



American Concrete Institute®
Advancing concrete knowledge


High-Strength and Corrosion-Resistant Reinforcing Steel for Concrete Structures, Part 2 of 2

ACI Fall 2010 Convention
October 24 - 28, Pittsburgh, PA

ACI WEB SESSIONS

ACI Web Sessions

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Advancing concrete knowledge


High-Strength and Corrosion-Resistant Reinforcing Steel for Concrete Structures, Part 2 of 2

ACI Fall 2010 Convention
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Poul-Erik Arnvig has more than 10 years of dedicated professional corrosion research and consulting experience, primarily within Outokumpu Stainless and its predecessors. He has held various senior managerial positions within the production, technical, and commercial groups. He is currently Vice President, Market Development for Outokumpu's activities and products in North America, based in Chicago, Illinois. He holds an M.Sc. in Chemical Engineering from the Danish Technical University, Copenhagen, Denmark, 1988.



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Stainless Steel Specification for Corrosive Environments

by
Poul-Erik Arnvig, Outokumpu Stainless &
Catherine Houska, TMR Stainless

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Impact on the environment minimized

- Outokumpu's stainless steel has an average recycled content of 90%
- Main production sites ISO 14001 compliant
- Minimal or no material replacement
 - High corrosion resistance extends life of entire system
- High end of life recapture rate
 - 92% goes into new metal
- High strength duplexes minimize initial rebar requirements
- Sustainable production
 - Use of non-emission energy sources
 - Reduced energy and emissions into water and air




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Two Piers, Progreso, Mexico

Stainless Steel solution
built in 1937- 41
Still operating

According to the Progreso Port Authority:
"No major repairs or significant maintenance activities have taken place over the lifetime of this structure."

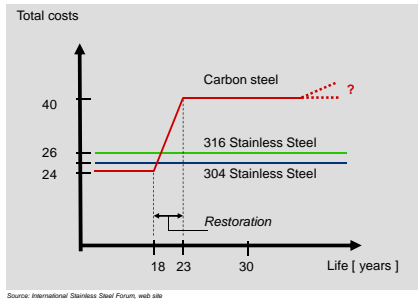


Carbon Steel
built in the 1960s
Failed < 30 years

Photo courtesy of the Nickel Institute

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Economies of using stainless reinforcement *Life cycle cost approach*



Source: International Stainless Steel Forum, web site

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Annual Cost of reinforcement corrosion to infrastructure

- Corrosion to bridges in USA
 - \$ 5.9 billion to \$ 9.7 billion
 - Corrosion resistant Alloys for Reinforced Concrete. The US Department for Transport Federal Highways Administration No. FHWA-HRT-09-020, 2009.
- Corroding concrete infrastructures in Western Europe
 - \$ 8 billion
 - Guide for the use of stainless steel reinforcement in concrete structures (NonCor) No. 04118, Nordic Innovation Centre, 1996.

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The stainless steel rebar advantage

- Reinforcement corrosion is the primary reason for premature failure usually due to chlorides penetrating the structure
- Highly corrosion resistant stainless steel rebar extends the life of structures exposed to chloride-containing environments
- Use it selectively in chloride-containing environments
- Minimize initial cost by replacing only the outermost layers of carbon steel rebar

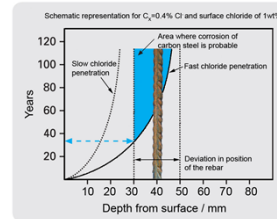


Long term decrease in maintenance costs

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Selective use of stainless steel rebar

- The penetration rate and the desired life-time for the structure must be known in order to predict the chloride penetration depth and concentration
- Today, several programs for this predictive modeling exist on the market



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Predictive modeling

- Using predictive modeling when specifying stainless steel rebar helps the structural engineer to decide where stainless steel rebars should be used
 - Taking this one step further, predictive modeling could also predict what stainless steel designation is necessary for the structure
- ➔ The chloride tolerance of each stainless steel designation in the concrete environment needs to be determined!

