than galvanized CSP on the soil side and 3.5 times longer on water side, depending on the exact environment. It also concluded that two pitting tendencies were observed. The higher pitting tendency was influenced by abrasion from the bed load and the lower pitting tendencies appeared to be linear in time.

Field Studies

Inspection Procedure

Most of the present field inspections were performed by the Chief Engineer of the National Corrugated Steel Pipe Association with assistance from local Department of Transportation and manufacturer representatives. Elzly participated in the inspection of Santiam Highway, Oregon locations. The equipment used during each inspection included:

- Digital Camera
- Dry Film Thickness gage (DFT)
- Ultrasonic Thickness gage
- Cordless drill with 1.5" hole saw bit
- pH paper
- Sample containers
- Assorted tools (shovel, machete, scrub brushes, hand tools)

At each site the following tasks were completed:

1. Photograph the specific pipe being evaluated
2. Use pH paper to evaluate water, if present, and evaluate bedload
3. Collect soil and water samples for evaluation
4. When possible, collect core sample from pipe, to be micro- and macroscopically evaluated
5. Use DFT gage to measure remaining Aluminum coating
6. Use Ultrasonic thickness gage to measure total thickness of corrugated steel pipe

In most cases duplicate core samples were removed from each pipe. One sample was returned to AK Steel while the other sample was returned to Elzly Technology for analysis. Analysis was completed in effort to determine the extent of coating degradation, if any, and to determine the extent of any pitting. The samples were prepared using standard metallographic techniques. All samples were photographed (on both water and soil side) in their "as-is" state, after cleaning with brush and water and after glass bead blasting to remove all corrosion product. The light glass bead process does not remove significant amounts of the Aluminized coating. Figure 1 shows a representative sample as received and after abrasive blasting. Once the samples are cleaned, the extent of remaining coated surface is estimated and the deepest pits are measured using a mechanical pit gage.

Fairplay, CO “as-received” Fairplay, CO “post-blasting”

Figure 1. Representative Sample Cleaning

Precision cuts were made through an area of interest on each sample. This was often through the most severe pitting found on the sample, but this single pit may not be representative of the pitting severity along the whole sample or the whole pipe. These pieces were mounted in epoxy and finished with a progressively finer abrasive. Finally, a Nital etchant was used to expose the aluminum-iron alloy formed during the pipe sheet production process. Once sample preparation was complete the samples were able to be observed under a microscope. Digital images were analyzed to determine the thickness of the Aluminized coating, alloy layer (when aluminum was removed) and depth of any pits observable within the sample. Figure 2 shows representative measurements.

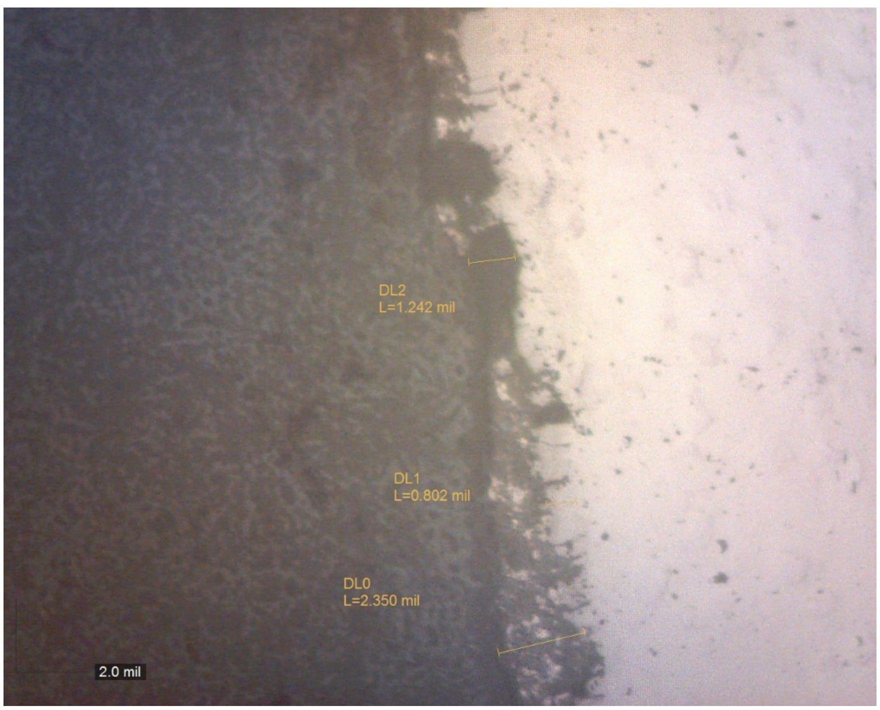


Figure 2. Representative Micrograph

Data Collection

Table 1 shows an inventory of the pipes evaluated grouped by the study with which they were originally associated.

Table 1. Inventory of Pipes Evaluated

Original Armco/**AK Steel Sites Approximately 60 years old**	**Sites From FHWA-RD-97-140**	**Test Sites not in previous studies**
• Morgan Co., IL • Marshall Co., IA (2 pipes) • Carter Co., MO • Dickinson Co., KS • Pratt Co., KS • Fairplay, CO • Bernalillo, NM • El Dorado, CA • San Benito, CA	• Santiam Highway, OR (9 sites) – 28 yrs old • Ripley, ME – 30 yrs old • Natchez Trace Parkway, AL (3 pipes) – 28 yrs old	• Anlauf, OR • Jefferson, OR • Snellville, GA • Memrancook, NB, Canada

A core sample was removed from the invert of each pipe in the study whenever possible. Some pipes were obstructed by high water or soil, making it impossible to remove a sample from the invert for testing. In total 26 samples were evaluated. Soil and water samples were collected, when possible, and evaluated for resistivity, pH and chlorides.

Table 2 shows a summary of the data for each pipe. In this table we show the type of pipe and approximate age, for those that are known, and water and soil side data. For both sides a visual estimate was made of the total percentage of the coupon surface area which has in-tact aluminum coating. Measurements of the maximum thickness of coating remaining, the minimum thickness of coating, maximum pit depth and thickness of alloy layer were made along the cross-section observed under the microscope. This section was selected in an attempt to be able to view the most significant pitting and coating loss on the coupon. An important consideration when reviewing the data, is that this is not necessarily representative of the entire pipe surface. In most cases the pipe invert experiences the most significant coating loss and pitting. Appendix A contains data and photographs for each core sample.

Table 2.Data from Removed Samples

Location		State	Age	FHWA Abrasion Level	Water Side						Soil Side					
					% Coating Remaining	Max AL (mils)	Min AL (mils)	Max Pit (mils)	Resistivity	pH	% Coating Remaining	Max AL (mils)	Min AL (mils)	Max Pit (mils)	Resistivity	pH
Natchez Trace	310.2	AL	31	3	80	1.25	0.00	2.50	NV	NV	100	1.63	0.73	0.87	NV	NV
Natchez Trace	311.9	AL	31	1	5	0.00	0.00	23.00	NV	NV	100	1.61	0.72	1.31	NV	NV
Natchez Trace	312.4	AL	31	1	100	2.03	0.00	1.38	NV	NV	100	2.55	0.84	16.00	NV	NV
Fairplay County		CO	60	3	0	0.00	0.00	8.50	NV	NV	0	0.00	0.00	5.21	3218	6.4
Snellville		GA	30	2	100	3.68	0.00	4.31	NV	6	100	2.32	1.24	1.21	NV	NV
Marshall County	#5	IA	60	2	40	0.89	0.00	2.57	NV	NV	20	1.40	0.00	1.31	1570	7.6
Marshall County	#7	IA	60	2	90	1.78	0.00	1.23	710	6.7	95	1.38	0.58	0.84	1330	7
Morgan County		IL	60	2	85	1.71	0.00	8.00	2174	6	100	2.53	0.00	1.97	2860	7
Dickinson County		KS	60	2	0	0.00	0.00	37.00	NV	NV	5	0.00	0.00	0.73	NV	NV
Pratt County		KS	60	2	5	0.00	0.00	12.00	NV	NV	5	0.00	0.00	14.00	NV	NV
Ripley		ME	30	2	0	0.00	0.00	41.00	NV	6	100	1.13	0.00	2.32	NV	NV
Carter County		MO	60	1	10	0.00	0.00	10.50	NV	NV	100	1.65	0.00	0.00	1420	6.7
Bernalillo		NM	60	2	0	0.00	0.00	26.00	NV	NV	0	0.00	0.00	57.00	NV	NV
Anlauf		Oregon	NA	2	90	2.69	0.77	4.97	10870	5	100	1.87	0.55	1.35	2860	NV
Jefferson		Oregon	NA	3	60	2.78	0.00	81.00	10010	100	2.361	1.63	0.00	81.00	NV	NV
Santiam Highway	18+20	Oregon	28	2	80	2.31	0.00	1.54	55500	4.5	100	1.45	0.00	0.94	14300	NV
Santiam Highway	38+12	Oregon	28	2	65	1.72	0.00	11.00	23810	5	100	2.54	0.00	1.60	9440	NV
Santiam Highway	44+50	Oregon	28	2	55	1.05	0.00	2.28	29410	5.5	100	3.01	1.00	0.87	29030	NV
Santiam Highway	90+38	Oregon	28	3	5	0.00	0.00	51.50	18520	5.5	30	0.88	0.00	35.50	14410	NV
Santiam Highway	100+15	Oregon	28	1	95	1.66	0.00	5.00	28570	5	100	1.42	0.87	3.38	14350	NV
Santiam Highway	104+45	Oregon	28	3	10	0.00	0.00	20.00	29410	4.5	100	2.09	0.93	1.16	14700	NV
Santiam Highway	123+76	Oregon	28	2	100	1.07	0.00	1.20	27780	5	100	1.46	0.00	1.13	31460	NV
Santiam Highway	New Site 1	Oregon	28	1	95	1.58	0.37	0.67	NV	NV	100	3.04	0.55	0.00	14470	NV
Santiam Highway	New Site 2	Oregon	28	1	95	2.02	0.00	9.00	NV	NV	100	2.18	0.94	1.02	NV	NV
Memrancook	Canada	New Brunswick	15	2	100	2.54	0.08	0.78	NV	6	100	3.02	0.00	1.55	NV	NV

Note: The Albuquerque, NM sample had such significant general corrosion that no original surface was available to make a measurement under the microscope. The reported maximum pit at this site is based on a needle micrometer measurement.

Discussion and Analysis

Durability and Service Life

All of the pipes inspected in this study were still performing their intended function. Two pipes were observed along the Natchez Trace in Alabama which had invert perforation. These locations were documented in previous FHWA studies. It is believed that these pipes were subject to abrasion beyond that which is recommended for Aluminized Type 2 service. Coupons were not removed from these inverts. Of the remaining locations, only six pipes had pitting in excess of 20% of the overall pipe thickness. Two of those samples had pitting from both soil and water side while the remaining four only had pitting from the water side.

The soil side of all but six of the samples has coating remaining on 100 percent of the surface. Of those six samples only one has been exposed for less than 60 years. The water side of the samples experiences varying degrees of degradation due to water corrosivity, wet and dry cycling and bed load and flow. All but nine of the samples had at least 40% of the surface coated. Based on the observations, all of the pipes are currently functioning as intended at this point in their life (30-60 years of service). The observed pipe conditions are consistent with the design guidance provided for Aluminized Type 2 CSP.

In an attempt to get a broader perspective of the performance of Aluminized coated CSP over time, all available data from AK Steel's reports (30, 43 and 50 year), FHWA-FLP-91-006 and FHWA-RD-97-140 and the current inspections was compiled. Each pipe was categorized into one of four categories based on the depth of pitting and extent of coating loss. Table 3 shows the rating scheme. In all, over 170 individual inspections were recorded and categorized. Figure 3 presents the total number of observations in each category. Note that the perforated pipes are those which have previously been identified as experiencing abrasion beyond the recommended level.

