Corrosion Protection for Concrete Structures in Marine Environments

D.B.McDonald, Ph.D., P.E, FACI

$182.3 billion

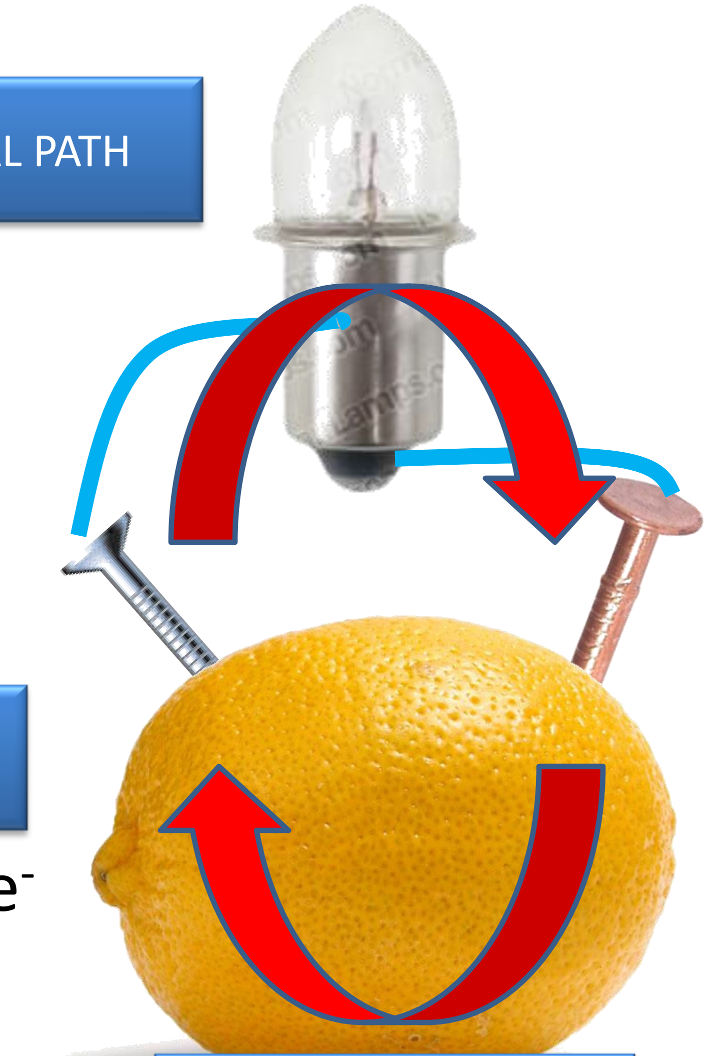
Koch, Brongers et al. 2001

http://www.fyfeco.com/images/projects/nassco-pier.jpg

