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FIELD ASSESSMENT OF TWO COATINGS FOR CORRUGATED STEEL PIPES:

GALVANIZED AND ALUMINIZED TYPE 2

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ABSTRACT:

Galvanized (zinc-coated) and aluminized type 2 steel culverts were compared for coating wear. A unique aspect of the culvert coating assessments in this research was that each culvert assessed was made from galvanized and aluminized type 2 sections. Field measurements of water chemistry were collected, and a visual abrasion assessment was conducted. The two coatings wore differently over time.

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INTRODUCTION

Galvanized (zinc-coated) steel culverts are used extensively as conduits for water management on resource roads. Designers and road builders are accustomed to using galvanized culverts, or corrugated steel pipe (CSP), for many applications but may not be aware of alternative coatings that may be better suited to local site and environmental conditions. Many factors need to be considered when designing a culvert to meet a specified service life; anticipated abrasion and bedload, culvert steel thickness, corrugation profile, coatings, and material selection are all important considerations that can affect the life expectancy of a culvert. The Corrugated Steel Pipe Institute (CSPI) has published bar charts showing the compatibility of culvert coatings for different levels of pH, water hardness, chlorides, and resistivity based on water chemistry, and an additional bar chart for abrasion levels based on the type of bedload (gradation) and anticipated flow velocity based on field observations (Corrugated Steel Pipe Institute [CSPI], 2013). The bar charts show suggested compatible ranges for three different culvert coatings: galvanized, aluminized type 2, and polymer-laminated. There are other materials and coatings available which are not discussed in this report, such as high density polyethylene (HDPE) culverts or steel culverts with a bituminous coating.

This technical report presents the site parameters identified in water samples that can be used as indicators to help attain design service life and discusses the influence of bedload abrasion and its ability to erode culvert coatings over time. A unique aspect of the culvert coating assessments in this research was that each culvert was made from galvanized and aluminized type 2 sections (joined using either a coupler or a lock seam). Having both coatings on the same culvert allowed for the comparison of site parameters. Recommendations on how to avoid premature corrosion of culverts was presented in Gillies and Penny (2011), where the authors discuss how to select coatings based on site parameters identified in water samples to obtain a typical design service life of either 25 or 50 years. Bedload movement and bedload gradation contribute to the removal of a culvert's coatings and need to be considered, along with water chemistry. This report discusses the effects of both water chemistry and bedload abrasion toward culvert coating thickness and wear. FPInnovations will continue research in the field of culvert coating wear and lead a technical report based on field visits to sites with anticipated high bedload and abrasion and present the results of coating wear.

BACKGROUND

The cost for galvanized steel culverts is less than that of aluminized type 2. The source coils for aluminized type 2 products originate in the U.S.A. The price for aluminized type 2 products has fluctuated over time and has been partially driven by tariffs (steel and aluminum) and currency exchange rates. In the past, the premium for aluminized type 2 compared to galvanized has been up to 25% - 30%; at time of report writing the premium is approximately 15% - 20%. The aluminized type 2 culvert sections in this study were provided as an acceptable substitute for galvanized culvert material (at the same or similar price as galvanized) due to the manufacturing company running short on the 3.5 mm galvanized steel to complete the specific order; this provided the unique opportunity for this study where the culverts were made of both materials.

Corrosion is the deterioration of a metal caused by an electrochemical reaction with its environment and is essentially a surface reaction. Low electrical resistivity and high quantities of soluble salts generally indicate the potential for high corrosivity. Easily measured water chemistry, such as pH, water hardness, and chlorides, can be used to help designers and planners choose the appropriate culvert coating for a given site. There is a direct correlation between resistivity and soluble salts. For this reason, resistivity is inferred by taking readings of water hardness and chlorides. Hardness is an indicator of the amount of calcium carbonate ion ($CaCO_3$) dissolved in water, which can buffer the effects of acidic inputs (rainwater or weathering of parent material). Water containing ample calcium carbonate (hard water) neutralizes acidity and forms a protective scale on the culvert's surface. pH is a measure of both acidity and alkalinity (measurement of dissolved hydrogen ions concentration), with low levels (pH $<$ 7) being acidic and high levels (pH $>$ 7) being alkaline, or basic. A pH of 7 indicates a neutral environment. Steel is negatively affected by both low and high pH levels. Field personnel can take three simple field measurements to determine pH, chlorides, and hardness (Figure 1).

Figure 1. Colour indicator test strips for pH and total hardness, and a low-range chloride titrator (centre).

