White Paper
Durability of Galvalume (55 Al-Zn) Coated Corrugated Steel Pipe

Introduction

Galvalume is an Aluminum-Zinc alloy coating which first became commercially available in 1972. The coating (generically referred to as 55Al-Zn) has a nominal composition by weight of 55% aluminum, 43.4% zinc and 1.6% silicon. The primary purpose of the silicon addition is to control growth of the steel intermetallic layer. While 55% aluminum by weight, the coating is approximately 80% aluminum by volume. The combination of zinc and aluminum was systematically determined to be an optimum combination of sacrificial protection (zinc) and low coating corrosion rate (aluminum). The 55Al-Zn coatings are applied to steel sheet in continuous hot dip coating lines with integrated cleaning and heat-treating steps.

The Corrugated Steel Pipe Institute (CSPI) Tech Bulletin 1, Performance Guideline for Corrugated Steel Pipe Culverts (300mm to 3,600mm Diameter) was designed to "help practitioners in selecting the most appropriate corrugated steel pipe coating available given the desired service life of the application and the environmental parameters unique to the culvert site." The 2013 version of the bulletin includes three corrugated steel pipe (CSP) materials: Polymer Laminated Galvanized Steel, Aluminized Type 2 Steel, and Galvanized Steel. This white paper provides the technical background for integrating 55Al-Zn coated CSP into the bulletin.

This white paper was prepared by Elzly Technology Corporation under contract to CSPI. Elzly is a consulting engineering firm specializing in corrosion and corrosion control for civil works, industrial structures and military equipment. Their experience includes more than 20 years studying the durability of corrugated metal structures and the benefits of various coatings. Elzly has a broad technical perspective on the use of protective coatings, metal plating, corrosion resistant metal alloys and chemical corrosion inhibitors.

Corrosion of Galvalume Coated Steel

In the 1960's a hybrid aluminum and zinc coating for corrosion protection was developed based on the idea that "the well-known durability of aluminum coatings could be combined with the unique galvanic property of galvanized coatings."(Townsend 1993) A series of studies were performed comparing corrosion resistance of steel coated with Al and Zn alloys at various ratios to that of galvanized steel. It was found that "55% Al-Zn alloy is the optimum coating composition…at least two to four times more corrosion resistant than that of an equal thickness galvanized coating" in atmospheric exposure. (Townsend 1993)

The outdoor performance of Galvalume has been observed and reported on in several studies. Because of its use as a roofing material, its performance in exterior atmospheric environments has been studied extensively. There are also reports in the literature on galvalume performance in culvert installations. To help inform this whitepaper, Arcelor Mittal conducted a test program which included evaluating the corrosion of Galvalume, Galvanized, and Aluminized Type 2 coatings over a period of 11 weeks in six waters. The following sections summarize the three data sources.

Atmospheric Corrosion Studies

An extensive series of exposure tests on the corrosion resistance of aluminum-zinc alloy coatings was initiated by Bethlehem Steel in the mid-1960's. A series of reports from 1979 through 1998 by Townsend, et. al. provides the results of atmospheric corrosion tests over 30 years in a variety of environments. The studies show a significant increase in the coating corrosion resistance when it contains 44.6% or more aluminum.

Table 1 lists the time to "first rust" for galvanized and Galvalume (55Al-Zn) coating and the observed corrosion rate of galvanized, 55Al-Zn, and Aluminum coatings in the four outdoor exposure environments. Time to first rust is defined as the time until approximately 2% of the panel surface was rusted over the 30-year exposure period. The corrosion rate is the rate predicted in year 5 based on 13 years of weight loss measurements.[2] The data support the conclusion that the 55AL-Zn coating will provide more than double the service life of galvanized coating in atmospheric exposure.