Electrochemistry

ALL
4 factors required
for corrosion to occur

ELECTRICAL PATH



ANODE
Release electrons

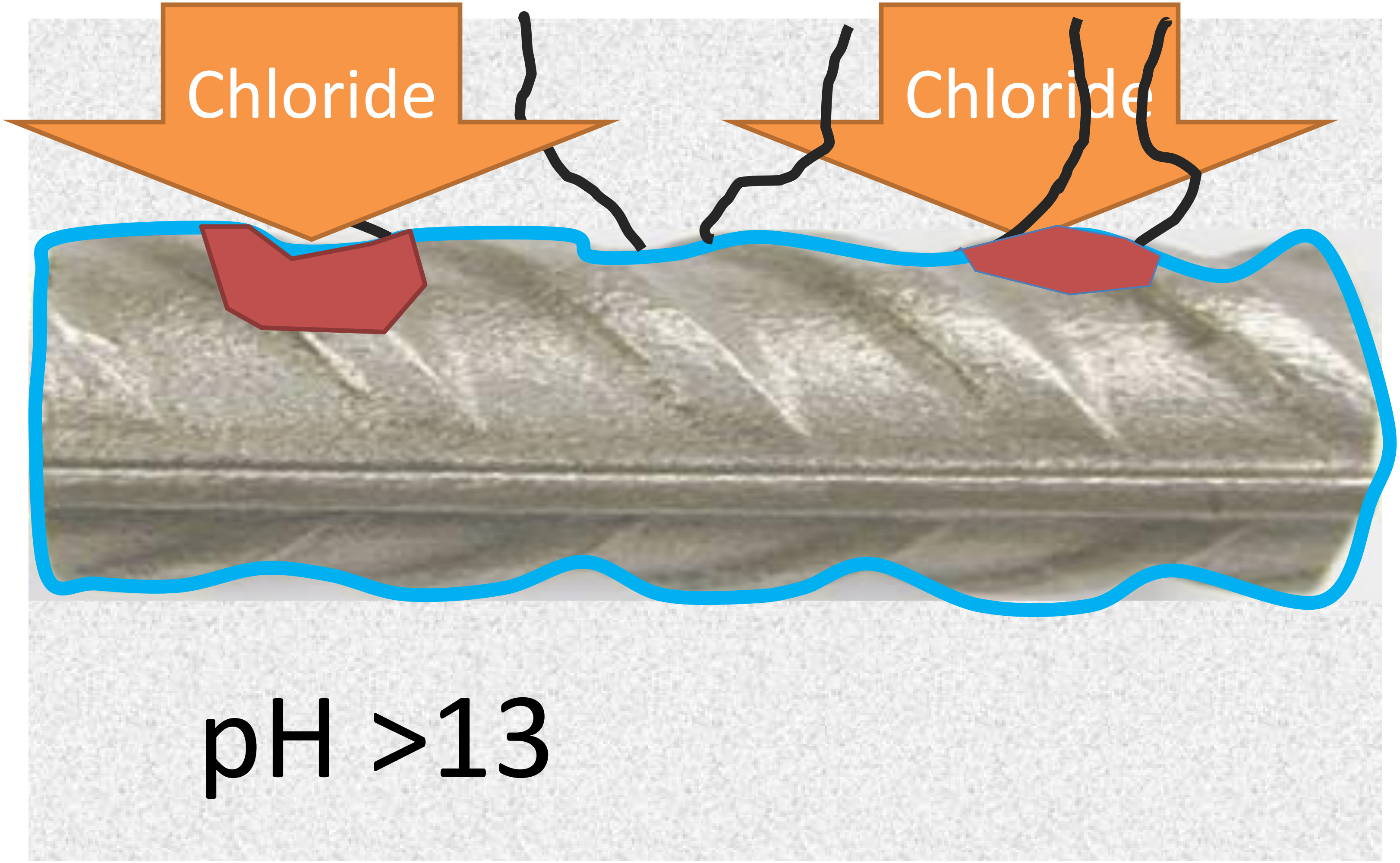
$Fe \rightarrow Fe^{2+} + 2e^-$

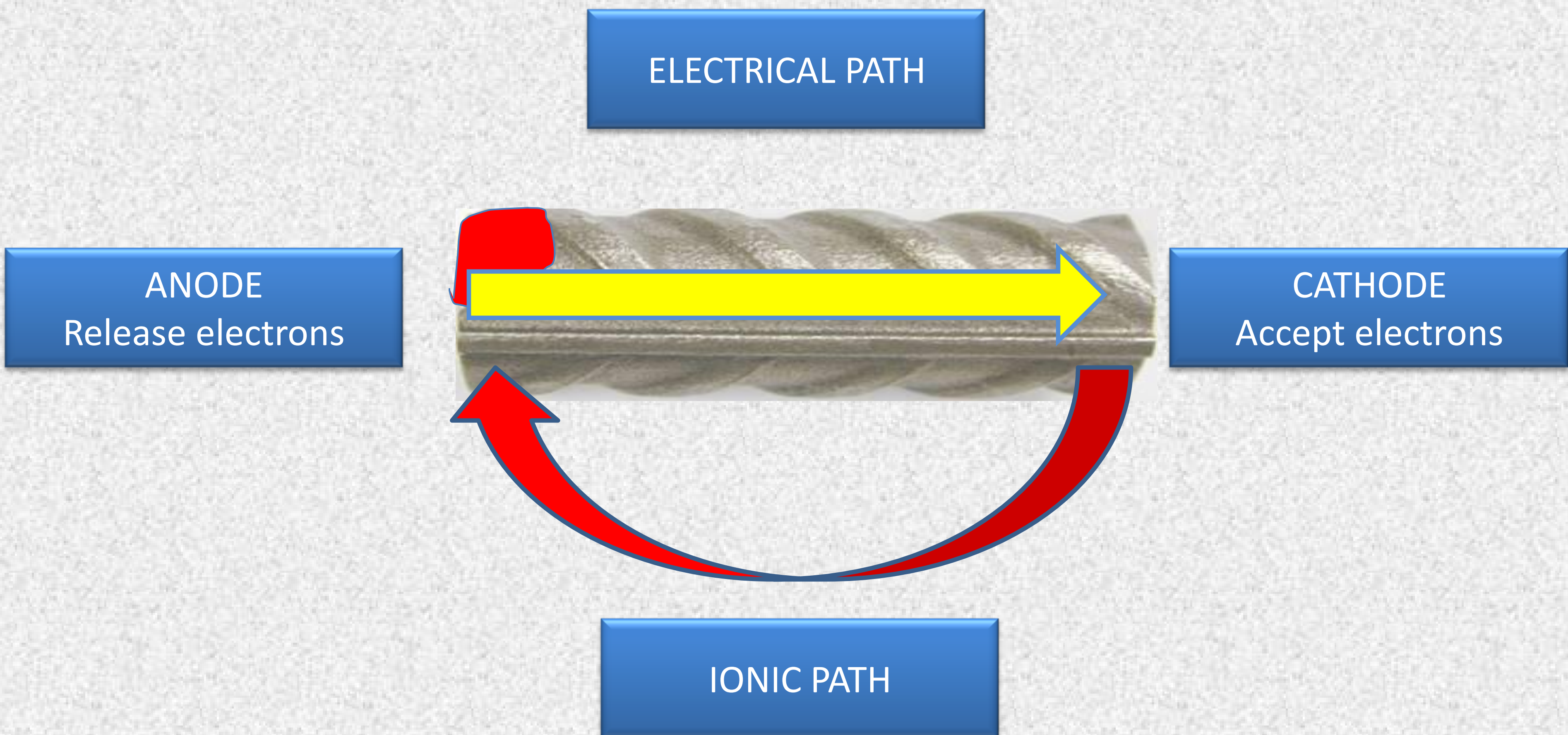
