# ADDED LONGEVITY WITH THERMOPLASTIC POLYMER COATED STRUCTURAL STEEL PLATE

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# ABSTRACT

Basic corrugated pipes were invented in 1896 since evolving into buried steel structures with the possibility of spans reaching upwards of 120 ft (40 m). To meet increasing design life requirements, galvanized and polymer laminate coatings have been developed to extend the life of steel. In general, galvanized coatings perform well in hard water and non-abrasive conditions whereas polymer coatings perform well in these conditions plus salt-laden, soft water and moderately abrasive environments. To date, polymer laminate systems have been restricted to shallow corrugation profiles with maximum spans of approximately 12 ft (3.6 m), thus limiting greater spanned buried steel structures as a solution in less adverse environments. To enable a large-span solution for applications requiring design lives of 50 to 100 years in adverse environments, a new thermoplastic polymer system, comprised of a zinc rich primer and ethylene acrylic acid topcoat, has been developed.

This paper introduces the new thermoplastic polymer system, comparing it to polymer laminated, galvanized and aluminized type 2 coatings. The coating has been used successfully since 2005 and recently completed a series of performance testing. Testing suggests the thermoplastic polymer coating meets, and in most cases exceeds, the performance of competing technologies. Discussion is focused on the laboratory tests, a recently developed performance guideline and field installations. Nearly 10 years of field experience, with over 20 structures designed and manufactured in Canada alone, support the laboratory results obtained and presented enabling readers to gain an understanding of applications this new coating facilitates.

# 1.0 INTRODUCTION

Corrugated steel pipe (CSP) has been available since 1896. Originally designed for small applications such as drainage, duct and small culverts, CSP has evolved to include structural plate corrugated steel pipe (SPCSP) whose deeper corrugations enable crossing and tunnel solutions for spans up to 120 ft (40 m) (*1*). SPCSP, more commonly known as buried structures, are a composite soil-steel system and are commonly used in the transportation infrastructure industry. Buried structures are economical, aesthetically pleasing solutions that permit rapid construction and have minimal future maintenance when designed considering their environmental conditions.

Design service lives are typically between 50 and 100 years. All materials are subject to degradation but their rate of material degradation is dependent upon the environmental conditions the material is subjected to. When designing a structure, it is imperative to understand the environmental conditions during its entire design life in order to evaluate the suitability of a material. To help meet design life requirements, steel is traditionally protected with hot-dip galvanized (HDG) and polymer laminate coatings. In general, HDG coatings perform well in non-abrasive, hard water and non-aggressive soils whereas polymer coatings perform well in these conditions plus salt-laden, soft water and moderately abrasive environments. A study conducted in the early 2000s by Hensley and Perry (*2*) confirms this by conducting inspections of several culverts in a variety of environments. The investigation recorded the environmental conditions and observed field performance in a comparative study.

To date, polymer laminate systems have been limited to CSP, which has maximum spans of approximately 12 ft (3.6 m) (*3*), making it challenging to design larger span buried structures in adverse environments. A new thermoplastic polymer system comprised of a zinc rich primer and ethylene acrylic acid (EAA) topcoat has been developed for deeper corrugations profiles. With this new coating, performance of SPCSP has improved to a level where buried steel structures are now a viable solution in adverse environments requiring design lives between 50 and 100 years. Sharing similar topcoat chemistry to polymer laminate but utilizing a thicker coating with an improved application process that results in enhanced adhesion, thermoplastic polymer systems can meet or exceed polymer laminate's current estimated material service life (*4*). In 2005 the first thermoplastic polymer system was applied to a structure erected near Kingston, Ontario. Since then, the polymer system is gaining widespread acceptance in Canada with existing structures sprinkled across the country.

## 1.1 Objective

The intent of this paper is to compare the new thermoplastic polymer system to polymer laminated, galvanized and aluminized type 2 coatings for CSP. Laboratory testing and field performance has been conducted to provide evidence that corrugated metal plate structures are a viable solution for applications with spans up to 120 ft (40 m), such as crossings or tunnels, in both non-aggressive and adverse environments.

# 2.0 MARKET HISTORY

The following subsections discuss CSP, SPCSP and common Canadian environmental conditions. Alternative coating solutions offering further corrosion protection than standard HDG will also be covered.

## 2.1 Steel Infrastructure

There are two forms of steel infrastructure discussed in this paper: corrugated steel pipe (CSP) and structural plate (SPCSP). Both are depicted in Figure 1. The following subsections provide more details on the differences and similarities of these two classifications of steel pipe.

**FIGURE 1 (a) Corrugated steel pipe. (b) Structural plate corrugated steel pipe (*5*).**

### *2.1.1 Corrugated Steel Pipe (CSP)*

CSP is manufactured through corrugating coated, stock, flat-rolled steel. Flat-rolled steel is available in three protective coatings: galvanized, aluminized type 2 and polymer laminated. Lengths of pipe are commonly developed through the use of helical lock-seams or rivets. In Canada, CSP has a maximum corrugation depth of 25 mm (1 in.), which limits its maximum span to approximately 12 ft (3.6 m). CSP is typically available in round and wider span, lower-rise pipe-arch shapes.

