CRRB Seminar – FHWA / FDOT

LDX 2101 and 2205 Duplex Stainless Steel

Proper Cleaning of Mill Scale

Catherine Houska & Tom Holsing

Outokumpu
– an international stainless steel company

Cloud gate in Millennium Park Chicago, USA

- Outokumpu is a global leader in stainless steel with the vision to be the undisputed number one
- Outokumpu Group employs some 8,000 people in more than 30 countries
- The Group's sales of EUR 4.23 billion in 2010
- Outokumpu has been listed on the NASDAQ OMX Helsinki since 1988

Stainless steel is one of the key building blocks of a sustainable future

Marina Bay Bridge, Singapore

- 92% diverted from landfills and used in new stainless steel
- Industry's highest stainless recycled content - 85 – 90%
- Dow Jones gave Outokumpu the highest sustainability score in the steel industry
- Outokumpu signed the UN Global Compact
- Stainless steel benefits
  - Corrosion-resistant
  - High-strength
  - Hygienic and aesthetic
  - Low life-cycle costs

Resisting Marine Chloride Induced Corrosion: Design Using Performance Specifications

Second Gateway Bridge
Brisbane, Australia
Sustainable 300 Year Design Life
LDX 2101®

Canadian Concrete Reinforcement Examples

- Alberta Transport - Rabbit Hill Road Bridge Project, 2304 duplex
- British Columbia MoT - Mission Bridge, 2304 duplex
- Alberta Transportation - Cameron Heights Bridge Project, 2304 duplex
- Alberta, Athabasca River Bridge Project, LDX 2101

Piers and Seawalls

- Sidney Australia harbor
- Deteriorating carbon steel reinforcement replaced by stainless steel

OUTO KUMPU

Outokumpu is one of the leaders in stainless

- Outokumpu's melting capacity totals 2.3 million tons and the finished product's capacity 1.9 million tons
- Outokumpu market shares
  - Stainless steel coil
    - 22% in Europe
    - 5% worldwide
  - Quarto plate over 20% globally
  - Duplex grades over 50% globally
  - 7% in North America – all products
- Outokumpu's main markets are
  - Europe 76%
  - North and South America 10%
  - Asia 11%

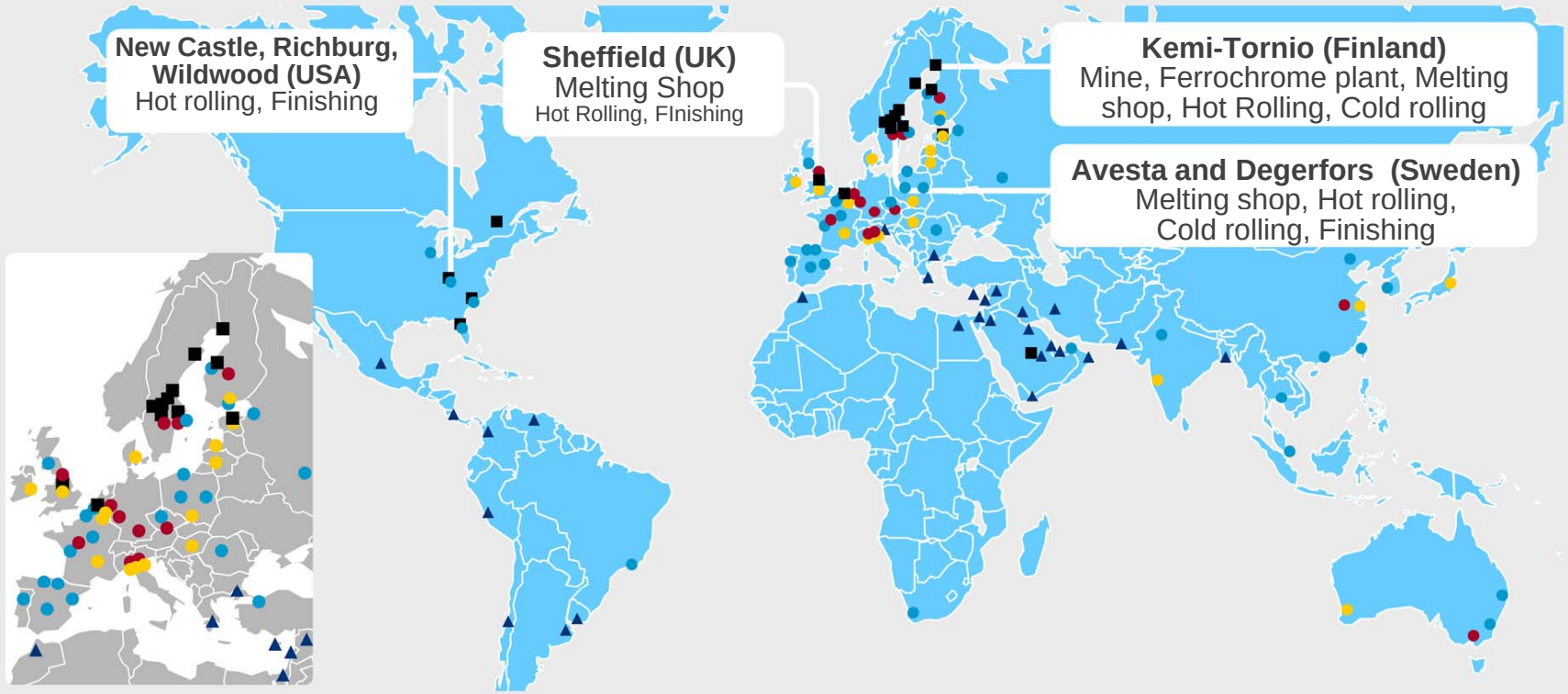
Top 7 Global Stainless Steel Producers
Estimated slab capacity , million mt

	2014	2011
Acerinox, Spain	3.28	3.28
Inoxum, Germany	2.90	3.90
Posco, South Korea	2.88	3.00
Aperam, Luxembourg	2.78	2.78
Yusco, Taiwan	2.78	2.78
TISCO, China	2.60	2.60
Outokumpu, Finland	2.30	2.30