Table 1 - Corrosion Data from Outdoor Exposure Studies

Location (Environment)	**Time to "first rust" – years[1]**		**Corrosion rate in year 5 - µm/yr (mil/yr)[2]**		
	galvanized	**55Al-Zn**	**galvanized**	**55Al-Zn**	**Aluminum**
Kure Beach, NC (Severe marine, 25-m lot)	4 years	15 years	1.51 (0.059)	0.88 (0.035)	0.43 (0.017)
Kure Beach, NC (Moderate marine, 250-m lot)	16 years	Over 30 years	1.10 (0.043)	0.61 (0.024)	0.22 (0.009)
Saylorsburg, PA (Rural)	14 years	Over 30 years	1.08 (0.042)	0.28 (0.011)	0.14 (0.006)
Bethlehem, PA (Industrial)	10 years	Over 30 years	1.96 (0.077)	0.27 (0.011)	0.14 (0.005)

Culvert Installation Studies

In 1973-1974, sixteen installations of galvalume and galvanized pipe were installed in parallel or tandem arrangements. Based on inspections over a 10-year period, galvalume performed better overall than the corresponding galvanized pipe. (Stavros 1984) The inverts and intermittently wet zones of the galvalume pipe took longer to show first rust than the galvanized pipe. At sites where abrasion was

[1] "First rust" is defined as the inspection when two percent (2%) of the panel surface exhibited steel corrosion (red rust).

[2] Corrosion rates have been shown to vary over exposure time. Equations were developed for corrosion rate-time relationships based on experimental data in these four environments. (Townsend, 1979) The corrosion rate provided in Table 1 is the average metal loss per year experienced in exposure year 5.

considered significant, the coatings had similar deterioration. The coatings performed similarly on the soil side, which was relatively benign in most installations.

In 1985, Pennsylvania DOT installed three pipe materials (galvanized, galvalume, and aluminized type 2) at each of three different sites to comparatively evaluate the coatings. A 1987 report details the construction procedures and initial coating thicknesses; however, no follow-up inspection reports have been identified. (Highlands 1987) The report contains researchers' observations of comparison test sites in Maine and New York. Briefly, in Maine they observed that the galvanized pipes had more severe signs of steel corrosion than Galvalume while in New York the opposite was observed. No further details of the observation were provided in the report.

Maine DoT reported on the durability of various culvert materials and/or coatings for durability. (Jacobs 1982) Over a roughly nine-year period, the 55Al-Zn coating had performed better than the galvanized coating (based on the DoT's condition rating system) at sites where both were installed.

A 1991 FHWA report investigated the performance of several different corrugated steel pipe coatings at sites in Arkansas, Mississippi, New York and Vermont. Limited 55AL-Zn was inspected in the field (including one pipe installation in Mississippi and a few plate pieces in New York). The authors stated, "The aluminum-zinc coated (Galvalume) pipe sample showed more metal loss than the aluminum coated pipe at that location, but less than that predicted by the California method, suggesting that aluminum-zinc coated performance lies between galvanized performance and aluminum coated performance." (Potter 1991) A 1997 follow-on to that study included two additional 55AL-Zn pipes in Maine. The observations from that report suggest that galvalume may perform 2.3 times better than the California curve would predict for galvanizing. (Ault 1997)

A 2006 white paper was prepared by DoFasco to support the merits of keeping 55% Aluminum-zinc alloy coated steel (AZM210) in the ASTM A929/A929M-01 specification. The paper contained technical data from laboratory testing and 11 field exposure locations in Canada and the United States. The paper concludes, in part that "Based on the coating properties and testing conducted, our engineering estimate of service life for 55 AL-Zn culvert is expected to be 1.2 times the service life for the galvanized culvert in the same environmental conditions." (DoFasco 2006) Subsequent industry experience suggests that this factor may be unnecessarily conservative.

The Corrugated Steel Pipe Institute (CSPI) has been monitoring the performance of two 55 Al-Zn culverts installed in 2015. Galvanized pipe segments are installed at each location for comparison. No coating degradation or corrosion has been observed after four years in service.