### *2.1.2 Structural Plate Corrugated Steel Pipe (SPCSP)*

Structural plate corrugated steel pipe (SPCSP) was developed to enable greater spans. Today, SPCSP's corrugation depth ranges from 50 mm (2 in.) to 237 mm (9.5 in.), enabling spans to upwards of 120 ft (40 m). SPCSP is formed from stock steel plates that are corrugated and then curved. Plates are traditionally bolted together on-site to form the required shape. Due to the structure being created from a series of individual plates, various shapes are available such as round structures, pipe arches, open-bottom arches and large-span, low-rise box shapes. The increased strength and versatility of SPCSP has extended market suitability to under/overpasses, stream enclosures, tunnels, bridges, mine site infrastructure and animal crossings (*6*).

## 2.2 Environmental Conditions

There are three primary environmental conditions to consider when determining what materials will be durable for a buried structure application: soil, water, and anthropogenic impacts. North America contains diverse environmental conditions dependent on season and location from the desert-like condition of the Nevada/Arizona region to nearly inhabitable regions of the severely northern territories, to the high humidity areas of the Atlantic Ocean coastline. HDG steel is suitable for a portion of these soils and waters but when soil/water electrochemical or abrasion properties exceed HDG's effective range (*6*) alternative coatings or materials are required.

When the SPCSP is in direct contact with water, there may be abrasion between the material carried in the water and the SPCSP. SPCSP is a solution that works well in low and moderately abrasive conditions. When high abrasion conditions are encountered, direct contact between the water and SPCSP should be eliminated through the use of wider span bottomless structures or concrete protective barriers.

While natural environments provide their own complications, anthropogenic loading of deicing salts is a significant contributor to the early deterioration of structural steel (*7*). Deicing salts are applied to road surfaces as a method to reduce ice formation in winter months. However, these added deicing products accumulate in road runoff, snow banks and road shoulders eventually making their way to waterways and/or percolating through the soil of a supporting soil-steel structure. In regions of heavy deicing salt usage, accumulation of deicing products has the potential to bring a soil's or water's chloride content to concentrations greater than originally accounted for (*7*). HDG structures are susceptible to higher chloride concentrations and as such, consideration of alternative coatings or barrier systems is needed in regions of high deicing salts usage.

### 2.3 Historical Approach

Hot-dip galvanized steel, the standard option when protecting a structure against degradation in mildly corrosion environments, is applied by dipping the steel substrate into a molten bath containing a minimum of 98 wt% zinc (*8*). Prior to dipping, the steel is first cleaned removing any oxides, grease, oil, dirt and scale. The zinc forms alloys with the iron in the steel creating a protective coating that is well adhered to the substrate. The coating can work as both a method of barrier and galvanic protection. Barrier protection, a physical barrier between the underlying steel substrate and the affecting environment, is the method of protection initially engaged. In the case of steel becoming exposed, galvanic protection, the sacrificial corrosion of the zinc coating delaying corrosion of the structural steel substrate until the first is completely depleted, presides.

HDG has demonstrated variability in performance with a direct relationship to service conditions. As industry learned from its successes and failures, alternative coatings were developed to enable buried steel structures in environments where HDG did not meet the service requirements. Alternative coating solutions that have been used in the past or are currently in use are:

- Double Zinc
- Epoxy
- Field Applied Polymer
- Asphalt
- Asbestos Bonded Asphalt

While there were several coating options established in the 1970s, polymer laminated was first developed in 1974 in response to establishing a replacement to asbestos bonded asphalt (*9*). It soon dominated the market and became the primary coating system in North America for environments not conducive to HDG as it has performed well in many adverse conditions. However, polymer laminate is not available in SPCSP due to stresses induced by the manufacturing process. Although a range of coatings have been developed providing good performance for a broad array of environmental conditions, traditional coatings for SPCSP have been limited to HDG.

## 3.0 POLYMER LAMINATED CSP

The following section overviews polymer laminated CSP and its history in North America.

### 3.1 Development

Polymer laminated protective coating is an ethylene acrylic acid (EAA) topcoat that is thermally laminated overtop the galvanized layer to both sides of CSP, adhering by bonding both chemically and physically. The nominal thickness of the coating is 250 μm and chemical composition is 87.74 wt% carbon and 12.26 wt% oxygen (*10*). Due to the application process, polymer laminated structures were limited to shallow corrugations and thin gauges with a maximum diameter of 3600 mm. Coating CSP with polymer laminate has enabled CSP to be used in more aggressive environmental conditions and increased the maximum flow velocity through a structure to 4.5 m/s (*3*).

Quality control in the application process is of great importance for proper adhesion. Oils and residues must be removed prior to the polymer being laminated on the HDG steel to avoid water infiltration and delamination. Polymer laminate is not utilized in tidal environments due to the widely fluctuating temperature changes over very short time periods; the rapid, extreme thermal cycling is not a conducive environment for polymer laminated steel (*8*). The oldest polymer laminated structures are 38 years old, installed in Wisconsin, 1974 (*9*). In Canada, installations did not begin until later in the 1970s in both New Brunswick and Ontario.

Since its initial release into the public domain, polymer laminated CSP has undergone significant testing with relative performance comparisons to galvanized, aluminized type 2 and asphalt coated steel. Additional knowledge has been gained through the performance of field installations, some of which have been in place for nearly 40 years. This knowledge has led to the development of design service life guidelines which outline the design life for polymer coatings in various soil and water conditions.