Table 3. Rating Criteria

		Aluminized Coating Attack	
		100% covered	100% Exposed
Pitting	Less than 2 mils	(green)	(yellow)
	2-6 mils	(yellow)	(yellow)
	Greater than 6 mils	(orange)	(orange)
	Perforation	(red)	(red)

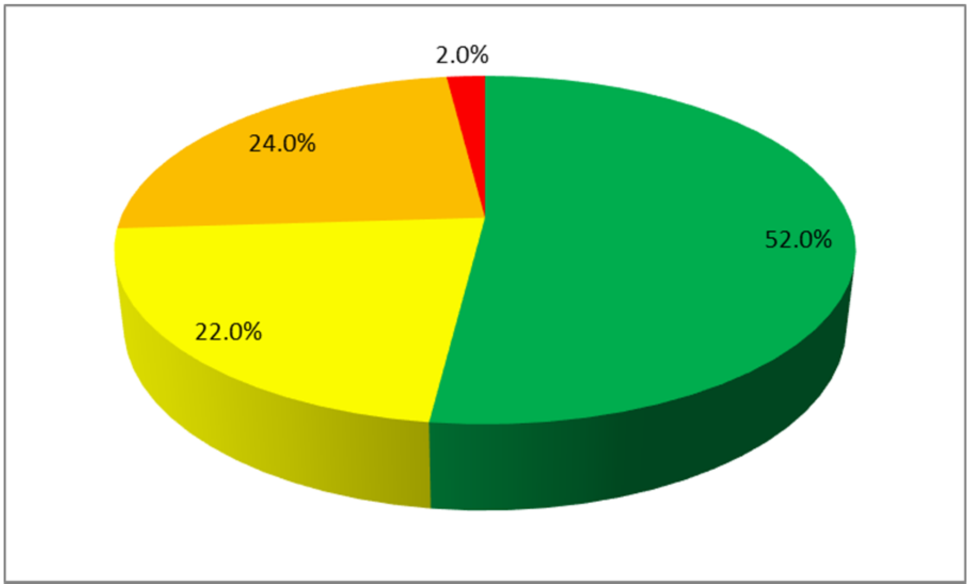


Figure 3. Distribution of Conditions

Figure 4 shows the same data as Figure 3 except it is separated by pipe age at the time of the inspections. The most data was collected when the pipes had between 21 and 30 years of service. At that period the number of pipes in the green category is very high. This shows that through 30 year of service almost no pitting is present (38 pipes). There are ten samples in each of the yellow and orange categories. Although these pipes are beginning to show signs of wear they still hold most of their steel substrate and, for those in yellow, often some of the Aluminized coating. As the pipes age a shift in the data can be seen. Note that no inspections were conducted of pipe with 31 to 40 years of service. At the 41 to 50 years of service sample categories begin to shift toward the yellow and orange. This means that around 50 years of service the Aluminized coating becomes penetrated at a higher rate. Following this phase of the coating breakdown the base metal steel will then begin to corrode. A limited number of sites were inspected at 60 years of service. Of the sites inspected, all remained in the same categories from their 50 year inspection.

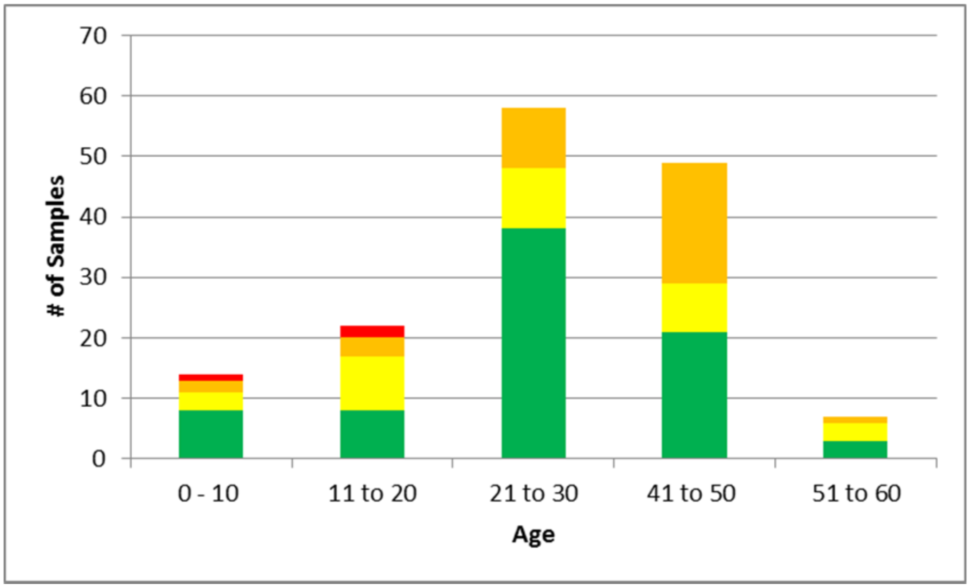


Figure 4. Samples Categorized by Grade and Age

Once the aluminum oxide and alloy layers are consumed the corrosion of the base steel will begin. The corrosion of steel in soil has been extensively studied. In the situation of CSP the soil side can be estimated using many of these models depending on soil characteristics. Water side estimates will vary in time with water characteristics. Using a typical model we could expect base metal steel corrosion rates of roughly 0.5 mils per year from the soil side and 2 mils per year at the invert under the waterline in an aggressive water-side environment. Considering this scenario of corrosion rates, a 16-gage (0.064 in) CSP will last more than 25 years beyond the coating life before perforation occurs.

Environmental Influences

CSP durability guidance is predominantly based on soil and water chemistry (typically resistivity and pH, although water hardness, chloride and sulfate content is sometimes also used). Obviously, soil and water conditions can change over the service life of the pipe. For example, changes in land use may cause the water run-off to become acidic or highly saline, both of which will increase corrosion rate.

The issue of variability in water characteristics was briefly investigated in the previously referenced FHWA Study. Including the present study, there are three sets of soil and water data from the inspected sites at Natchez Trace Parkway, Alabama (NT) and Santiam Highway, Oregon (SH). The three sets of data were compiled for analysis. Figures 5 through 8 present how water and soil conditions can change over the service life of these pipes. The differences among the data sets are not terribly significant relative to the CSP service life selection criteria. However, the 1991 and 2000 data appear more consistent than the 2013 data. The 2013 data seems to suggest that the Oregon water and soil are higher resistivity, though it is difficult to tell if this is a seasonal effect, random observation, or a long-term trend.

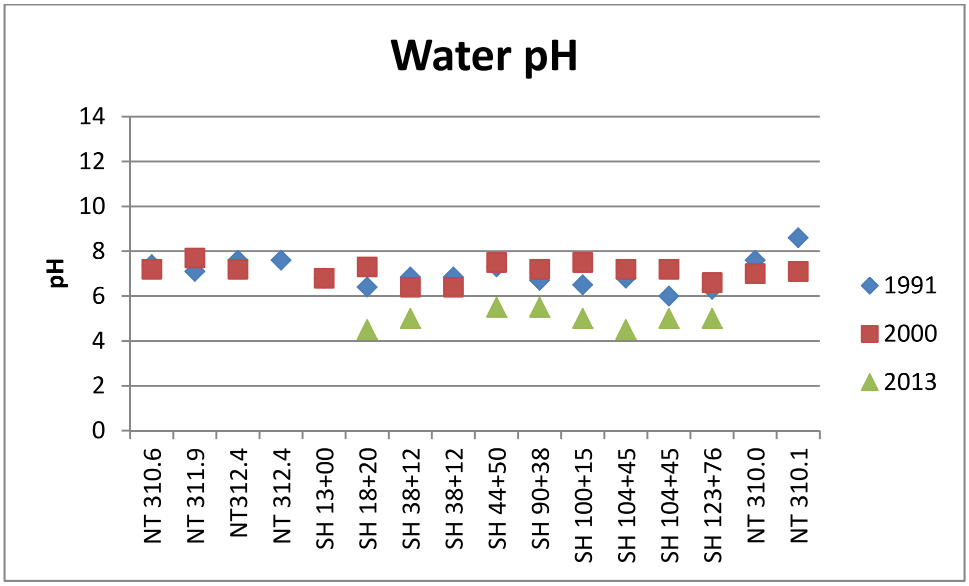


Figure 5. Change in Water pH

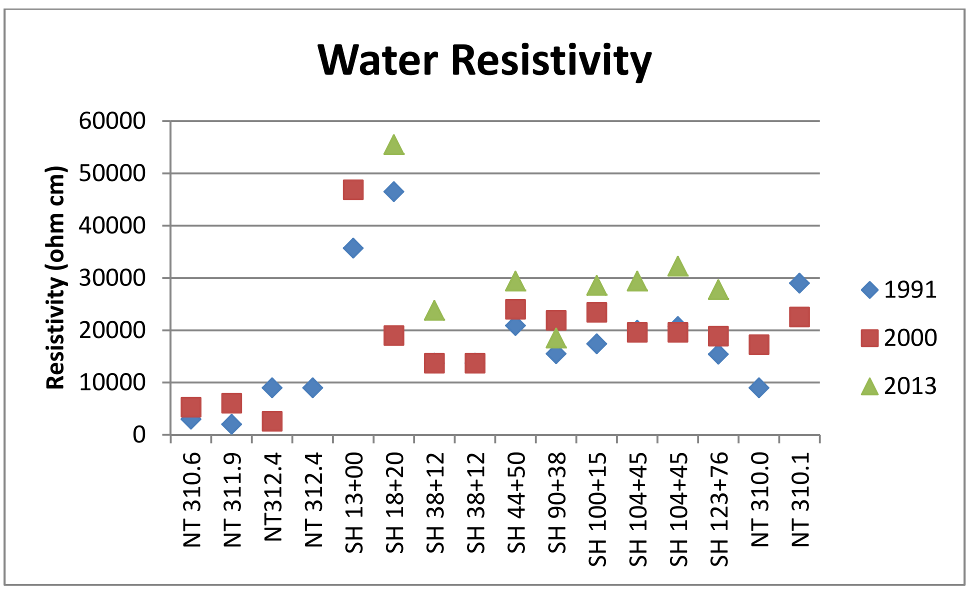


Figure 6. Change in Water Resistivity

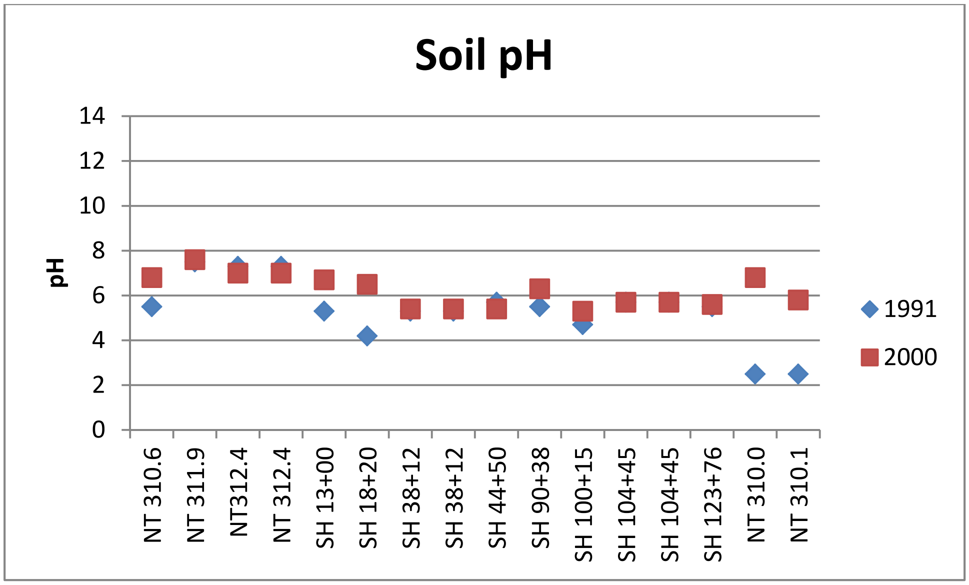


Figure 7. Change in Soil pH

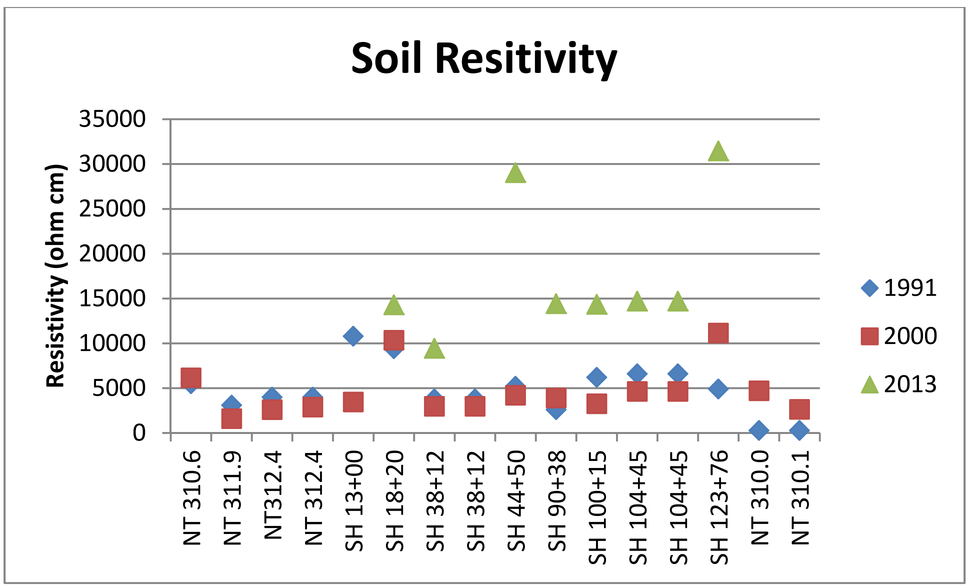


Figure 8. Change in Soil Resistivity

One additional important parameter in the study of CSP is the bedload experienced. The effect of bedload on Aluminized pipe is obvious from the wear patterns in the aluminum oxide layer. As would be expected, bedload only wears the Aluminized coating from the upstream side of the corrugation. Figure 9 and Figure 10 show examples with wear on one side of the corrugation. The lower portion of the sample is a darker color, because bare steel is exposed due to abrasion. Analysis of the pits on each sample reveals two unique characteristics of pitting. In samples where abrasion is a clear concern we see a large density of pits on the upstream half of the sample (see Figure 9). These pits typically have a wide mouth in comparison to their depth, and are also deeper than most general corrosion pits. Pitting which is associated with general corrosion typically has a low pit density, is scattered throughout the entire surface area of the sample and has shallower depth than pits in areas subject to abrasion. Typically, these pits are also much narrower than those found in abrasion areas. If abrasion levels beyond those recommended are present, a decrease in service life is to be expected.