Microbially influenced corrosion (MIC) is a form of corrosion. MIC is the deterioration of a metal by corrosion processes directly or indirectly by the results of metabolic activity of microorganisms (Peng, Park, & Patenaude, 1994). MIC can be caused by sulphate-reducing bacteria (SRB), which is commonly found in naturally soft water and which can influence the corrosion of galvanized steel. MIC is instigated from bacterial growth on the surface of a culvert, forming a biofilm (West, 2013). SRB create the condition needed to attack galvanized and bare steel, and their metabolic reactions may maintain the condition that ultimately cause pit corrosion. To preserve anaerobic conditions for the SRB on the submerged surface of a culvert, slime-forming bacteria produce a protective bubble surrounding the SRB. If this bubble is abraded by bedload movement, it can release the underlying black SRB, leaving a pit in the surface of the steel. Aggressive pitting deteriorates coating thickness, and coupled with abrasion, it can erode the culvert over time. SRB does not readily attack aluminized type 2 steel or polymer-laminated coatings, as both coatings provide a barrier that resists these corrosive environments. The process and film-forming bubbles may look similar to those in Figure 2.

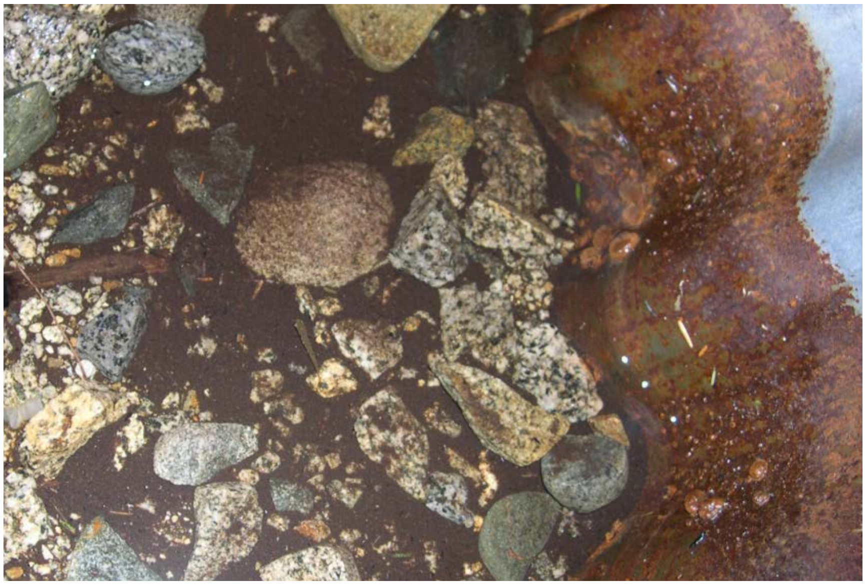

Figure 2. Possible MIC on the metal of a culvert, showing a film, or anaerobic bubbles, forming (This picture was not taken at any of the sites discussed in this report).

Considering that aqueous corrosion of steel is a surface reaction, protecting the surface with a coating is a logical method of combatting the reaction and providing longer service life. A common practice for many years has been to use a zinc coating (galvanizing) on ferrous base metals because of its effectiveness and low cost (Armco Drainage and Metal Products of Canada, Ltd., 1955). Different coatings and liners have been developed to help meet the design service life of conduits for numerous applications, and various standards are used to meet the coating criteria for both galvanized (American Association of State Highway and Transportation Officials [AASHTO] M36, ASTM A929) and aluminized type 2 sheets (AASHTO M274, ASTM A929). The typical zinc application for galvanized culverts provides a thickness of 0.043 mm, on each surface. For aluminized type 2 culverts, the pure aluminum coating has a thickness of 0.048 mm, on each surface. The zinc and aluminum applications can both be applied at other acceptable (greater) coating thicknesses. The initial manufactured coating thicknesses of the culverts studied for this research report were unknown; the comparisons for coating wear were made with respect to the thickness of the culvert at strategic locations.

SITE ATTRIBUTES AND DATA COLLECTION

Culvert Site and Design Considerations

Background information for the three culverts specific to the sites studied is provided in the sections of the report below. All three culverts had sections containing galvanized and aluminized type 2 coatings. The dates of installation vary (1997, 2005, and 2010), as well as the lengths and diameters.

A-Branch (2.2 km)

The aluminized sections were at the upstream end of the culvert. The galvanized section was approximately 4.4 m in length at the outlet of the culvert and was attached to the aluminized section using a lock seam (not at a coupler). The culvert is a 2,700 mm diameter x 23 m long CSP, installed at a 6% grade. The culvert was ordered from Armtec with the 125 mm x 25 mm corrugation profile, of 3.5 mm gauge galvanized steel. Armtec provided an aluminized section due to the company running short on the 3.5 mm galvanized steel to complete the order. The culvert has been inspected over time by StoneCroft Engineering.

This structure was designed to replace a failing 1 m x 2.5 m wood box culvert. The site was total-station surveyed in February, 2005, and a draft design was completed in March, 2005. Installation was completed by Three Leaf Contracting Ltd. In October, 2005, under contract to Weyerhaeuser, Stillwater Division, in Powell River. Stream flow was pumped around the construction site, and a temporary sacrificial culvert was installed to bypass water and maintain clean stream flow around the work site.