### 3.2 Product Approval

Polymer laminated CSP is commonly used throughout North America. It initiated with usage in the United States, followed quickly by Canadian installations. While there were polymer laminated structures prior to, Alberta was the first Canadian province to officially approve polymer laminated CSP in 2002. In response to this approval, polymer laminated CSP was used in high alkali regions and expressways with high frequency deicing salts applications. Ontario was the second province to approve of polymer laminated CSP. In 2005, polymer laminate was used on several highway projects relining existing culverts.

## 4.0 THERMOPLASTIC POLYMER COATED STRUCTURAL PLATE

The following section discusses thermoplastic polymer coated structural plate; comparative testing and relative performance of the coating system to polymer laminated and HDG steel substrates.

### 4.1 Development

The thermoplastic polymer system is comprised of the steel substrate, a zinc rich primer containing a minimum of 60 wt% zinc and an EAA copolymer topcoat containing a minimum of 85 wt% EAA (*11*). Uncoated steel plates are first roughened, cleaned with an eight-stage pretreatment wash and then coated. Rather than being laminated, the copolymer is sprayed in powder form, attracted to the metallic plates by electrostatics. The powder is cured in a temperature-controlled oven prior to traveling through a cooling tunnel (Figure 2). The minimum thickness of the coating system is 250 μm per side of coated plate. However, the typical thickness of the system is far greater with the average being 400 μm per side of coated plate (*12*).

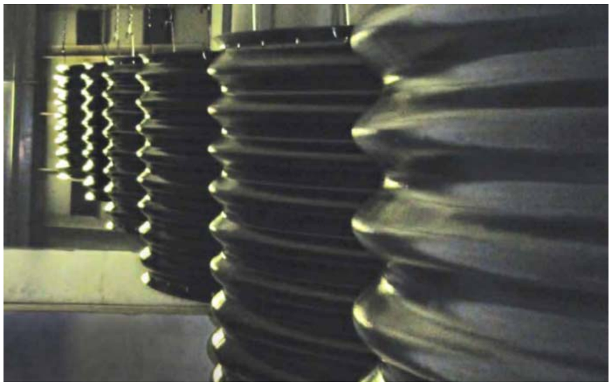

**FIGURE 2 Thermoplastic polymer coated structural steel plate (*12*).**

Due to the application process being powder spray and thermal activation, the polymer coated system is available on all corrugated steel plate as well as specialty accompanying items, such as steel footings and base channels. The application process also allows for plate edges and bolt holes to be coated and protected from edge delamination in adverse environments.

Research on product suitability and appropriate service conditions began in 2005 for thermoplastic polymer coated plate. The research included a series of comparative testing conducted at third party facilities. The testing evaluated thermoplastic polymer coatings to industry standards, HDG steel, aluminized type 2 and polymer laminate.

## 4.2 Comparative Testing

The following tables outline the comparative test results (*10*) completed on galvanized, aluminized type 2, polymer laminated and thermoplastic polymer coated steel. All testing was completed according to the stated standard. The tests have been divided into three categories according to resistance properties: chemical (Table 1), mechanical (Table 2) and environmental (Table 3).

Chemical resistance is important for soil-steel structures for applications in industrial and mining applications. Structures may be exposed to harsh environments with chemicals not found in typical transportation applications.

**TABLE 1 Chemical Properties (*10*)**

| Property | Testing Standard | Standard Title | Surface Preparation/Notes | Results | | | |
|---|---|---|---|---|---|---|---|
| | | | | Galvanized | Aluminized Type 2 | Polymer Laminate | Thermoplastic Polymer |
| **Imperviousness** | ASTM D543 (*13*) | Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents | Sulfuric acid (50%); sodium hydroxide (50%); sodium chloride (saturated) | N/A | N/A | 48 hrs; demonstrated no changes | 2160 hrs; demonstrated no changes |
| **Chemical Resistance** | ASTM D1308 (*14*) | Standard Test Method for Effect of Household Chemical on Clear and Pigmented Organic Finishes | Ambient temperature; 24 hrs exposure; chloroform, methylene chloride, tetrahydrofuran | N/A | N/A | No changes during or following exposure | No changes during or following exposure |
| **Resistance to Acids & Bases** | N/A | N/A | Hydrochloric acid (35%), nitric acid (5%), aluminum hydroxide & sodium hydroxide (50%) | N/A | N/A | All solutions at 10% for 1400 hrs; no changes | 2160 hrs; demonstrated no changes |
| **Resistance to Microbial Attack** | ASTM G22 (*15*) | Standard Practice for Determining Resistance of Plastics to Bacteria | 21 day incubation period | N/A | N/A | Demonstrated no visible effects | Demonstrated no visible effects |

As soil-steel structures are constructed in the field with nuts and bolts followed by backfilling in addition to often having flowing watercourse running through, abrasion and impact resistance are of high importance. The absence of holidays and adequate adhesion also play a significant role in the success of a coating as deficiencies in these areas allow for delamination and increased localized corrosion. For example, the thermoplastic polymer system was originally applied over hot-dip galvanized steel. However, due to poor adhesion, torquing the bolts caused damage to the coating and delamination in the vicinity of the bolt holes, posing a potential risk for localized corrosion in that region. Since the system was modified and applied over black steel such issues have been corrected.