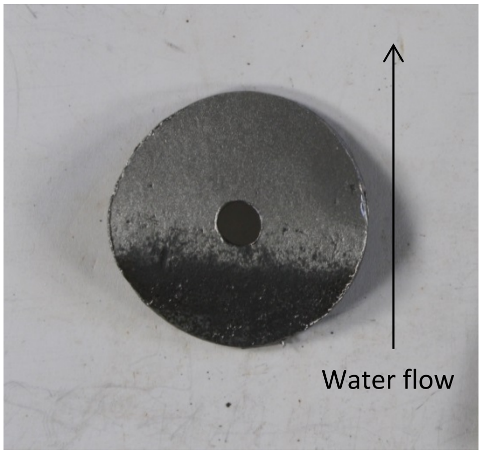


Figure 9. Coating removed due to bed load

Figure 10. Coating removed due to bed load

Inspection Procedure Enhancements

As part of this inspection an investigation was conducted to determine if enhancements could be made to the inspection techniques. With current techniques, a core sample (often multiple) is taken from each pipe. This core sample is physically evaluated using pit gages, microscopic and visual techniques. The process is somewhat tedious and leaves a hole in the pipe (though observation of sample locations twenty years after they were taken shows no adverse effect on the pipe).

During this project, we evaluated the use of electronic Dry Film Thickness (DFT) gages to measure coating thickness and Ultrasonic Thickness gages to measure remaining pipe wall thickness. These tools eliminate the need to remove a core sample to determine the degradation rate of the pipe. DFT gages use electronic circuitry to convert a reference signal into coating thickness when a non-magnetic coating is applied over a ferrous or non-ferrous substrate. When measuring on Aluminized Type 2 CSP it is important to verify the gage reading on an aluminized sample of known thickness. Electronic gages require a field adjustment to a standard coating of known thickness. The gages will also provide more accurate readings on flat surfaces versus the crest of the corrugation.

Table 4 compares coating thickness measured using an electronic DFT gage and that determined from microscopic evaluation of core samples. The differences are easily explained by sample size. Microscopic measurements can only be made along a relatively short cross section (nominally one inch long) and reflect an observation of a very small cross section at nominally 100X magnification.

Electronic DFT measurements are made throughout the pipe and reflect an average thickness measurement over the probe diameter.

Table 4. Microscopic vs. Electronic Coating Thickness

Location	Median Microscopic Thickness Measurement (mils)	Coating Thickness Gage Reading	
		Average (mils)	Range (mils)
100+15	1.66	1.56	1.18-2.08
38+12	1.72	1.93	1.33-3.38
44+50	1.05	1.77	1.54-2.15
Anlauf	3.19	2.12	1.54-3.09
Exit 244	2.79	2.70	1.81-3.88
New Site 1	1.58	1.32	0.99-1.65
New Site 2	2.02	1.28	0.87-1.51

Figure 11 illustrates how coating thickness can vary across a sample even with small cross sections. In this image a coating thickness of over 5 mils is measured in one location with only 2 mils of coating thickness a short distance from that.

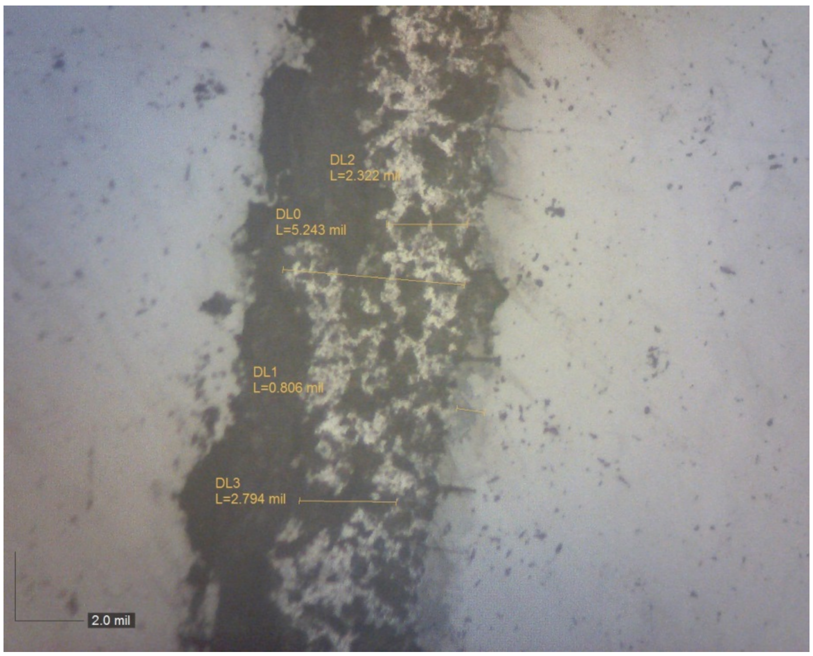


Figure 11. Potential Variation in Coating Thickness

Ultrasonic Thickness gages are used to measure overall thickness of a material. With the assistance of a conductive gel, the gage emits an ultrasonic wave into the material. By measuring the time and amplitude of the reflective wave off the material boundary it can accurately measure the material thickness to within .001”. The measurement is not sensitive to small, isolated pits, therefore the measurement is more indicative of general thinning versus narrow mouthed pits. If the depth of narrow mouth pits are significant, a needle pit depth gage could potentially be used to measure them in the field if they can be accessed. Because of variability in sheet thickness, it is recommended that reference thickness measurements be made at the top of the pipe where coating loss is unlikely and compared to the invert where thickness loss is typically the worst. Figure 12 presents UT measurements made in Oregon during this study.

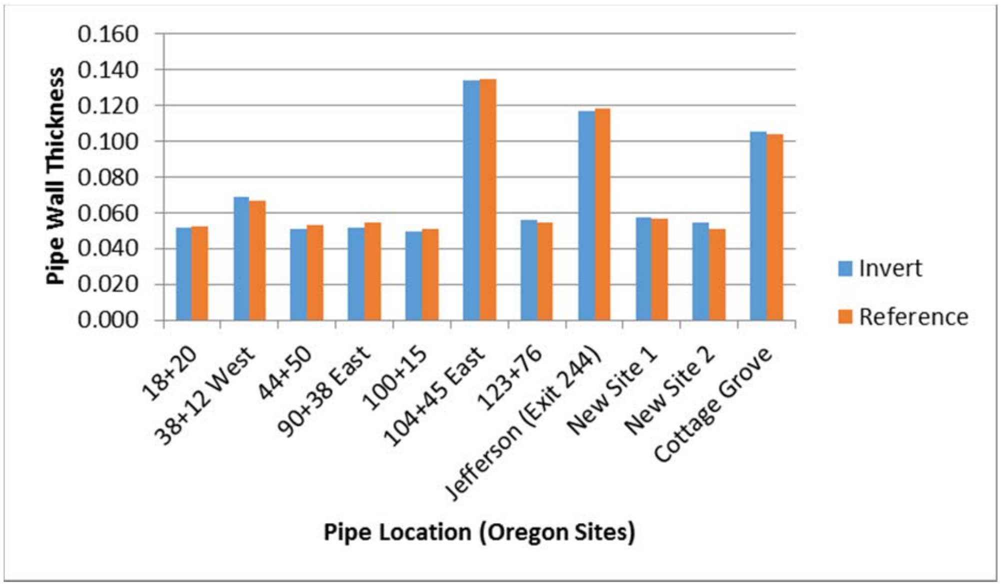


Figure 12. Comparison of Pipe wall thickness measurements.

The addition of these tools to the standard testing procedure will prevent unneeded removal of core samples. Additionally, less total time will be required for inspection. The extra time spent taking measurements in the field is significantly less than that required to microscopically analyze each sample. Another benefit of using digital gauges is a larger sample size, when using core samples the coating thickness and pit depth can only be measured over a small cross section. The removed section may not be representative of the whole pipe's condition, a situation that will create problems. Using the gages many measurement can be made over the entire pipe. Doing it this way will provide a clearer picture of the condition of the pipe. Unfortunately, no coating measurement can be made underwater, even in just an inch or two of water which normally a core sample can still be removed from.

Appendix B contains a recommended standard inspection procedure for use with future inspections.

Appendix A – Detailed Data from Each Sample

Natchez Trace 310.2, Alabama

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
54"	16 (0.064 IN)	ESTIMATED 1984	AUGUST, 2012
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
3 X 1	ALUMINIZED TYPE 2	PH: N/A	PH: 5
		RESISTIVITY: 2,860 Ω-CM	RESISTIVITY: 10,870 Ω-CM
			FHWA ABRASION LEVEL: 3
			CHLORIDES: DRY
			$CaCO_3$: DRY

IMAGES:

SOIL SIDE ALUMINUM COATING DATA:

- Surface area coated: 100%
- Minimum thickness: 0.73 mils
- Maximum thickness: 1.63 mils (41.5 µm)
- Maximum pit depth: 1.31 mils

WATER SIDE ALUMINUM COATING DATA:

- Surface area coated: 80%
- Minimum thickness: 0.00 mils
- Maximum thickness: 1.25 mils (32 µm)
- Maximum pit depth: 2.73 mils

Natchez Trace 310.2, Alabama

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP AVG = 0.057
- INVERT AVG = 0.062

  * Avg of a minimum of 4 readings after cleaning using TI-25M Ultrasonic Wall Thickness Gauge

COMMENTS:

- Pipe is in good condition
- Installed in an abrasive environment

Natchez Trace 311.9, Alabama

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
72”	16 (0.064 IN)	ESTIMATED 1984	AUGUST, 2012
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
3 X 1	ALUMINIZED TYPE 2	PH: N/A	PH: N/A
		RESISTIVITY: N/A	RESISTIVITY: N/A
			FHWA ABRASION LEVEL: 1
			CHLORIDES: DRY
			$CaCO_3$: DRY

IMAGES:

SOIL SIDE ALUMINUM COATING DATA:

- Surface area coated: 100%
- Minimum thickness: 0.72
- Maximum thickness: 1.61 (41 µm)
- Maximum pit depth: 0.87 mils

WATER SIDE ALUMINUM COATING DATA:

- Surface area coated: 5%
- Minimum thickness: 0.00
- Maximum thickness: 0.00
- Maximum pit depth: 23.00 mils

Natchez Trace 311.9, Alabama

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP AVG = 0.060
- INVERT AVG = 0.052

  * Avg of a minimum of 4 readings after cleaning using TI-25M Ultrasonic Wall Thickness Gauge

COMMENTS:

- Pipe is in good condition
- No pavement distress

Natchez Trace 312.4, Alabama

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
18”	16 (0.064 IN)	ESTIMATED 1984	AUGUST, 2012
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: N/A	PH: N/A
		RESISTIVITY: N/A	RESISTIVITY: N/A
			FHWA ABRASION LEVEL: 1
			CHLORIDES: DRY
			$CaCO_3$: 100 PPM

IMAGES:

SOIL SIDE ALUMINUM COATING DATA:

- Surface area coated: 100%
- Minimum thickness: 0.84 mils
- Maximum thickness: 2.55 mils (65 µm)
- Maximum pit depth: 16.00 mils

WATER SIDE ALUMINUM COATING DATA:

- Surface area coated: 100%
- Minimum thickness: 0.00 mils
- Maximum thickness: 2.03 mils (51 µm)
- Maximum pit depth: 1.38 mils

Natchez Trace 312.4, Alabama

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP AVG = 0.060
- INVERT AVG = 0.060

  * Avg of a minimum of 4 readings after cleaning using TI-25M Ultrasonic Wall Thickness Gauge

COMMENTS:

- Pipe and coating are in good condition
- No pavement distress

El Dorado/Georgetown, California

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
18”	16 (0.064 IN)	ESTIMATED 1952	NOVEMBER, 2012
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: 6.6	PH: DRY
		RESISTIVITY: 6,430 Ω-CM	RESISTIVITY: DRY
			FHWA ABRASION LEVEL: 1
			CHLORIDES: DRY
			$CaCO_3$: DRY