Corrosion in Immersed Environments

In part due to the lack of long-term case histories of Galvalume in culvert installations or other immersion service, Arcelor Mittal conducted an investigation to enhance the credibility of culvert service life predictions. (Arcelor Mittal 2019). The study reported comparative performance of Galvalume, Aluminized Type 2, and Hot Dip Galvanized steel coatings. A particularly relevant element of the study was to determine comparative corrosion rates of the alloys when immersed in six different waters. The chemistry of the waters is shown in Table 2

Table 2 – Water Chemistry used for Testing

Water Sample	Resistivity (Ω-cm)	Chloride (ppm)	pH	Hardness (ppm $CaCO_3$)
Distilled Water	500,000	0.67	6.3	25
Lake Water	17,857	8.6	6.8	50
Synthetic Soft Water	8,197	1.8	6.2	50
Aggressive Water	1,241	42	2.5	120-250
Synthetic Water – Very Hard	1,618	8.2	7.9	>425
Hard Water - 1000	602	740	5.5	>425

Metallic coated steel samples were fully immersed in the water solutions for a period of 11 weeks. The coating corrosion rates were determined based on periodic polarization resistance measurements. After exposure, the corrosion product on the coating surfaces was microscopically evaluated. For the purposes of this white paper, the data was evaluated to determine the reasonableness of achieving a 100-year service life. The measured corrosion rates tended to be higher during weeks 1 and 2 but settle to a steady state from weeks 4 through 11. Assuming the corrosion rate remains constant and evenly attacks the coating, a maximum achievable coating life can be calculated. Figure 1 present the Maximum coating life based on the laboratory corrosion rate data. The data illustrate the susceptibility of all three metallic coatings to aggressive water (pH = 2). The data also show the markedly improved performance of Galvalume and Aluminized Type 2 versus galvanized in the soft waters. The similar performance of the metallic coatings in the soft lake water may be due to an unreported variable. For the purposes of positioning the Galvalume coating among the Aluminized Type 2 and Hot Dip Galvanized, the data support the hypothesis that Galvalume will perform comparably to Aluminized Type 2.