**TABLE 2 Mechanical Properties (*10*)**

| **Property** | **Testing Standard** | **Standard Title** | **Surface Preparation/Notes** | **Results** | | | |
|---|---|---|---|---|---|---|---|
| | | | | **Galvanized** | **Aluminized Type 2** | **Polymer Laminate** | **Thermoplastic Polymer** |
| **Abrasion Resistance** | N/A | Modified MTQ Testing Procedures | 1 cycle: water jet & Ottawa silica sand C-109 (REF) at 10 MPa & 570 g/min for 43:20 mins; testing duration 4 cycles | Lost 48.5 µm of original 58 µm zinc | Removed after 2 cycles; no aluminum remaining of original 33 µm | Lost 15 µm of original 309 µm polymer laminate | Lost 2 µm of original 400 µm thermoplastic polymer |
| **Adhesion** | ASTM D3359 (*16*) & ASTM D4541 (*17*) | Standard Test Methods for Measuring Adhesion by Tape Test & Standard Test Method for Pull Off Strength of Coatings Using Portable Adhesion Testers | Scribed with "X" and Elcometer 99 Tape Only thermoplastic polymer for second test method | N/A | N/A | Rating 5A | Rating 5A; Glue was failure mechanism |
| **Impact Resistance** | ASTM D2794 (*18*) | Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact) | Gardner Impact Tester, 0.625 in. Indenter & 4 lb weight; ambient temperature & -40°C | N/A | N/A | 160 in-lb at ambient temperature & 140 in-lb at -40°C | 160 in-lb at ambient temperature & 140 in-lb at -40°C |
| **Holiday** | ASTM G62 (*19*) | Standard Test Methods for Holiday Detection in Pipeline Coatings | Tested according to Method A | N/A | N/A | No holidays detected | No holidays detected |

As the purpose of coating a SPCSP structure is for increased durability in a variety of environments, corrosion resistance is of utmost importance. The primary properties tested for included resistance to deicing salts, water immersion, temperature fluctuations and other environmental factors.

**TABLE 3 Environmental Properties (*10*)**

| Property | Testing Standard | Standard Title | Surface Preparation/Notes | Results | | | |
|---|---|---|---|---|---|---|---|
| | | | | **Galvanized** | **Aluminized Type 2** | **Polymer Laminate** | **Thermoplastic Polymer** |
| **Resistance to Salt Spray** | ASTM B117 (*20*) | Standard Practice for Operation Salt Spray (Fog) Apparatus | samples scribed & unscribed; evaluated every 500 hrs up to 3500 hrs | Removed at 3000 hrs due to excessive corrosion; only 7 - 15 µm zinc remaining | Removed at 3000 hrs due to excessive corrosion; entire thickness of aluminum disintegrated | Demonstrated poor adhesion around scribe & edges; Delamination primary failure mechanism | Very little corrosion of underlying steel; very little delamination |
| **Cyclic Corrosion Resistance** | SAE J2334 (*21*) | Cosmetic Corrosion Lab Test | Test duration to failure of 5 mm; vertical scribe; 1 cycle: 6 hrs exposure to water fog/condensing humidity, 15 mins salt water immersion, 17.75 hrs air drying; samples evaluated every 20 cycles up to 60 cycles | Removed following 20 cycles due to excessive corrosion | Removed following 40 cycles due to excessive corrosion | After 60 cycles corrosion on face with rust rating between 9S & 10 (*22*) | Following 60 cycles earned rust rating 10 with only 1 blister on scribe (*22*) |
| **Weatherability** | ASTM A742 (*23*) & ASTM G154 (*24*) | Standard Specification for Steel Sheet, Metallic Coated and Polymer Precoated for Corrugated Steel Pipe & Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure on Nonmetallic Materials | UVA 340 bulbs with irradiance 0.89; condensation cycle 4 hrs at 50°C & UV cycle 8 hrs at 60°C; evaluated every 504 hrs up to 3000 hrs | N/A | N/A | No evidence of cracking, blistering, discolouration, etc.<br>ΔE UV stability rating 0.98 - 1.20 (*25*) | No evidence of cracking, blistering, discolouration, etc.<br>ΔE UV stability rating 0.68 - 0.84 (*25*) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Freeze-Thaw** | ASTM A742 (*23*) | Standard Specification for Steel Sheet, Metallic Coated and Polymer Precoated for Corrugated Steel Pipe | 1 cycle: 8 hrs at -18°C followed by 16 hrs of immersion in water at room temperature; test duration 100 cycles | N/A | N/A | No evidence of spalling, disbonding or any other detrimental effects | No evidence of spalling, disbonding or any other detrimental effects |
| **Water Immersion** | ASTM D870 (*26*) | Standard Practice for Testing Water Resistance of Coatings Using Water Immersion | Immersed in deionized water for 240 hrs at 38°C | N/A | N/A | No evidence of blistering or any other appearance changes | No evidence of blistering or any other appearance changes |

Figure 3 demonstrates the final results of testing to investigate the resistance of salt spray exposure. The galvanized and aluminized type 2 samples were removed following 3000 hrs of exposure due to excessive corrosion while the polymer laminate and thermoplastic polymer were left in the exposure chamber for 3500 hrs.

