Innovative Steel Microstructure for Corrosion-Resistant, High-Strength Rebar

Technical Presentation for Kentucky Society of Professional Engineers

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MMFX Steel

- Founded in 1998, HQ in Irvine, California, with Suppliers across the Globe
- Markets and sells ChrōmX 2100, 4100, 4120, 9100 and 9120 branded concrete reinforcing steel throughout North America
- ChrōmX Steel Bar is manufactured in Oregon, USA

ChrōmX Innovative Steel Technology Offering
- Up to 5x more corrosion resistant than uncoated conventional steels
- Up to 2x stronger than conventional steels, and ductile

ChrōmX Concrete Reinforcement Advantages
- Longer-service life and lower life-cycle costs
- High-Strength allows design with up to 50% less steel, less weight, lower over all project delivery costs and improved constructability
MMFX Steel Innovative Products

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MMFX Steel Innovative Products

Up to 5x more corrosion resistant
than uncoated conventional steels
What makes ChrōmX (ASTM A1035) branded concrete reinforcing steel different from other rebar?

**Controlled Production**

Production process facilitates a unique steel microstructure that is:
- Corrosion Resistant
- High Strength with Ductility

**Controlled Rolling Process**

**Steel Bar Corrosion Mechanisms?**

The Effect of Micro-galvanic Cell

**Conventional Steel Microstructure**

- Free Iron-Carbide and Ferrite Phases lead to the 'Battery Effect'

**ChrōmX Microstructure**

- Dislocated laths of martensite (2) separated by stable retained nano sheets of austenite (1)
- Low Carbide Microstructure
  - Eliminates Formation of Microstructural Galvanic Cells
- Small Grain, Lath Structure Provides
  - High strength with ductility
  - Fracture toughness
**Rebar Corrosion Mechanism in Reinforced Concrete**

Chlorides penetrate concrete

Chloride threshold of steel is reached

Corrosion initiates

Cracking and spalling of concrete

Deterioration continues until repair or end of useful life

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**Independent Research – Federal Highway Administration**

“Corrosion Resistant Alloys for Reinforced Concrete”
FYWA–HRT-09-020, April 2009

**Overview:**
- 6 year study to look at various types of reinforcement cast in concrete –
  - Exposure time – in excess of 4 years
  - Tested: Various Stainless Steel Grades, Stainless Steel Clad, ChrōmX 9100, and Conventional bar

**Results**
- Ranking of samples – Corrosion Resistance
  - Black Bar < 2101 Stainless < ChrōmX 9100 ≈ 3Cr12
- Chloride threshold to initiate corrosion in ChrōmX 9100 was 4 times higher than ASTM A615 (Black Bar)
Why ChromX?
Uncoated Corrosion-Resistant

Life-Cycle Cost Analysis (LCCA) Based on 100-Year Service Life

<table>
<thead>
<tr>
<th>Bridge Deck</th>
<th>Concrete Type</th>
<th>Minimum Cover</th>
<th>Reinforcement Type</th>
<th>Lifetime Cost with Repair *</th>
<th>Replacement Life</th>
<th>Cost per square foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge LP</td>
<td>1.5 in.</td>
<td>Black Bar at Gr. 60</td>
<td>$20.14</td>
<td>26 yr. replacement</td>
<td>$20.14</td>
<td>$1.08</td>
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<tr>
<td></td>
<td></td>
<td>Epoxy Coated at Gr. 60</td>
<td>$17.79</td>
<td>35 yr. replacement</td>
<td>$17.79</td>
<td>$0.89</td>
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<tr>
<td></td>
<td></td>
<td>Galvanized at Gr. 60</td>
<td>$14.86</td>
<td>64 yr. replacement</td>
<td>$14.86</td>
<td>$0.74</td>
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<tr>
<td></td>
<td></td>
<td>ChromX 9100 at Gr. 60</td>
<td>$14.40</td>
<td>&gt; 100 yr</td>
<td>$14.40</td>
<td>$0.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ChromX 9100 at Gr. 75</td>
<td>$11.28</td>
<td>&gt; 100 yr</td>
<td>$11.28</td>
<td>$0.56</td>
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<tr>
<td></td>
<td></td>
<td>ChromX 9100 at Gr. 100</td>
<td>$8.64</td>
<td>&gt; 100 yr</td>
<td>$8.64</td>
<td>$0.43</td>
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<tr>
<td></td>
<td></td>
<td>Stainless at Gr. 60 (UNS 32304)</td>
<td>$30.36</td>
<td>&gt; 100 yr</td>
<td>$30.36</td>
<td>$1.52</td>
</tr>
</tbody>
</table>

* US$ per square foot

- ChromX 9100 provides best 100-year solution
- Initial cost is minimized by use of higher grade of ChromX

Life Cycle Cost Analysis has driven agencies standardizing on ChromX for corrosion protection:
- State of Virginia
- Province of Alberta
**MMFX's uncoated corrosion resistant dowel and tie bars**

*Extend pavement service life and lower maintenance cost*

- Smooth round pavement dowels serve as load transfer devices (LTD’s) at transverse joints in plain jointed concrete pavement (PJCP).