IMAGES:

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.059 (0.059, 0.059, 0.058, 0.058, 0.059)
- INVERT: AVG = 0.058 (0.059, 0.058, 0.057, 0.059, 0.059)

*Measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 37
- INVERT: 31

*Avg of a minimum of 4 readings after cleaning using DCF3000FX

COMMENTS:

- Aluminized Type 2 coating in good condition
- No pavement distress
- Previous trepan holes were not corroded further

San Benito, California

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
30" - RIVETED	14 (0.079 IN)	ESTIMATED 1952	NOVEMBER, 2012
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: 5.1	PH: DRY
		RESISTIVITY: 630 Ω-CM	RESISTIVITY: DRY
			FHWA ABRASION LEVEL: 1
			CHLORIDES: DRY
			$CaCO_3$: DRY

IMAGES:

ULTRA-SONIC PIPE THICKNESS (IN):

- INVERT: AVG = 0.070 (0.070, 0.071, 0.068, 0.072)
  *Measured using TI-25M Ultrasonic Wall Thickness Gauge

COMMENTS:

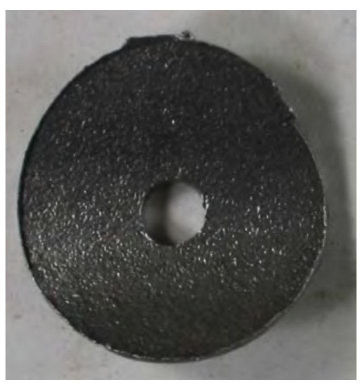
- Did not appear to be any coating remaining at the invert
- No pavement distress
- Local property owner says they work well

Fairplay, Colorado

DIAMETER	**GAGE**	**YEAR INSTALLED**	**INSPECTION DATE**
24”	14 (0.079 IN)	ESTIMATED AT 1952	JUNE, 2012
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: 6.4	PH: DRY
		RESISTIVITY: 3,218 Ω-CM	RESISTIVITY: DRY
			FHWA ABRASION LEVEL: 3
			CHLORIDES: DRY
			$CaCO_3$: DRY

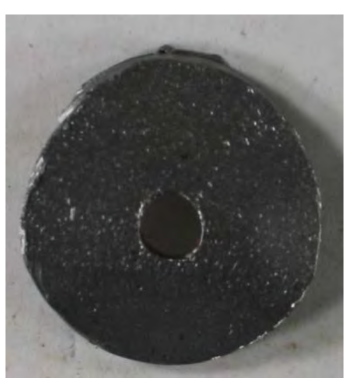
<u>IMAGES:</u>


<u>SOIL SIDE ALUMINUM COATING DATA:</u>

- Surface area coated: 0%
- Minimum thickness: 0.00
- Maximum thickness: 0.00
- Maximum pit depth: 8.50 mils

<u>WATER SIDE ALUMINUM COATING DATA:</u>

- Surface area coated: 0%
- Minimum thickness: 0.00
- Maximum thickness: 0.00
- Maximum pit depth: 5.21 mils

Fairplay, Colorado

<u>ULTRA-SONIC PIPE THICKNESS (IN):</u>

- TOP: AVG = 0.078
- INVERT AVG = 0.078

  * Avg of a minimum of 4 readings after cleaning using TI-25M Ultrasonic Wall Thickness Gauge

<u>COMMENTS:</u>

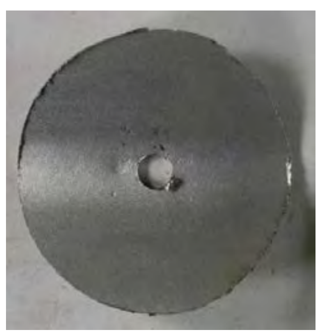
- There was no pavement distress
- No further corrosion of trepan holes
- Pipe is in good condition

Snellville, Georgia

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
48"	16 (0.064 IN)	ESTIMATED 1993	JULY, 2012
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: N/A	PH: 6
		RESISTIVITY: N/A	RESISTIVITY: N/A
			FHWA ABRASION LEVEL: 2
			CHLORIDES: N/A
			$CaCO_3$: 100 PPM

IMAGES:

SOIL SIDE ALUMINUM COATING DATA:



- Surface area coated: 100%
- Minimum thickness: 1.24 mils
- Maximum thickness: 2.32 mils (60 µm)
- Maximum pit depth: 1.21 mils

WATER SIDE ALUMINUM COATING DATA:

- Surface area coated: 100%
- Minimum thickness: 0.00 mils
- Maximum thickness: 3.68 mils (93 µm)
- Maximum pit depth: 4.31 mils

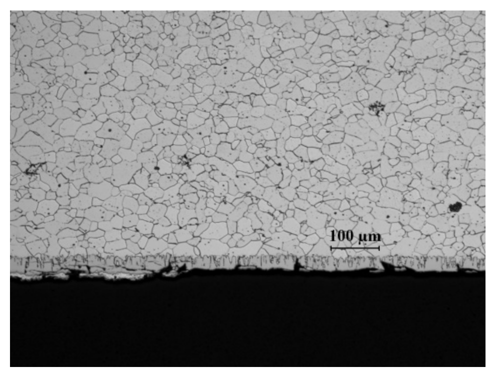
Marshall County #5, Iowa

DIAMETER	**GAGE**	**YEAR INSTALLED**	**INSPECTION DATE**
36” - RIVETED	12 (0.109 IN)	ESTIMATED AT 1953	MAY, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: 7.6	PH: N/A
		RESISTIVITY: 1,570 Ω-CM	RESISTIVITY: N/A
			FHWA ABRASION LEVEL: 2
			CHLORIDES: DRY
			$CaCO_3$: DRY

IMAGES:


SOIL SIDE ALUMINUM COATING DATA:

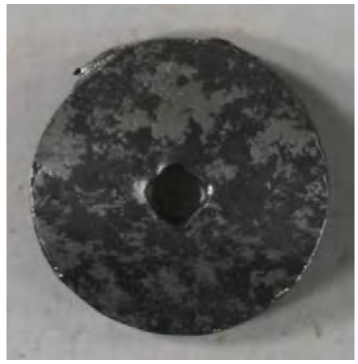
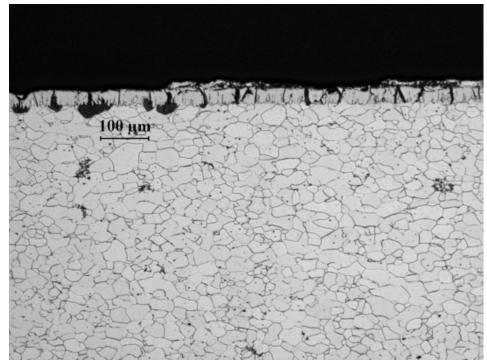




- Surface area coated: 20%
- Minimum thickness: 0.00 mils
- Maximum thickness: 1.40 mils (35.5 µm)
- Maximum pit depth: 1.31 mils

Marshall County #5, Iowa

WATER SIDE ALUMINUM COATING DATA:

- Surface area coated: 40%
- Minimum thickness: 0.00 mils
- Maximum thickness: 0.89 mils (22.5 µm)
- Maximum pit depth: 2.57 mils

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.109
- INVERT: AVG = 0.111

  * Avg of a minimum of 4 readings after cleaning measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 41
- INVERT: 24

  *Avg of a minimum of 4 readings after cleaning

COMMENTS:

- Pipe in good condition
- No pavement distress
- No further corrosion of previous trepan holes

Marshall County #7, Iowa

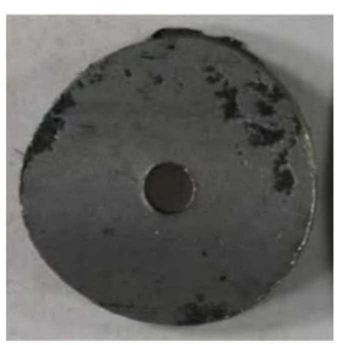
DIAMETER	**GAGE**	**YEAR INSTALLED**	**INSPECTION DATE**
36” - RIVETED	12 (0.109 IN)	ESTIMATED AT 1953	JUNE, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: 7	PH: 6.7
		RESISTIVITY: 1,330 Ω-CM	RESISTIVITY: 710 Ω-CM
			FHWA ABRASION LEVEL:2
			CHLORIDES: DRY
			$CaCO_3$: DRY


IMAGES:

SOIL SIDE ALUMINUM COATING DATA:


- Surface area coated: 95%
- Minimum thickness: 0.58 mils
- Maximum thickness: 1.38 mils (35 µm)
- Maximum pit depth: 0.84 mils

WATER SIDE ALUMINUM COATING DATA:

- Surface area coated: 90%
- Minimum thickness: 0.00 mils
- Maximum thickness: 1.78 mils (45 µm)
- Maximum pit depth: 1.23 mils

Marshall County #7, Iowa

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.114
- INVERT: AVG = 0.110

  * Avg of a minimum of 4 readings after cleaning measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 44
- INVERT: 17

  *Avg of a minimum of 4 readings after cleaning

COMMENTS:

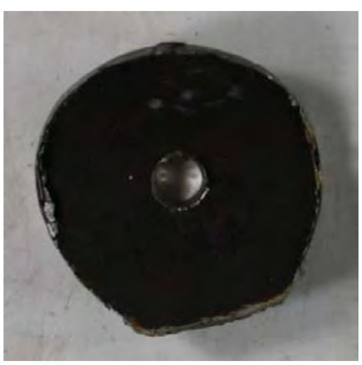
- Pipe in good condition
- No pavement distress
- No further corrosion of previous trepan holes

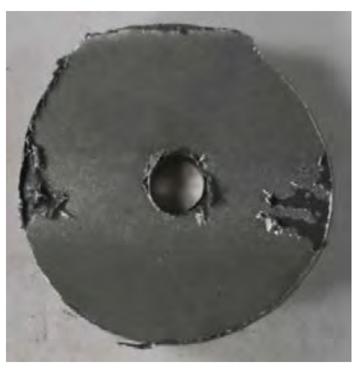
Morgan, Illinois

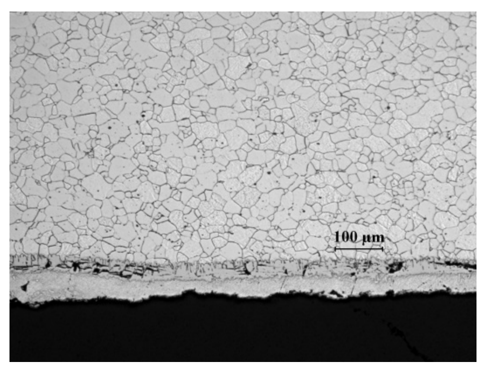
DIAMETER	**GAGE**	**YEAR INSTALLED**	**INSPECTION DATE**
36” - RIVETED	12 (0.109 IN)	ESTIMATED AT 1953	MAY, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: 7	PH: 6.0
		RESISTIVITY: 2,860 Ω-CM	RESISTIVITY: 2,175 Ω-CM
			FHWA ABRASION LEVEL: 2
			CHLORIDES: N/A
			$CaCO_3$: 200 PPM

IMAGES:

SOIL SIDE ALUMINUM COATING DATA:



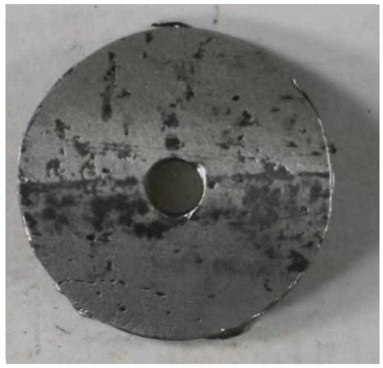


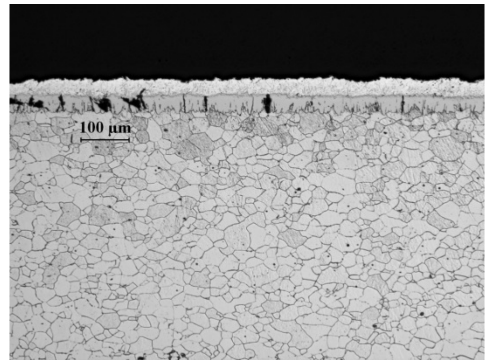


- Surface area coated: 100%
- Minimum thickness: 0.00 mils
- Maximum thickness: 2.53 mils (64 µm)
- Maximum pit depth: 1.97 mils

Morgan, Illinois

WATER SIDE ALUMINUM COATING DATA:





- Surface area coated: 85%
- Minimum thickness: 0.00 mils
- Maximum thickness: 1.71 mils (43 µm)
- Maximum pit depth: 8.00 mils

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.110
- INVERT: AVG = 0.111

*Measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 51
- INVERT: 31

*Avg of a minimum of 4 readings after cleaning

COMMENTS:

- Pipe in good condition
- No pavement distress
- No further corrosion of previous trepan holes

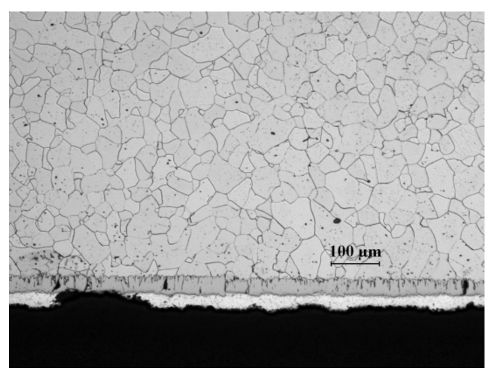
Dickinson County, KS

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
36” - RIVETED	12 (0.109 IN)	ESTIMATED AT 1953	MAY, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: 7.1	PH: N/A
		RESISTIVITY: 1,640 Ω-CM	RESISTIVITY: N/A
			FHWA ABRASION LEVEL: 2
			CHLORIDES: DRY
			$CaCO_3$: DRY

IMAGES:


SOIL SIDE ALUMINUM COATING DATA:



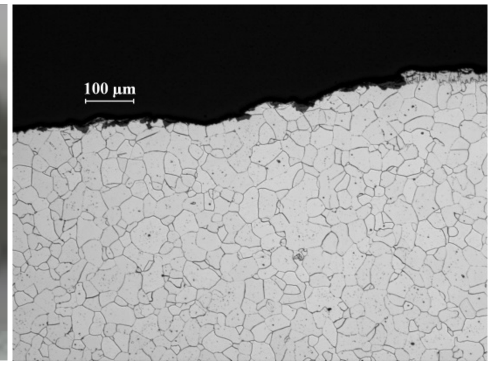


- Surface area coated: 5%
- Minimum thickness: 0.00 mils
- Maximum thickness: 0.00 mils
- Maximum pit depth: 0.73 mils

Dickinson County, KS

WATER SIDE ALUMINUM COATING DATA:





- Surface area coated: 0%
- Minimum thickness: 0.00 mils
- Maximum thickness: 0.00 mils
- Maximum pit depth: 37.00 mils

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.107
- INVERT: AVG = 0.122
- 4 o'clock AVG = 0.111

  * Avg of a minimum of 4 readings after cleaning measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 45
- INVERT: 16

  *Avg of a minimum of 4 readings after cleaning

COMMENTS:

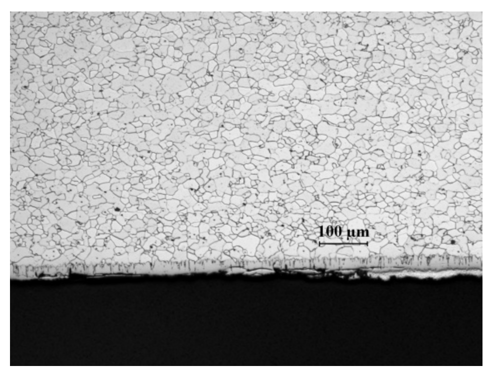
- Scaling at the invert could be cause for increase in thickness measurements
- Pipe is in good condition
- No further corrosion of previous trepan holes

Pratt County, Kansas

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
36" - RIVETED	14 (0.079 IN)	ESTIMATED AT 1953	MAY, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: 7	PH: N/A
		RESISTIVITY: 3,290 Ω-CM	RESISTIVITY: N/A
			FHWA ABRASION LEVEL: 2
			CHLORIDES: DRY
			$CaCO_3$: DRY

IMAGES:

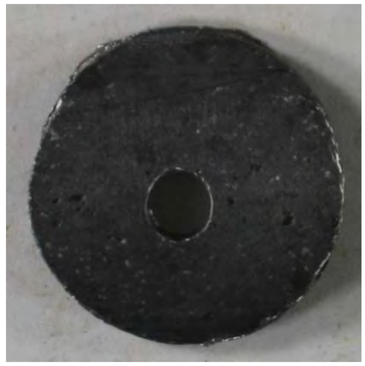
SOIL SIDE ALUMINUM COATING DATA:

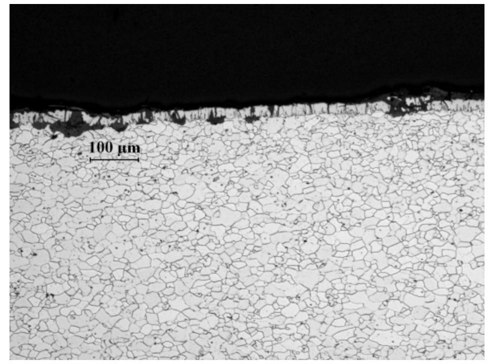


- Surface area coated: 5%
- Minimum thickness: 0.00 mils
- Maximum thickness: 0.00 mils
- Maximum pit depth: 14.00 mils

Pratt County, Kansas

WATER SIDE ALUMINUM COATING DATA:





- Surface area coated: 5%
- Minimum thickness: 0.00 mils
- Maximum thickness: 0.00 mils
- Maximum pit depth: 12.00 mils

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.081
- INVERT: AVG = 0.080

* Avg of a minimum of 4 readings after cleaning measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 41
- INVERT: 20

*Avg of a minimum of 4 readings after cleaning

COMMENTS:

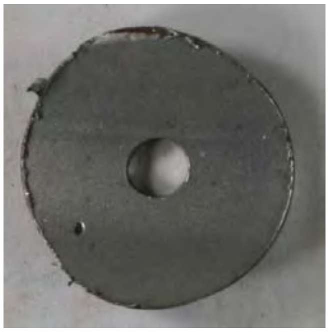
- Pipe is in good condition
- No further corrosion of previous trepan holes

Ripley, Maine

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
48"	12 (0.109 IN)	ESTIMATED 1984	JUNE, 2012
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: N/A	PH: 6
		RESISTIVITY: N/A	RESISTIVITY: N/A
			FHWA ABRASION LEVEL: 2
			CHLORIDES: N/A
			$CaCO_3$: 100

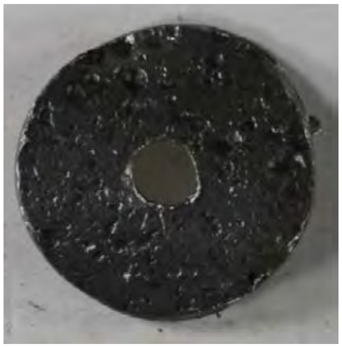
IMAGES:


SOIL SIDE ALUMINUM COATING DATA:

- Surface area coated: 100%
- Minimum thickness: 0.00
- Maximum thickness: 1.13 (29 µm)
- Maximum pit depth: 2.31 mils

WATER SIDE ALUMINUM COATING DATA:

- Surface area coated: 0%
- Minimum thickness: 0.00
- Maximum thickness: 0.00
- Maximum pit depth: 41.00 mils

Ripley, Maine

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP AVG = 0.095
- INVERT AVG = 0.090

  * Avg of a minimum of 4 readings after cleaning using TI-25M Ultrasonic Wall Thickness Gauge

COMMENTS:

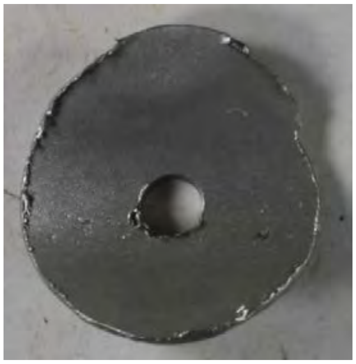
- Pipe and coating were in good condition

Carter County, Missouri

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
30" - RIVETED	14 (0.079 IN)	ESTIMATED AT 1953	JUNE, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: 6.7	PH: N/A
		RESISTIVITY: 1,420 Ω-CM	RESISTIVITY: N/A
			FHWA ABRASION LEVEL: 1
			CHLORIDES: DRY
			$CaCO_3$: DRY

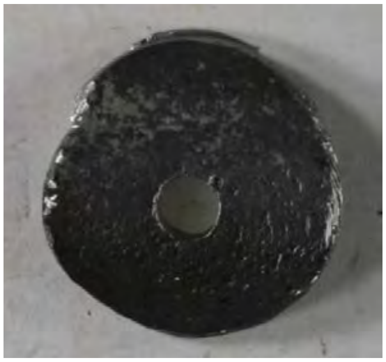
IMAGES:

SOIL SIDE ALUMINUM COATING DATA:



- Surface area coated: 100%
- Minimum thickness: 0.00 mils
- Maximum thickness: 1.65 mils (42 µm)
- Maximum pit depth: 0.00 mils

WATER SIDE ALUMINUM COATING DATA:



- Surface area coated: 10%
- Minimum thickness: 0.00 mils
- Maximum thickness: 0.00 mils
- Maximum pit depth: 10.50 mils

Carter County, Missouri

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.076
- INVERT: AVG = 0.074

  * Avg of a minimum of 4 readings after cleaning measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 31
- INVERT: 18

  *Avg of a minimum of 4 readings after cleaning

COMMENTS:

- Pipe is in good condition
- No further corrosion of previous trepan holes

Bernalillo, New Mexico

DIAMETER	**GAGE**	**YEAR INSTALLED**	**INSPECTION DATE**
30”	14 (0.079 IN)	ESTIMATED AT 1952	JUNE, 2012
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: 7.7	PH: DRY
		RESISTIVITY: 2,750 Ω-CM	RESISTIVITY: DRY
			FHWA ABRASION LEVEL: N/A
			CHLORIDES: DRY
			$CaCO_3$: DRY

IMAGES:

SOIL SIDE ALUMINUM COATING DATA:

- Surface area coated: 0%
- Minimum thickness: 0.00
- Maximum thickness: 0.00
- Maximum pit depth: 57.00 mils

WATER SIDE ALUMINUM COATING DATA:

- Surface area coated: 0%
- Minimum thickness: 0.00
- Maximum thickness: 0.00
- Maximum pit depth: 26.00 mils

Bernalillo, New Mexico

ULTRA-SONIC PIPE THICKNESS (IN):

- INVERT AVG = 0.083
  * Avg of a minimum of 4 readings after cleaning using TI-25M Ultrasonic Wall Thickness Gauge

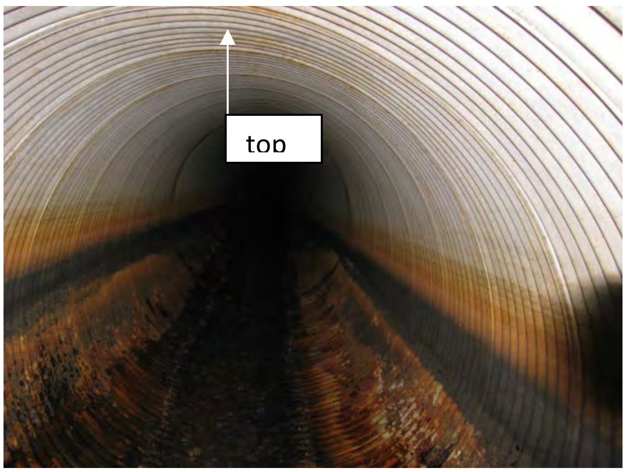
COMMENTS:

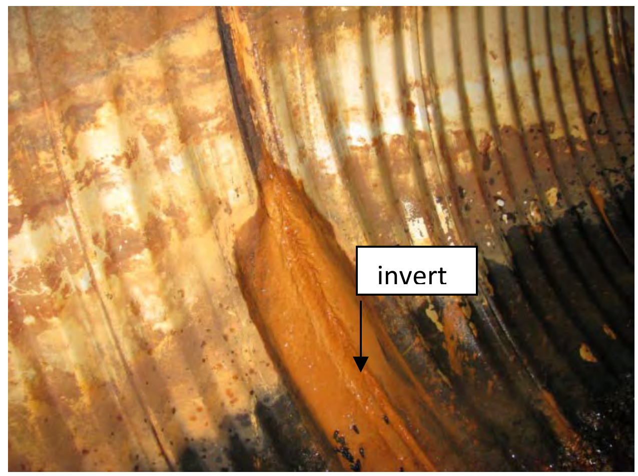
- Pipe appeared to be in fair condition
- Pipe is too full of silt to perform

Cottage Grove (Anlauf), Oregon

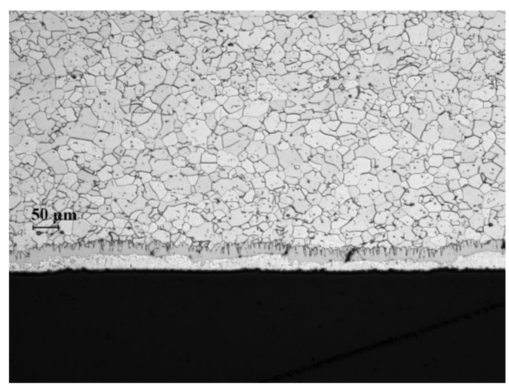
DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
66”	12 (0.109 IN)	ESTIMATED AT 1993	MAY, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: N/A	PH: 5.0
		RESISTIVITY: 2,860 Ω-CM	RESISTIVITY: 10,870 Ω-CM
			FHWA ABRASION LEVEL:
			CHLORIDES: <1
			$CaCO_3$: 40 - 80 PPM