**FIGURE 3 Galvanized steel and aluminized type 2 steel at 3000 hours. Polymer laminated steel and thermoplastic polymer coated steel at 3500 hours.**

## 4.3 Current Field Installations

The first installed structure was erected near Kingston, Ontario in 2005. The structure was an underpass for Ontario's Ministry of Transportation (MTO) and was coated only on the outside (soil side) of the structure. Since its inception, thermoplastic polymer coated buried structures have been supplied across the country. There are approximately 20 structures in Canada with locations in five provinces: New Brunswick, Quebec, Ontario, Saskatchewan and British Columbia. Applications range from mine site infrastructure to steep installations and inverts for relining existing concrete structures. All structures are performing as expected. Thermoplastic polymer coated plate is gaining acceptance in Canada, is common in Russia and just now entering the United States.

The following table, Table 4, outlines the Canadian structures coated, or partially coated with the newly developed thermoplastic polymer system. Due to proprietary reasons, only structures designed and manufactured by Atlantic Industries Limited are listed.

1 **TABLE 4 Canadian Installations Designed and Manufactured by AIL (*Dave Penny, Canadian Corrugated Steel Pipe Institute, unpublished data*)**

| Install Year | Prov | Location | Description | Visit Date | Comments |
|---|---|---|---|---|---|
| **2005** | ON | Hwy 401; East of 132 Kingston | Deep Corrugated CSP Arch; old railway reline coating North end exterior over galvanizing | 17-Aug-12 | Some rusting of bolts and galvanized obvert; coating in good condition |
| **2007** | ON | Lakeshore Rochester Line | SP Pipe-Arch; only invert coated | | |
| **2010** | ON | Talbot Trail | SP Pipe-Arch | 24-Aug-12 | Excellent; debris in inlet |
| **2010** | ON | Talbot Trail | SP Pipe-Arch | 24-Aug-12 | Excellent; some damage at bolts due to torque guns |
| **2010** | ON | Talbot Trail | SP Pipe-Arch | 24-Aug-12 | N/A |
| **2010** | QC | 188 Rang St George | SP Ellipse | 18-Aug-12 | Salt leaching through top; coloured by bolt rust |
| **2011** | BC | Port Hardy Dick Booth | 4 - 5 m diameter SPCSP | | High abrasion load; concrete invert; soft water application |
| **2011** | BC | Delta Slipline | Twin SP Pipe-Arch reline of same | | Submerged Fraser Delta water |
| **2011** | ON | Kingsville; Prince Albert St | | 24-Aug-12 | Excellent; water pH 8, chloride content 164 ppm & backfill high in sulphates |
| **2011** | QC | St Lawrence River; South of St Barthelemy | Deep Corrugated Arch | 11-Apr-12 | Excellent |
| -- | ON | Ralaigh Planes Drain | Deep Corrugated SP Arch | 24-Aug-12 | Excellent; flowing full |
| -- | ON | 13th Line; East of Bloomfield Rd | Deep Corrugated Box with galvanized ends | 24-Aug-12 | Excellent; slight buckle in sidewall may be manufacturing or construction defect |
| -- | QC | Lavaltrie Station | Twin SP | 11-Apr-12 | Excellent; fragmites |
| -- | ON | Near Chatham | TLP reline | | |

# 5.0 ESTIMATED MATERIAL SERVICE LIFE (EMSL)

A structure is designed with a pre-determined design service life (DSL), often dictated by the Customer/Owner. The life expectancy of a buried structure is determined by the Designer and termed estimated material service life (EMSL). In other words, the EMSL must exceed the DSL for the structure to satisfy all design requirements. In order for a designer to evaluate an EMSL he/she must have an understanding of the environmental conditions over the DSL and what environments can be achieved with specific materials and exposure conditions.

## 5.1 HDG Steel

The Canadian Highway Bridge Design Code (CHBDC) outlines various methods for determining coating requirements and metal loss calculations but these guidelines do not incorporate recent industry knowledge and have resulted in SPCSP being used in environments where it had inappropriate performance. In response, a SPCSP performance guideline recognizing HDG and thermoplastic polymer systems was developed to outline the EMSL for various environmental conditions (*6*). The EMSL approach calculates the estimated life of the coating and if applicable, subsequent metal loss due to degradation during the design life of the structure. Contrary to CSP, which has a history of successful performance using a design to first perforation approach, the SPCSP guideline utilizes a uniform corrosion approach and the addition of sacrificial thickness to the steel substrate (*4*).

A recently published technical bulletin produced by the Corrugated Steel Pipe Institute (CSPI) of Canada estimates the corrosion allowance using the EMSL approach for metal loss rates defined by both AASHTO and the United Kingdom Durability Guideline. The classifications of environmental parameters as presented in the technical bulletin are recreated in Table 5.