CATHODE
Accept electrons

$Cu^{2+} + 2e^- \rightarrow Cu$

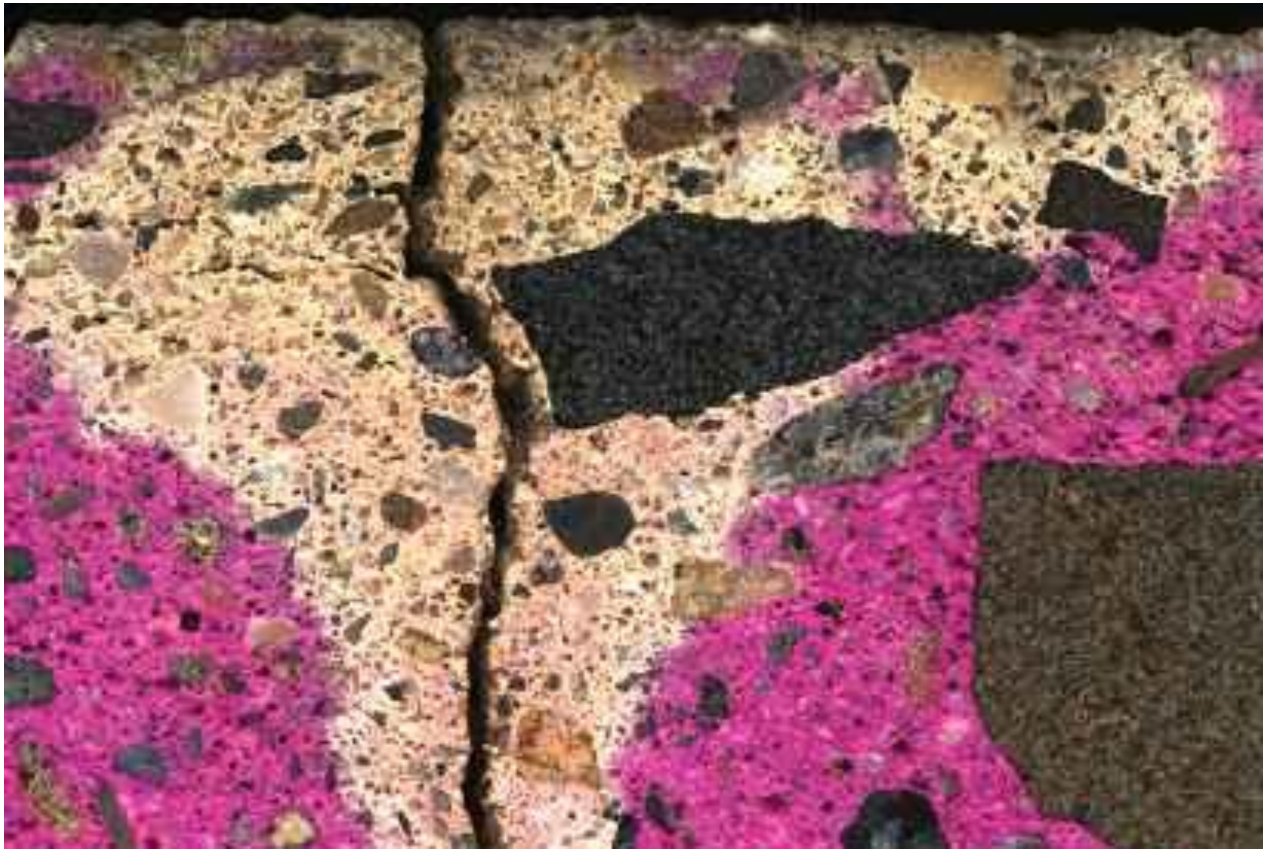
IONIC PATH

Rebar in Concrete




ELECTRICAL PATH
ANODE
Release electrons
CATHODE
Accept electrons
IONIC PATH

Carbonation