Source: CRU

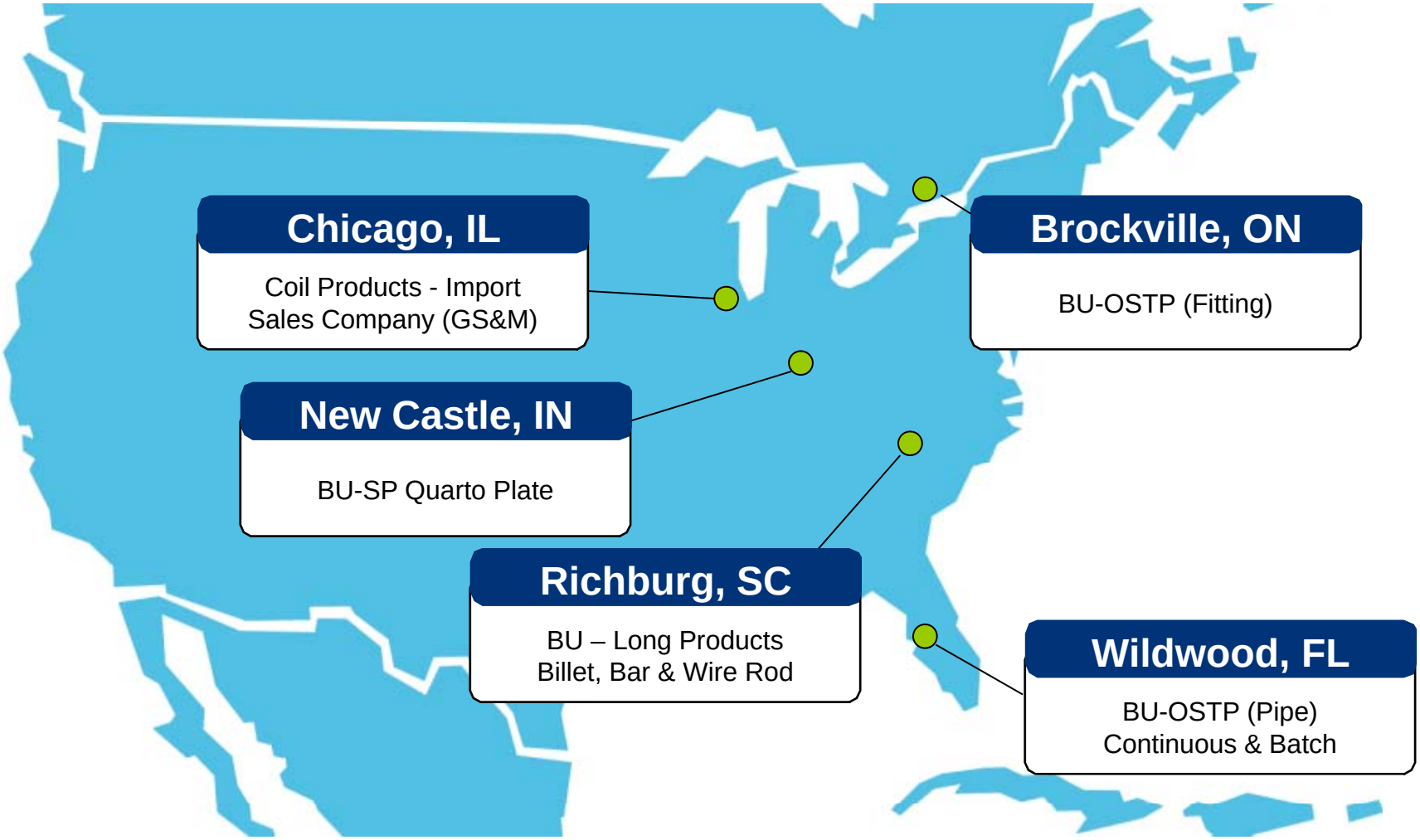
Geographical presence

Outokumpu's global operations



■ Production facilities ● Sales and Service Centres ● Sales Offices ● Sales & Stock ▲ Agents

