Use of ASTM A1035-CS Uncoated Corrosion Resistant Reinforcing Steel In The Edmonton Valley Line LRT Project

Hans Geber
Product Technical Manager
CMC
Madison, VA, US
Hans.geber@cmc.com

Ben Sadawi, MS, MBA, P.Eng, PE, LEED AP
Product Technical Manager
CMC
San Diego, CA, US
ben.sadawi@cmc.com

Paper prepared for the session ST - Transportation Structures
2024 Transportation Association of Canada (TAC) Conference & Exhibition
Vancouver, British Columbia

Acknowledgement

Kent Wong, Marc Ta-ala, Kawsar Ahmed, City of Edmonton Infrastructure
Omar Kandar, Marigold Infrastructure Partners
Nisreen Salameh and Hassan Yassin, Parsons Canada
Chad Ekdahl, A&H Steel, Inc.

20-Apr-2024

Use of ASTM A1035-CS Uncoated Corrosion Resistant Reinforcing Steel In The Edmonton Valley Line LRT Project

Abstract

Valley Line Light Rail Transportation Project Description

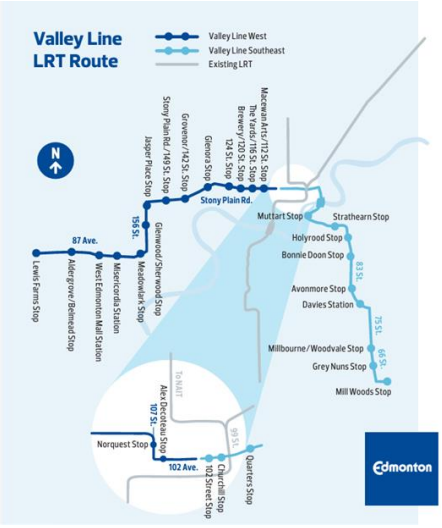
The Valley Line Light Rail Transportation (LRT) is a 27 km low-floor, urban line that will operate between Mill Woods in the southeastern neighborhood of the City of Edmonton and Lewis Farms in west Edmonton, Alberta. The project is being built in 2 stages: Valley Line Southeast and Valley Line West. Figure 1 shows the Valley Line LRT route and stations.

Valley Line LRT is owned by The City of Edmonton Infrastructure and AECOM is the owner's engineer. Marigold Infrastructure Partners is a design-build joint venture agreement between Colas France and Parsons Canada. Parsons Canada is the Engineer-of-Record (EOR).

Valley Line Southeast (Downtown to Mill Woods)
Construction of stage one of the Valley Line Light Rail Transit (LRT) is connecting Mill Woods to downtown Edmonton with about 13.1 km of light rail transit. This stage includes 11 stops, an elevated station incorporating a transit center and Park & Ride, and a transfer point to the existing LRT routes at Churchill Square.

Valley Line West (Downtown to Lewis Farms)
The $2.6 billion Valley Line West project is a 14 km light-rail extension from 102 Street downtown to Lewis Farms. It is the second stage of the Valley Line and includes 14 stops and 2 stations: an urban-style, 27 km LRT line that will operate between Mill Woods in southeast Edmonton and Lewis Farms in west Edmonton.

Figure 1: Valley Line LRT route and stations



Source: www.edmonton.ca

Use of ASTM A1035-CS Uncoated Corrosion Resistant Reinforcing Steel In The Edmonton Valley Line LRT Project

Valley Line West LRT Design and Construction

Valley Line West LRT Construction Documents are developed based on the City of Edmonton's Infrastructure Specifications, which are consistent with the practices of Alberta Transportation (AT). Carbon steel reinforcing bar CSA G30.18:21/ASTM A615 is used to reinforce concrete structures' elements, and Stainless steel reinforcing bar ASTM A955 Grade 2304 Grade 420 is specified in the exposed elements, such as brine splash zones.
During and post-pandemic, specialty materials procurement became a serious challenge for constructors due to shortages and increased mineral costs.