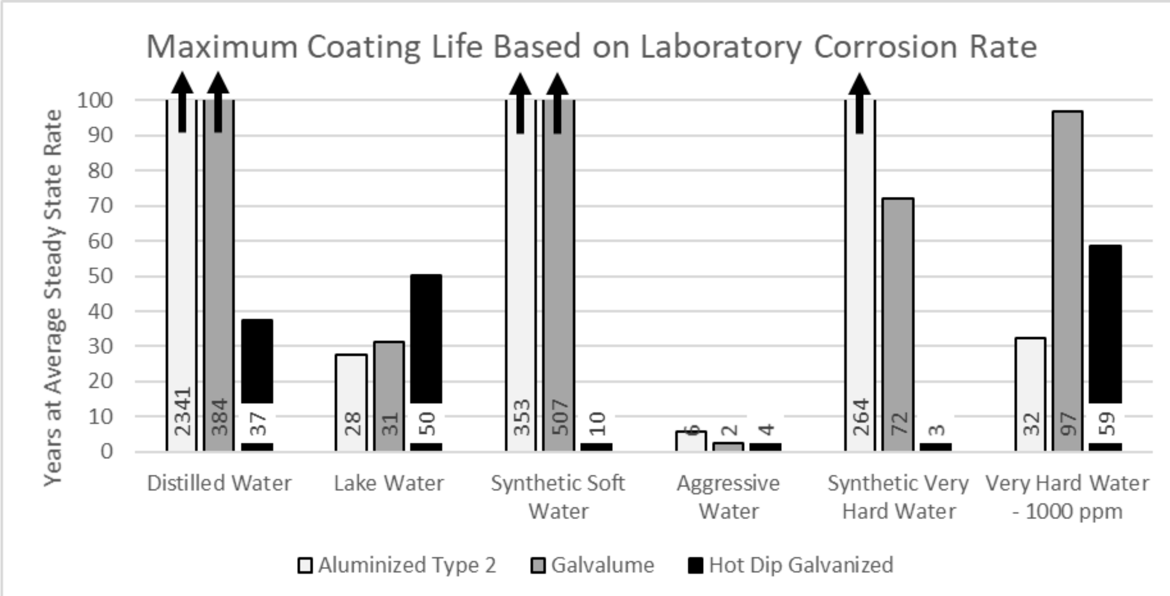

Figure 1. Calculated maximum coating life based on corrosion rates measured in laboratory immersion tests.

Performance Parameters for Galvalume Coated Corrugated Steel Pipe Culverts

This section discusses the performance of galvalume coated corrugated steel pipe culvert relative to the guideline steps contained in CSPI Tech Bulletin One. (CSPI 2013)

Abrasion Condition (TECH ONE section 3.3.3)

Section 3.3.3 defines four abrasion levels and identifies which CSP materials are suited for each level. Galvalume has a higher Vickers hardness (80 kg/µm²) than aluminum or zinc (60 kg/µm² and 44 kg/µm², respectively), (DoFasco 2006) but it is still comparable to most soft metals. An NCSPA evaluation of coating durability suggests a similar abrasion resistance of four metallic coatings. (NCSPA 1996) There is no reason to expect Galvalume to resist significantly higher levels of abrasion than either aluminized or galvanized coatings. Galvalume is recommended for Abrasion Level 1 and 2.

Use Design Charts (TECH ONE section 3.4)

Section 3.4 contains charts indicating appropriate ranges of pH and Resistivity for various materials at design service lives of 25, 50, 75, and 100 years. For galvanizing, the charts are based on the service life prediction methodology provided in Chapter 8 of The Handbook of Steel Drainage and Highway Construction Products. The ranges for Aluminized and Polymer coated pipe are based on industry experience. Based on the available data, Galvaume boundaries should be between the galvanized and Aluminized boundaries, tending toward aluminized at higher resistivities and toward galvanized at higher pH.

Appendix 1 shows proposed changes to incorporate Galvalume into the Design Service Life Charts. Since higher resistivity conditions appear suitable for Galvalume (see resistivity section), the resistivity range for Galvalume can be extended above 100,000 Ω·cm, tending toward the Aluminized pH limit above 10,000 Ω·cm, reflecting the good performance of both materials in this regime. As the resistivity decreases, there is some differentiation between the Aluminized and Galvalume performance, reflected by shifting Galvalume minimum pH slightly. At alkaline pH, the galvalume boundary follows the galvanized resistivity limit. These modifications should be re-visited based on additional field experience with Galvalume.

pH vs. Culvert Material (TECH ONE section 4.1, Figure 7)

Table 3 and Figure **2** demonstrates the improved corrosion resistance of Galvalume over galvanized in waters of pH 5 through 9. (Stavros 1984). The data is based on exposure of coated panels for 90 days in distilled water containing 45 ppm of SO^{2-}_4 and 10 ppm of Cl^- ion at pH values from 3 to 11. The pH was adjusted by adding an appropriate amount of sulfuric acid or sodium hydroxide. Galvanizing corroded approximately 4 time faster than Galvalume at pH 5 to 9. At pH 3 and 11, Galvanizing corroded 20-40% faster than Galvalume.