- Dowel bars are 18" long by 1 ¼ “or 1 ½” in diameter at 12” spacing across the joints.

- Longitudinal high strength (100 ksi) tie bars offer extended pavement service life and help reducing tie bar material requirements.

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**Up to 2x stronger than conventional steel, and ductile**
**The Mechanical Properties of ChrömX Series High-Strength**

Grade 100 [690] and Grade 120 [830] are up to 2x stronger than conventional steel products

- Ductile high-strength steel
- Less Rebar Congestion – improved constructability
- Cost effective due to engineering strength
  - Up to 50% less steel
  - Up to 60% less labor

**ASTM A1035/A1035M**

Deformed and Plain, Low-carbon, Chromium Steel Bars for Concrete Reinforcement

- First Standard issued in 2004
- Primary Specification for MMFX
- Grade 100 (690 MPa) and Grade 120 (830 MPa) rebar
- Meets/exceeds all mechanical properties of ASTM A615 – conventional rebar – Grade 75 and 80
ASTM A1035 is being modified
ASTM A1035 CL, CM and CS

- ASTM A1035 revisions were approved and passed by ASTM Steel Reinforcement Subcommittee A01 main ballot
- Revised version will be available within 60 days

<table>
<thead>
<tr>
<th>Type</th>
<th>ASTM A1035 CL</th>
<th>ASTM A1035 CM</th>
<th>ASTM A1035 CS</th>
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<tbody>
<tr>
<td>Composition%</td>
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<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>0.3</td>
<td>0.2</td>
<td>0.15</td>
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<tr>
<td>Chromium</td>
<td>2.0 – 3.9</td>
<td>4.0 – 7.9</td>
<td>8.0 – 10.9</td>
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<tr>
<td>Grade (ksi)</td>
<td>100</td>
<td>120</td>
<td>100</td>
</tr>
<tr>
<td>Tensile Strength (ksi)</td>
<td>130</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Yield Strength (ksi)</td>
<td>100</td>
<td>120</td>
<td>100</td>
</tr>
<tr>
<td>Elongation in 8 in. (%)</td>
<td>#3 through #11</td>
<td>7</td>
<td>7</td>
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<tr>
<td></td>
<td>#14 and #18</td>
<td>6</td>
<td>6</td>
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</table>

The Mechanical Properties of ChrōmX 9120
High-Strength

According to ASTM:
Yield strengths determined by 0.2% offset method.
AASHTO MP18M/MP 18-09
Uncoated, Corrosion-Resistant, Deformed and Plain Allow, Billet Steel Bars for Concrete Reinforcement and Dowels

- Reference standard for steel use in ACI, AASHTO, and ICC-ES design guides

Guidelines, Codes and Specifications for Designing to 100 ksi (690 MPa)

ACI ITG-6R (2010)
Design Guide for the Use of ASTM A1035/A1035M Grade 100 (690 MPa) Steel Bars for Structural Concrete

ICC-ES AC429 (February 2014)
Acceptance Criteria for High-Strength Steel Reinforcing Bars

AASHTO LRFD Bridge Specification (Edition 7, 2014)
Bridge Design Code for the Use of ASTM A1035/A1035M Grade 100 (690 MPa) Steel Bars for Bridge Structures
5.4.3.1 and C5.4.3.1 Reinforcing Steel, General
Permits the use of reinforcing steel with specified minimum yield strengths up to 100 ksi [690 MPa] where allowed by specific articles.

5.4.3.3 and C5.4.3.3 Reinforcing Steel, Special Applications
Permits the use of reinforcing steel with specified minimum yield strengths up to 100 ksi for non-seismic elements.

5.5.3.2 and C5.5.3.2 Fatigue Limit State, Reinforcing Bars
Modifies the fatigue equation for reinforcing bars to allow the equation to be used for specified minimum yield strengths up to 100 ksi.
AASHTO - Designing Bridges to 100 ksi (690 Mpa)
LRFD Edition 7 2014

Article 5.4.3.3
“Where permitted by specific articles reinforcing steel with specified minimum yield strengths of less than or equal to 100 ksi may be used for all elements and connections in Seismic Zone 1.”

Article C5.4.3.3
Reinforcing steels with a minimum specified yield strength between 75.0 ksi and 100 ksi may be used in seismic applications, with the Owners approval, only as permitted in the AASHTO Guide Specifications for LRFD Seismic Bridge Design.

Optimizing Bridges
with ChrōmX Grade 100
The Experimental Program
The program was designed to evaluate how flexural performance at service and ultimate limit states are affected by a one-to-one replacement of Grade 60 with CRR bars, a reduction of concrete clear cover, and a reduction in rebar size.

ChrōmX 9100
For reduced bar size and clear cover (2.00 in instead 2.50 in), ASTM A1035 specimens proved to have similar deformability ratios and crack widths that comply with current AASHTO requirements, with as much as 36% less steel.

Applied Moment-Max Crack Width
Comparison for the ChrōmX 9100 Experiments to the Grade 60 Controls
RECOMMENDATIONS
VDOT’s Structure and Bridge Division should consider:

- Reducing the bar size for CRR. Experimental and analytical results showed that ASTM A1035 specimens can be designed such that they provide ductility and serviceability limits consistent with AASHTO requirements.