In 2021, the availability of ASTM A955 corrosion-resistant steel was limited, with extended lead times and significant price increases, negatively impacting construction budgets and timelines. As a result, Marigold Infrastructure Partners with its EOR, PARSONS, decided to substitute ASTM A955 with ASTM A1035-CS, a Low Carbon/Chromium reinforcing steel with a minimum yield strength of 690 MPa, based on the 0.2% offset method. The choice for A1035-CS was based on research reports showing that only A1035 CS and Stainless Steel S2304 met the requirements of 100 years of service life before major repairs would be needed, as well as wide availability and low price volatility of A1035-CS.

In May 2022, Marigold submitted a Design Development Change Record (DDCR) to the City of Edmonton, the project owner, requesting the acceptance of using ASTM A1035-CS in lieu of ASTM A955 for Splash Zone Surfaces for the following technical and commercial benefits:

1. ASTM A1035-CS provides a higher tensile-to-yield ratio for better structural concrete elements stabilization.
2. Its superior rebar/concrete bond minimizes concrete cracks width and depth.
3. No risk of dissimilar metal issues with CSA G30.18:21/ASTM A615 and/or ASTM A955 in current zones. It can be spliced with either metal.
4. It is readily available in North America.
5. ASTM A1035-CS pricing has been stable over the years and consistent with the steel market. It costs 20% to 40% less than ASTM A955.

Introduction

ASTM A1035-CS corrosion-resistant, high-strength reinforcing steel rebar is designed for the infrastructure, construction, and precast concrete industries. It offers more strength and corrosion resistance than CSA G30.18:21/ASTM A615 reinforcing steel. These qualities improve constructability and sustainability.

Even though ASTM A1035-CS does not have the level of corrosion resistance as ASTM A955 S2304, both A1035 CS and Stainless Steel S2304 meet the requirements for a 100-year service life before major repairs would be needed, but designers can meet 100-year service life requirements called for on many infrastructure projects by modifying the concrete design and/or the use of additional concrete cover.

What is ASTM A1035-CS?

ASTM A1035-CS is uncoated corrosion-resistant and high-strength Chromium Austenitic/Martensitic Steel classified as "Performance Steel Rebar" for concrete applications that require corrosion resistance for a 100-year to first repair.

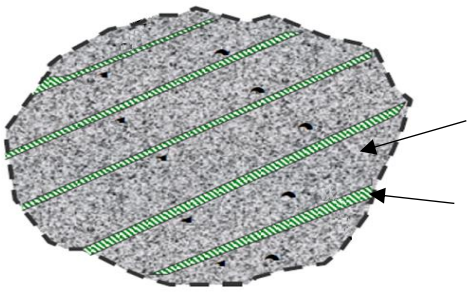
Meeting Codes and Specifications of Buildings, Bridges and Infrastructure for design with a minimum 100ksi strength:

- Low carbon/chromium reinforcing steel shall conform to ASTM A1035. The alloy type shall be CS with a minimum yield strength of 690 MPa, based on the 0.2% offset method.
- ASTM A1035 commercially called ChromX®. It's available in two chromium levels. Typical grade names are ChromX9100 (CS) and ChromX4100 (CM).
- Scientifically engineered, uncoated steel achieves its superior corrosion resistance properties because of the steel microstructure formed during production.
- Manufactured from recycled scrap metal by two independent mills in North America: CMC in SC and Cascade in OR.
- ASTM A1035-CS has been independently tested and proven to meet 100-year service life requirements.
- It offers the design engineers the ability to utilize its high strength to reduce the reinforcement quantities by up to 35%, resulting in a reduction of concrete and a reduction of overall cost.
- ASTM A1035-CS and CM reduction in quantities offer the ability to reduce carbon footprint by reducing steel quantities, concrete volume, and concrete cover. It is available as "Rebar Zero" for carbon-neutral applications.