Table 3 - Coating weight loss after 90-day immersion

pH	Calculated Thickness Loss – µm (mil)	
	55 Al-Zn	**Galvanized**
3	20.1 (0.79)	25.4 (1)
5	4.8 (0.19)	25.4 (1)
7	3.3 (0.13)	23.4 (0.92)
9	3.0 (0.12)	25.4 (1)
11	10.9 (0.43)	14.7 (0.58)

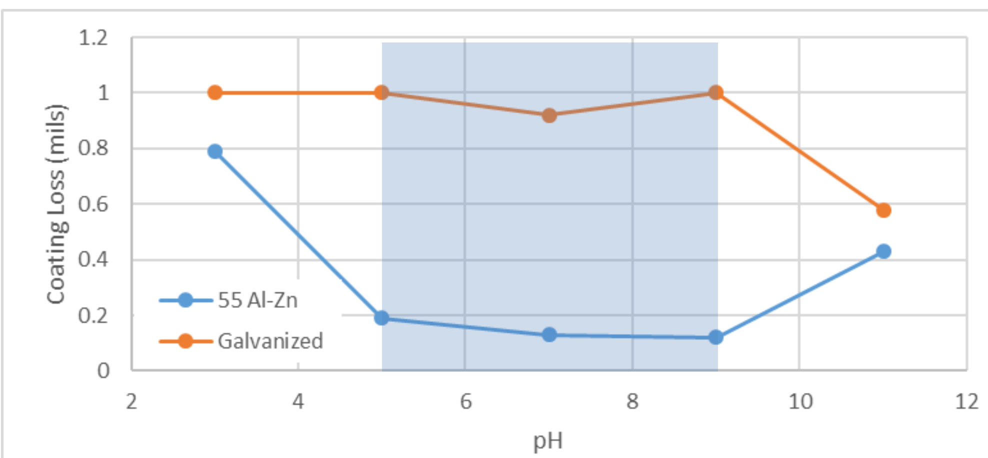

Figure 2**. Coating loss rate at various pH levels.**

Maine DoT reported on the performance of various pipe materials after 90-day immersion of coupon samples in a pH 4 solution of H_2SO_4 and a pH 4 solution of acetic acid. (Jacobs 1982). After H_2SO_4 exposure, the Galvalume coating had "minor etching" of those areas in solution but a loss of coating at the interface line for the panels with exposed edges. After acetic acid exposure, the Galvalume coating had nearly 100% loss of coating for the area which was in solution. The studies support an acceptable pH range of 5 to 10.

Resistivity vs. Culvert Material (TECH ONE section 4.1, Figure 8)

Galvalume culverts have been observed to last more than 9 years in high resistivity water and soil. As reported in the hardness section, Galvalume loss was roughly 1% of galvanized loss after 56 days exposure in distilled water, which would be in the range of 100,000 Ω·cm. At this rate, the Galvalume coating would last over 200 years.

The Arcelor Mittal study discussed above evaluated galvalume corrosion rates in waters with resistivities between 602 Ω·cm and 500,000 Ω·cm. Corrosion rates were low enough to support a coating life in excess of 30 years in all but the lowest resistivity water.

Based on the available data, it seems reasonable to set an upper resistivity limit to over 100,000 Ω·cm and a lower resistivity limit for Galvalume of 1,500 Ω·cm.

Hardness vs. Culvert Material (TECH ONE section 4.1, Figure 9)

The behavior of 55Al-Zn in waters of varying hardness has been investigated. One reference reports a coating thickness loss of 0.015µm (0.0005 mils) after 56 days of immersion in distilled water. (ASM 1993) For comparison, galvanized thickness loss in the same test was 1.06µm (0.042 mils), about two orders of magnitude higher.

Another investigator reported the condition of various CSP coatings after sections of pipe were cyclically exposed to standing distilled water. (Stavros 1984) The testing involved pouring 750 mL of distilled water into a "trough" fabricated from a section of coated CSP. The water was allowed to dry at ambient conditions after which another 750 mL of distilled water was added. After 24 wetting cycles spanning 260 days, a similar amount of rust specks and staining were observed on the Galvalume and galvanized samples. Aluminized Type 2 exhibited slightly more rust speck that the other two materials.

The Arcelor Mittal study discussed above evaluated galvalume corrosion rates in waters with hardnesses from 25 ppm as $CaCO_3$ to over 425 ppm as $CaCO_3$. The data show comparable corrosion of the Aluminized Type 2 and Galvalume coatings in most of the waters tested.