IMAGES:





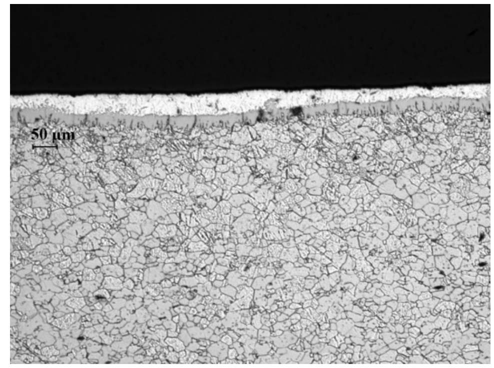
SOIL SIDE ALUMINUM COATING DATA:



- Surface area coated: 100%
- Minimum thickness: 0.00 mils
- Maximum thickness: 1.87 mils (47.5µm)
- Maximum pit depth: 1.60 mils

Cottage Grove (Anlauf), Oregon

WATER SIDE ALUMINUM COATING DATA:



- Surface area coated: 90%
- Minimum thickness: 0.00 mils
- Maximum thickness: 2.19 mils (55.5µm)
- Maximum pit depth: 11.00 mils

  *Note: largest visible pit is a result of the removal process

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.104 (0.104, 0.104, 0.103, 0.103, 0.105)
- INVERT: AVG = 0.106 (0.106, 0.107, 0.108, 0.105, 0.102)

  *Measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 41
- INVERT: 37

  *Avg of a minimum of 4 readings after cleaning

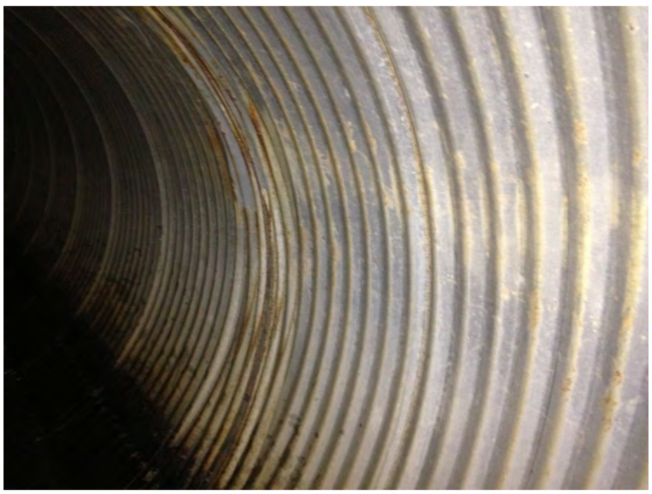
COMMENTS:

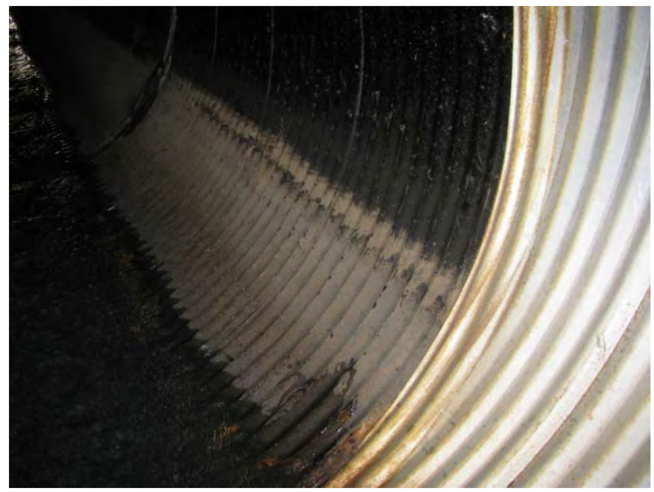
- Black scaling on the invert
- This is long run of pipe (a few hundred feet) under high fill

Jefferson, Oregon

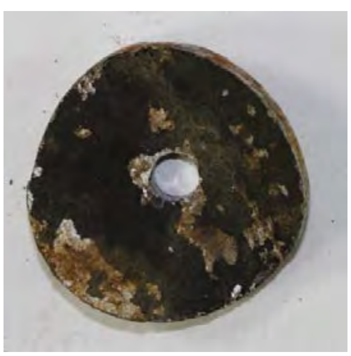
DIAMETER	**GAGE**	**YEAR INSTALLED**	**INSPECTION DATE**
72”	10 (0.0138 IN)	ESTIMATED AT 1993	MAY, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: N/A	PH: 5
		RESISTIVITY: 8,720 Ω-CM	RESISTIVITY: 10,010 Ω-CM
			FHWA ABRASION LEVEL: 3
			CHLORIDES: N/A
			$CaCO_3$: 100 PPM

IMAGES:



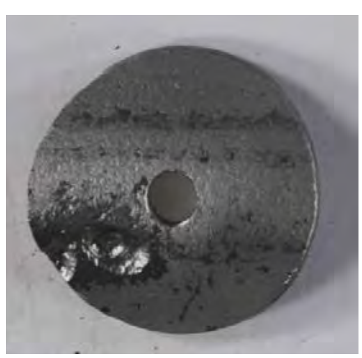


SOIL SIDE ALUMINUM COATING DATA:



- Surface area coated: 100%
- Minimum thickness: 1.63 mils
- Maximum thickness: 2.36 mils (60 µm)
- Maximum pit depth: 0.00 mils

WATER SIDE ALUMINUM COATING DATA:



- Surface area coated: 60%
- Minimum thickness: 0.00 mils
- Maximum thickness: 2.78 mils (70 µm)
- Maximum pit depth: 81.00 mils

*Note: largest visible pit is a result of the removal process

Jefferson, Oregon

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.119 (0.119, 0.120, 0.117, 0.132, 0.134)
- INVERT: AVG = 0.117 (0.120, 0.115, 0.115, 0.116)
- 9 o'clock position AVG = 0.117 (0.118, 0.117, 0.117)

  *Measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 56
- INVERT: 69

  *Avg of a minimum of 4 readings after cleaning

COMMENTS:

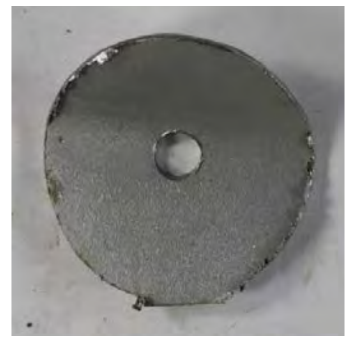
- Pipe is comprised of approximately 160 ft of ALT2 and 60 ft of asphalt coated galvanized at the upstream end
- Some cracking in the haunch areas of 3 sections appears to be from clay backfill that was used
- Maximum pit depth taken from section where another pilot hole had be started for the trepan evaluation

Santiam Highway 18+20, Oregon

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
30"	16 (0.064 IN)	ESTIMATED AT 1985	APRIL, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: N/A	PH: 4.5
		RESISTIVITY: 14,300 Ω-CM	RESISTIVITY: 55,000 Ω-CM
			FHWA ABRASION LEVEL: 2
			CHLORIDES: <2
			$CaCO_3$: <40 PPM

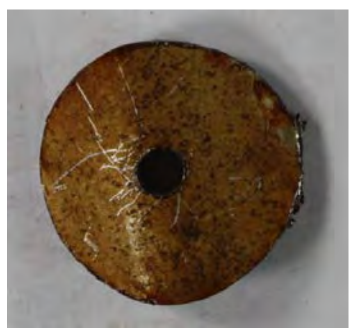
SOIL SIDE ALUMINUM COATING DATA:

- Surface area coated: 100%
- Minimum thickness: 0.00 mils
- Maximum thickness: 1.45 mils (37 µm)
- Maximum pit depth: 0.94 mils



WATER SIDE ALUMINUM COATING DATA:

- Surface area coated: 80%
- Minimum thickness: 0.00 mils
- Maximum thickness: 2.31 mils (58.5 µm)
- Maximum pit depth: 1.54 mils



ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.051 (0.054, 0.051, 0.055, 0.050, 0.051)
- INVERT: AVG = 0.052 (0.049, 0.056, 0.049, 0.051, 0.052)

  *Measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 52
- INVERT: 65

  *Avg of a minimum of 4 readings after cleaning using DCF3000FX

COMMENTS:

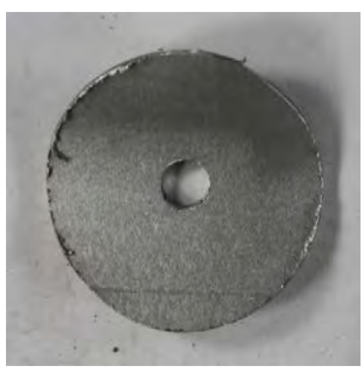
- This is a combination of ALT2 and galvanized pipe with total installation length of approximately 180 ft

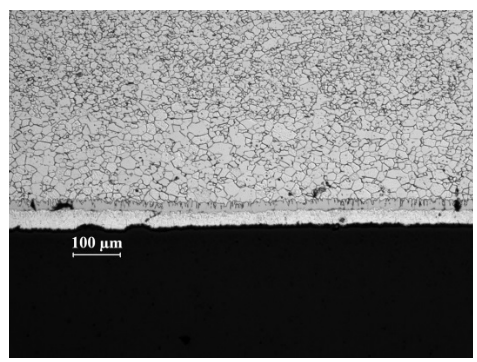
Santiam Highway 38+12, Oregon

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
54"	14 (0.079 IN)	ESTIMATED AT 1985	MAY, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: N/A	PH: 5.0
		RESISTIVITY: 9,440 Ω-CM	RESISTIVITY: 23,810 Ω-CM
			FHWA ABRASION LEVEL: 2
			CHLORIDES: <2
			$CaCO_3$: <40 PPM

IMAGES:

SOIL SIDE ALUMINUM COATING DATA:

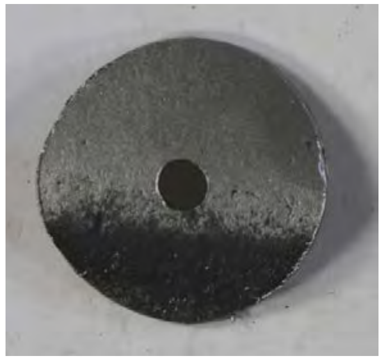


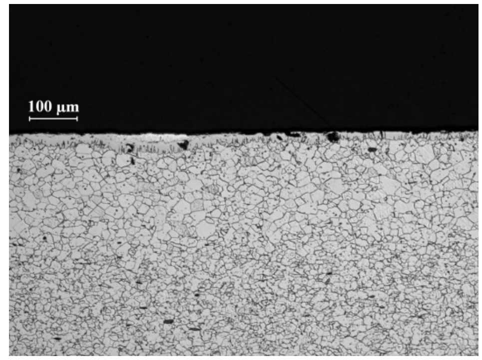


- Surface area coated: 100%
- Minimum thickness: 0.55 mils
- Maximum thickness: 2.28 mils (58 µm)
- Maximum pit depth: 1.35 mils

Santiam Highway 38+12, Oregon

WATER SIDE ALUMINUM COATING DATA:





- Surface area coated: 65%
- Minimum thickness: 0.00 mils
- Maximum thickness: 1.72 mils (43.5µm)
- Maximum pit depth: 4.97 mils

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.067 (0.067, 0.066, 0.069, 0.067, 0.066)
- INVERT: AVG = 0.069 (0.069, 0.073, 0.068, 0.067, 0.068)

  *Measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 46.5
- INVERT: 31

  *Avg of a minimum of 4 readings after cleaning

COMMENTS:

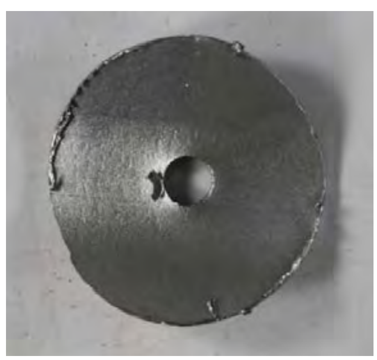
- This is a twin pipe barrel installation
- Data collected from the west side where abrasion appeared to be more severe