North American Locations

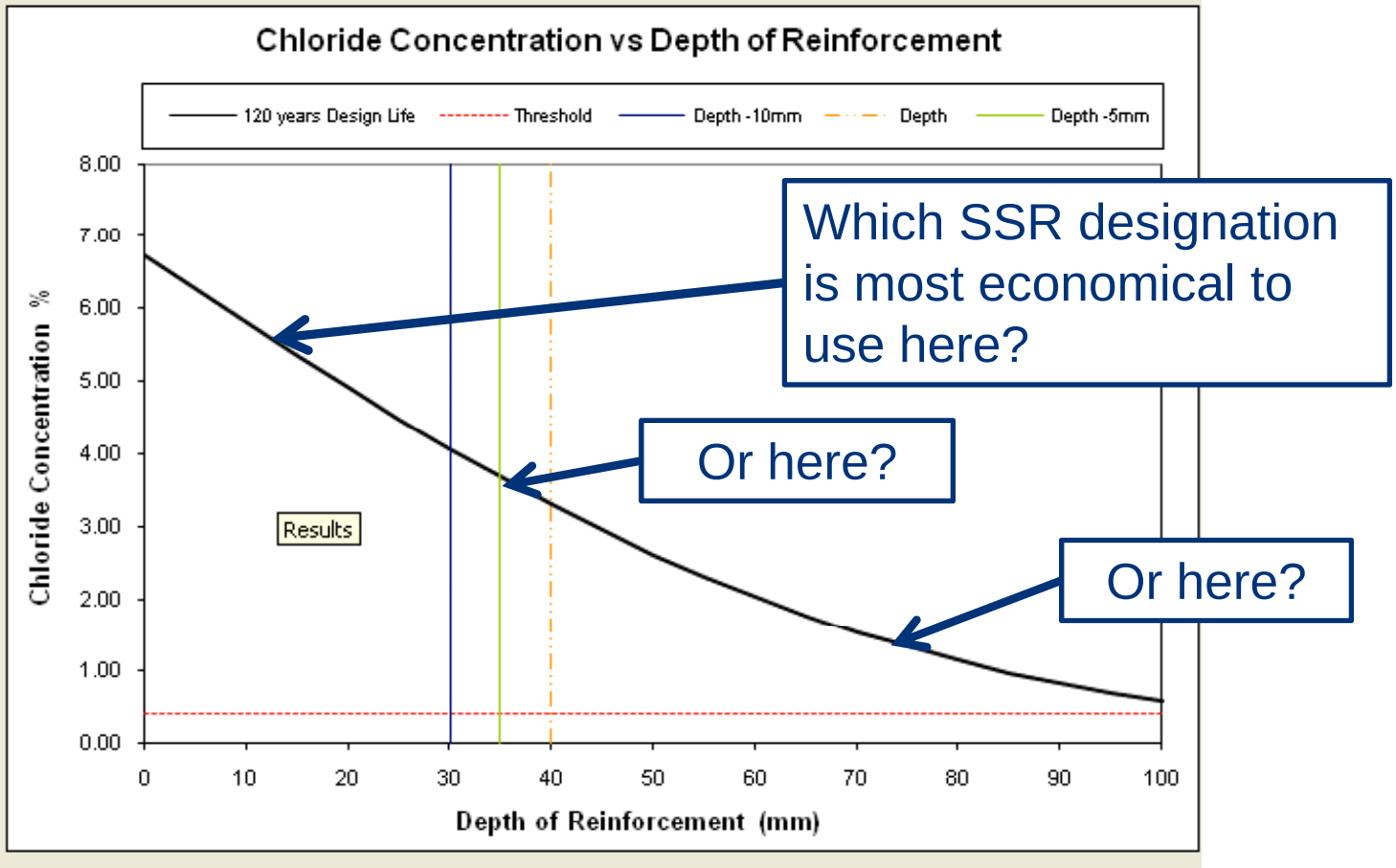


Determining Critical Chloride Threshold Levels for Stainless Steel reinforcement

www.outokumpu.com

Why are critical chloride thresholds needed?

- Cost effective selective use of stainless steel reinforcement requires knowledge of where it should be used

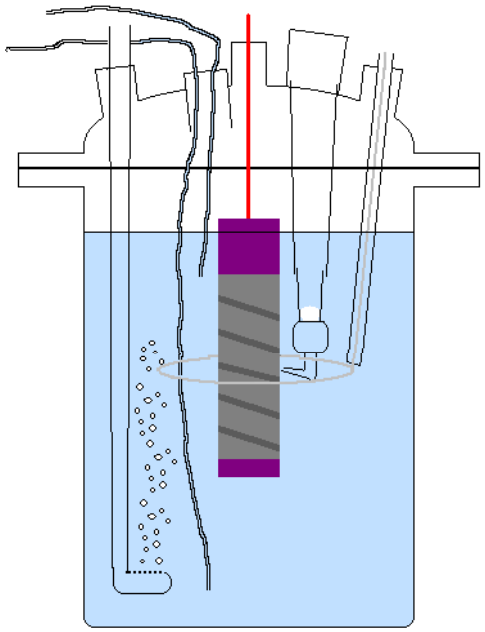


Testing program

- Goal: Obtain reliable data for the chloride tolerance of different types of commercially produced stainless steel reinforcement
- We are not measuring chloride diffusion, time to corrosion etc.
- Measurements should be simple, fast and able to produce statistically consistent data
- Three steps:
  - in-solution tests,
  - cast-in solution tests and
  - concrete blocks

The simple start – in-solution testing

- A synthetic version of the pore-solution of an OPC ($Ca(OH)_2$, KOH and NaOH)
- Increase the potential of the specimen to force corrosion and measure the current (+200 mV vs. SCE)
- Chlorides added slowly (0.35 wt.% every 12th hour) up to 10.6 wt.% (by weight of solution).
- Method used by Bertolini** et al. and Hurley and Scully*

