Performance Guideline for Buried Aluminum Structural Plate Structures

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Introduction

Although aluminum structural plate has been in the marketplace for over 50 years, few best practice guidelines exist in the public domain and little detailed information exists in the Canadian Highway Bridge Design Code.

First developed in 1962, aluminum structural plate is made from aluminum alloy 5052-H141. Aluminum is unique in that it protects itself from aggressive environments with a self-healing oxide when exposed to atmosphere or any oxygen carrying environment. The oxide is dense, resists mars and scratches due to its hardness and adheres well to the underlying aluminum.

Objectives

- As users are often left wondering whether an aluminum buried structure is a suitable solution, address this by building on previous literature with laboratory testing and field inspections of existing structures; and
- Create a practical performance guideline ready for industry use to identify which environments aluminum structural plate is suitable for and outline best design and installation practices for various applications.

Literature Review

Environmental Parameters & Abrasion Limitations

Organization	pH	Resistivity of soil, backfill or effluent Ω-cm	Flow Velocity ft/s (m/s)	Bedload Characteristics & Special Notes
FHWA* & TxDOT*	4 - 9	≥ 500		≥ 25 Ω-cm when backfill is free-draining or saltwater applications
Aluminum Association	4 - 9	≥ 500		≥ Expect good performance in sea water (~ 35 Ω-cm) when surrounding soil is clean
Kaiser Aluminum Corp.*	4 - 9	≥ 1,500	≤ 10 (3.0)	Flows containing large bedload; sandy bedload allows for higher velocities
US Military Specification	4 - 9	—		Even in seawater applications
ODOT*	4.5 - 10	≥ 1,500		
MTO*	4.5 - 9	≥ 200	≤ 5 (1.5)	If buried with free draining backfill material, resistivity is permitted to be as low as 25 Ω-cm; Minor bedloads of sand and gravel
US Army Corps, Crane Materials Int. & Alcan Inc.	4 - 9	—		Recommended against use in non-draining clay-organic soils
FDOT*	5 - 9	≥ 1,000	≤ 8 (2.4)	Moderate bedload volumes of sand and gravels; 1.5 in. (3.8 cm) max
Caltrans*	5.5 - 8.5	≥ 1,500	≤ 5 (1.5)	Abrasive channel materials
Highway Design Manual*	5.5 - 8.5	≥ 1,500	≤ 8 (2.4)	Bedloads of sand, silts or clays regardless of volume

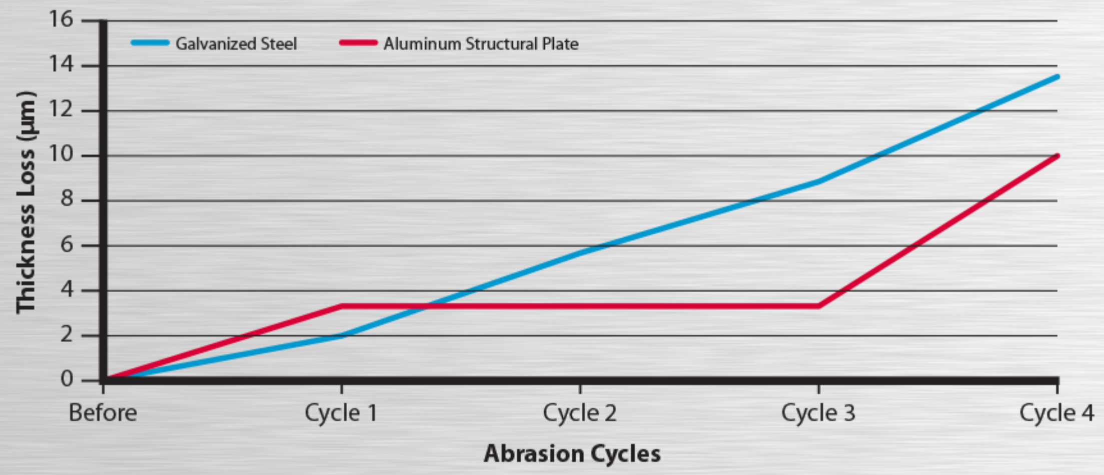
*Note: *Information pertains to aluminum CMP (AA3004-H32) not aluminum structural plate (AA5052-H141). AA5052 is a superior aluminum alloy with respect to hardness, impact and abrasion resistance. Maximum recommended flow velocities and bedload characteristics are based on no metal loss; flow velocity and/or bedload can be greater if abrasion counter measures are considered (i.e. sacrificial thickness added, abrasion plates, invert paving, etc.)*

Laboratory Testing

Testing was completed for abrasion resistance as well as resistance to salt spray.