CO_2 reacts with cement



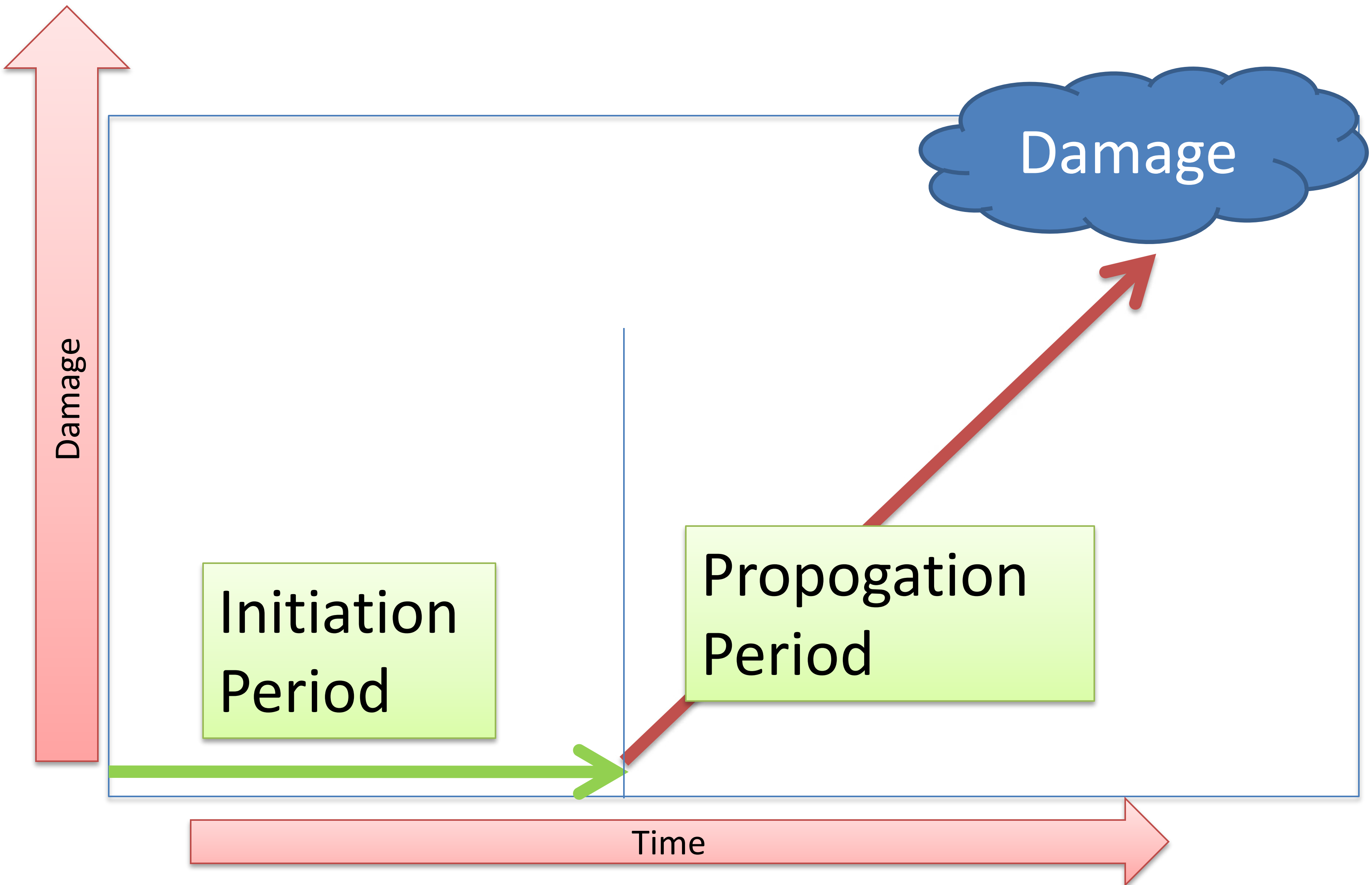
Chloride

- Deicing salts
- Marine waters
  - iron chloro-complex
  - green rust
- Expansion occurs

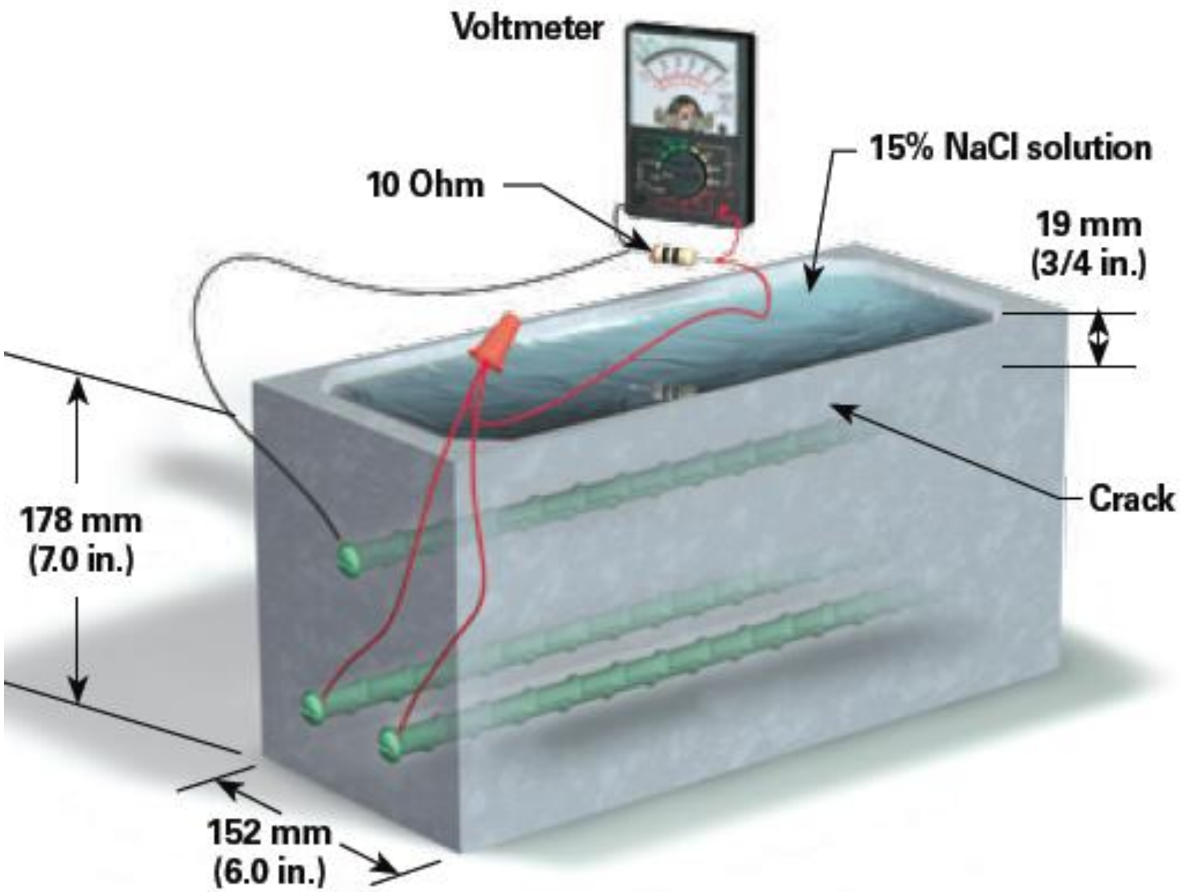
Not well understood!