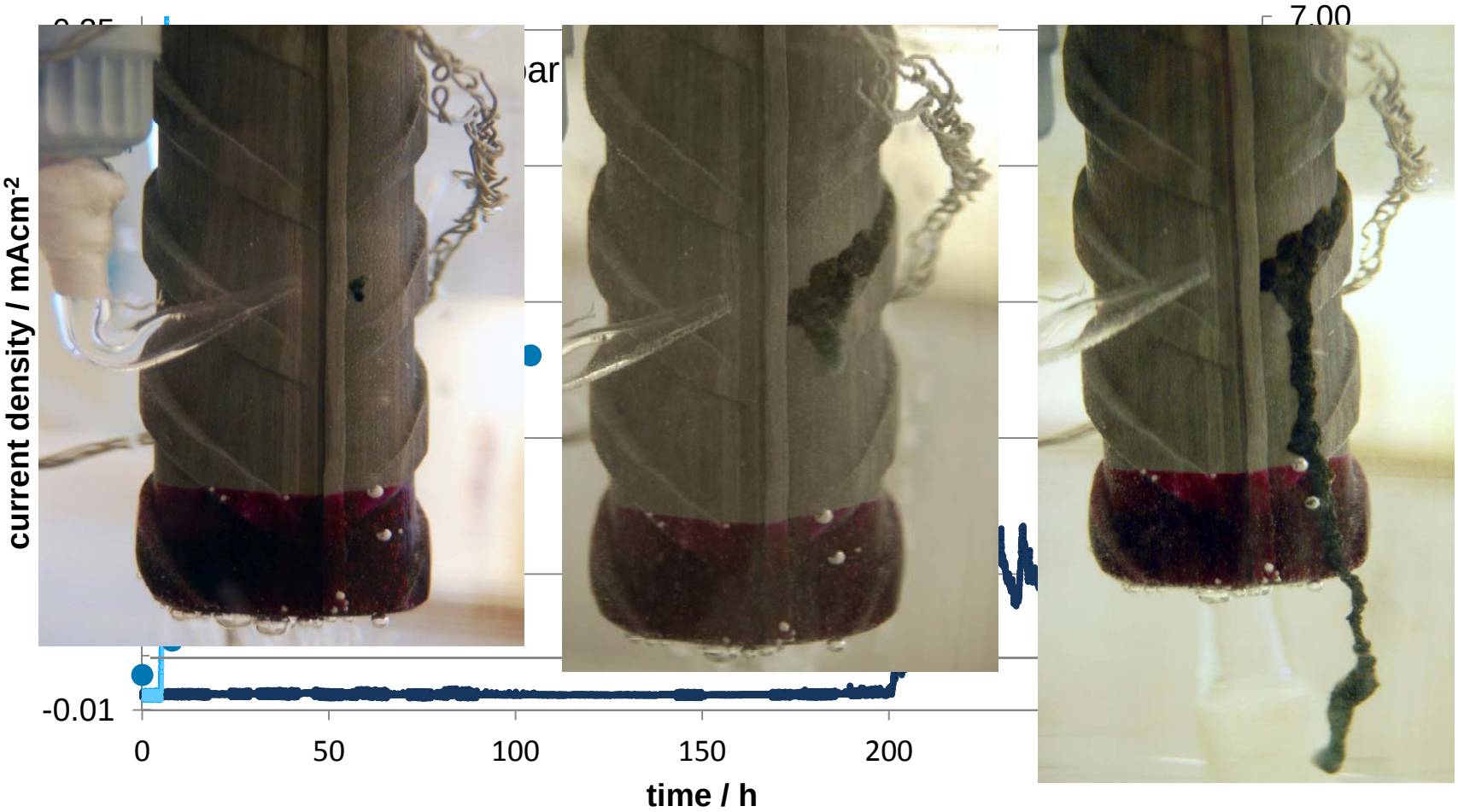


+ Homogenous distribution of chlorides
+ All chlorides are free chlorides
+ Homogenous environment (pH, oxygen, temperature, moisture)
+ Visible onset of corrosion

- **No solid concrete matrix**
- Rather rapid chloride increase
- Effect of the increased potential

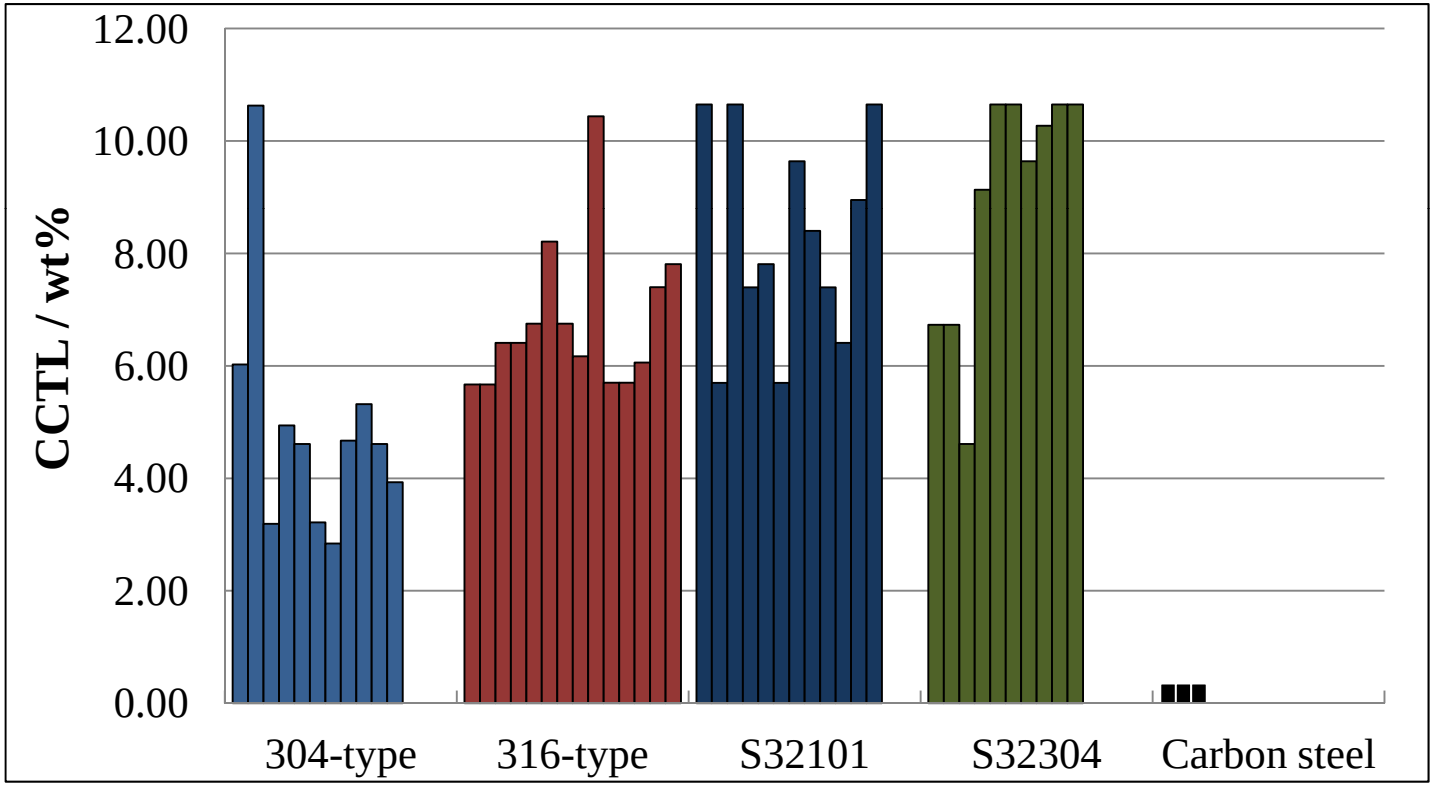
*Hurley M.F., Scully J.R. Corr. 62 (10) (2006) 892-904
**Bertolini L., Bolzoni F., Pastore T., Pedeferri P., Br. Corr. J. 13 (1996), 218-222