Abrasion testing was completed following internal procedures defined by MTQ using Ottawa silica sand (a) and an controlled abrasion test apparatus (b).

Results of abrasion resistance testing.



Note: Samples were also weighed both prior to and following each abrasion cycle. Mass loss for all samples was less than 1 g.


Samples following 3,000 hrs of exposure to salt spray in accordance with ASTM B117: a) HDG steel and b) aluminum structural plate.

While test results cannot be exclusively relied upon to relate directly to expected field service, the test results substantiate the claims made by various organizations outlined in the literature review. In addition, testing was completed side by side hot-dip galvanized steel, which served as a qualitative benchmark.

Field Inspections

Field inspections were completed on aluminum structural plate structures across New Brunswick. Applications varied from stream crossings in residential neighbourhoods, to highway accesses with concrete baffles to facilitate fish passage, and to allow influxes of tidal waters under the TransCanada Highway.

The age of the structures ranged from 10 to 22 years old and all structures were given a condition rating of 8 or higher according to the condition rating criteria given in Item 62 – Culverts of the FHWA's Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges (1995); there were no indications of degradation caused by abrasion or corrosive environments on any of the structures. While some structures contained an aluminum invert, many of the structures inspected contain concrete fish baffles or are open bottom structures. Open bottom structures offer a great deal of security as energy is lost on the natural streambed rather than the invert of the crossing; there is negligible abrasion on the aluminum structural plate itself.

Photos taken of various successful aluminum structures can be seen below.

Bathurst, NB - 2003

Tantramar Marsh, NB - 1992

Torbay, NL - 2010

Performance Guideline

Environmental Parameters

Aluminum structural plate performs just as well in soft water as it does in hard. Additionally, aluminum structural plate is not affected by chlorides and sulphates individually, other than in severe cases where their combined effect on soil / water resistivity brings the measured value less than 500 Ω-cm.

Laboratory testing and field experiments support and complement the conducted literature review stating aluminum is suitable for use in environments up to and including Abrasion Level 2 as defined by the Corrugated Steel Pipe Institute of Canada (CSPI).

pH	Resistivity (Ω-cm)	Organic Content (%)	Total Hardness ($CaCO_3$ ppm)	Chlorides (Cl^- ppm)	Sulphates (SO_4^{2-} ppm)	Flow Velocity (m/s)	Bedload Characteristics
4.5 - 9	≥ 500	1	NL	NL	NL	≤1.5	Low Abrasive: minor bed loads of sand and gravel

Note: Maximum recommended flow velocities and bedload characteristics are based on no metal loss; flow velocity and / or bedload can be greater if abrasion counter measures are considered (i.e. sacrificial thickness added, abrasion plates, invert paving, etc.)

Performance Guideline

Service Life

Service life of aluminum structural plate is dependent on the environment – primarily pH, resistivity and abrasion. FDOT developed an equation for determining the service life of an aluminum structure based on a first perforation corrosion model:

$$SL = \frac{T_p}{R_{pH} + R_r}$$

Where:
SL = Service Life; time to first perforation (yrs)
T_p = Thickness of Plate (in.)
R_{pH} = Corrosion Rate for pH (in./yr)
R_r = Corrosion Rate for Resistivity (in./yr)

The above equation implies that provided localized corrosion does not penetrate the entire thickness of an aluminum structural plate, the strength and structural integrity of a structure is unaffected. Tables for RpH and Rr values can be found in the publically available State of Florida Department of Transportation's Drainage Culvert Service Life Performance and Estimation (1993).

Fasteners

- Hot-dip galvanized fasteners are more desirable than aluminum in less aggressive environments (i.e. hard water) as they offer superior strength and installation benefits
- Aluminum fasteners, manufactured from an appropriately resistant alloy, are recommended in high chloride (> 250 ppm), soft water and brackish water applications
- Austenitic stainless steel is an alternative to aluminum in aggressive applications requiring high strength fasteners

Contact with Concrete

- Aluminum can be paired with concrete (i.e. collars or fish baffles), provided none of the following criteria are met or have the potential to be satisfied during the service life of the structure:
  - Steel or rebar is embedded in the concrete, electrically connected or not;
  - Deicing salts are or will be applied in the vicinity;
  - Calcium chloride is contained in the concrete mix; or
  - Structure is in or near salt water.
- If any of the above criteria have been satisfied, aluminum must be isolated (i.e. with a bond breaker) from contact with the concrete by one of the following two means:
  - Coat rebar with paint of bitumastic material to isolate the dissimilar metals preventing galvanic corrosion and prolonging the service life of the components; or
  - Separate aluminum from concrete to prevent chemical corrosion using nylon, neoprene or bitumastic material.

Typical aluminum structural plate bottomless arch on concrete footings.