Courtesy W.R. Meadows

Tutti Model



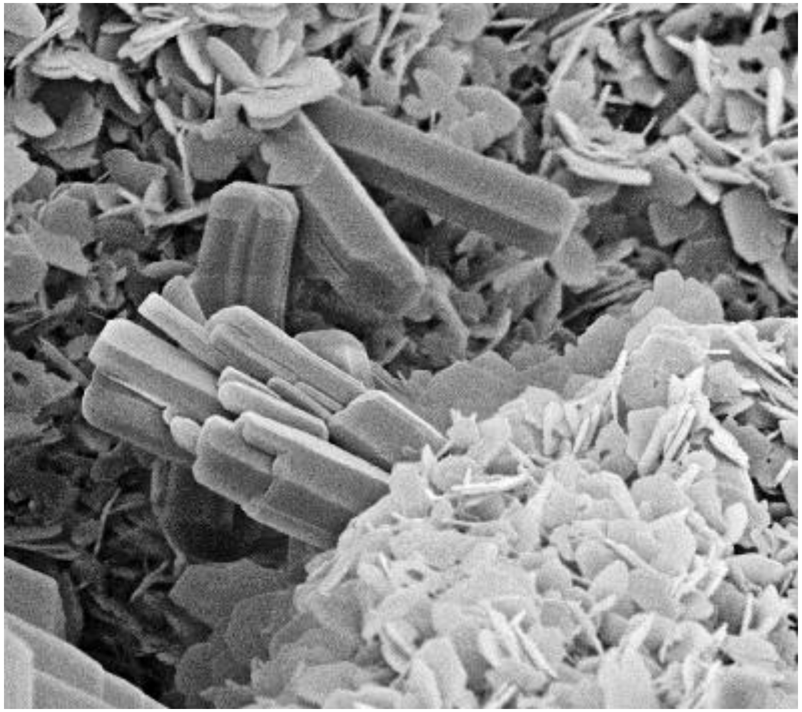
Chloride Threshold



Cracked Beam (CB) Specimen

Concrete Modification

- Reduce permeability
  - w/cm
  - Pozzolans
    - silica fume
    - fly ash
    - slag cement



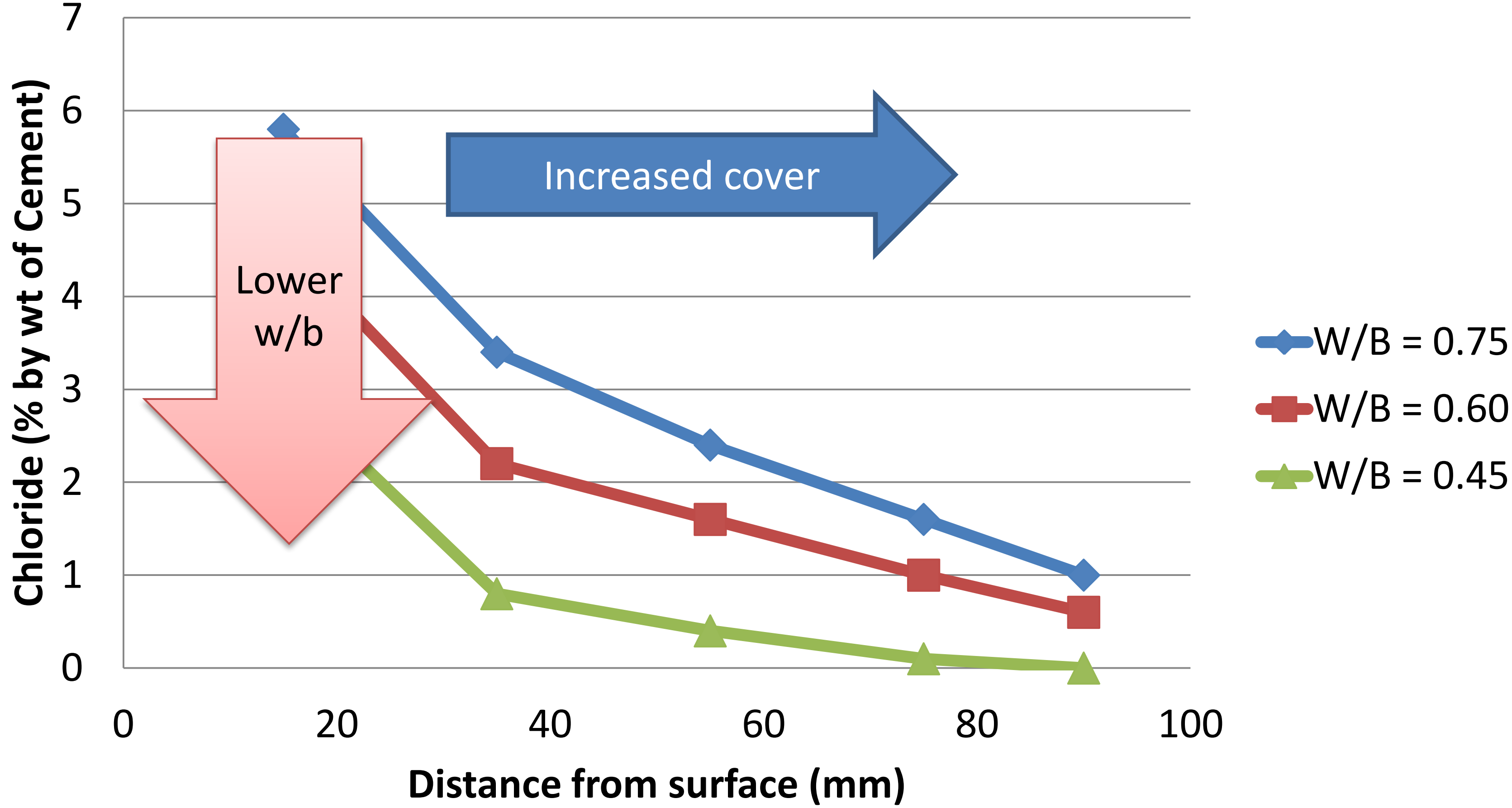
Increased risk of cracking

Concrete Cracking

- ASTM C1581
- Thermal and early age cracking
  - Curing
  - Placement
  - Form removal

http://www.cement.org/tech/images/cracking_3a.jpg

Effect of w/b on chloride penetration



Swamy, R.N., "Design for Durability with Galvanized Reinforcement," in Galvanized Steel Reinforcement in Concrete, Ed. Yeomans, S.R., Elsevier, 2004.

Corrosion Inhibitors

- ASTM C1582
- Dependent on the dosage
- “Report on Chemical Admixtures for Concrete.”
  - ACI Committee 212
- Do these leach?
- Performance in cracked concrete?