**TABLE 5 Environmental Parameters for Galvanized Steel (*6*)**

| Property | Limit | | |
|---|---|---|---|
| | AASHTO | UK Non-Aggressive | UK Aggressive[1] |
| **Resistivity** | > 3 000 Ω-cm | > 3 000 Ω-cm[2] | 2 000 - 8 000 Ω-cm |
| **pH** | 5 - 10 | 6 - 9 | 5 - 6 |
| **Chlorides** | < 100 ppm | < 50 ppm | 50 - 250 ppm |
| **Sulphates** | < 200 ppm | < 240 ppm | 240 - 600 ppm |
| **Organics** | < 1 wt% | < 1 wt% | N/A |
| **Hardness[1]** | > 80 ppm | > 80 ppm | > 80 ppm |

*Notes: 1. For water environments only. 2. For water environments: 2 000 – 8 000 Ω-cm. N/A indicates "not applicable".*

HDG structures are only an acceptable solution in the environments outlined above as they do not satisfy the AASHTO corrosion model. For each classification, AASHTO, UK Non-Aggressive and UK Aggressive, there is an associated metal loss rate. Metal loss rates are used to determine the corrosion allowance and sacrificial thickness required on buried steel structures. Corrosion allowances are calculated according to the exposure environment and design life. Therefore, a culvert invert, which is exposed to compacted soil on the outside and flowing water on the inside, requires the summation of an appropriate soil and water corrosion allowance for each side of the structure. For example, soil and water within the limitations for AASHTO environment classification has a corrosion allowance 774 µm per side of plate for a 75 year DSL; the steel thickness of a culvert application is required to be 1548 µm (774 µm per side) greater than meets the strength requirements to ensure the stability of the structure is not compromised at the end of the 75 year DSL. If even one parameter is just mildly outside the limitations in a given classification, the entire environment is disqualified from using the estimated metal loss rates for that particular classification (*6*).

## 5.2 Abrasion Considerations

A second consideration for determining the predicted service life of a material is the abrasion condition. When a culvert is designed and constructed for applications containing a flowing watercourse, the flow velocity and bedload characteristics are the determining factors when selecting an appropriate material if it is in contact with the water. Bedload and abrasion conditions are presented in Table 6.

**TABLE 6 Abrasion Levels (*6*)**

| Abrasion Level | Bedload Description | Anticipated Maximum Flow Velocity (m/s)[1] |
|---|---|---|
| **1** | **Non Abrasive**: very low velocities and no bedload (e.g. storm sewers, stormwater detention systems, arches, etc.) | N/A |
| **2** | **Low Abrasive**: minor bedloads of sand and gravel | 1.5 |
| **3** | **Moderately Abrasive**: moderate bedloads of sand and gravel | 4.5 |
| **4** | **Severely Abrasive**: heavy bedloads of sand, gravel and rock | > 4.5 |

*Notes: 1. Abrasion velocities should be evaluated on the basis of frequency and duration. A frequent storm, such as a two year event (Q2) or mean annual discharge (Q2.33), should be used to determine the velocity. N/A indicates "not applicable".*

Both galvanized and aluminized type 2 steel is limited to Abrasion Level 2, while polymer laminate and thermoplastic polymer coated steel are suitable for conditions up to and including Abrasion Level 3. When Abrasion Level 4 conditions exist, use of a concrete protective coating or wide span open bottom structure is recommended.

While polymer coatings do wear down when exposed to abrasive conditions, their resistance is significantly greater than that of metallic coatings (see Table 2 Abrasion Resistance). For Abrasion Levels 1 and 2, the service life expectancy is estimated to well exceed 80 years. For Abrasion Level 3, the estimated life expectancy of the coatings, both polymer laminate and the thermoplastic polymer coating system, is 70 years.(*6*) These life expectancies have been determined by the comparative abrasion testing conducted combined with field performance of both galvanized structures and structures coated with the thermoplastic polymer system. Following the depletion of the coating, the underlying steel would assume the metal loss rates previously stated, dependent on the environmental service conditions. It is important to note that this statement is also applicable for areas of coating damage to the substrate and any holidays. For this reason, quality assurance and material compliance is of utmost importance as well as following proper repair methods in any affected areas to ensure the coating integrity is not compromised.

## 5.3 Polymer Laminated and Thermoplastic Polymer Coated Steel

When a polymer coating is applied service life is primarily dependent on the resilience of the coating. As a result, no corrosion allowance or sacrificial metal loss is calculated as is required for HDG structures, allowing for thinner gauged buried steel structures.

Acceptable environmental conditions and related service lives of polymer laminated HDG steel have been previously determined by correlating laboratory testing with field service performance. As the chemistry of the thermoplastic polymer topcoat is similar to that of polymer laminated and all testing confirmed that the thermoplastic polymer coating met or exceeded the relative performance of polymer laminated, polymer laminate's environmental limits presented in Table 7 are applicable to thermoplastic polymer coatings.

**TABLE 7 Environmental Parameters and Design Service Life for Thermoplastic Polymer Coated Structural Steel Plate (*6*)**

| Property | DSL | | |
|---|---|---|---|
| | **50** | **75** | **100** |
| **Resistivity** | > 100 Ω-cm | > 750 Ω-cm | > 1 500 Ω-cm |
| **pH** | 3 - 12 | 4 - 9 | 5 - 9 |

## 6.0 FUTURE CONSIDERATIONS

Structural steel plate is connected using HDG fasteners. Traditionally, primary issues with poorly performing HDG structures were related to plate corrosion. With more durable plates available attention needs to be given to potential bolt performance issues in aggressive environments. Staining from galvanized bolts on thermoplastic polymer coated plates has provided indication of an opportunity for improvement. The three primary considerations when investigating additional protection for fasteners are:

- Compatibility with plate coating
- Structural and assembly considerations are not compromised
- Any damage caused by torquing, either on the plate or the fastener, will not be targeted for localized attack

To date, preliminary testing has been completed on HDG and duplex metallic coated bolts. Testing on non-scribed bolts was completed was according to ASTM B117 (*21*) *Standard Practice for Operating Salt Spray (Fog) Apparatus*. Comparatively, the duplex coated fasteners had almost three times the exposure capability of HDG bolts (Figure 4). Further evaluation of these and other fasteners is ongoing.