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Main strategies for evaluating corrosion resistance of Stainless Steel rebar

- In-concrete testing
 - + Good resemblance to the real application
 - Slower, especially if chlorides are diffusing into the structure
 - Parameters such as pH, T, chloride level are not as easily determined
- In-solution testing
 - + Faster
 - + Parameters can be varied and are easily determined
 - The solid concrete matrix is not present

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Stainless Steel Rebar

Stainless Steel designation	UNS	Micro-structure	Cr	Ni	Mo	Mn	N	C
304	S30400	Austenitic	18.1	8.1	-	-	-	0.04
316	S31600	Austenitic	16.9	10.7	2.6	-	-	0.04
LDX 2101®	S32101	Duplex	21.5	1.5	0.3	5	0.22	0.03
2304	S32304	Duplex	23	4.8	0.3	-	0.10	0.02

LDX 2101®

- available as Grade 75 in designation 3 – 14
- meets the corrosion resistance requirements of ASTM A955*
- meets A955 tensile requirements with an elongation >25%

* LDX2101® meets the requirements of ASTM A955-09b, Annex A2
M. O'Reilly, W. J. Sturgeon, D. Darwin, & J. Browning, Rapid Macrocell Tests of LDX2101® Stainless Rebars, Structural Engineering and Engineering Materials, SL Report 10-2, University of Kansas Center for Research, Lawrence, Kansas, May 2010

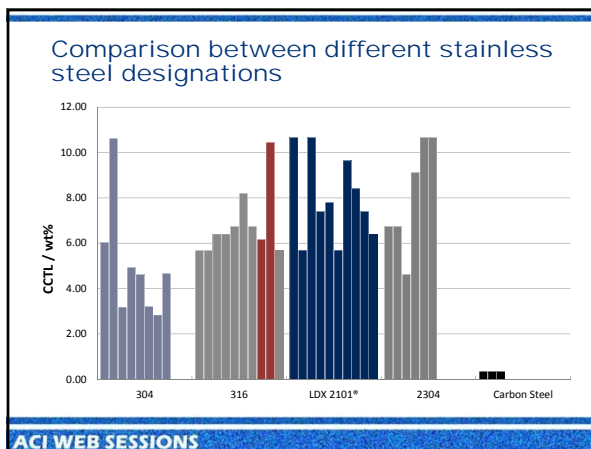
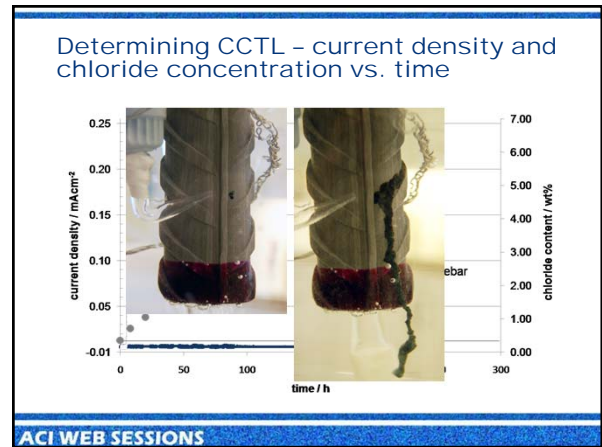
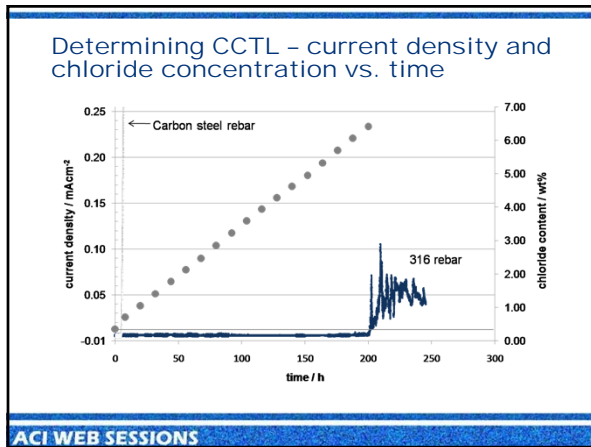
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The in-solution potentiostatic method