- Decreasing the concrete cover requirements for bridge deck slabs when using CRR to improve the serviceability requirements and the flexural capacity. A 0.5 in reduction in the concrete cover improved the flexural behavior (i.e. flexural capacity, deformability and crack widths) of CRR specimens.

A 100 year life cost analysis

Even though CRR is two times more costly than Grade 60 rebar on a first cost basis but...

It can actually result in 40% to 45% savings in life cycle costs and 50% to 70% savings considering a 2% inflation over a 100 years of service life due to minimized repair costs.
Optimizing the Design of Pier Cap with MMFX ChrōmX Gr100

Conventional
Gr60 Reinforcement Post-tensioning

Optimizing the Design of Pier Cap with MMFX ChrōmX Gr100

ChrōmX 9100
Gr100 Reinforcement Precast
Optimizing the Design of Pier Cap with MMFX ChrömX Gr100

Comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Original Design</th>
<th>MMFX Design</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>yard$^3$</td>
<td>60.900</td>
<td>28.600</td>
<td>53%</td>
</tr>
<tr>
<td>Flexure Reinforcement</td>
<td>tons</td>
<td>2.763</td>
<td>2.580</td>
<td>7%</td>
</tr>
<tr>
<td>Vertical Shear Reinforcement</td>
<td>tons</td>
<td>2.242</td>
<td>1.486</td>
<td>34%</td>
</tr>
<tr>
<td>Horizontal Shear Reinforcement</td>
<td>tons</td>
<td>1.637</td>
<td>0.833</td>
<td>49%</td>
</tr>
</tbody>
</table>

Designing to 100 ksi (690 MPa)
ASTM A1035 in Confinement

- Full-Size Replica of two columns

60 ksi (420 MPa) confinement ties
#5 @ 2 ¼" vertical spacing

100 ksi (690 MPa) confinement ties
#5 @ 4" vertical spacing
Constructability

**Building with ChrōmX Steel Reinforcement Bar**
Ease of Job Site Handling leads to Cost Savings

**MMFX keeps it simple!**
... Lower costs and faster construction ...

**Compared to stainless steel**
- No dissimilar metals issues
- No need to isolate ChrōmX bars
- Easier QA/QC process

**Uncoated Corrosion-Resistance**
- No risks of coating damage from handling, shipping, or placing
- No field repairs
- Easier QA/QC process

**Fabrication**
- No heating
- No special equipment
- Same bend diameters as standard steel
Mechanical Splices & Anchorages (Headed Bars)

Partnership

Uncoated Corrosion Resistant Steel Bar

- Shear Bolts
- Tie-Downs & Tie-Downs
- Micropiles
- Rock Anchors
- Cam-Locks
- Wind Turbine Foundation Bolts
- Marine Bucklehead Stud Tie-Downs
World Class Structures
Reinforced with
ChrōmX

World Class Structures and Buildings built with ChrōmX Steel Bar
Reinforced with MMFX Steel Bar

- Bridges, Highways & Roads
- High Rise Condominiums
- Low Rise Condominiums
- Seawalls
- Architectural Precast
- Drilled Shafts
- Foundation slabs

- Concrete Pavements Dowels
- Marinas
- Canals
- Dams and Spillways
- Residential Coastal Structures
- Ferry Terminals
- Piers
**Corrosion Applications**

**Precast Concrete Pier**

US Navy – Naval Facilities Engineering Command
Modular Hybrid Pier (MHP), Tacoma to San Diego

- Precast Concrete Modular Floating Pier
- Corrosion Resistant Reinforcing
- 75 to 100 years repair-free service life
- Constructed in Tacoma, WA
- Towed 1,200 miles to San Diego, CA

**Corrosion Applications**

**Virginia DOT**

Huguenot Bridge Replacement
Completed in 2013
**Corrosion Applications**
Aquariums/Foundations

Seawater Lagoon Dolphin Tank
Marineland, Florida

- To minimize blast damage in the event of an explosion; #7 ChrömX steel bar was used to reinforce a 16" thick concrete slab rail spur that crossed several gas pipes

**High-Strength Applications**
ASTM A1035 in Vopak Terminals in Dow Chemical Site in Houston, Texas

- To minimize blast damage in the event of an explosion; #7 ChrömX steel bar was used to reinforce a 16" thick concrete slab rail spur that crossed several gas pipes
Closing Notes

**Conclusion**

- **ChrōmX** Steel Reinforcing Bars are the **lowest cost solution** for corrosion over the Service Life of a structure
  - Return on investment realized by the 1st repair of conventional steel reinforcing rebar

- Utilizing **ChrōmX** high strength (100 ksi) reduces **upfront build costs**
  - Immediate savings in materials and construction

- Reinforcing Steel ultimately determines the structure's service life

- Since the first heat early 2000, a 100,000 tons of **ChrōmX** steel reinforcing bar has been used to reinforce concrete structures across the United States
Thank You!

MMFX

TODAY’S STEEL STANDARD™

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