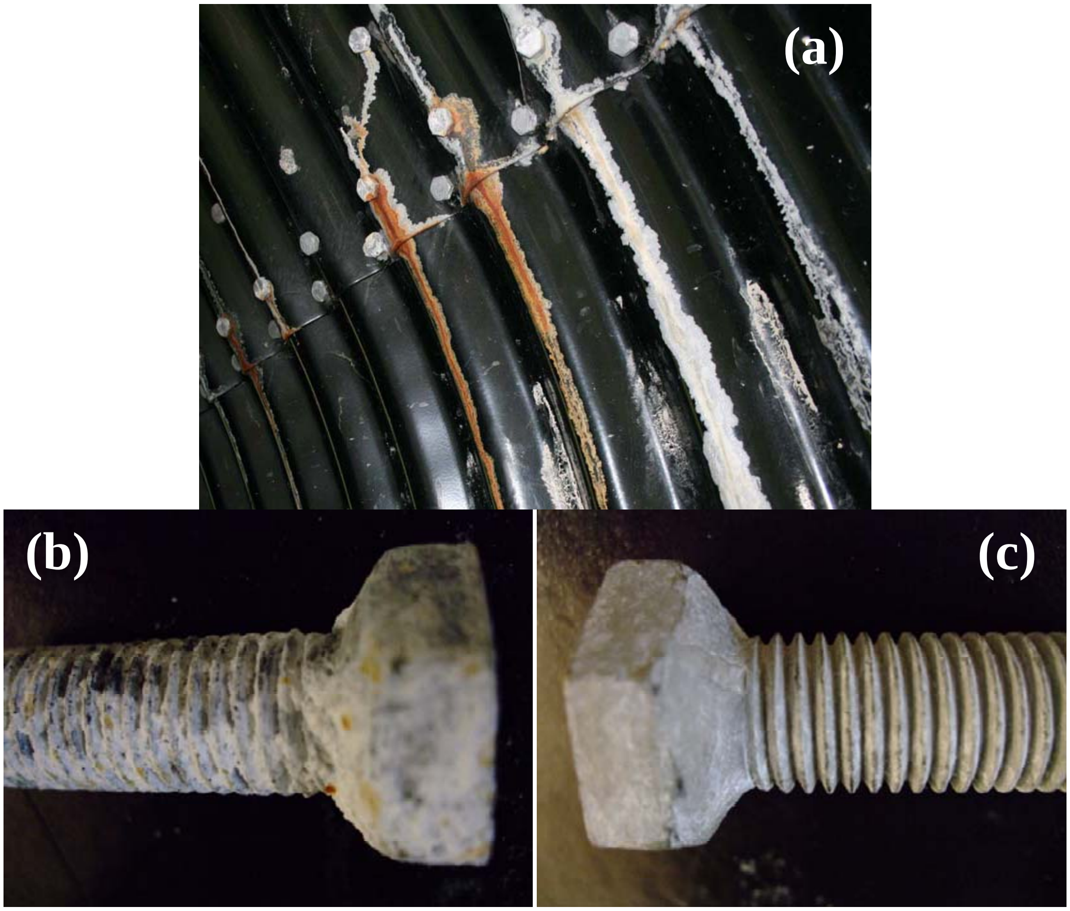

**FIGURE 4 (a) Example of staining in the obvert of a structure coated with the thermoplastic polymer system. (b) Galvanized bolt following removal from test chamber compared to (c) duplex coated bolt at three times the exposure time.**

A second consideration is the combined effect of corrosion and abrasion. Testing has been conducted to classify resistance to salt spray, cyclic corrosion and various other environmental factors as well as chemical reagents. Separate testing has also been conducted to determine appropriate abrasive levels and expected material loss due to mechanical wearing. However, the combined effects of mechanical and electrochemical degradation have yet to be investigated in a laboratory setting.

## 7.0 CONCLUSIONS

Corrugated steel pipe is installed in applications across North America and exposed to a variety of service conditions. Due to compromised performance of HDG structures in certain environments, an alternative solution was investigated in the early 1970s. Polymer laminated was the solution settled upon in North America as a result of excellent performance in a wide range of service conditions. However, due to the lamination process, this type of polymer coating is limited to shallow corrugation profiles and thin gauged substrates. In 2005 a newly developed thermoplastic polymer coating surfaced, sharing similar chemistry to the polymer laminated coating but with an application process allowing structural plate to be coated post corrugating and curving.