Design and Management Considerations

1. Permanent long-term branch road, with intermittent industrial use.
2. A low-maintenance structure with a long-term design service life was preferred.
3. Large (>2,000 mm diameter) culverts are typically more economical to install and maintain than permanent bridges at the same site.
4. Large amount of good backfill material available on site.

Engineering Considerations

1. Non-fish (S5) stream.
2. Consistent road grade across site of 10% to 15% favourable, which is steeper than typical safe grades for permanent bridges with concrete and steel decks, at a maximum of 4% to 5%.
3. Two to six metres fill depth on centreline would require a longer bridge than the minimum required to pass the 100-year flood design flood capacity.
4. Creek alignment skewed to road favoured a culvert as opposed to a bridge.

Rainbow Main (6.6 km)

The aluminized section was at the downstream end of the culvert and was attached by a coupler. The culvert is a 2,700 mm diameter x 20 m long CSP, installed at a 9% grade. The culvert has been inspected by StoneCroft Engineering, who first noted significant differences in CSP invert corrosion on the galvanized sections compared to the aluminized sections during routine inspections in 2012 and 2016.

This structure was installed on a previously undeveloped site. The site was total station surveyed in January, 1997, and a draft design completed in January, 1997. Installation was completed by Three Leaf Contracting Ltd. and Grief Point Construction during summer 1997 under contract to MacMillan Bloedel, Stillwater Division, in Powell River.

Design and Management Considerations

1. Permanent long-term branch road, with intermittent industrial use.
2. A low-maintenance structure with a long-term design service life was preferred by the client.
3. Large (>2,000 mm diameter) culverts are typically more economical to install and maintain than permanent bridges at the same site.

Engineering Considerations

1. Non-fish (S5) stream.
2. Pipe diameter was oversized (larger than Q100 flow event) to pass typical woody debris and reduce future maintenance costs.
3. Low to moderate energy and bedload/debris transport stream causes minimal abrasion of culvert invert.
4. Creek skewed to road (culvert lengthened to maintain mainline road width).
5. Original creek channel not well confined; extensive riprap groin shown on conceptual and installed.

Loon Lake (0.9 km)

The aluminized section was the middle of three culvert sections and was attached using couplers. The culvert is a 3,000 mm diameter x 19 m long CSP, installed at a 3% grade. The culvert has been inspected by StoneCroft Engineering, who noted during 2014 loss of zinc coating and minor steel corrosion on the galvanized sections, while the aluminized section was in excellent condition

The culvert was installed on a newly constructed road just off of “the hump” on Port Alberni Highway 4. The site was total station surveyed in February, 2008 and installed in July 2010 by Coastal Bridge and Construction for Island Timberlands.

Management Considerations

1. Permanent long-term branch road, with intermittent industrial use.
2. Large (>2,000 mm diameter) culverts are typically more economical to install and maintain than permanent bridges at the same site.
3. A low-maintenance structure with a long-term design service life was preferred by the client.

Engineering Considerations

1. Non-fish (private land, class E) stream in a 4 m to 5 m deep draw.
2. Low to moderate energy and bedload/debris transport stream causes minimal abrasion of culvert invert.
3. A horizontal curve with a 20 m radius through the crossing and the desire for lowbed truck access, requiring an 8 m wide running surface and deep fill, made a culvert an ideal crossing option instead of a long span, wide-deck bridge.
4. An additional option was for a 9 m span log bridge on 4-log-high (approximately 2.5 m) cribbing as a temporary access.

Field Protocol for Water Chemistry and Coating Thickness Measurements

Water chemistry was collected using test strips for pH and total hardness, and a low-range chloride titrator. Test strips were exposed to stream water and the correlating colour of the activated pad was compared to colour markings printed on the bottle (pH and total hardness). A titrator was placed in a small sample of steam water held in a cup and allowed to titrate for a few minutes until the results could be read from the strip. Water chemistry was measured during the Fall (A-Branch and Rainbow Main sites) and Winter (Loon Lake site) seasons.

All three culvert sites are described below. Coating thickness measurements were collected using an Elcometer 345 Coating Thickness Gauge (Figure 3). The gauge is accurate to a hundredth of a millimetre. Readings were taken within the culvert at seven strategic locations, shown in Figure 4. The locations were chosen to reflect the following assumptions and are located similar to a clock: At locations 3 and 9, the coating is likely to be unaffected by stream flow or bedload passage and is likely similar to the thickness at manufacturing. Locations 4 and 8 were considered to be seasonal high water points, with a potential to be affected. Locations 5 and 7 were as close to running water as the instrument could measure (instrument can not be used below water) and had the highest potential to show reduced coating thickness. Location 12 was taken at the top and outside the culvert. Note that the measurement at location 12 could not be collected at the Loon Lake site for the aluminized type 2 culvert section because it was located in the middle of three sections and was under the road.