- Method based on the work by Bertolini et al.¹ and Hurley and Scully²
- The specimens are immersed in a synthetic pore solution and +200mV_{SCE} is applied to the specimen
- Chlorides are added incrementally (0.35wt% chlorides every 12th hour)
- The critical chloride level is determined as the chloride level when corrosion has occurred with a rate of 0.01mA/cm² for at least 5h

¹ Bertolini L, Balzani F, Pastore T, Pedersen P. Br. Corr. J., (1996) 31, 218-222
² Hurley MF, Scully JR, Corr. Sci., (2006), 62, 892-904

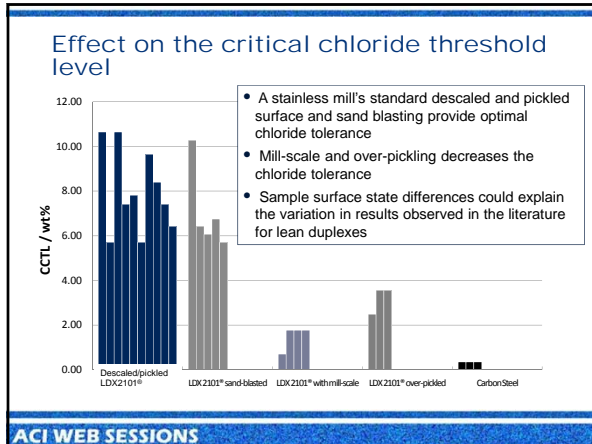
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The influence of the surface state

- Four different surface states were compared for LDX 2101®
 - mill descaled/pickled surface
 - sand blasted surface,
 - as-rolled, non-pickled surface
 - over-pickled material

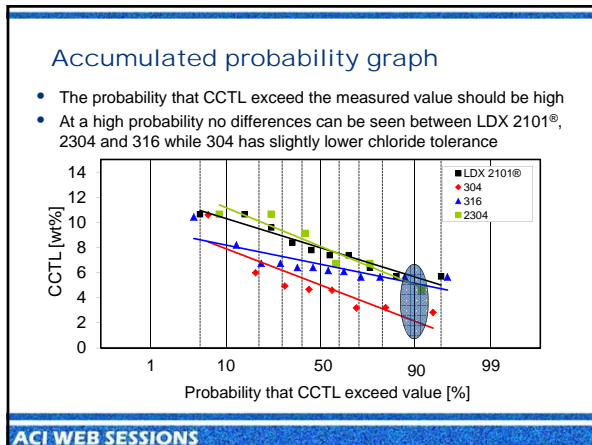
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Reproducibility and scatter

- Some scatter is observed in the results independent of the stainless steel designation
- Should the CCTL be reported as a discrete number?
- For carbon steel in concrete, chloride tolerance is instead reported as an increasing risk of corrosion where CCTL is determined as the chloride concentration when there is a low risk of corrosion
- How does this approach work for stainless steel rebar?

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Conclusions 1 (2)

- Use transport modeling to estimate when stainless steel is needed based on
 - CCTL (Critical Chloride Threshold Levels)
- Chloride tolerance should be seen as a probability instead of a discrete number
- Rebar surface state determines chloride tolerance
 - Always specify a descaled and pickled stainless rebar surface to obtain optimum corrosion resistance
 - Mill-scale and over-pickling lowers chloride tolerance

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Conclusions 2 (2)

- Stainless rebar can and should be used in conjunction with carbon steel rebar for critical components
- LDX2101® is a very cost competitive grade 75 that meets A955 corrosion resistance test requirements
- The chloride tolerance of LDX 2101® and 2304 is comparable to type 316 and superior to that of type 304

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Acknowledgements

- The CCTL experimental parts of this presentation was originally from a presentation by

S. Randström, M. Adair, M. Almén, R. Pettersson,
P-E Arvig, Stainless Steel World 2010, Houston, October 2010

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Activating Your Ideas.

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David DeValve is a graduate of the University of Connecticut with a B.S. in Civil Engineering (1989). He has worked in various consulting offices in the Transportation and/or Structural engineering fields with field experience on many construction sites, primarily in the New England markets.