Visual confirmation of the results

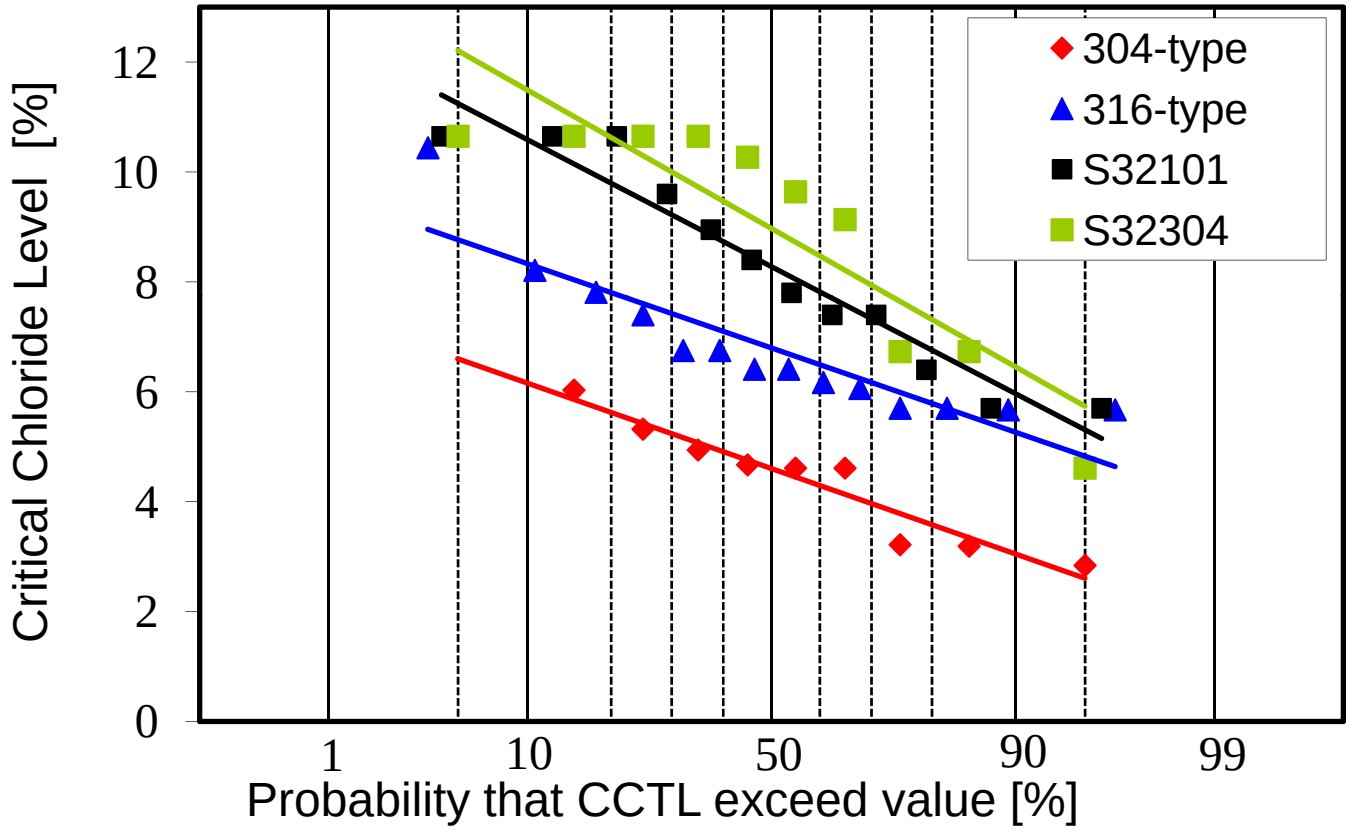


From: S. Randström, M. Almén, R. Pettersson, M. Adair, Stainless steel rebars – Influence of the surface state on the Critical Chloride Threshold Level , Stainless Steel World 2010, Oct. 5-7, Houston, 2010

Doing this over and over again for different stainless steels grades...



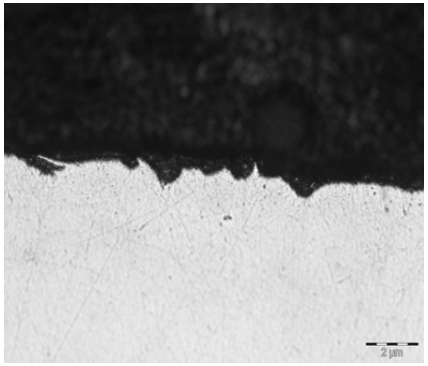
And treat it as a probability rather than a mean value



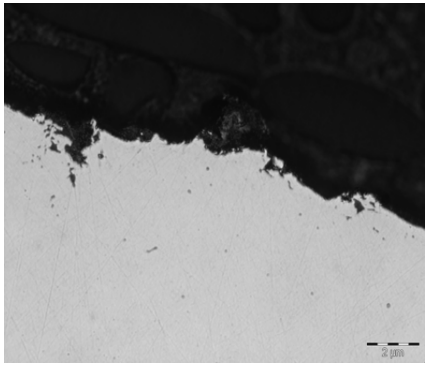
S. Randström, M. Almén, R. Pettersson, M. Adair, Reproducibility of critical chloride threshold levels for stainless steel reinforcement, Structural Faults and Repair 2010, Edinburgh

The influence of surface finish and texture

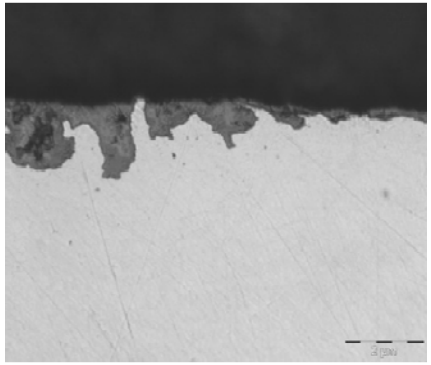
- Test comparison: properly pickled surface, sand blasted surface, non-pickled mill scale surface and over-pickled surface