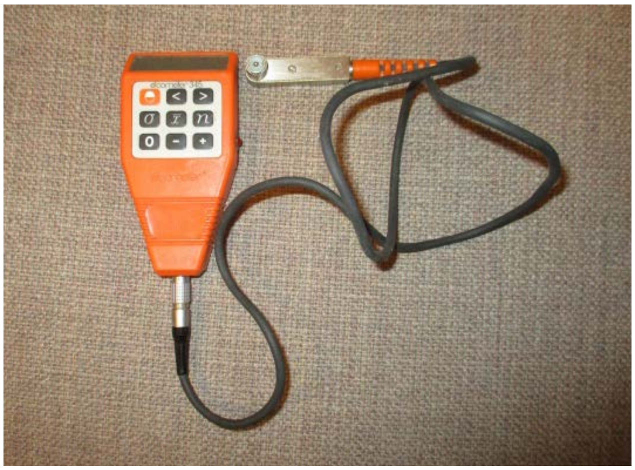

Figure 3. Elcometer 345 coating thickness gauge, with sensor facing upward at the end of an extension cable.

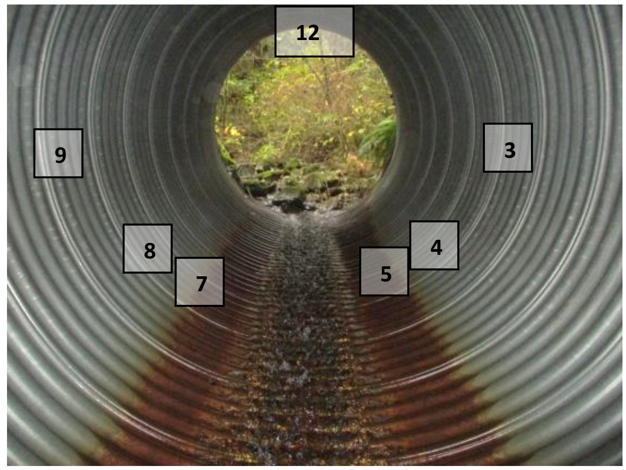

Figure 4. Locations where coating thickness measurements were taken (indicated by numbers). (Note that this is a galvanized section of culvert).

For sites A-Branch and Rainbow Main, sections of the culvert (coupons) were removed with a cold cut saw. The thickness of these sections was later measured using a micrometer. The portion of culvert removed was at the bottom and near the top of the two culverts.

Coating Thickness Measurements

Table 1 shows a summary of the culverts at the three sites. A-Branch and Rainbow Main are located near Powell River, B.C., and Loon Lake is located near Port Alberni, B.C. Culvert properties, coating thickness, and water chemistry are presented together for easy comparison.

Table 1. Culvert properties/data, coating thickness, and water chemistry from three culvert site visits

Culvert properties, coating thickness, and water chemistry measurements						
Culvert data	A-branch (2.2 km)		Rainbow main (6.6 km)		Loon lake (0.9 km)	
Date of installation	October 2005		Summer 1997		July 2010	
Diameter (mm)	2,700		2,700		3,000	
Length (m)	23		20		19	
Thickness (mm)	3.5		3.5		3.5	
Corrugation profile (mm)	125 x 25		125 x 25		125 x 25	
Number of sections	2		2		3	
Design gradient (%)	6		9		3	
Coating thickness (mm) (range/average)	A-branch (2.2 km)		Rainbow main (6.6 km)		Loon lake (0.9 km)	
Location	Galv.	Alum.	Galv.	Alum.	Galv.	Alum.
3, 9 (sides of culvert)	0.03–0.06/ **0.04**	0.03–0.07/ **0.04**	0.05–0.08/ **0.06**	0.03–0.05/ **0.04**	0.03–0.06/ **0.04**	0.02–0.05/ **0.04**
4, 8 (seasonal high Water)	0.03–0.07/ **0.04**	0.04–0.05/ **0.04**	0.04–0.07/ **0.06**	0.03–0.05/ **0.04**	0.02–0.05/ **0.03**	0.03–0.07/ **0.05**
5, 7 (near flowing water)	0.00–0.03/ **0.01**	0.01–0.03/ **0.02**	0.01–0.04/ **0.02**	0.03–0.05/ **0.04**	0.00–0.02/ **0.01**	0.04–0.05/ **0.04**
12 (top)	0.04–0.06/ **0.05**	0.04–0.06/ **0.05**	0.04–0.07/ **0.05**	0.03–0.06/ **0.04**	0.03–0.05/ **0.04**	N/A
Coupon thickness (mm)	A-branch 2200		Rainbow main		Loon lake	
Top/bottom	3.518/3.366	3.404/3.406	3.366/3.264	3.264/3.353	N/A	N/A
Water chemistry	A-branch 2200		Rainbow main		Loon lake	
pH	4–5		4–5		7	
Hardness ($CaCo_3$) (ppm)	25		25		50–120	
Chlorides (Cl) (ppm)	none		none		none	

