Case Studies for 100-Year Service Life Utilizing Black Bar, High Strength Low Chromium, and Stainless Steel Reinforcing Bars

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A Few Words About Michael Sprinkel

- I knew Michael for over 30 years
- He always was trying to do his best for VDOT
- He was open to new technologies, but made sure that they were cost effective for the DOT
- He shared his knowledge through his participation in ACI and other professional organizations, and we all benefited from this
- I miss him!

Overview

- Mitigating the corrosion of steel in concrete is critical to have extended concrete structure service life in a severe environment such as deicing or marine salt exposure.
- Several means to extend time to corrosion damage:
  - Reducing chloride ingress
    - Increasing concrete cover
    - Lower permeability
    - Membranes and sealers
  - Improving the corrosion resistance of the bars
    - Corrosion resistant reinforcing bars
      - Alloys
      - Coatings
    - Corrosion inhibitors
  - Cathodic protection (mostly rehab)
- Modeling can be used to assess service life improvements of the above protection systems and combinations of them.

Today

- Service Life Monitoring of Chromium containing alloys for a bridge deck case study.
  - Service life predictions
  - Economic benefits
- Performance Based on In-House Testing and Literature Values
  - Lower values used for deterministic models
  - Values are adjusted upward for probabilistic models
  - Deterministic model used today with STADIUM®

Reinforcing Bars Evaluated

- Black Bar—BB
- A1035
  - 9% Cr—1035-9Cr
  - 4% Cr—1035-4Cr
- Duplex Stainless Steel—S32304

Steel Properties

Steel	Yield (ksi)	Tensile (ksi)	Elong. % (in 8")	Composition (Wt.%) Balance is Fe														
				C	Ni	Mn	Cr	P	Mo	S	V	Si	Cb	Cu	Sn	N	B	C.E
BB	63.8	102.9	13.0	0.40	0.14	1.23	0.17	0.140	0.033	0.034	0.006	0.23	0.003	0.32				0.64
A1035-9	134	174	9.5	0.12	0.10	0.69	9.50	0.009	0.020	0.015	0.019	0.34			0.008	0.01		1.19
S3204	101	123	23.0	0.02	3.58	1.71	22.76	0.020	0.290	0.001		0.45		0.16		0.18	0.002	