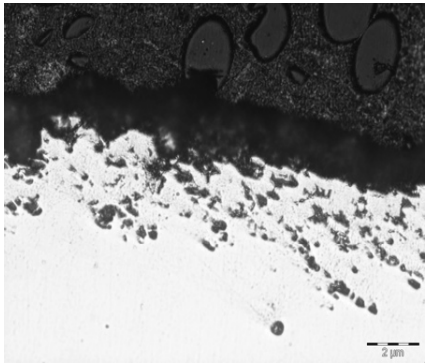
Standard properly pickled



Sand-blasted



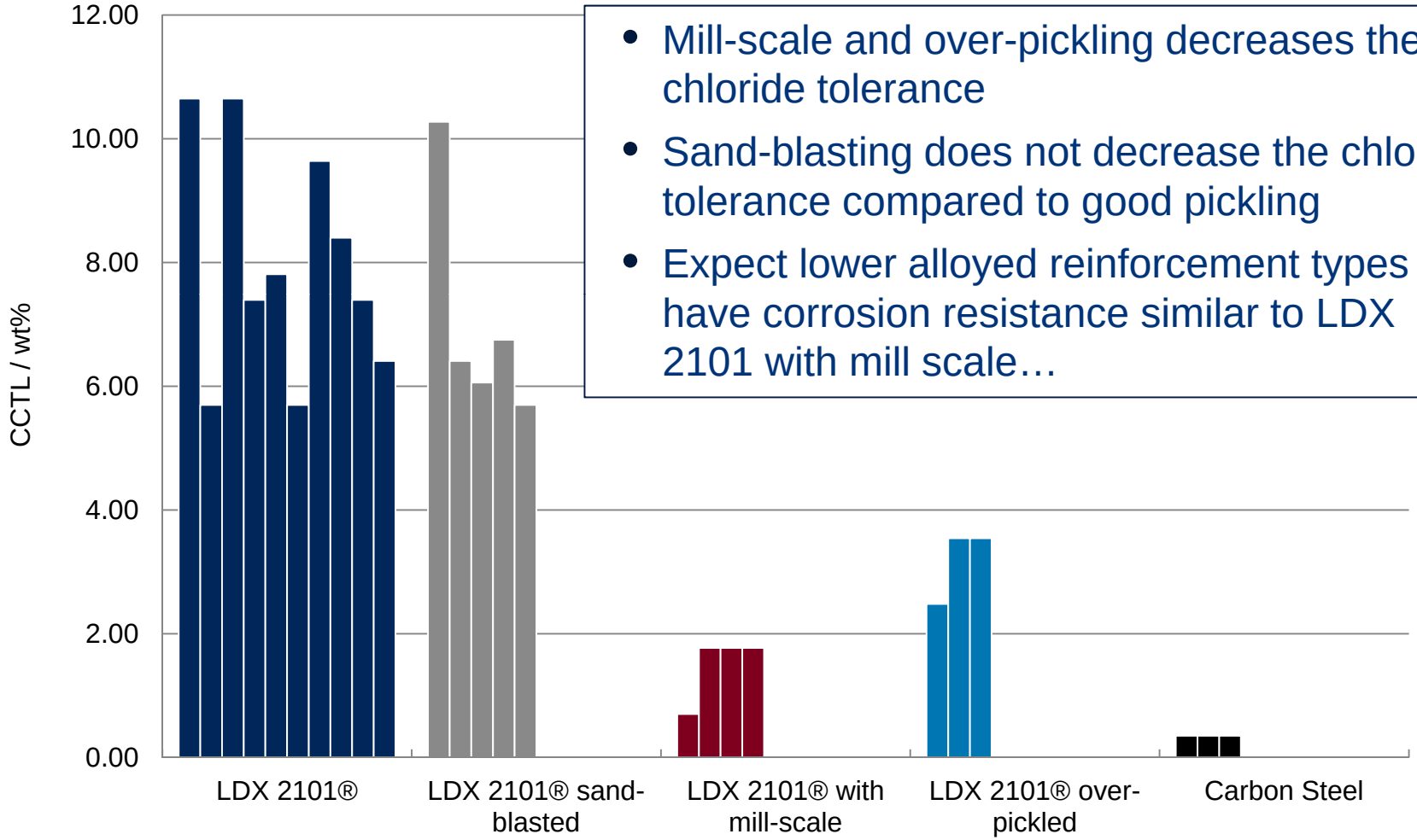
As-rolled (with mill scale)



Over-pickled

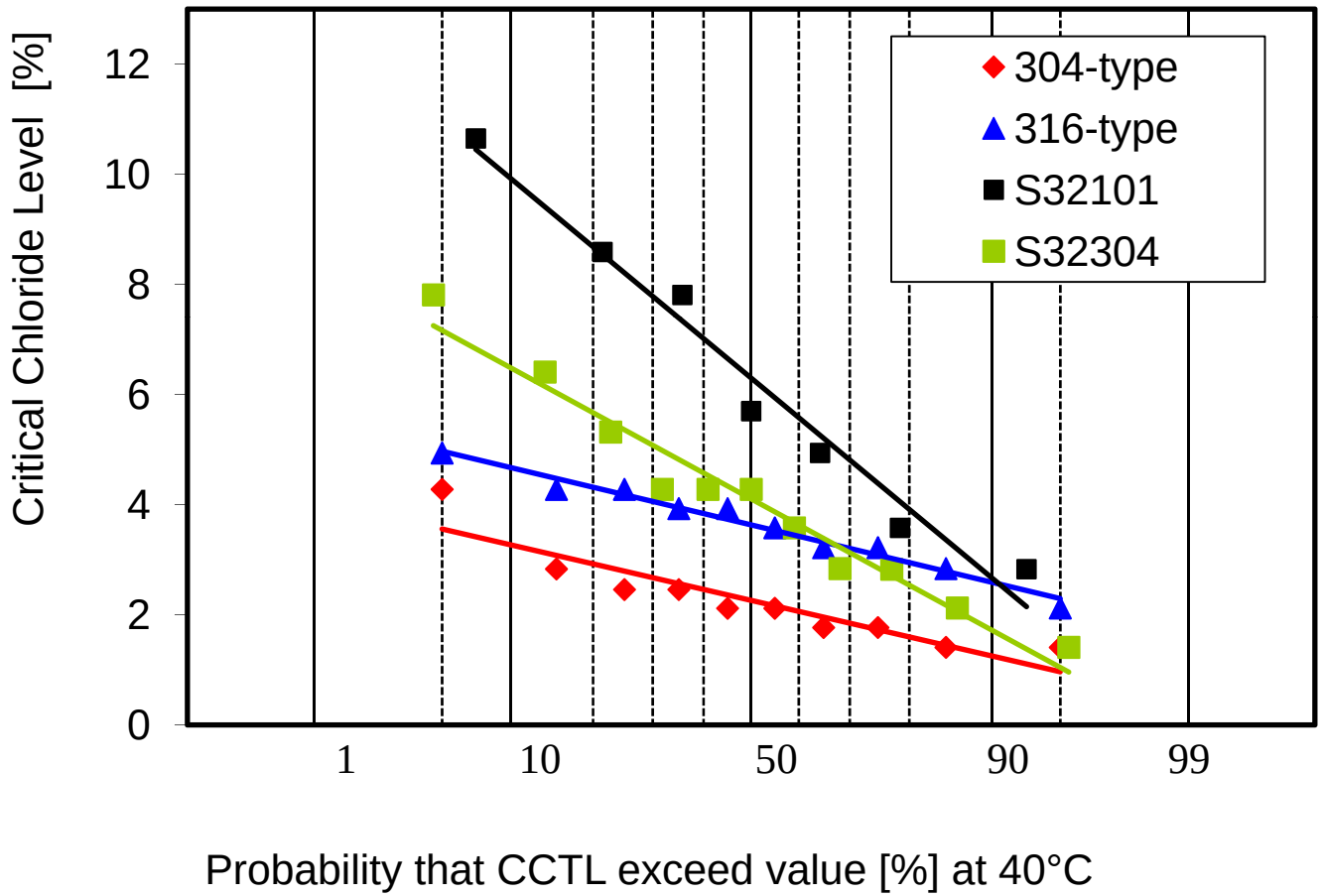
S. Randström, M. Almén, R. Pettersson, M. Adair, Stainless steel rebars – Influence of the surface state on the Critical Chloride Threshold Level, Stainless Steel World 2010