The corrosion resistance of ASTM A1035-CS reinforcing steel is derived from the unique microstructure of the steel, which is fundamentally different from that of standard carbon steel. Standard carbon steels consist of ferrites and carbides. When exposed to a chloride solution, the ferrites (anodes) and carbides (cathodes) establish a chemical reaction called a micro-galvanic cell that causes the breakdown of the carbides, resulting in the expansion of the steel, i.e., the corrosion of the steel.

In contrast to standard CSA G30.18:21/ASTM A615 reinforcing steel, the ASTM A1035-CS microstructure consists of dislocated laths of Martensite separated by thin layers of retained Austenite and is relatively free of carbides. This martensitic, austenitic microstructure and the minimizing of carbides in ASTM A1035-CS inhibit the formation of micro-galvanic cells. Figure 2 represents a diagram of ASTM A1035-CS microstructures.

Figure 2: ASTM A1035-CS microstructures diagram.



Source: www.cmc.com

Why ASTM A1035-CS Reinforcing Steel?

Recent independent research studies on concrete specimens reinforced with ASTM A1035-CS and other corrosion-resistant reinforcing steel subjected to typical loadings and environmental conditioning established the corrosion-resistant superiority of the ASTM A1035-CS reinforcing steel reinforced systems over ASTM A955 due to the service load bond characteristics, resulting crack behavior, deflection, and flexural capacities.

The microstructure of ASTM A1035-CS reinforcing steel makes it unlikely to result in any galvanic corrosion risk when coupled with either Carbon Reinforcing Steel CSA G30.18:21/ASTM A615, Stainless reinforcing steel ASTM A955 2205, or 2304.

Description and Reason for Change

In May 2022, the Valley Line West LRT Design-Build JV Marigold submitted DDCR No.0183 to the City of Edmonton requesting the acceptance of using ASTM A1035-CS instead of ASTM A955 for Splash Zone Surface reinforcement. This method provides an efficient and compatible use of materials in the structure, and most significantly, it eliminates the potential for dissimilar material corrosion concerns encountered on an electrified system.

The City of Edmonton Infrastructure Project Agreement (PA) for the Valley Line West LRT states concrete reinforcing in Splash Zone Surfaces for Building Structures and Transportation Structures shall

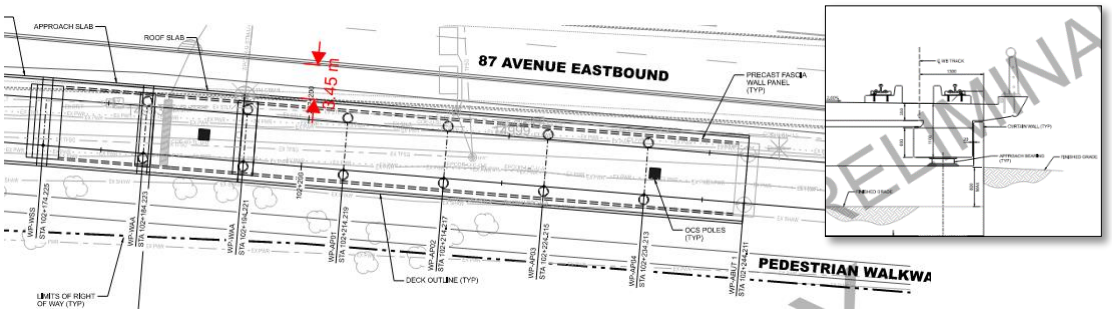
be ASTM A955 in accordance with the Project Concrete Reinforcement requirements. The DDCR requested ASTM A1035-CS may be used in lieu of ASTM A955, provided it is demonstrated the reinforcement achieves the Design Service Life requirements of the project agreement. The Design Service Life calculations for locations using ASTM A1035-CS reinforcement in lieu of ASTM A955 presented justifiable results to achieve a 100-year service life by modifying the concrete design or the use of additional concrete cover.