REINFORCING BAR

Types

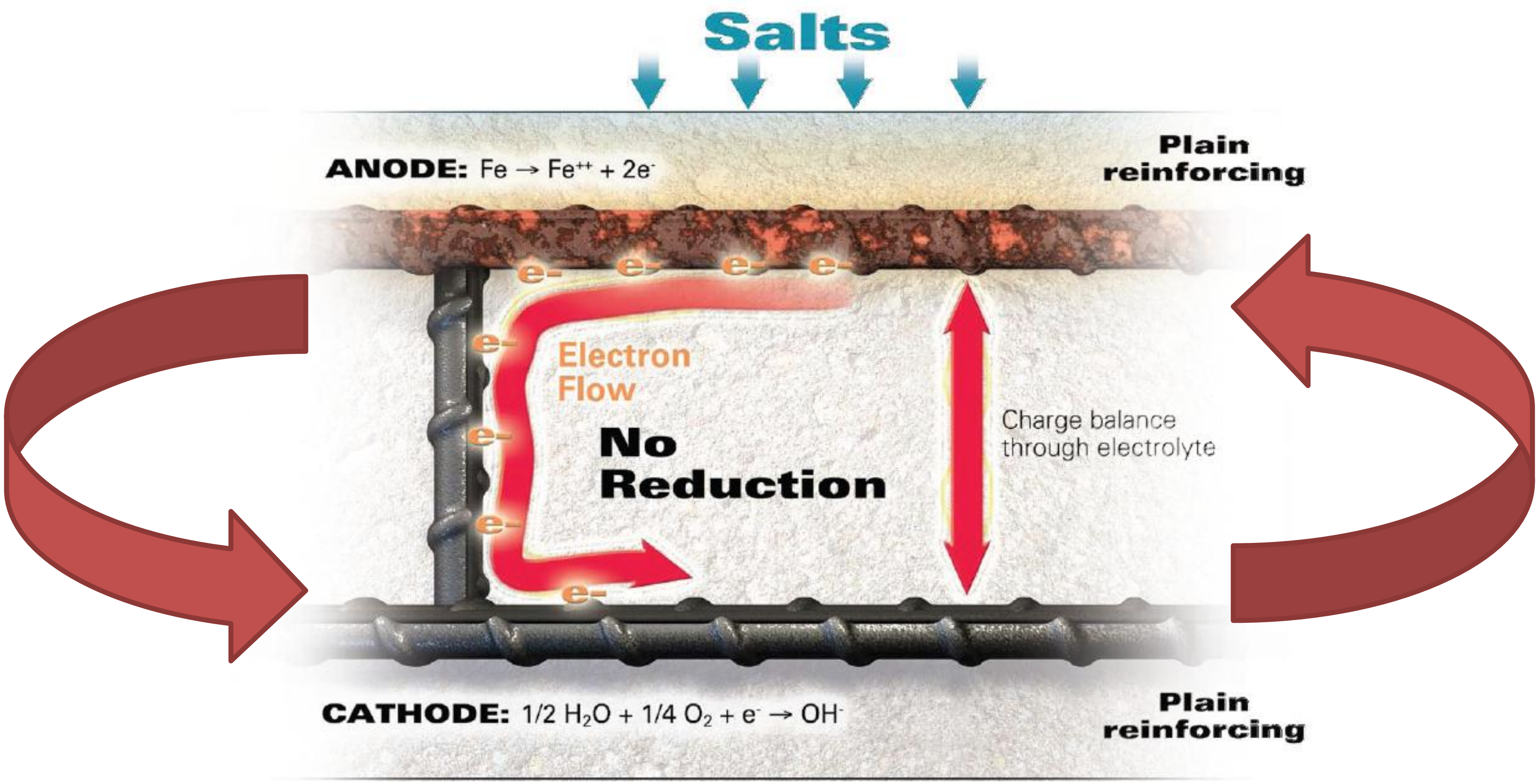
- Epoxy-coated
  - ASTM A775, A934
- Galvanized
  - ASTM A767
- Stainless Steel
  - ASTM A955
- Others
  - ASTM A1035, A1055, Glass Fiber

Epoxy-coated Reinforcing Steel

- ~600,000 ton/year
  - 10 to 15% of all reinforcing steel (USA/Canada)
- Over 100,000 structures
- Standards
  - A775 (Green)
  - A934 (purple/grey)