RESULTS

The results of the coating thickness analysis and water chemistry measurements for the three culverts assessed are presented by site; abrasion levels within each culvert is also discussed. The accuracy of the gauge used to measure the coating thickness is one hundredth of a millimetre (0.01 mm); field measurements can vary due to environmental conditions (e.g. moisture). The thicknesses measurements presented in Table 1 were taken in the field and varied for any one of the strategic locations; range in measurements are given to highlight the variability of measurements. Below the water along the invert of all three culverts (where the instrument could not make measurements) it was observed that galvanized sections showed areas with no coating, and bare, pitted steel; compared to observations of aluminized sections which still showed a coating. Coupon thickness were measured with a micrometer.

Site 1: A-Branch (2.2 km)

Site 1 is located near the community of Powell River in mainland B.C. The galvanized section is located at the outlet of the culvert (Figures 5 and 6).

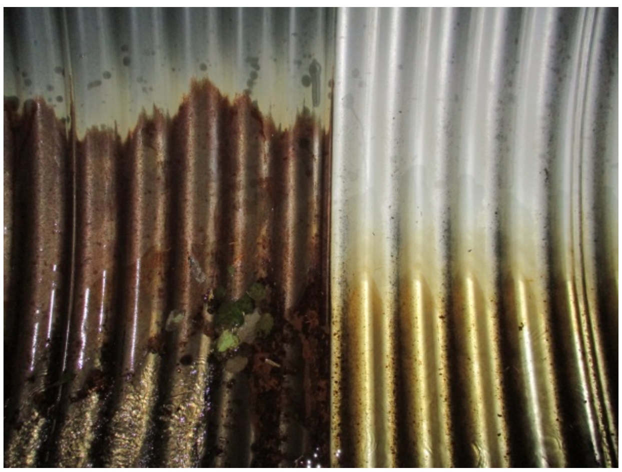

Figure 5. Galvanized coating (left) and aluminized coating (right) joined at a lock seam.

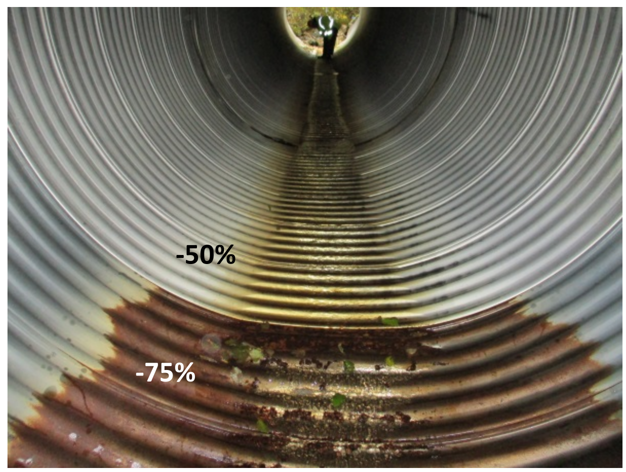

Figure 6. View toward the culvert inlet. This image shows minimal flow during the field visit, obvious corrosion of the galvanized section, and the average percentage of coating lost (locations 5 and 7) compared to that on the sides (locations 3 and 9) of the culvert.

Comparing the average readings from the sides of the culvert (locations 3 and 9) to the seasonal high flow points (4 and 8), there was no significant change in coating thickness for the galvanized or the aluminized sections. Comparing the sides of the culvert (3 and 9) to the points near the flowing water (5 and 7), the change on the galvanized section was greater than on the aluminized; the galvanized was reduced by 75%, and the aluminized was reduced by 50%. This site had the highest percentage of coating reduction for both galvanized and aluminized type 2 coatings. It also had the lowest flow, which may be attributed to measurements being taken lower (toward the invert) at locations 5 and 7, where even minimal bedload movement could contribute to abrasion. Coupon thickness from top to bottom samples showed some reduction on the galvanized coating, and the aluminized type 2 remained unchanged. Some corrosion build-up on the coupon samples resulted in thicker measurements than steel and coating alone. It was observed that on the galvanized coupons at the bottom of the culvert, the coating had worn away on the water side and the soil side.

Abrasion within the culvert was more pronounced on the upstream side of the corrugations than the downstream side, and especially near the flowing water at the invert/bottom of the culvert. Figures 7 and 8 show the differences in measurement from the upstream (0.01 mm) to the downstream (0.04 mm) of a corrugation within the area of the invert visually affected by bedload movement and abrasion. The galvanized section and the aluminized type 2 section had abrasion on the upstream side of the corrugations, which removed the coating and exposed the steel beneath; the downstream side of the corrugations along the invert retained the coating, with only minor pitting. The range in coating measurements near the flowing water (5 and 7) for the galvanized section extended to zero, correlating to a measurement of bare steel. This site showed the greatest wear for any aluminized or galvanized section which may be due to the very low flow at time of field visit allowing measurements to be taken along the true invert where even minor bedload abrasion would be more constant.