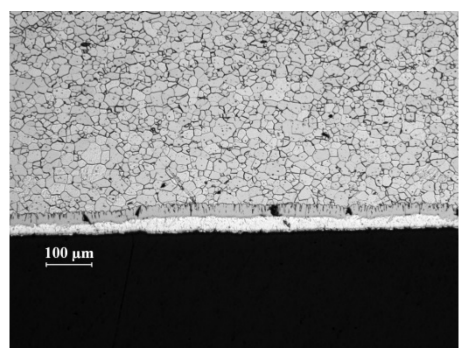
Santiam Highway 44+50, Oregon

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
30"	16 (0.064 IN)	ESTIMATED AT 1985	MAY, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: N/A	PH: 5 - 6
		RESISTIVITY: 29,030 Ω-CM	RESISTIVITY: 23,410 Ω-CM
			FHWA ABRASION LEVEL: 2
			CHLORIDES: <1
			$CaCO_3$: 0-40 PPM

IMAGES:

SOIL SIDE ALUMINUM COATING DATA:

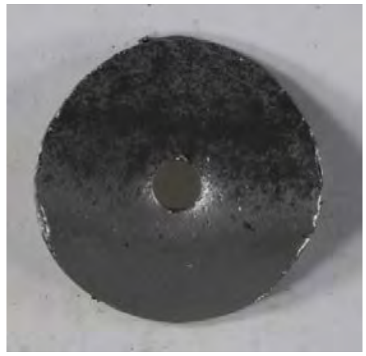


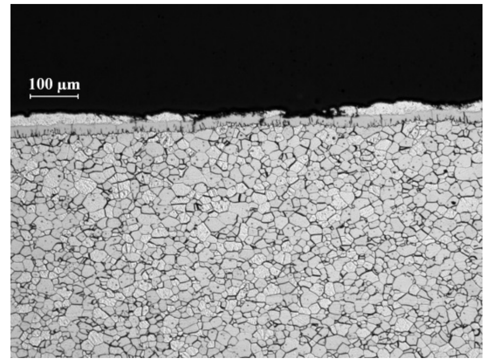


- Surface area coated: 100%
- Minimum thickness: 1.00 mils
- Maximum thickness: 3.01 mils (76.5 µm)
- Maximum pit depth: 0.87 mils

Santiam Highway 44+50, Oregon

WATER SIDE ALUMINUM COATING DATA:





- Surface area coated: 55%
- Minimum thickness: 0.00 mils
- Maximum thickness: 1.05 mils (26.5 μm)
- Maximum pit depth: 2.28 mils

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.053 (0.052, 0.051, 0.052, 0.055, 0.055)
- INVERT: AVG = 0.051 (0.051, 0.053, 0.050, 0.051, 0.049)

  *Measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 49
- INVERT: 41

  *Avg of a minimum of 4 readings after cleaning

COMMENTS:

- Coating is stained at the invert but in good condition as is the overall pipe

Santiam Highway 90+38, Oregon

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
36"	16 (0.064 IN)	ESTIMATED AT 1985	APRIL, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: N/A	PH: 5.5
		RESISTIVITY: 14,410 Ω-CM	RESISTIVITY: 18,520 Ω-CM
			FHWA ABRASION LEVEL: 3
			CHLORIDES: <1
			$CaCO_3$: 0-40 PPM

IMAGES:

SOIL SIDE ALUMINUM COATING DATA:

- Surface area coated: 30%
- Minimum thickness: 0.00
- Maximum thickness: 0.88 (22 µm)
- Maximum pit depth: 35.50 mils

WATER SIDE ALUMINUM COATING DATA:

- Surface area coated: 0%
- Minimum thickness: 0.00
- Maximum thickness: 0.00
- Maximum pit depth: 51.50 mils

Santiam Highway 90+38, Oregon

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.055 (0.051, 0.057, 0.055, 0.055, 0.056)
- INVERT (@ 8 o'clock position): AVG = 0.051 (0.048, 0.051, 0.056, 0.050, 0.052)

  *Measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 35
- INVERT: 37

  *Avg of a minimum of 4 readings after cleaning using DCF3000FX

COMMENTS:

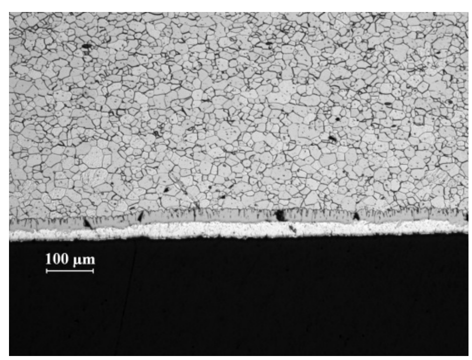
- This is a twin barrel installation where both culverts appear to experience high velocity abrasive flow

Santiam Highway 100+15, Oregon

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
30”	16 (0.064 IN)	ESTIMATED AT 1985	MAY, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: N/A	PH: 5
		RESISTIVITY: 14,350 Ω-CM	RESISTIVITY: 28,570 Ω-CM
			FHWA ABRASION LEVEL: 1
			CHLORIDES: <1
			$CaCO_3$: 0-40 PPM

IMAGES:

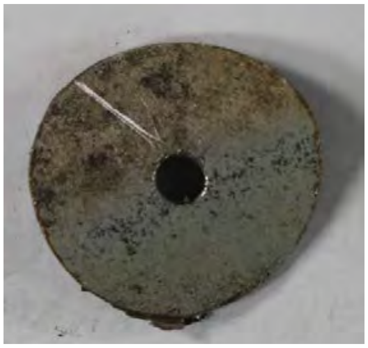
SOIL SIDE ALUMINUM COATING DATA:

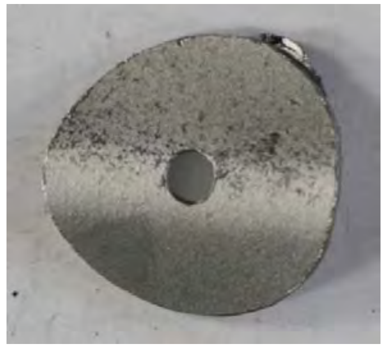


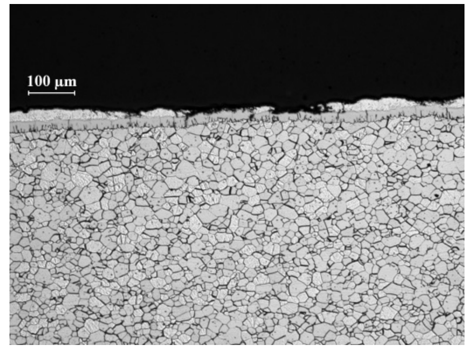
- Surface area coated: 100%
- Minimum thickness: 0.87 mils
- Maximum thickness: 1.42 mils (36 µm)
- Maximum pit depth: 3.38 mils

Santiam Highway 100+15, Oregon

WATER SIDE ALUMINUM COATING DATA:







- Surface area coated: 95%
- Minimum thickness: 0.00 mils
- Maximum thickness: 1.66 mils (42 µm)
- Maximum pit depth: 5.00 mils

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.051 (0.050, 0.050, 0.052, 0.051, 0.051)
- INVERT: AVG = 0.049 (0.047, 0.051, 0.051, 0.048, 0.049)

*Measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 49
- INVERT: 29

*Avg of a minimum of 4 readings after cleaning

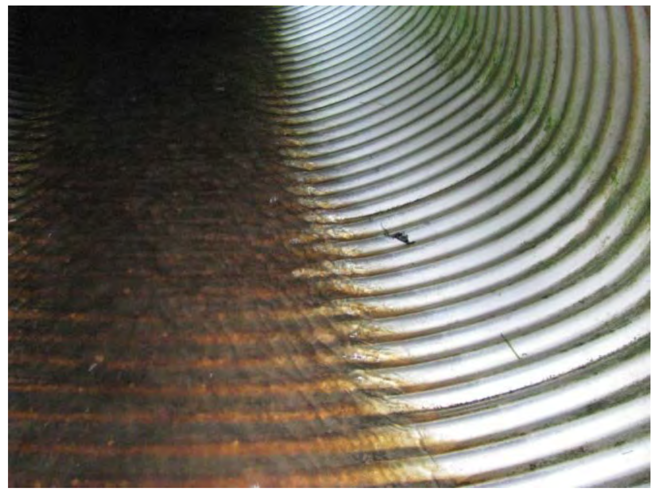
COMMENTS:

- The pipe appears to be in good condition
- There is no pavement distress
- The total length of the installation is approximately 66 ft

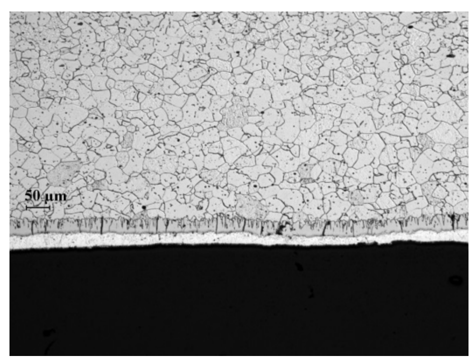
Santiam Highway 104+45 East & West, Oregon

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
71” X 47” ARCH PAIR	10 (0.0138 IN)	ESTIMATED AT 1985	MAY, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: N/A	PH: 5
		RESISTIVITY: 14,700 Ω-CM	RESISTIVITY: 32,258 Ω-CM
			FHWA ABRASION LEVEL: 3
			CHLORIDES: <1
			$CaCO_3$: 0-40 PPM

IMAGES:



SOIL SIDE ALUMINUM COATING DATA:



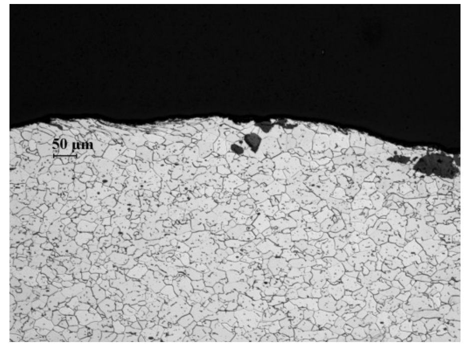
- Surface area coated: 100%
- Minimum thickness: 0.93 mils
- Maximum thickness: 2.09 mils (53 µm)
- Maximum pit depth: 1.16 mils

*Note: largest visible pit is a result of the removal process

Santiam Highway 104+45 East & West, Oregon

WATER SIDE ALUMINUM COATING DATA:





- Surface area coated: 10%
- Minimum thickness: 0.00 mils
- Maximum thickness: 0.00 mils (42 µm)
- Maximum pit depth: 20.00 mils

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.135 (0.136, 0.135, 0.136, 0.132, 0.134)
- INVERT: AVG = 0.139 (0.139, 0.137, 0.141)
- Splash Zone (@ 5 o'clock position) AVG = 0.134 (0.135, 0.135, 0.134, 0.134, 0.134)

  *Measured using TI-25M Ultrasonic Wall Thickness Gauge

  **Readings taken from east pipe

COATING THICKNESS COMPARISON (microns):

- TOP: East = 33 West = 38
- INVERT: East = 9 West = 14

  *Avg of a minimum of 4 readings after cleaning

COMMENTS:

- This is a twin barrel installation where the west pipe appears to receive heavier and faster flow due to the approach angle
- Data presented is from both pipe barrels

Santiam Highway 123+76, Oregon

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
36”	16 (0.064 IN)	ESTIMATED AT 1985	APRIL, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: N/A	PH: 5.0
		RESISTIVITY: 31,460 Ω-CM	RESISTIVITY: 27,780 Ω-CM
			FHWA ABRASION LEVEL: 2
			CHLORIDES: <1
			$CaCO_3$: 0-40 PPM

SOIL SIDE ALUMINUM COATING DATA:

- Surface area coated: 100%
- Minimum thickness: 0.00 mils
- Maximum thickness: 1.07 mils (27 µm)
- Maximum pit depth: 1.20 mils

WATER SIDE ALUMINUM COATING DATA:

- Surface area coated: 100%
- Minimum thickness: 0.00 mils
- Maximum thickness: 1.46 mils (37 µm)
- Maximum pit depth: 1.13 mils

  *Note: largest visible pit is a result of the removal process

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.055 (0.052, 0.057, 0.058, 0.055, 0.053)
- INVERT: AVG = 0.056 (0.056, 0.060, 0.059, 0.052, 0.056)

  *Measured using TI-25M Ultrasonic Wall Thickness Gauge

COMMENTS:

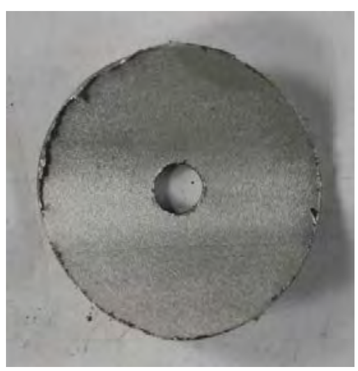
- Pipe is in good condition
- No pavement distress
- Total installation length is approximately 80 ft.