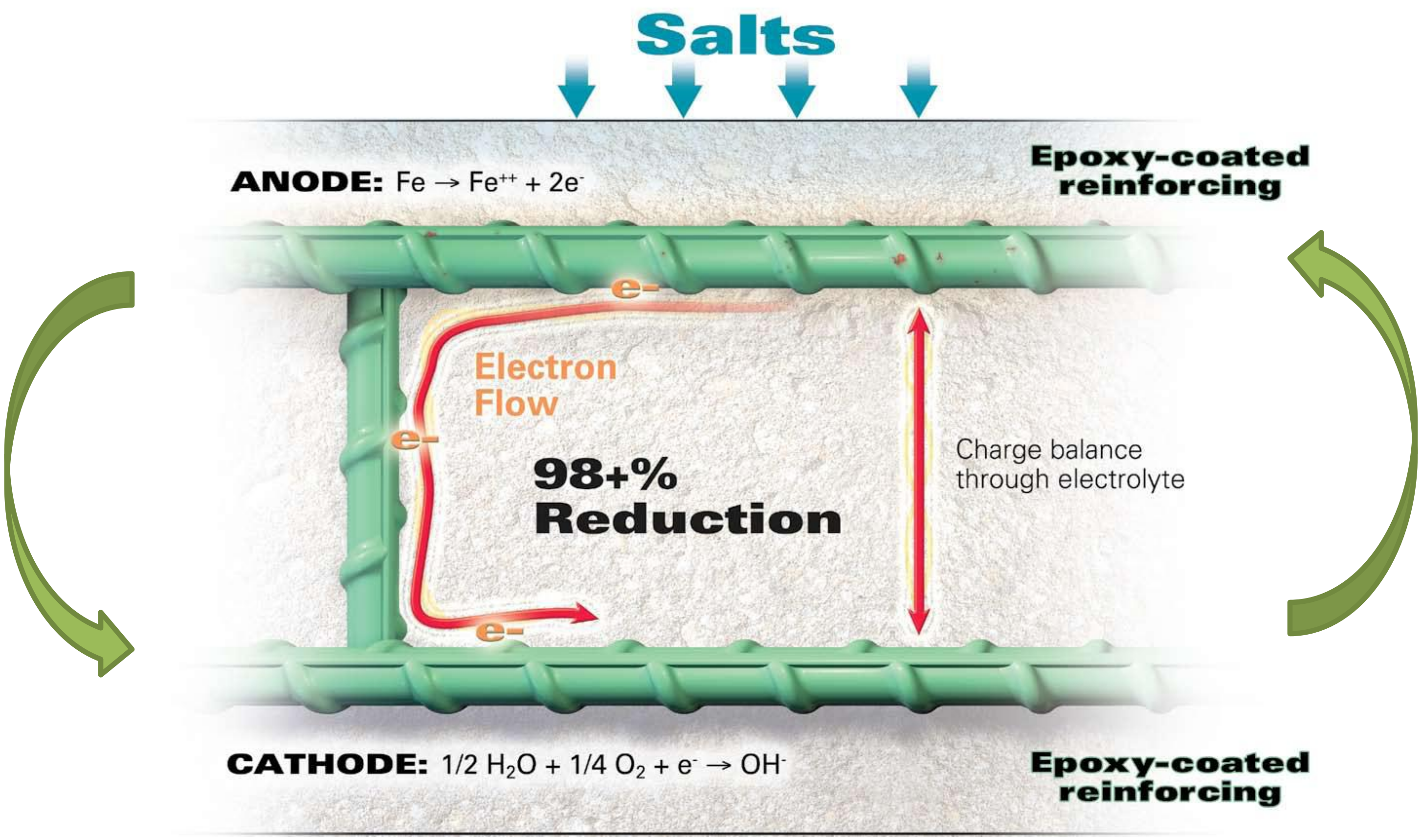
http://www.kiewit.com/projects/transportation/~/media/assets/projects/transportation/Hood%20Canal%20Bridge/65075_009.ashx

Black bars



Salts
ANODE: $Fe \rightarrow Fe^{++} + 2e^-$
Plain reinforcing
e-
Electron Flow
No Reduction
Charge balance through electrolyte
CATHODE: $1/2\ H_2O + 1/4\ O_2 + e^- \rightarrow OH^-$
Plain reinforcing

Epoxy-coated Bars



98% reduction in corrosion rate
Substantially higher chloride threshold

Certification

- Only corrosion-resistant bars under an Independent certification program
- Certification required by over 25 Transportation Agencies

Marine Performance

- Florida DOT
- 2010 paper - most predicted to have 100 year life

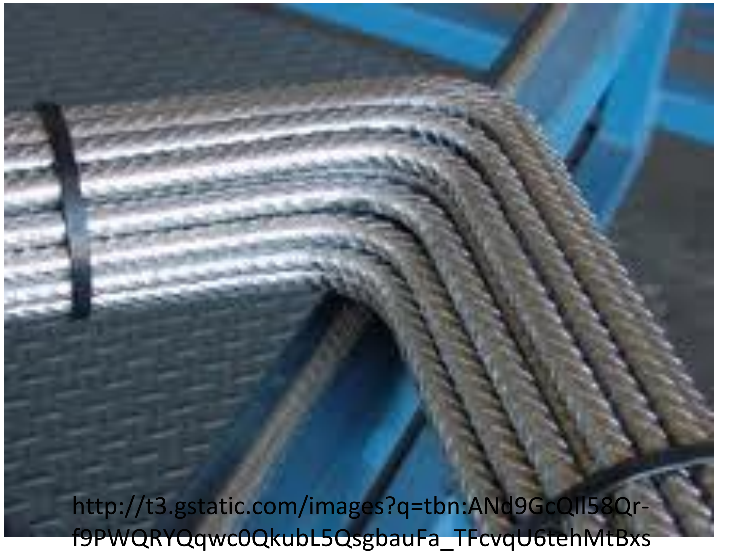
- Few structures: Poor performance
  - Poor materials
  - Poor workmanship
  - Severe environment

Galvanized Reinforcing

- ASTM A767
- Develop oxide layer for protection
  - Dependant on cement and zinc chemistry
  - Microstructure may significantly affect performance
- May galvanically corrode

Stainless Steel Reinforcing

- "Stainless steel isn't"
  - Roper 1986
- ASTM A955
  - Contains corrosion tests
- Performance largely depends on the chemistry
  - Excellent: 316, 2205, 2304
  - Fair: 2201, 3Cr12



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Progreso Pier (1940)

- Generally good performance

- “serious laminated corrosion on the visible reinforcement and the reinforcement area was reduced to approximately 60 – 70%.”

Naval Facilities Engineering Command

- Magnetic Silencing Facility, Point Loma

http://farm3.static.flickr.com/2718/4389549311_eb08812cb4.jpg

- Losses of stainless steel cross-section exceeded 50 percent
- *The reinforcement is inadequate for its environment*
  - *despite being of stainless steel composition, which has generally been considered superior in marine concrete*