Mr. DeValve currently holds a PE in Oklahoma and Texas. In his current position at Oklahoma Steel & Wire in Madill, OK, he is an engineer and construction manager. He is a member of ACI 439 and 560, and is an associate member of ACI 314 and ASCE 7. In 2006, he and his wife contracted the building of their own ICF house.



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High Strength Welded Wire for High Performance Concrete Reinforcement

Or
Performance Criteria -
The Sky is the Limit!?

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FOCUS POINTS:

- What is HS WWR!?
- Where it has come from-brief background?
- Discuss some issues associated with HS Mat'ls.
- Show some detailing of HS WWR.
- What are current corrosion resistant applications.
- Where we are headed [or can go] with HS WWR.

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Overview-Learning Objectives

- Learn what is high performance [strength] reinforcing.
- General detailing and the difference high strength reinforcing came make.
- General overview of corrosion protection & the role played in HPC.
- How it can make a difference in today's concrete structures!

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What is High Performance Concrete?

- Higher strengths:
 - in 1960's [>5 ksi]; thru 1980's [>10 ksi]; now [>20 ksi]. NC(3-10), HSC(10-20), UHPC(20-30+)
- Better corrosion protection:
 - Additives to concrete mix (mix design)
 - leads to lower maintenance costs [LCC]; longer service lives

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What is High Performance Concrete?

- Better corrosion protection (continued):
 - Coatings for materials cast into concrete.
 - Special inserts to control conductivity
 - Special surface protection coatings
 - paints, sealers, thin overlays (white toppings)

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What is High Performance [Strength] Reinforcing?

- Higher strengths :
 - in 1960's- 40 & 60 ksi; 1980's-60 ksi; now- looking towards 100-120 ksi.
- Better control of input materials:
 - leads to better products-longer life
- Better machines & technology
- Better protective coatings

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Why is HS Reinforcing needed?

- More use of HPC in structural components.
 - HPC [$f'c > 10$ ksi (69MPa), etc.]
- Reduce congestion at critical sections.
 - Bms, Col's, Grd's, & Connecting Elements
- Better Life Cycle Costs [LCC]
 - maintenance & service life
- Greater load resistance at service conditions.

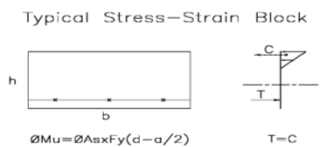
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HS WWR Reinforcing has been around...?

- HS WWR since 1960's...
- HS reinforcing for spirals & ties since 2003.
- Up to 100% of steel comes from recycled content & is recyclable.
- What are issues involved with HS reinforcing- [esp. WWR].

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Stress Block Analysis



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Typical Welded Wire S-S Curves

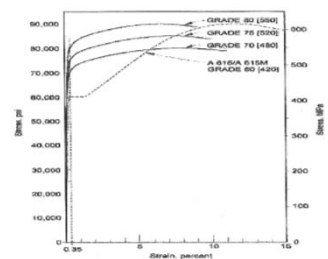
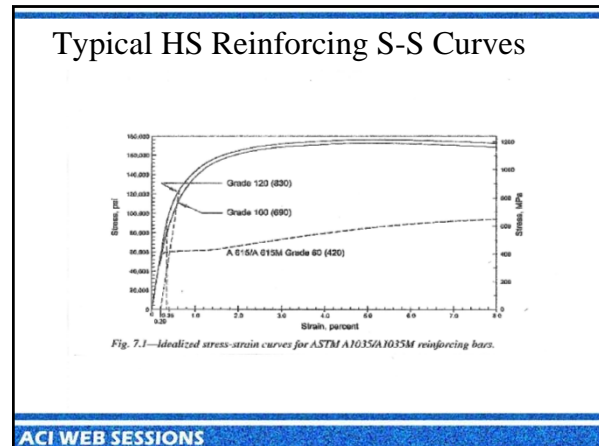
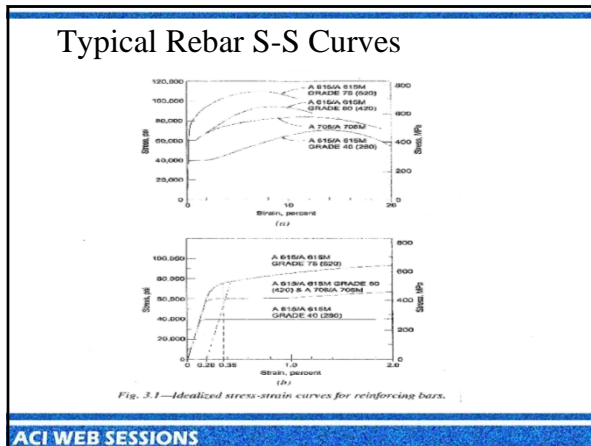