Proposed LRT Sections for Utilizing ASTM A1035-CS

DDCR proposed ASTM A1035-CS for the following Valley Line West LRT sections, but not limited to:

1. Elevated Guideway Approaches: Avoids mixing of reinforcing and CSA G30.18:21/ASTM A615/ ASTM A955 interfaces in proximity to stray current collector mat. Figure 3 illustrates the proposed locations in Elevated Guideway Approaches where ASTM A1035-CS can be utilized to provide corrosion protection and eliminate the risk of metal dissimilarity.

   Figure 3: Proposed LRT locations along 87 Avenue Eastbound where ASTM A1035-CS can be used in Elevated Guideway Approaches



Source: Marigold Infrastructure Partners

2. Low-Speed Access Road Turn: Avoids mixing of reinforcing and CSA G30.18:21/ASTM A615/ ASTM A955 interfaces in proximity to stray current collector mat. Figure 1

Service Life Design

In compliance with fib 34 (fib 2006) and AASHTO Guide Specification for Service Life Design of Highway Bridges (AASHTO 2020-1), Marigold JV demonstrated that ASTM A1035-CS meets the 100-year service life with increased cover. The service life design considered the following criteria, but not limited to:

1. Sulfate Attack (external)
2. Freeze-Thaw (above frost line only)
3. Chloride Content (initial)
4. Scaling (Splash Zone Surfaces only)

5. Alkali Carbonate Reactivity, Alkali-Silica Reactivity, and Other Aggregate Limits
6. Early-Age Thermal Cracking (also thermal stress cracking)
7. Preservice cracking (inclusive of shrinkage)
8. Abrasion

Performance Supporting Studies and Modelling Analysis

Meeting the required corrosion properties (Chloride Threshold and Corrosion Rate) to be used in computer models to achieve 100-year service life to 1st Repair:

- The University of Kansas Center for Research, Inc., published a 2021 report on 'Corrosion Performance of ASTM A1035-CS reinforcing steel' establishing the chloride threshold (2500 ppm) and corrosion rate (15% of carbon steel) for ASTM A1035-CS reinforcing steel.

- NACE International Paper No. CCC15-6945 published in Concrete Service Life Extension Conference in 2015, "Case Studies for 100-Year Service Life Utilizing High Strength Low Chromium Reinforcing Bars" by Tourney Consulting Group, LLC concluded that only A1035-CS and ASTM A955 S2304 met 100 years of service life before major repairs would be needed. The research also established the chloride threshold of ASTM A1035-CS in cracked concrete.

The findings of the research established the following Chloride Threshold and Corrosion Rates for Corrosion Resistant reinforcing bars:

Parameters to be used in the Stadium Model:

- Chloride Threshold: ASTM A1035-CS (2500 ppm Chloride Threshold with corrosion rate of 15% of Carbon Bars).
- Corrosion Rate: ASTM A1035-CS corrosion rate is 15% of Black Bar.
- Concrete Mix Design is dependent on asset owners' mix designs.
- Concrete Cover: AASHTO LRFD allows the cover reduction for ASTM A1035-CS and ASTM A955 by 50 mm.
- Environmental Conditions and Location of Bridge: These parameters are controlled by the structures location and the amount of de-icing chemicals used per year.

Stadium Model service life to 1st repair establishes the following timeline for uncoated corrosion-resistant reinforcing steel in harsh environments:

- ASTM A1035-CS reinforcing steel (>100-years)
- ASTM A955 Stainless Steel S2304 reinforcing steel (>100 years)

Valley Line West Service Life Modeling Outputs

Implementing ASTM A1035-CS requires additional cover to achieve 100-year service life in Splash Zones Surfaces. Table 1 provides Minimal additional cover requirements using ASTM A1035-CS in lieu of ASTM A955 prepared by Marigold for DDRC No.0183.