Figure 7. Upstream side of an aluminized corrugation, showing a coating measurement of 0.01 mm.

Figure 8. Downstream side of an aluminized corrugation, showing a coating measurement of 0.04 mm.

Site 2: Rainbow Main (6.6 km)

Site 2 is located near the community of Powell River in mainland B.C. The galvanized section is located at the inlet of the culvert (Figures 9 and 10).

Figure 9. View of the galvanized section. Areas below the water were observed and felt to be slightly pitted, likely due to bedload movement causing abrasion.

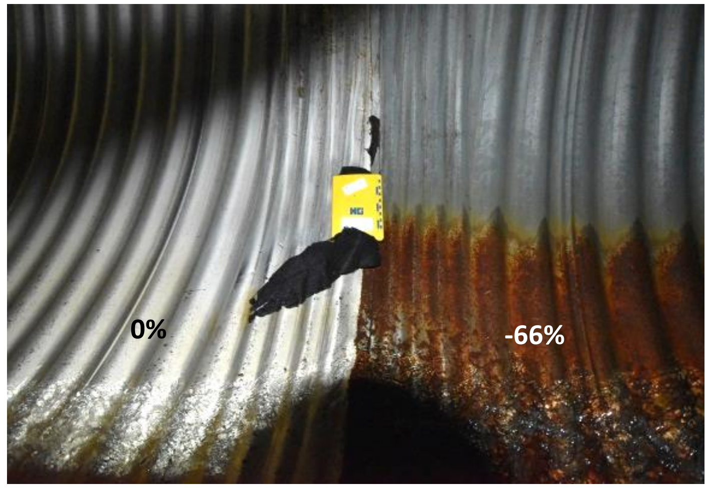

Figure 10. View of an aluminized (left) and galvanized (right) section joined at a coupler. The notebook was included for scale and was resting on a piece of geotextile fabric, which would have been placed next to the coupler on the outside of the culvert during installation. The numbers indicate the average percentage of coating lost near flowing water (locations 5 and 7) compared to the sides (locations 3 and 9) of the culvert.

Comparing the average readings from the sides of the culvert (locations 3 and 9) to the seasonal high flow points (4 and 8), there was no significant change in coating thickness for the galvanized or the aluminized sections. Comparing the sides of the culvert (3 and 9) to the points near the flowing water (5 and 7), the change on the galvanized section was greater than on the aluminized; the galvanized was reduced by 66%, and the aluminized was reduced by 0%. Coupon thickness from top to bottom samples showed some reduction on the galvanized coating, and the aluminized type 2 gained thickness. Some corrosion build-up on the samples resulted in thicker measurements than steel and coating alone.

Abrasion at this site was more pronounced visually on the galvanized section, and the site appeared to have a low to medium movement of bedload. On the aluminized section, the upstream side of the corrugations had minor "pock" marks, and an estimated 90% of coating remained intact; the downstream side had no abrasion (Figure 11). The galvanized section showed overall greater wear (Figure 12). Although the culvert at this site was installed the longest (1997), the higher stream flows during the site visit kept the near flowing water measurements (5 and 7) to be further from the true invert which could have removed some of the effect of bedload abrasion, resulting in the measurements showing more coating remaining.

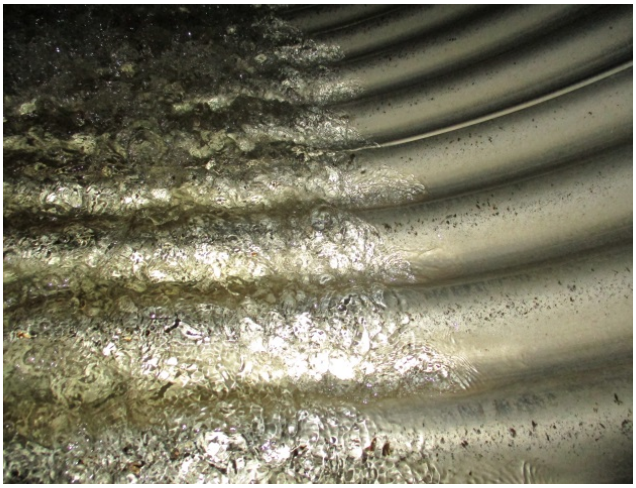

Figure 11. View of aluminized coating, showing only minor abrasion along the upstream side of the corrugations along the invert.

Figure 12. View of galvanized zinc coating, showing a greater amount of surface corrosion; the upstream portion of corrugation had minor pitting, and the galvanized zinc coating had worn off.

Site 3: Loon Lake (0.9 km)

Site 3 is located near the community of Port Alberni on Vancouver Island, B.C. The aluminized type 2 section was in the middle of the culvert, and the galvanized sections were at the inlet and the outlet of the culvert (Figures 13 and 14).