Based on this data, the acceptable hardness range for 55Al-Zn can be same as for Aluminized Type 2 steel.

Chlorides vs. Culvert Material (TECH ONE section 4.1, Figure 10)

The behavior of 55Al-Zn in waters of varying chloride content has been reported in the literature. One reference reports a coating thickness loss of 0.133µm (0.005 mils) after 56 days of immersion in 85 ppm NaCl. (ASM 1993). For comparison, galvanized thickness loss in the same test was 1.26µm (0.049 mils), about an order of magnitude higher.

Another investigator reported the condition of various CSP coatings after sections of pipe were cyclically exposed to standing 0.05% NaCl (500 ppm). (Stavros 1984) The testing involved pouring 750 mL of 500ppm NaCl water into a “trough” fabricated from a section of coated CSP. The water was allowed to dry at ambient conditions after which another 750 mL of 500ppm NaCl water was added. After 24 wetting cycles spanning 260 days, only a few rust specks were visible on the Galvalume sample. The galvanized sample was 10% rusted and the Aluminized Type 2 sample was 100% rusted at the end of the test.

Maine DoT reported on the performance of various pipe materials after 90-day immersion of coupon samples in ASTM Standard Artificial Seawater. (Jacobs 1992). After artificial seawater exposure, the Galvalume coating had slight etching and discoloration of the immersed portion of the coupon.

The outdoor exposure data described earlier in this white paper includes data for moderate and severe marine exposure, both of which would be subjected to significant chlorides. The data demonstrate increased durability of galvalume versus galvanized in these environments. It is difficult to translate the performance differences to aqueous chloride concentrations except to say that the observations are certainly consistent with the idea that galvalume can tolerate higher levels of chloride than galvanizing.

This data suggests that the acceptable chloride range for 55Al-Zn can be extended beyond the limits for galvanized and aluminized Type 2. For perspective, seawater has approximately 35,000 ppm NaCl and typical city water is less than 100ppm. The data supports chloride levels as high as 500ppm, however such a solution would be less than 1000 Ω·cm. It is recommended that the acceptable maximum chloride level for Galvalume should be 250 ppm, which would be 1800 Ω·cm if no soluble salts other than sodium chloride were present.

Summary

The studies reviewed and discussed herein suggest that Galvalume possesses performance characteristics that distinguish it from galvanized and aluminized coated steel. These differences suggest that the material will behave better than galvanized. Appropriate design guidance should be incorporated into CSPI TECH ONE.

References

ASM Specialty Handbook, Aluminum and Aluminum Alloys, ASM International, 1993.

Arcelor Mittal Technical Report 6550_051_TECH_2019 titled “Aluminized Type 2 vs Galvalume” dated November 26, 2019.

Ault, J.; Ellor, J. "Durability Analysis of Aluminized Type 2 Corrugated Metal Pipe," FHWA-RD-97-140, Federal Highway Administration, 1997.

CSPI, Tech. Bulletin One - Performance Guideline for Corrugated Steel Pipe Culverts (300mm to 3,600mm Diameter), Corrugated Steel Pipe Institute, August 2013.

DoFasco Technical Paper "55% Aluminum-Zinc Alloy Coated Steel for Corrugated Steel Pipe Applications," June 30, 2006.AMD presentation "Customer Presentation for Galvalume"

Highlands, Keith and Maurer, Dean, Field Evaluation of Metallic-Coated Steel Pipe Construction Report. Pennsylvania DOT Research Project #84-105. June, 1987.

Jacobs, Kenneth M. *Durability of Drainage Structures, Final Report*, Maine DOT, Report No. BP-82(547), June 1982.

NCSPA, Evaluation Methodology for Corrugated Steel Pipe Coating/Invert Treatments, National Corrugated Steel Pipe Association, March 1996.