Table 1 – Minimal additional cover requirements using ASTM A1035-CS in lieu of ASTM A955

Nominal Minimum covers in mm			
Description	Plan Cover	Spec Tol	Ingress Period
CIP deck	75	10	100
CIP deck	75	10	100
Top of integral straddle bent	85	20	100
Top of integral straddle bent	85	20	100
Segment deck and exterior	55	5	100
Segment deck and exterior	55	5	100
Segment deck + 5yr sealer	55	5	95
Segment deck + 5yr sealer	55	5	95
Segment deck + 10yr sealer	55	5	90
Segment deck + 10yr sealer	55	5	90

Source: Marigold Infrastructure Partners

Dissimilar Material Corrosion Concerns

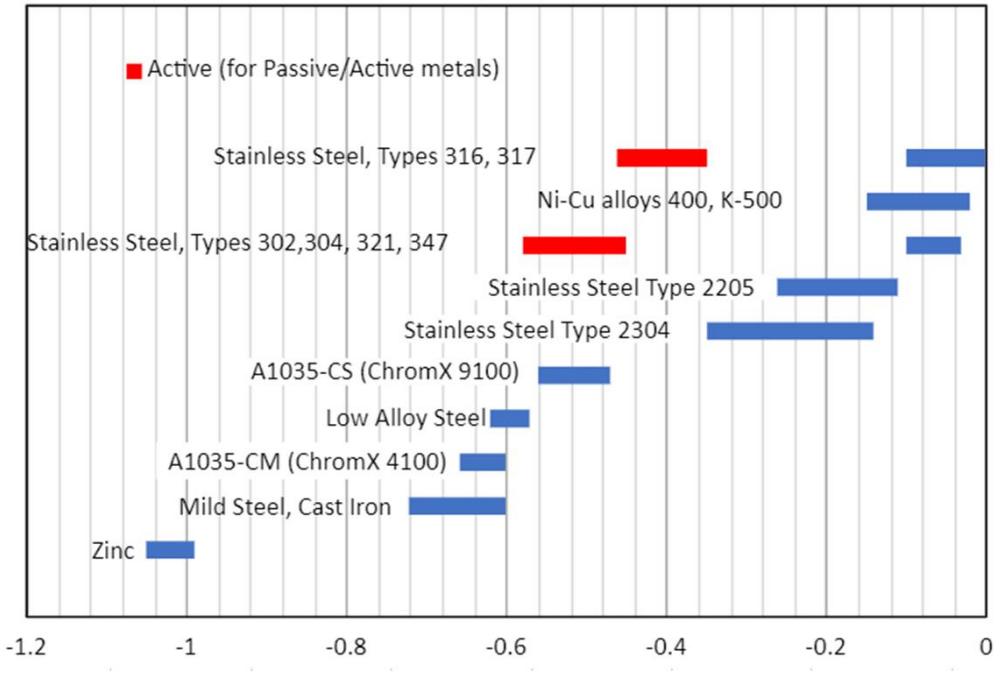
When two different metals are in contact and exposed to a common electrolyte, one of the metals experiences accelerated corrosion while the other is protected. This type of accelerated corrosion between dissimilar metals is referred to as galvanic corrosion.

Based on research by the University of Kansas Center for Research, Inc., a report published in 2021 titled "Galvanic Corrosion Potential of ASTM A0135 Reinforcement" concluded that A1035-CS and CM reinforcement is unlikely to result in increased galvanic corrosion activity when coupled with either Carbon Reinforcing Steel CSA G30.18:21/ASTM A615, Stainless reinforcing steel ASTM A955 2205, or 2304. Figure 4 illustrates the minimal galvanic corrosion potential of ASTM A1035-CS and CM reinforcing steel when in contact with Carbon Reinforcing Steel CSA G30.18:21/ASTM A615, Stainless reinforcing steel ASTM A955 2205, or 2304 in active current zones.