Fig. 4.1—Idealized stress-strain curves for cold-rolled ASTM A62/A62M and ASTM A496/A496M wire.

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Rebar Chemistry

Grade 60.85		Grade 60.80	
Chemistry (AISI)		Chemistry (AISI)	
Min.	Max.	Min.	Max.
C	0.45	0.45	0.50
Mn	0.50	0.50	0.70
P	0.025	0.025	0.025
S	0.05	0.05	0.05
Si	0.15	0.35	0.60
Al	LAP	Ni	0.0120
Cr	0.03	B	0.0030
V	0.003	Cu	0.0030

Must Be Struckout Chemistry Tolerance: Standard AISI for Carbon Steel for Wire Rod

WWR Chemistry

Grade 100B		Grade 108B	
Chemistry (AISI)		Chemistry (AISI)	
Min.	Max.	Min.	Max.
C	0.45	0.45	0.50
Mn	0.50	0.50	0.70
P	0.025	0.025	0.025
S	0.05	0.05	0.05
Si	0.15	0.35	0.60
Al	LAP	Ni	0.0120
Cr	0.03	B	0.0030
V	0.003	Cu	0.0030

Must Be Struckout Chemistry Tolerance: Standard AISI for Carbon Steel for Wire Rod

General Detailing

- WWR [&/or Rebar] @ 60ksi
- WWR [&/or Rebar] > 100ksi
 - 40%+ reduction in area
 - or a combination reduction in area & increase in spacing...

VS.

Combined WWR ASTM Code provisions...

- ASTM A1064 [combines A82, A185, A496, & A497]...states:
 - in footnote to table 6 “Tension Test Req’mts...”- For material testing over **100ksi** tensile strength, the reduction of area shall be <25%.

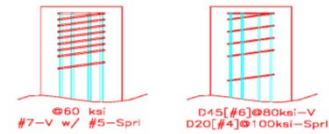
So the code allows WWR @ >100ksi - if processed according to code provisions...!

What does that mean – detailing...?



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What else can be done....



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WWR Protective Coatings Systems

- Epoxy [or Vinyl] Coating
- Galvanizing
- Stainless Steel [esp. for large projects]
- Stainless Steel clad or Dual clad [Zn, N, Cu, Ti]+[Epoxy]
- Others
 - polymers
 - inserts

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What coating system is the best...!?

- Depends...?
 - On who you ask?
 - On how material is handled?
 - on initial cost vs. LCC?
 - How the reinforcing is produced?
 - Chemistry & how/where to be used?
 - On how you interpret research test data?

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Most commonly used coatings for WWR:

- Galvanizing
 - before or after welding; many places to do
- Epoxy
 - few places in US to do large sheets
- Others
 - need for field applied system(s)
 - combination of systems [i.e. dual clad]

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Summary Questions:

- Why is HS WWR needed...?
 - To keep balanced with today's HPC [$F_c' > 10$ ksi].
- What is it...?
 - $F_y \geq 80$ ksi [note: code allows $F_y = 80$ ksi]
- How to make it...?
 - Control chemistry and machine processing
- Where is it headed [the sky's the limit]...?
 - To help concrete structures last...!?!]

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Conclusions:

- It is possible today to...make WWR >100ksi
 - yes-control chemistry & processing
- More research needed to...
 - define best performance criteria
- Codes need to keep up...
 - to help advance innovation & technology

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Thanks!

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