Figure 13. View of a galvanized section in the foreground and the aluminized type 2 section in the middle of the culvert.

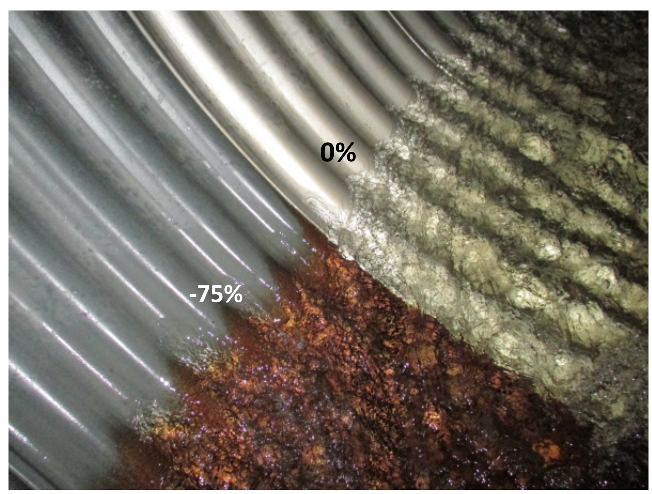

Figure 14. Junction of the galvanized and aluminized type 2 materials. The numbers indicate the average percentage of coating lost near flowing water (locations 5 and 7) compared to the sides (locations 3 and 9) of the culvert.

Comparing the average readings from the sides of the culvert (locations 3 and 9) to the seasonal high flow points (4 and 8), there was a slight reduction (25%) in coating thickness for the galvanized section. There was no significant change on the aluminized section. Comparing the average readings from the sides of the culvert (3 and 9) to the points near the flowing water (5 and 7), the galvanized section was reduced by 75%. Again, there was no significant change on the aluminized section. The culvert at this site was the newest installation (2010) of all three sites studied.

The flow at site 3 was high during the site visit. Abrasion at the site showed corrosion and pitting below the water line on the galvanized section (Figure 15), with some signs of steel showing (no coating remaining). The range in readings of the coating thickness also provides insight into coating wear, and in this case, the galvanized coating had a range extending to zero near the flowing water location (5 and 7). This correlates with the visual abrasion assessment, which noted bare steel visible in some areas. On the aluminized section, there was minimal corrosion and pitting, with much of the coating intact (Figure 16).

Figure 15. View of step-bevelled inlet made of galvanized steel.

Figure 16. View of the aluminized type 2 section at a helical lock seam joint.

CONSIDERATIONS FOR CULVERT SELECTION

Four guidance charts showing three culvert coatings well suited for various site parameters are presented in Figure 17. The three most common coatings are presented, though other materials and coatings are available. The characteristics shown on the charts (pH, hardness, resistivity, and chlorides) relate to water chemistry and potential corrosion. Steel is most negatively affected by corrosion where the pH is low (pH < 7) (West, 2013). Areas with low pH values (acidic) are more common in areas of high rainfall and tend to be more corrosive (CSPI, 2007). Typically, a galvanized coating has the most restricted range of use, aluminized type 2 has a greater range than galvanized, and polymer-laminated has the greatest range. Although a galvanized culvert is the most common choice of coating in the forest industry, it may not be well suited for various environments; aluminized type 2 or polymer-laminate are alternative coatings.

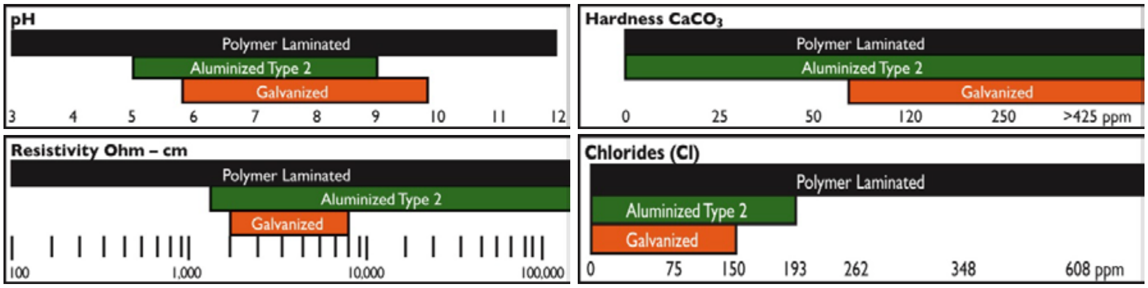

Figure 17. Bar charts showing the ranges in water chemistry measurements and their associated appropriate culvert coatings. (Courtesy of CSPI.)