The DDCR explained the benefits of using ASTM A0135-CS for Segment rebars and Integral Bent Cap rebars at Stations Drivers, where it helped to bring dissimilar metals "closer" to avoid the use of epoxy,

troublesome conditions like jumpers between CSA G30.18:21/ASTM A615 and ASTM A955 in the stray current mat, etc.

Figure 4: Galvanic corrosion potential of ASTM A1035-CS and CM reinforcing steel.



Source: www.cmc.com

Concrete/Reinforcing Steel System Structural and Durability Studies

Published research studies have investigated the overall behavior of the 'concrete/rebar system' under simulated harsh environments while under cyclic loads. These studies considered the corrosion resistance characteristics as well as bond, cracking, deflection, ductility, and ultimate capacities of the 'concrete/rebar system'. The findings recognized the homogenous effects that ASTM A1035-CS reinforcing steel behavior and its bond strength have on the overall concrete/rebar system's superior performance as it relates to durability when compared to Stainless reinforcing steel ASTM A955.

- Published report on "Alternative Reinforcement Products in Design of Concrete Structures Durability Performance, University of Calgary/Stantec, September 2020".
    - Crack patterns: Beams with ASTM A1035-CS experienced the narrowest cracks compared to ASTM A955 and CSA G30.18:21/ASTM A615 beams reducing the crack width by 22%.
    - Flexural Capacity / Flexural Stiffness: Beams reinforced with ASTM A1035-CS reinforcing steel experienced the best flexural capacity and stiffness compared with all other beams, including those reinforced with ASTM A955 and CSA G30.18:21/ASTM A615.

  - Corrosion Resistance of Reinforcing Steel: All beams corrosion data resulted in high corrosion resistance under the investigation compared to beams reinforced with CSA G30.18:21/ASTM A615.

- Cracking Behavior of Slabs with Corrosion-Resistant and High-Strength Reinforcing Bars, ACI Structural Journal, September 2020.
  - Twelve slabs reinforced with ASTM A615 reinforcing steel and six different corrosion-resistant reinforcing steel were tested to evaluate the influence of various materials on cracking.
  - In addition, the effect of the spacing of the reinforcement and the effect of high reinforcement stresses that can be obtained using high-strength reinforcement were considered.

  The following findings are based on the test results of this study:

  - To control crack widths, it is recommended that crack widths be based on ASTM A615 and multiplied by the modification factors.
  - These factors can be used for both average and maximum crack widths. Design code approaches can directly incorporate these factors to reduce the bar spacing of the selected reinforcing steel type by dividing the ASTM A615 spacing by these modification factors:

    - ASTM A615 reinforcing steel control = 1.0
    - Modification Factor for ASTM A1035-CS = 1.0
    - Modification Factor for ASTM A955 Stainless reinforcing steel = 1.3

  ASTM A955 reinforcing steel has lower bond strength than ASTM A1035-CS, which leads to 30% more cracking of concrete-reinforced structures. As a result, a modification factor of 1.3 is recommended for concrete structures reinforced with ASTM A955.

Reinforcing Steel Substitution Benefits to Fabrication Shops

Marigold Infrastructure Partners commissioned A&H Steel Ltd. in the City of Edmonton to procure, fabricate, and place reinforcing steel for the Valley Line West LRT project. A&H Steel supported DDCR No.0183, which requested the acceptance of using ASTM A1035-CS instead of ASTM A955 for Splash Zone Surfaces reinforcement for the following benefits:

- Can be bent in A&H facility while ASTM A955 fabrication is limited to specialized fab shops
- There is no concern for cross-contamination between equipment and ASTM A1035-CS (unlike ASTM A955)
- Bending ASTM A1035-CS is more accurate than ASTM A955 reinforcing steel
- It can be stocked at A&H facility's yard
- ASTM A1035-CS is more readily available
- It is significantly less expensive than ASTM A955

- A&H has utilized ASTM A1035-CS reinforcing steel in multiple transportation projects, such as bridges and LRT structures, where corrosion is a concern

Conclusions

Over the years, ASTM A1035-CS reinforcing steel has been proven to provide a 100-year service life until the first repair of reinforced concrete structures. It is an almost entirely resistant to corrosion concrete reinforcing steel.