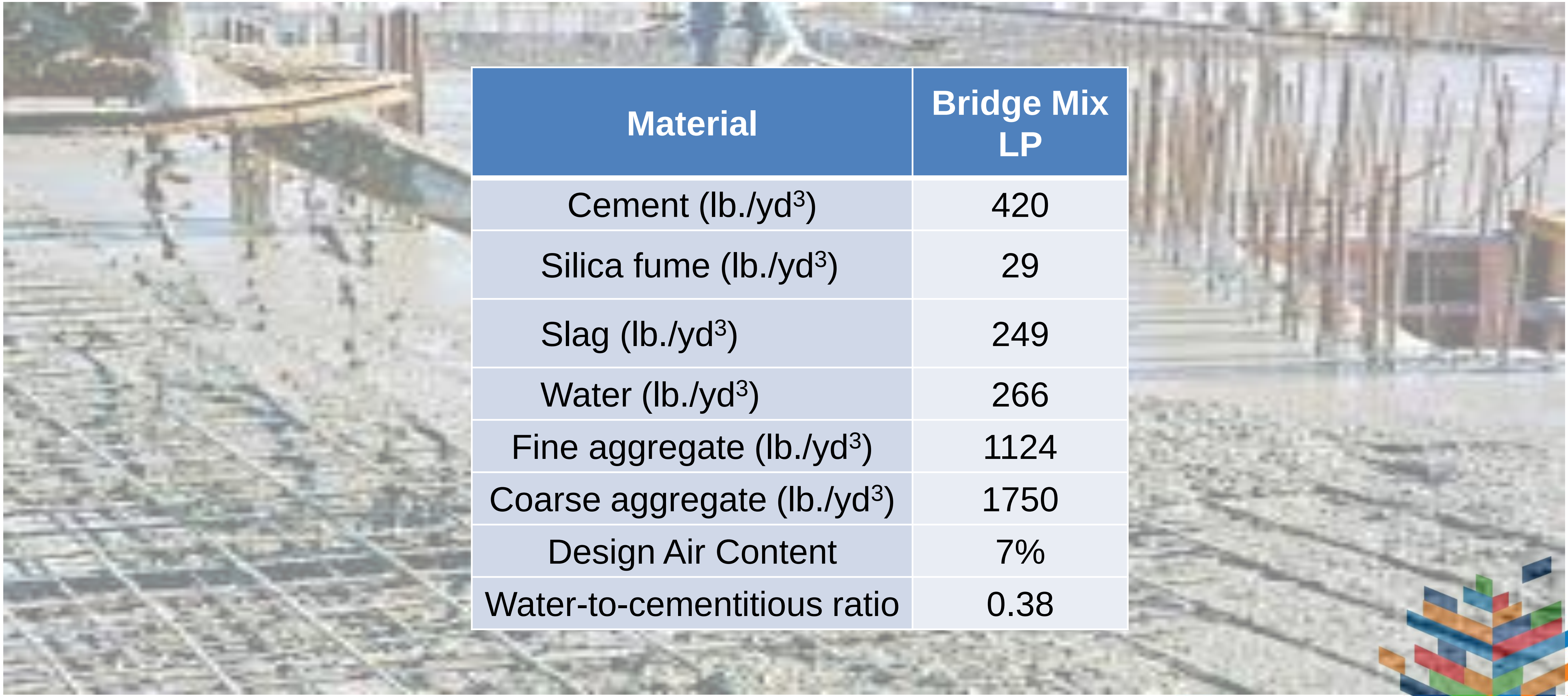
Case Study

- Compare Cr containing alloys to BB
- Midwest Bridge Deck
- In-place unit cost includes cost savings of using less steel for higher grades of strength.
- STADIUM® Analysis for chloride ingress for 100 year design before corrosion initiation
- Literature data and data from in-house experiments used for chloride initiation values for the reinforcing bars

Properties of Commercial Bars in Case Study

Reinforcement Type	Design Yield Strength Ksi (MPa)	Corrosion Threshold (PPM)	Propagation Time (estimated years)	In-Place Unit Cost ($/lb.)
BB	60 (414 MPa)	500	5 to 7	**0.75**
A1035-4CR-60	60 (414 MPa)	1000	15 to 20	**1.35**
A1035-4CR-75	75 (517 MPa)	1000	15 to 20	**1.08**
A1035-4CR-100	100 (690 MPa)	1000	15 to 20	**0.81**
A1035-9CR-60	60 (414 MPa)	2000	15 to 20	**1.95**
A1035-9CR-75	75 (517 MPa)	2000	15 to 20	**1.55**
A1035-9CR-100	100 (690 MPa)	2000	15 to 20	**1.17**
SS 2304-60	60 (414 MPa)	5000	50 +	**2.75**
SS 2304-75	75 (517 MPa)	5000	50 +	**2.26**