At sites 1 (A-Branch) and 2 (Rainbow Main), the measured pH (4–5) and hardness (25) were outside the suggested range for galvanized coatings and were within the suggested range for aluminized type 2. The chlorides (none) were within the suggested range for both coatings. At site 3 (Loon Lake), the measured pH (7) and chlorides (none) were within the suggested range for both coatings. The hardness was within the suggested range for the aluminized type 2 coating and at the border of the suggested range for galvanized. Based on a resistivity calculator (CSPI.ca/resources/calculators) using inputs for hardness and chlorides, sites 1 and 2 are approximately 16 000 ohm·cm (outside the suggested range for galvanized), and site 3 is approximately 5 500 ohm·cm (within the range of both coatings). The field measurements showed the aluminized type 2 coating as having a greater amount of coating remaining at all three sites. The suggested ranges for water chemistry provide good guidance, but the abrasion level must also be considered when planning expected service life.

The abrasion of a culvert is a type of degradation through the means of erosion. The flow and water depth, the size and bedload composition, and the slope of the structure all contribute as mechanisms toward abrasion. Bedload and flow velocities are key indicators of the anticipated level of abrasion and are the two parameters used in determining it (Table 2). The slope of a culvert has an affect on flow velocity and therefore also influences the level of abrasion. Abrasion can be significant where water velocity is high (above 5 m/s) (CSPI, 2007). Larger aggregate, such as boulders and gravel, has a much greater effect on the wear and erosion of a culvert compared to finer materials like sand. Suggested abrasion ranges for coating are presented in Figure 18. FPInnovations will continue researching abrasion with respect to coating wear.

Table 2. Definition of abrasion level by bedload description and flow velocity (Courtesy of CSPI.)

Abrasion Level	Bedload Description	Anticipated Flow Velocity (m/s)	
		Minimum	Maximum
1	No bedload regardless of velocity (e.g. storm sewer or stormwater detention facility)	NA	NA
2	Minor bedload of sand and gravel	0	1.5
3	Bedload of sand and gravel	1.5	4.5
4	Heavy bedload of gravel and rock	4.5	Above 4.5

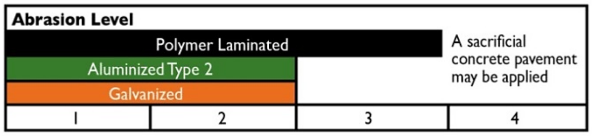

Figure 18. Bar chart showing the suggested range in abrasion level and the associated appropriate culvert coatings. (Courtesy of CSPI.)

DISCUSSSION AND CONCLUSIONS

This report presented the results of field investigations conducted on three culverts installed in 1997, 2015 and 2010 where galvanized and aluminized type 2 coating where used. The objective was to compare the performance of each coating in relation to water chemistry and abrasion.

A similar trend for coating thickness by sample location within the culvert was found across the three study sites. The thickness measurements of galvanized and aluminized coatings at the sides of the culvert (locations 3 and 9) were similar to that at the top of the culvert, which likely represents a close approximation of the thickness at manufacturing. The highest amount of measured coating wear was near the level of flowing water through the culvert and was greater on the galvanized coating.

Abrasion was noted along the culvert corrugations predominantly near flowing water and at slightly higher than flowing water locations, correlating with seasonal high-water flow. Mild abrasion was noted as small pock marks, starting on the upstream side of the corrugation, with minimal or no marks on the downstream side. A visual assessment of the two coating sections showed greater abrasion and erosion on galvanized coatings. Wear over time is likely greatest along the true invert, which could only be assessed visually; where stream flow was low (site 1) measurements could be taken closer to the true invert where abrasion was likely to be more constant.

The culverts in this study ranged in age with no clear trend in coating wear by installation date. The culvert installed in 2010 (youngest) showed greater galvanized coating wear (location 5 and 7) than the culvert installed 13 years earlier (1997), and the 2010 culvert was exposed to a neutral pH. For each culvert the aluminized section was outperforming the galvanized section, especially with respect to the visual estimation of abrasion and coating wear along the invert. Although the range in coating measurements extended to zero for locations 5 and 7 within the culvert, this does not correspond to a failed, or end of life for the culvert. When a coating is completely removed, the culvert is no longer protected by the coating and the steel is susceptible to the effects of the environment (water chemistry and abrasion). The steel can still function for a period of time without a coating. It is when the steel has deteriorated through that the culvert becomes more prone to failure.

The Elcometer 345 Coating Thickness Gauge worked well for measuring coating thickness, except for below the flowing water along the culvert invert where the instrument could not be used/submerged. Through observations, the highest level of coating wear at all sites was at the culvert inlet along the invert (bottom), which was much higher for galvanized sections compared to aluminized. The thickness of cut coupons included a build-up of corrosion; there was a slight reduction in thickness from top to bottom on the galvanized sections.

The current cost for aluminized type 2 culverts is approximately 15% to 20% higher than galvanized. Resource managers will need to determine if the premium is acceptable by considering the anticipated design service life of the structure, along with the site-specific attributes (water chemistry and anticipated levels of abrasion).

Future FPInnovations culvert coating research will include the assessment of sites with known high abrasion levels.

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