Effect of surface finish on critical chloride threshold level



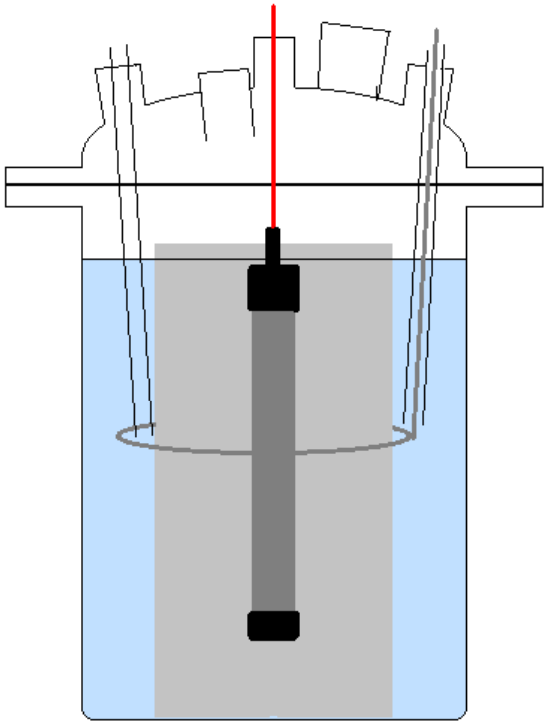
- Mill-scale and over-pickling decreases the chloride tolerance
- Sand-blasting does not decrease the chloride tolerance compared to good pickling
- Expect lower alloyed reinforcement types to have corrosion resistance similar to LDX 2101 with mill scale…

Influence of temperature



Next step – add a solid mortar matrix

- The standard test EN 480-14:2006 (European) has a similar setup but with a solid mortar matrix
- Originally developed to test the detrimental effect of admixtures on carbon steel
- But modified by
  - Mixing in chlorides as the admixture for testing stainless

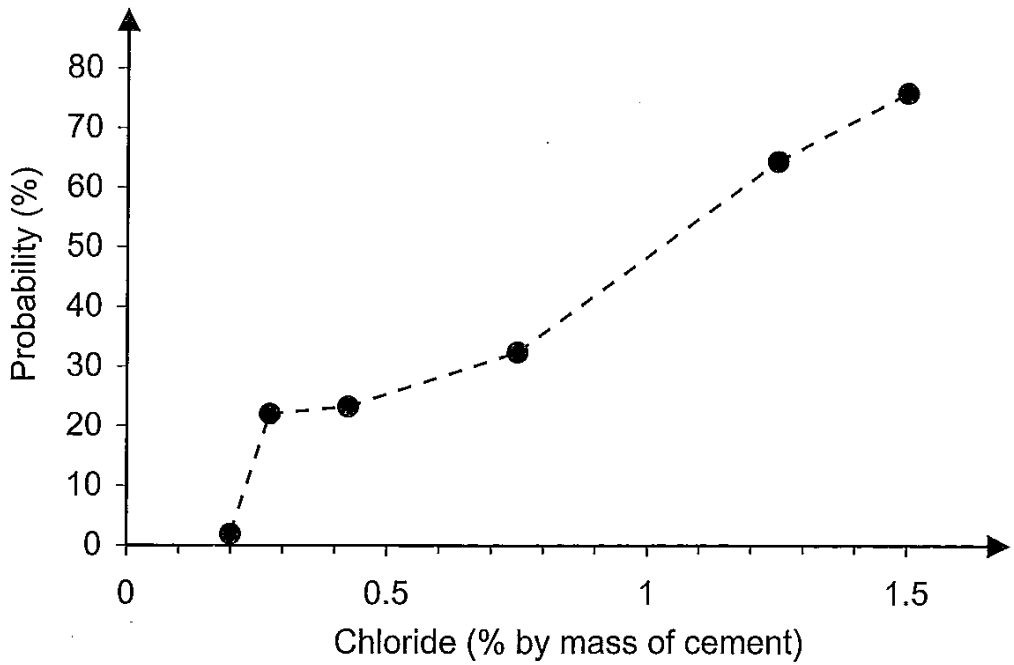


+ Solid matrix present
+ Homogenous distribution of chlorides
+ Constant T, pH and moisture

- Fixed chloride level
- Mixed-in chlorides
- Effect of the increased potential

Using probability to predict performance

- A 90% probability for passing the test means at least ten tests per alloy
- Specimens with a crevice beneath the protective lacquer were disregarded



Relationship between chloride content found in bridge decks and percentage of reinforcement showing corrosion

Image from: L. Bertolini, B. Elsener, P. Pedeferri, R. Polder: Corrosion of Steel in concrete, Wiley, 2004, but originally from P.R. Vassie, Proceedings of the Institution of Civil Engineers, 1984