The Valley Line West LRT Design-Build JV Marigold was successful in their decision to seek alternatives to ASTM A955 reinforcing steel, which is solely sourced in North America to control the project delivery schedule and avoid serious delays, stay within the allocated construction budget, and eliminate the potential for dissimilar material corrosion concerns encountered on an electrified system.

The City of Edmonton accepted DDCR No.0183 submittal justifications. Successfully, ASTM A1035-CS was approved in lieu of ASTM A955 for Splash Zone Surfaces reinforcement to provide an efficient and compatible use of materials in the structure requested. Marigold demonstrated ASTM A013-CS reinforcing steel achieves the Design Service Life requirements of the City of Edmonton project agreement. Furthermore, the Design Service Life calculations for locations using ASTM A1035-CS reinforcement in lieu of ASTM A955 presented justifiable results to achieve a 100-year service life by modifying the concrete design or the use of additional concrete cover.

References

1) ASTM A1035/A1035M-20 Specification "Deformed and Plain, Low-carbon, Chromium, Steel Bars for Concrete Reinforcement" - American Society For Testing And Materials - West Conshohocken, PA 19428 – 2020
2) ASTM A955/A955M-20c Specification "Standard Specification for Deformed and Plain Stainless Steel Bars for Concrete Reinforcement" American Society For Testing And Materials - West Conshohocken, PA 19428
3) Case Studies for 100-Year Service Life Utilizing High Strength Low Chromium Reinforcing Bars –NACE- Concrete Service Life Extension Conference- N Berke, R. Vijayakumar, July 2015
4) Hudecek, M, Skabar, K, and El-Hasha, R., "Alternative Reinforcement Products in Design of Concrete Structures – Durability Performance"2020 TAC Conference and Exhibition
5) O'Reilly, M., and Darwin, D., "Galvanic Corrosion Potential of ChromX Reinforcement" SL Report 21-2, The University of Kansas Center for Research, Inc., Lawrence, KS, July 2021
6) ACI Journal Proceedings, 117-S114, September 2020, pp. 245 – 257, Sim, C and Frosch, R., " Cracking Behavior of Slabs with Corrosion-Resistant and High-Strength Reinforcing Bars, ACI Structural Journal
7) https://www.edmonton.ca/projects_plans/transit/valley-line-west
8) Marigold Infrastructure Partners: The City of Edmonton, Project Agreement, Valley Line West LRT, Schedule 5 – D&C Performance Requirements, Part 4: Transportation Structures and Building Structures
9) Marigold Infrastructure Partners: Design Development Change Record DDCR No.0183 for 'Use of low Carbon Chromium reinforcing steel', prepared by Parsons Canada/Marigold Infrastructure Partners for City of Edmonton, Owner, dated 27-May-2022
10) Marigold Infrastructure Partners: Edmonton Valley Line West, Design Service Life Demonstration and Splash Zone Surface Concrete Report, VLW-DNR-00000036-ST-0001, prepared by Parsons Canada/Marigold Infrastructure Partners for City of Edmonton, Owner, dated 29-Mar-2023
11) Marigold Infrastructure Partners: PowerPoint Presentation, prepared by Parsons Canada/Marigold Infrastructure Partners for City of Edmonton, Owner, dated 5-Jan-2023: Splash Zone: Special Cases and Practical Detailing, EG Splash Zone Modelling Output, and Service Life Plan Update: Special Topic: Elevated Guideway Approaches, Future Work and Low Speed Access Road Turn
12) https://www.cmc.com
13) CMC White Paper: ASTM A1035-CS: The Case for 100-Year Service Life to First Repair, prepared by Dr. Salem Faza – 2023