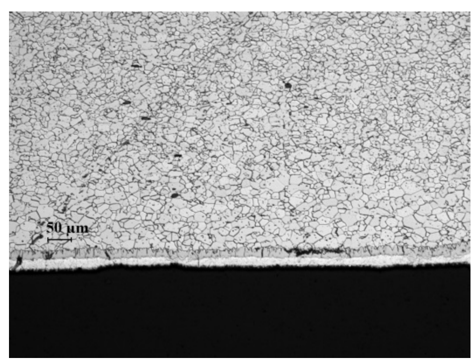
Santiam Highway New Site 1, Oregon

DIAMETER	**GAGE**	**YEAR INSTALLED**	**INSPECTION DATE**
30”	16 (0.064 IN)	ESTIMATED AT 1985	APRIL, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: N/A	PH: DRY
		RESISTIVITY: 14,470 Ω-CM	RESISTIVITY: DRY
			FHWA ABRASION LEVEL: 1
			CHLORIDES: DRY
			$CaCO_3$: DRY

IMAGES:

SOIL SIDE ALUMINUM COATING DATA:

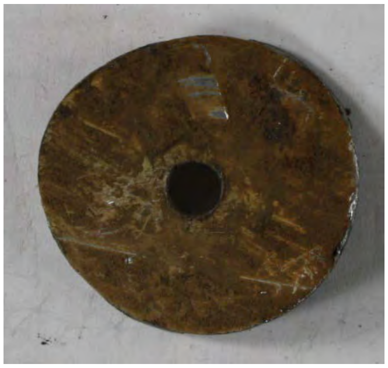
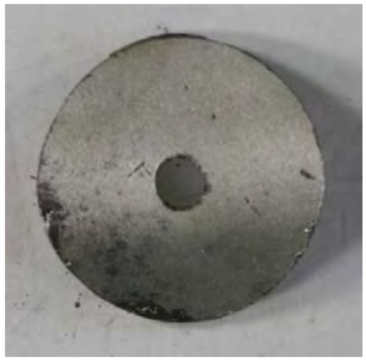
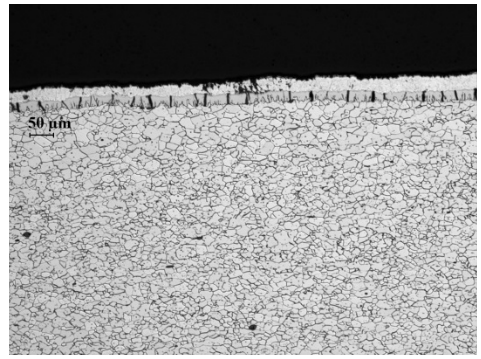




- Surface area coated: 100%
- Minimum thickness: 0.55 mils
- Maximum thickness: 3.04 mils (77 µm)
- Maximum pit depth: 1.60 mils

Santiam Highway New Site 1, Oregon

WATER SIDE ALUMINUM COATING DATA:

- Surface area coated: 95%
- Minimum thickness: 0.37 mils
- Maximum thickness: 1.584 mils (40 µm)
- Maximum pit depth: 0.67 mils

  *Note: largest visible pit is a result of the removal process

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.057 (0.060, 0.059, 0.055, 0.055, 0.056)
- INVERT: AVG = 0.058 (0.059, 0.054, 0.056, 0.061, 0.058)

  *Measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

- TOP: 38
- INVERT: 29

  *Avg of a minimum of 4 readings after cleaning using DCF3000FX

COMMENTS:

- Pipe in good condition
- No pavement distress

Santiam Highway New Site 2, Oregon

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
30”	16 (0.064 IN)	ESTIMATED AT 1985	APRIL, 2013
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
2 2/3 X 1/2	ALUMINIZED TYPE 2	PH: N/A	PH: DRY
		RESISTIVITY: 18,590 Ω-CM	RESISTIVITY: DRY
			FHWA ABRASION LEVEL: 1
			CHLORIDES: DRY
			$CaCO_3$: DRY

SOIL SIDE ALUMINUM COATING DATA:

- Surface area coated: 100%
- Minimum thickness: 0.94 mils
- Maximum thickness: 2.18 mils (55 µm)
- Maximum pit depth: 1.02 mils

WATER SIDE ALUMINUM COATING DATA:

- Surface area coated: 95%
- Minimum thickness: 0.00 mils
- Maximum thickness: 2.03 mils (51.5 µm)
- Maximum pit depth: 9.00 mils

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP: AVG = 0.051 (0.051, 0.050, 0.051, 0.056, 0.056)
- INVERT: AVG = 0.055 (0.051, 0.055, 0.055, 0.056, 0.056)

*Measured using TI-25M Ultrasonic Wall Thickness Gauge

COATING THICKNESS COMPARISON (microns):

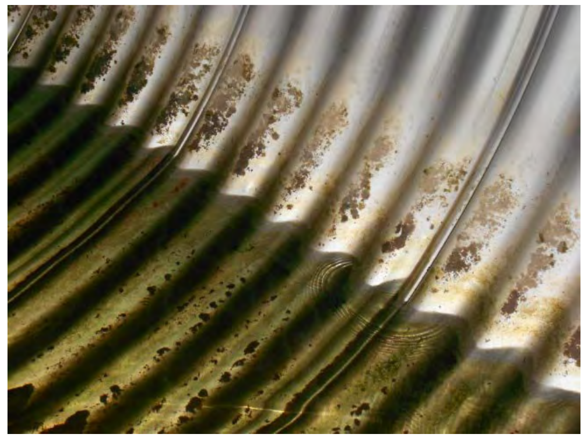
- TOP: 32
- INVERT: 32

*Avg of a minimum of 4 readings after cleaning using DCF3000FX

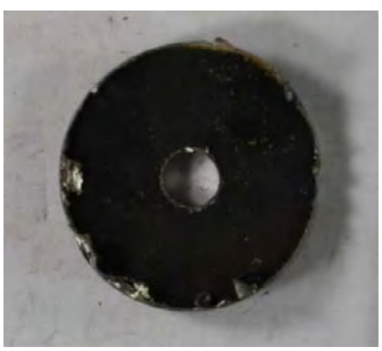
Memrancook, New Brunswick, Canada

DIAMETER	GAGE	YEAR INSTALLED	INSPECTION DATE
72"	12 (0.109 IN)	ESTIMATED 1996	JUNE, 2012
PROFILE	**COATING**	**SOIL DATA**	**WATER DATA**
5 X 1	ALUMINIZED TYPE 2	PH: N/A	PH: 6
		RESISTIVITY: N/A	RESISTIVITY: N/A
			FHWA ABRASION LEVEL: 2
			CHLORIDES: N/A
			$CaCO_3$: D100

IMAGES:

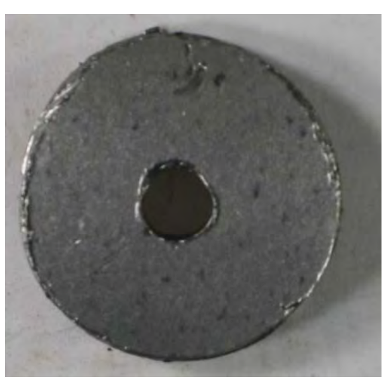



SOIL SIDE ALUMINUM COATING DATA:




- Surface area coated: 100%
- Minimum thickness: 0.00
- Maximum thickness: 3.02 (76.5 µm)
- Maximum pit depth: 0.78 mils

WATER SIDE ALUMINUM COATING DATA:

- Surface area coated: 100%
- Minimum thickness: 0.83
- Maximum thickness: 2.54 (64.5 µm)
- Maximum pit depth: 1.55 mils

Memrancook, New Brunswick, Canada

ULTRA-SONIC PIPE THICKNESS (IN):

- TOP AVG = 0.095
- INVERT AVG = 0.092

  * Avg of a minimum of 4 readings after cleaning using TI-25M Ultrasonic Wall Thickness Gauge

COMMENTS:

- Pipe and coating in good condition
- Pipe has baffles installed in the invert

Appendix B – Recommended Inspection Procedure

TOOLS

This list could vary depending on the scope of the assessment. For instance, if the objective is only to show the remnant pipe thickness, this list could be reduced to the first seven items:

- Project inspection notebook – recommend a permanently bound book with numbered pages that is used only for on-site comments, raw data collection and site location information.
- Ultrasonic thickness gauge and coupling gel, scotch-bright pads, paper towels
- Representative reference coupon(s) - see section on calibration
- Digital Camera
- DCF 3000FX coating thickness gauge is used to measure the thickness of non-magnetic coatings on ferrous substrates. This is not a calibrated instrument; it only measures and compares water-side metallic coating thickness. A useful comparison results when performed near the invert and the crown.
- Quart size zip-loc freezer bags for representative soil samples
- 250 ml sample bottles for water samples
- Shovel, Garden Spade, Machete or sickle
- pH paper (Hatch)
- Hand cleaner, insect repellant, bottled water and more paper towels
- If you plan to cut core samples from the pipes, you will need:
    - 18V (or stronger) cordless drill, 1.5” diameter hole saw(s),¼” drill bits, center punch, hammer, spare battery pack, charger, power inverter that plugs into a cigarette lighter. *After one site inspection, the reader will likely be able to modify this list as necessary.

CALIBRATION

It is recommended to use a reference coupon of Type 2 that is comparable in thickness to the pipe being inspected. Most projects are made of 16, 14, 12 or 10 gauge material or 0.064”, 0.079”, 0.109” or 0.138” nominal thickness, respectively. A flat-head micrometer that has been calibrated using standards that are traceable to NIST should be used to measure the thickness of the reference coupons. This thickness, scribed onto the coupon, can then be used to verify / standardize the ultrasonic thickness gauge in the field prior to each use. The reference coupons should be sheathed to protect them from abrasion or rough handling and carefully packed along with the ultrasonic thickness gauge. Data and comments referencing field calibration results should be entered into the project inspection notebook.

PROCEDURES

To measure the remaining pipe thickness after a number of years of service, enter the title and location of the project via map, GPS, or driving instructions in the inspection book.

The ultrasonic thickness gauge should be field calibrated (inspection notebook entry) and the surfaces to be measured should be wiped clean of debris, thus allowing firm steady contact of the probe head and the pipe surface. Gentle repetitive rubs with a scotch-bright pad will easily remove any crust or debris from the metallic coating, followed by cleaning with a paper towel.

Photograph the freshly cleaned metallic coating at/near the invert to document the coating condition.

Take digital images documenting the project’s location, and thickness testing positions.
Take and record multiple thickness readings at/near the crown and at/near the invert. The writer recommends a minimum of three if there is agreement (less than 0.002” or 0.05mm variation between the highest and lowest reading).

If the corrugations are annular, then thickness testing should be on the flatter upstream portion of the annular corrugation. If the pipe is spiral rib, then the large flat regions should be representative.

In the inspection notebook, write down the condition of the upstream-facing edge of the spiral ribs; whether abraded, pitting or smooth. Record these observations and ultrasonic thickness readings and average this raw data in the inspection notebook. Take digital images to support the comments recorded.

The crown of the pipe is assumed to represent the pipe's original thickness. The difference between the average thicknesses (crown vs. invert) would represent the material consumed during the years of service.

If the surfaces at the invert and crown have aluminized coating intact, use the DCF-3000FX to compare the thickness of the metallic coatings on the water side of the pipe. Several rubs with a scotch-bright may be needed to remove buildup on the coating near the invert to determine if metallic coating remains.

Water (if available) and soil samples be collected and labeled by site. The soil sample should be representative of the backfill in contact with the soil side of the pipe. These should submitted to an independent lab with the credentials to test the soil and water for pH, resistivity (units: ohm-cm) and test for the presence of sulfates (ppm) and chlorides (ppm).

If the inspector plans to procure coupons, the following instructions are subordinate and complementary to normal safety procedures that govern work involving power tools at remote locations outlined by the inspector's employer.

Select a representative location as near to the invert as possible/practical. Use the hammer and center punch to designate a starting point to drill. If the pipe is annular, select a peak, if it is spiral rib, select a flat adjacent to the rib in order to represent that portion of the spiral rib that faces upstream.

Drill a ¼" hole first, then install the hole saw equipped with a solid center shaft (1/4" diameter) where the drill bit would go. This technique will prevent breaking drill bits in the hole saw while drilling cores in steel pipe. This two-stage practice may seem time consuming, but changing broken drill bits on a hole saw or running out of drill bits in the field is much more time consuming.

Remove the core from the hole saw, label the downstream portion and insert in a labeled bag. These cores can be measured, photographed and mounted metallographically to assess the condition of the metallic coating.

SUMMARY

The recommended procedures for measuring pipe wall and coating thickness, sampling soil and water and recording representative images of a project should be done objectively such that an independent observer could repeat the same steps and arrive at comparable conclusions. These summaries should be beneficial for promoting Aluminized Type 2 CSP because the data collected is from sites with more regional significance or environmental relevance to the owners and engineers responsible for establishing project material specifications. If pipes are failing prematurely then the information gathered can help establish the failure mode.