Results 4 wt% chlorides

- 4 wt% chloride level is not likely to be exceeded in marine splash zone[1]
- All of the tested stainless steel rebars passed the test at 4% chlorides by cement weight

Stainless steel grade	304L	316L	LDX 2101®	2304	CS
Total number of specimens tested	10	12	13	12	3
Number of specimens with crevice corrosion (i.e. disregarded specimens)	0	2	1	1	0
Number of approved tests	10	9	11	11	0
Number of specimens failing the test	0	1	1	0	3

1. Using LIFE 365 prediction model, assuming concrete cover of 40mm and a diffusion coefficient of 10^{-12} m^2/s.

From: M. Schönning, S. Randström , M. Adair, Adaption of EN 480-14:2006 as a test method for determining a critical chloride threshold level for stainless steel rebar , Eurocorr 2011

And third step: Cast-in blocks

- Already tested
  - Blocks with cast-in chlorides up to 2.6 wt% by mass of cement*
  - Swedish outdoor environment for 2 years.
  - Swedish Corrosion Institute (KIMAB), the nuclear power industry, Swedish Transport Authorities and Gothenburg port
- The stainless steel grades tested in this environment did not corrode including 304, 316, LDX 2101®.
- Ongoing
  - New project with up to 10wt% chlorides

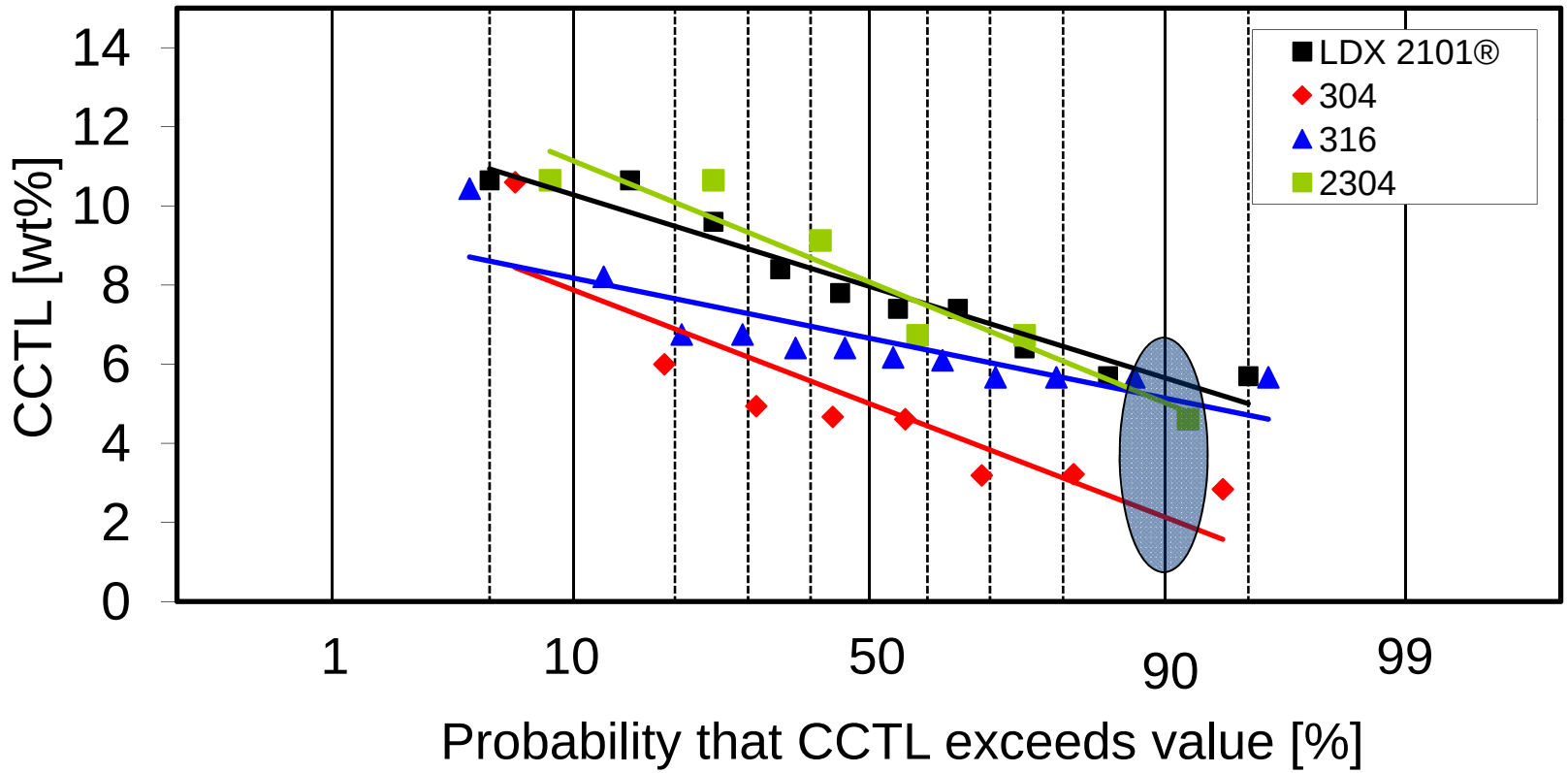
*B. Sederholm, J. Almqvist, S. Randström, Corrosion Properties of Stainless Steels as Reinforcement in Concrete in Swedish Outdoor Environment, Paper 09203, CORROSION 2009, Atlanta

Reproducibility and scatter

- Some scatter was observed independent of the stainless steel designation
- Should the CCTL be reported as a discrete number?
- For carbon steel in concrete, chloride tolerance is 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?

Accumulated probability graph

- The probability that CCTL exceeds measured value should be high
- At 90% probability, no differences can be seen between LDX 2101®, 2304 and 316 while 304 has slightly lower chloride tolerance



Conclusions 1 (2)

- Use modeling to estimate when and where 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 finish 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

Conclusions 2 (2)

- Stainless rebar can and should be used in conjunction with carbon steel rebar for more cost effective design of critical components in corrosive chloride environments

- LDX2101® is a very cost competitive grade 75
  - Meets ASTM A955 corrosion resistance test requirements

- The chloride tolerance of LDX 2101® and 2304 are comparable to Type 316 and superior to Type 304

Questions??