Potter, J.C.; Lewandowski, I.; White, D.W., *Durability of Special Coatings for Corrugated Steel Pipe*, Federal Highway Administration, Report No. FHWA-FLP-91-006, June 1991.

Stavros, A.J., Galvalume Corrugated Steel Pipe: A Performance Summary. Transportation Research Record 1001, 1984, Washington DC.

Townsend, H. E.; Zoccola, J. C., Atmospheric Corrosion Resistance of 55% Al-Zn-Coated Sheet Steel: Thirteen-Year Test Results, Materials Performance, 18 (10), 13-20, October (1979).

Townsend, H. E.; Meitzner, C. F., Corrosion Resistance of Zinc/4% Aluminum and Zinc/7% Aluminum Alloy Coatings Compared to Zinc and Zinc/54% Aluminum Coatings, Materials Performance, 22(1), 54 (1983)

Townsend, H. E.; Borzillo, A. R., Twenty-Year Atmospheric Corrosion Tests of Hot-Dip Coated Sheet Steel, Materials Performance, 26 (7), 37-41 (1987).

Townsend, H. E., Twenty-Five-Year Corrosion Tests of 55% Al-Zn Alloy Coated Steel Sheet, Materials Performance, 32 (4), 68-71 (1993).

Townsend, H. E.; Borzillo, A. R., Thirty-Year Atmospheric Corrosion Performance of 55% Aluminum-Zinc Alloy-Coated Sheet Steel, Materials Performance, 35 (4), 30-36 (1996).

Townsend, H. E., Atmospheric Corrosion of Skyward- and Groundward-Exposed Surfaces of Zinc- and 55% Al-Zn Alloy-Coated Steel Sheet, Corrosion, 54(7), 561-565 (1998).