Other Materials

- ASTM A1035/3CR12
  - Low grade stainless steels

- ASTM A1055
  - Epoxy and zinc layers

- Glass and Basalt fiber bars
  - largely considered experimental

OTHER FACTORS

Other Factors

- Sustainability
- Availability
- Cost

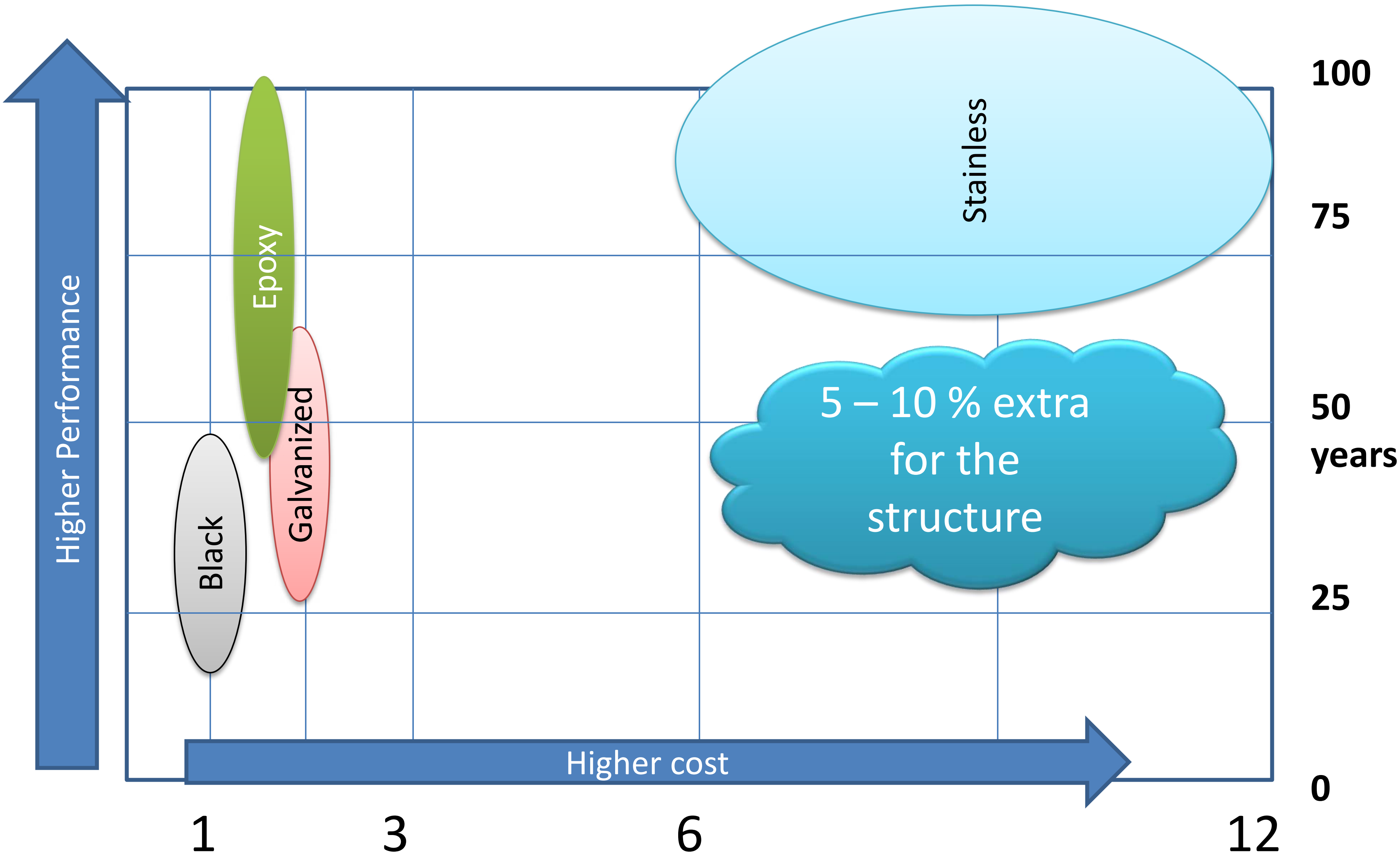
http://facilities-dc.sr.unh.edu/Project_Files/MarineResearchFacility/images/20070620TopRebarCageBent7.jpg

Sustainability

- Epoxy-coated and galvanized bars
  - over 95 percent of recycled materials

- Stainless
  - over 75 percent recycled materials
  - High processing energy

Performance vs. Cost



Availability

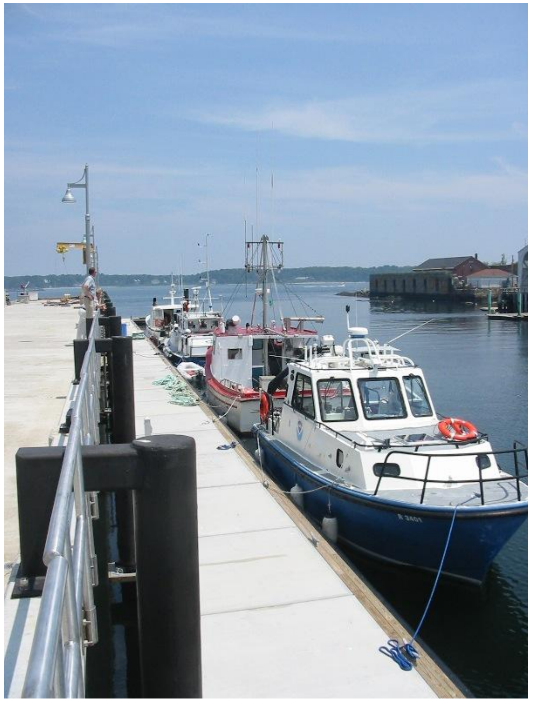
- Galvanizing
  - few have experience with reinforcing bars
  - Bar lengths
  - Chromate treatment

- Epoxy-coated reinforcing bars
  - widely available

- Stainless steel reinforcing
  - Lead times
  - Care during Fabrication

Summary And Conclusions

- Wide choice in the selection of materials for corrosion protection.
- Concretes with a low water-cement ratio and pozzolans should be chosen.
- Epoxy-coated bars
  - lowest cost method of meeting 100 year design in marine environments
- Overall performance is not the only criteria
  - Sustainability
  - Initial and Life-cycle Cost
  - Availability



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