Bridge Deck Concrete Mixture Design

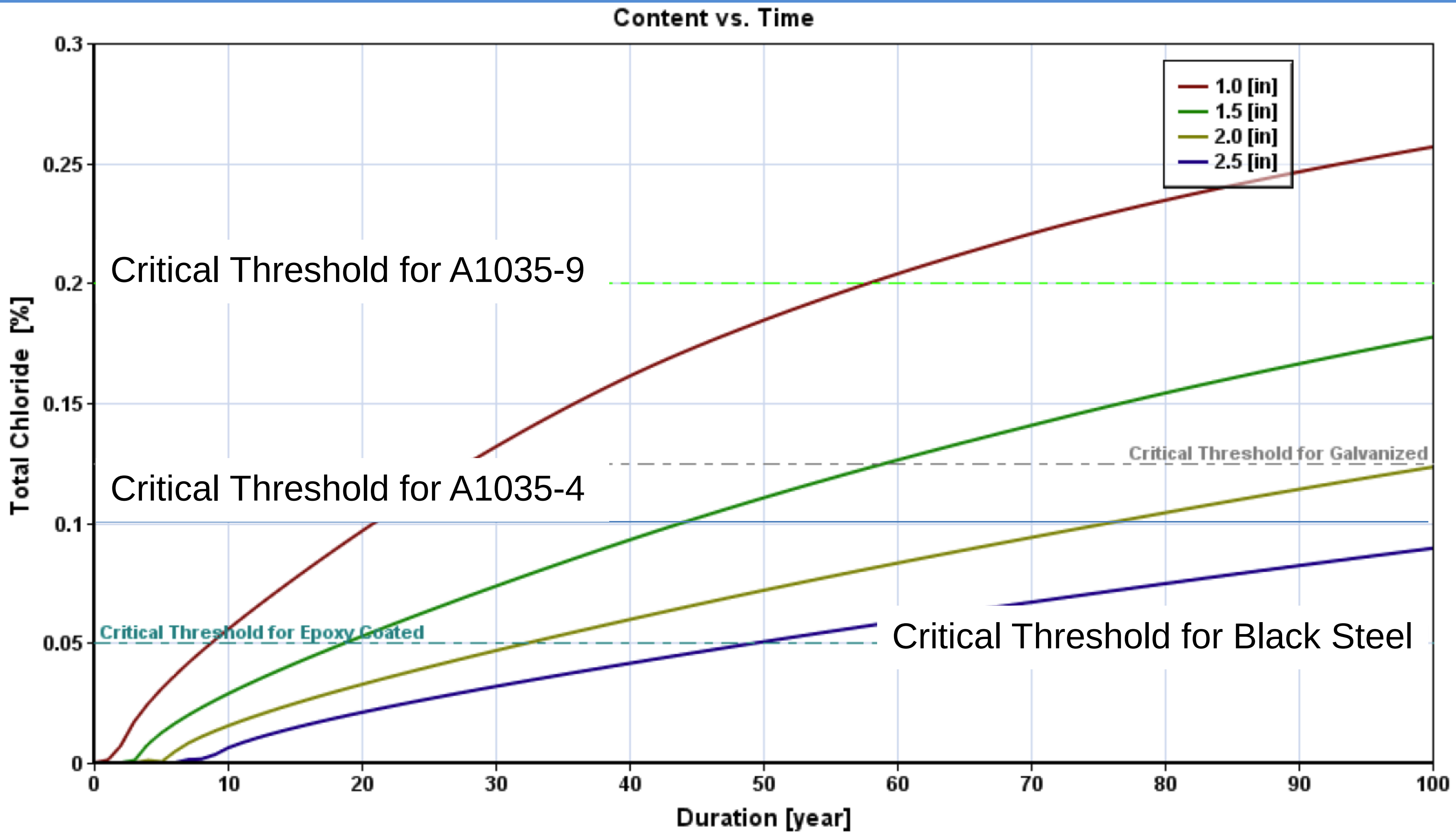


Material	Bridge Mix LP
Cement (lb./yd³)	420
Silica fume (lb./yd³)	29
Slag (lb./yd³)	249
Water (lb./yd³)	266
Fine aggregate (lb./yd³)	1124
Coarse aggregate (lb./yd³)	1750
Design Air Content	7%
Water-to-cementitious ratio	0.38

Concrete Parameters for Modeling of Bridge Deck Concrete Mixture - STADIUM

Mixture	Porosity % (Volume)	Permeability x 10^{-22} m^2/s	IDC* or OH^- Diffusion $(10)^{-11}$ m^2/s	Hydration Parameter a	Hydration Parameter - alpha (1/s)
Bridge Mix	**12**	**1**	**2**	**1.0**	**0.0015**

Predicted Chloride Profiles



Case Study Corrosion Service Life

Concrete Type	Bridge LP
Exposure	Deicing Salts
Cover (min.)	1.5 in (38.1 mm)

Reinforcement Type

BB	19 yr	25 yr
A1035-4Cr	43 yr	61 yr
A1035-9Cr	>100 yr	>100 yr
S32304	>100 yr	>100 yr

Service Life Analysis for Bridge Deck (100 y solutions vs. BB)

Concrete Type	Bridge LP				
Exposure	Deicing Salts		Rebar Initial Cost	1st Repair NPR	**Total Cost Initial +All Repairs NPR**
Cover (min.)	1.5 in (38.1 mm)		\$/ft²	\$/ft²	**\$/ft²**
Reinforcement Type	Estimate to Initiate (Y)	Estimate to 1st repair(Y)			
BB	19	25	18.75	12.91	**46.28**
A1035-9CR-60	>100	>100	48.75	0	**48.75**
A1035-9CR-75	>100	>100	38.84	0	**38.84**
A1035-9CR-100	>100	>100	29.33	0	**29.33**
SS 2304-60	>100	>100	68.75	0	**68.75**
SS 2304-75	>100	>100	55.65	0	**55.65**

Case Study Conclusions

- A1035-9Cr has a lower service life cost than BB when utilizing the higher strength in the bridge design.
  - If user costs such as traffic control, lost time etc. are added then both A1035-9Cr and S32304 have lower costs than BB.
- A1035-9Cr and S32304 met 100 years of service before major repairs would be needed.
- Significant cost savings are possible when the designer can utilize the higher strength grades available for A1035 and S32304.
- Both A1035-9Cr and S32304 are used by the Virginia DOT.

Thank You!
Questions
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