Appendix 1 – Proposed Modifications to the DSL Charts

Figure 4.1 – 100 Year DSL Chart

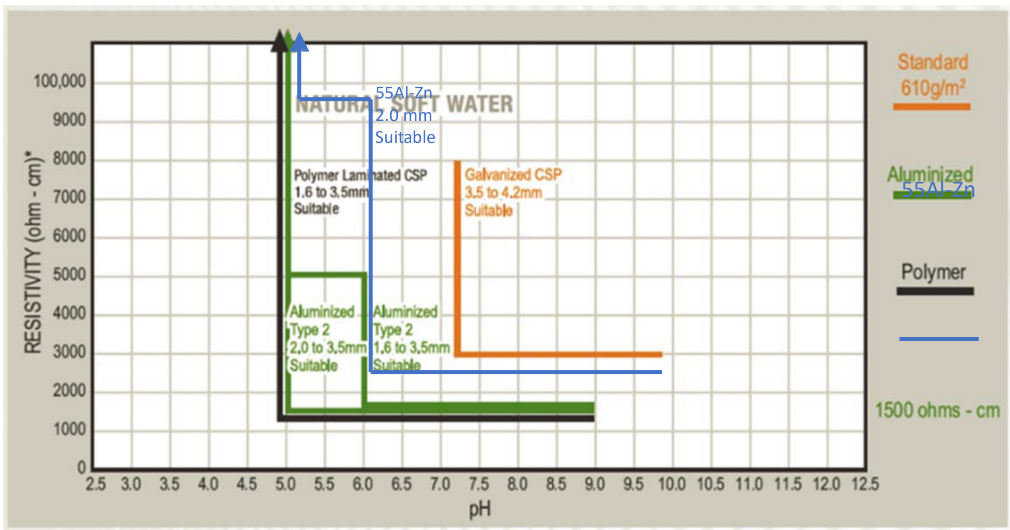

Figure 4.2 – 75 Year DSL Chart

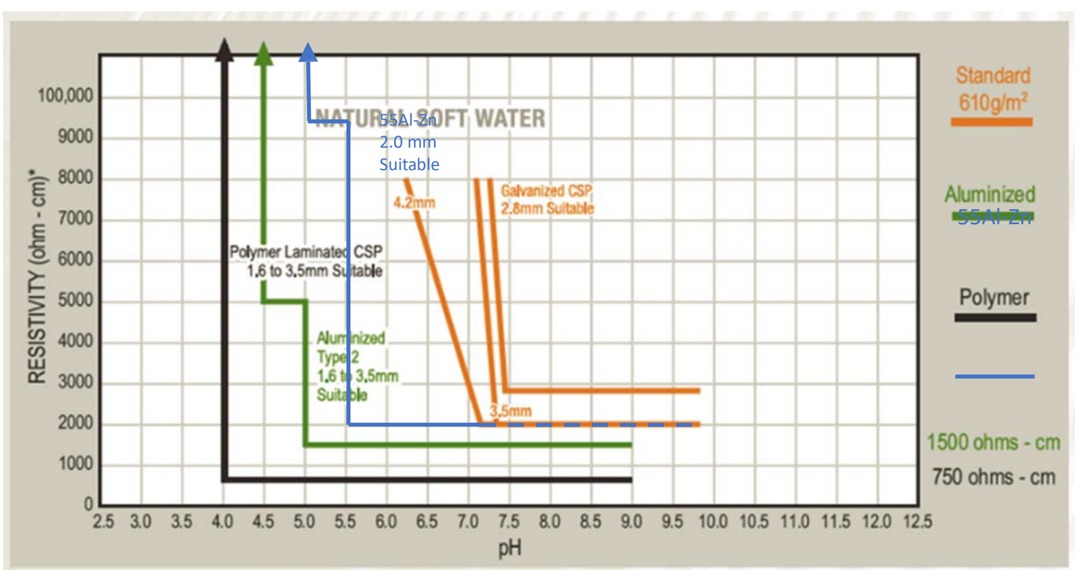

Figure 4.3 – 50 Year DSL Chart

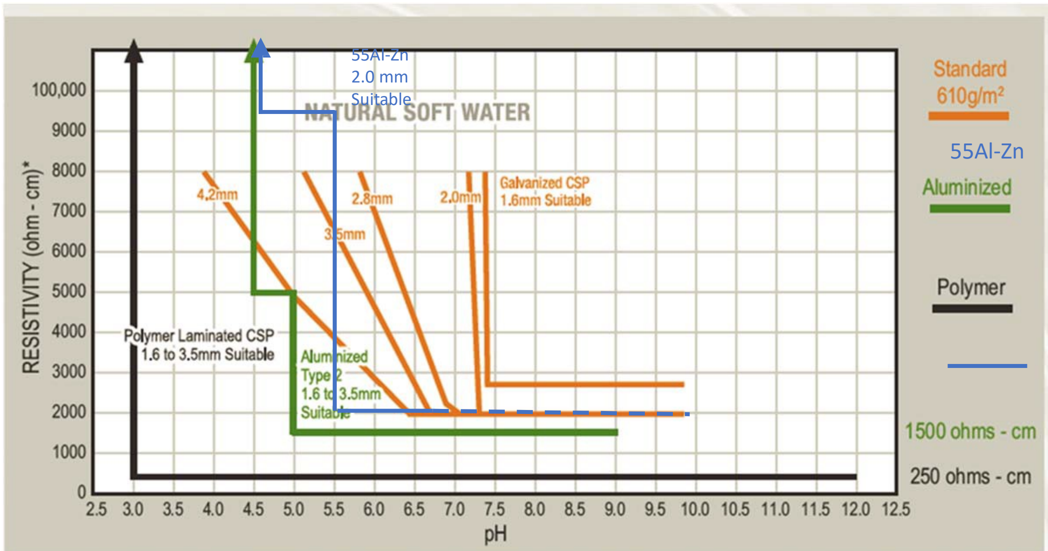

Figure 4.4 – 25 Year DSL Chart