The thermoplastic polymer coating has since undergone a series of performance tests, going head to head with polymer laminated steel as well as galvanized and aluminized type 2 steel. In every aspect of testing the thermoplastic polymer coating system has at a minimum met, but in most cases exceeded, the performance of the three other competing technologies. Two tests of primary interest were corrosion resistance, as measured by resistance to salt spray exposure, and abrasion resistance. The polymer coatings outperformed the metallic coatings by exceeding salt spray exposure time by 5000 hrs. In addition, the thermoplastic polymer coating did not demonstrate the delamination and corrosion of the steel substrate that the polymer laminated samples did. When subjected to abrasion testing, the aluminized type 2 coating was fully depleted following two cycles. After completing the full four cycles, 84% of the original galvanized thickness was gone, 5% of the polymer laminate and only 0.5% of the thermoplastic polymer coating. As a result of the testing, thermoplastic polymer coated structural plate is anticipated to provide longevity to buried steel structures in a far broader range of environments than previously possible.

Since the first installation in Kingston, Ontario in 2005 thermoplastic polymer coated plate has grown in popularity and spread across the country with over 20 installations throughout five provinces. As the plate products continue to break into more aggressive environments, fastener durability needs to be addressed in the near future. Staining of hot-dip galvanized bolts on the surface of the black thermoplastic polymer coating has provided indication of opportunity for product development improvement. With continued research and growing confidence in field performance, thermoplastic polymer coated buried structures are expected to serve in applications and enter into markets not previously attainable by the corrugated steel industry.

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# REFERENCES

1. Williams, K.; MacKinnon, S. and Newhook, Dr. J. New and Innovative Developments for Design and Installation of Deep Corrugated Buried Flexible Steel Structures. *II European Conference "Buried Flexible Steel Structures"*. Rydzyna: April 23 – 24, 2012.
2. Hensley, S. and Perry, P. Long-Term Durability Study: Long-Span Structures. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1736, Transportation Research Board of the National Academies, Washington, DC., 2006, pp. 62 – 70.
3. Corrugated Steel Pipe Institute. *Performance Guideline for Corrugated Steel Pipe Culverts (300mm to 3,600mm Diameter)*. Technical Bulletin. Issue One: February 23, 2012. Cambridge, Ontario.
4. Ault, P. *White Paper: Performance Guideline for Buried Steel Structures*. Elzly Technology Corporation, 2012. Ocean City, New Jersey.
5. Atlantic Industries Limited. Products: *AIL's product innovation ensures your project's success*. http://www.ail.ca/en/home/products/default.aspx Accessed July 20, 2012
6. Corrugated Steel Pipe Institute. *Canadian Performance Guideline for Structural Plate Corrugated Steel Pipe and Deep Corrugated Structural Plate Structures*. Technical Bulletin. Issue Thirteen: October 24, 2011. Cambridge, Ontario.
7. Lax, S.; Peterson, E.W. *Characterization of chloride transport in the unsaturated zone near salted road*. Environ Geol. Vol. 58, 2009, pp. 1041-1049.
8. American Galvanizers Association. *The Hot-Dip Galvanizing Process*. https://www.galvanizeit.org/about-hot-dip-galvanizing/what-is-hot-dip-galvanizing/hdg-process. Accessed July 27, 2012.
9. Corrpro Companies Incorporated. *Field Performance Evaluation of Polymer Coated CSP Structures in Wisconsin*. Prepared for National Corrugated Steel Pipe Association, 2002.
10. Warner Custom Coating Testing. *Comparative Test Results: Coatings Used in the Corrugated Steel Pipe Industry*, 2012. Guelph, Ontario.
11. Canadian Standards Association. *G401 Corrugated steel pipe products*. Revisions up for review, 2012.
12. Berry, I. *Uniquely Engineered Coating for Storm Sewers and Culverts*. Warner Custom Coating. Presentation, 2012. Guelph, Ontario.
13. ASTM D543-03. *Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents*. American Society for Testing and Materials International. 2003.
14. ASTM D1308-02(2007). *Standard Test Method for Effect of Household Chemicals on Clear and Pigmented Organic Finishes*. American Society for Testing and Materials International. 2002.
15. ASTM G22-76(1996). *Standard Practice for Determining Resistance of Plastics to Bacteria*. American Society for Testing and Materials International. 1976.
16. ASTM D3359-09. *Standard Test Methods for Measuring Adhesion by Tape Test*. American Society for Testing and Materials International. 2009.
17. ASTM D4541-02. *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*. American Society for Testing and Materials International. 2002.
18. ASTM D2794-93(2010). *Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation*. American Society for Testing and Materials International. 1993.
19. ASTM G62-03. *Standard Test Methods for Holiday Detection in Pipeline Coatings*. American Society for Testing and Materials International. 2003.
20. ASTM B117-11. *Standard Practice for Operating Salt Spray (Fog) Apparatus*. American Society for Testing and Materials International. 2011.
21. SAE J2334. *Surface Vehicle Standard, J 2334 Cosmetic Corrosion Lab Test*. Society of Automotive Engineers. 2005.
22. ASTM D610-08. *Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces*. American Society for Testing and Materials International. 2008.

23. ASTM A742-03. *Standard Specification for Steel Sheet, Metallic Coated and Polymer Precoated for Corrugated Steel Pipe*. American Society for Testing and Materials International. 2003.

24. ASTM G154-06. *Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials*. American Society for Testing and Materials International. 2006

25. ASTM D714-02. *Standard Test Method for Evaluating Degree of Blistering of Paints*. American Society for Testing and Materials International. 2002.

26. ASTM D870-09. *Standard Practice for Testing Water Resistance of Coatings Using Water Immersion*. American Society for Testing and Materials International. 2009