COLUMBUS STAINLESS (Pty) Ltd

3CR12

100 YEARS OF STAINLESS STEEL

ACERINOX

your future in STAINLESS

Stainless Steels for Hot Water Tanks

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Hot Water Tanks

* **Columbus Stainless**
  - History
  - Processes
* **Material Selection for hot water tanks**

  Austenitic, ferritic and duplex stainless steels
* **History of Duplexes**
  - Around the world
  - Columbus Stainless
* **Duplexes for hot water tanks**
  - Laboratory testing
  - Conclusions

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History of Columbus Stainless

1966	First stainless produced in Middelburg, part of Rand Mines Group
1979-1981	Expansion to 150 000 tons/year
1991	Columbus Joint Venture formed (IDC, Highveld Steel & Vanadium, Samancor)
1992-1995	Expansion to 500 000 tonnes/year
2002	Acerinox acquired 64% of Columbus Stainless
2002-2004	Investment plans implemented and achieved 720 000 tons 2004
2005	Acerinox acquired Highveld Steel & Vanadium's 12% shareholding in Columbus Stainless
2011 →	Investment to improve quality and flexibility

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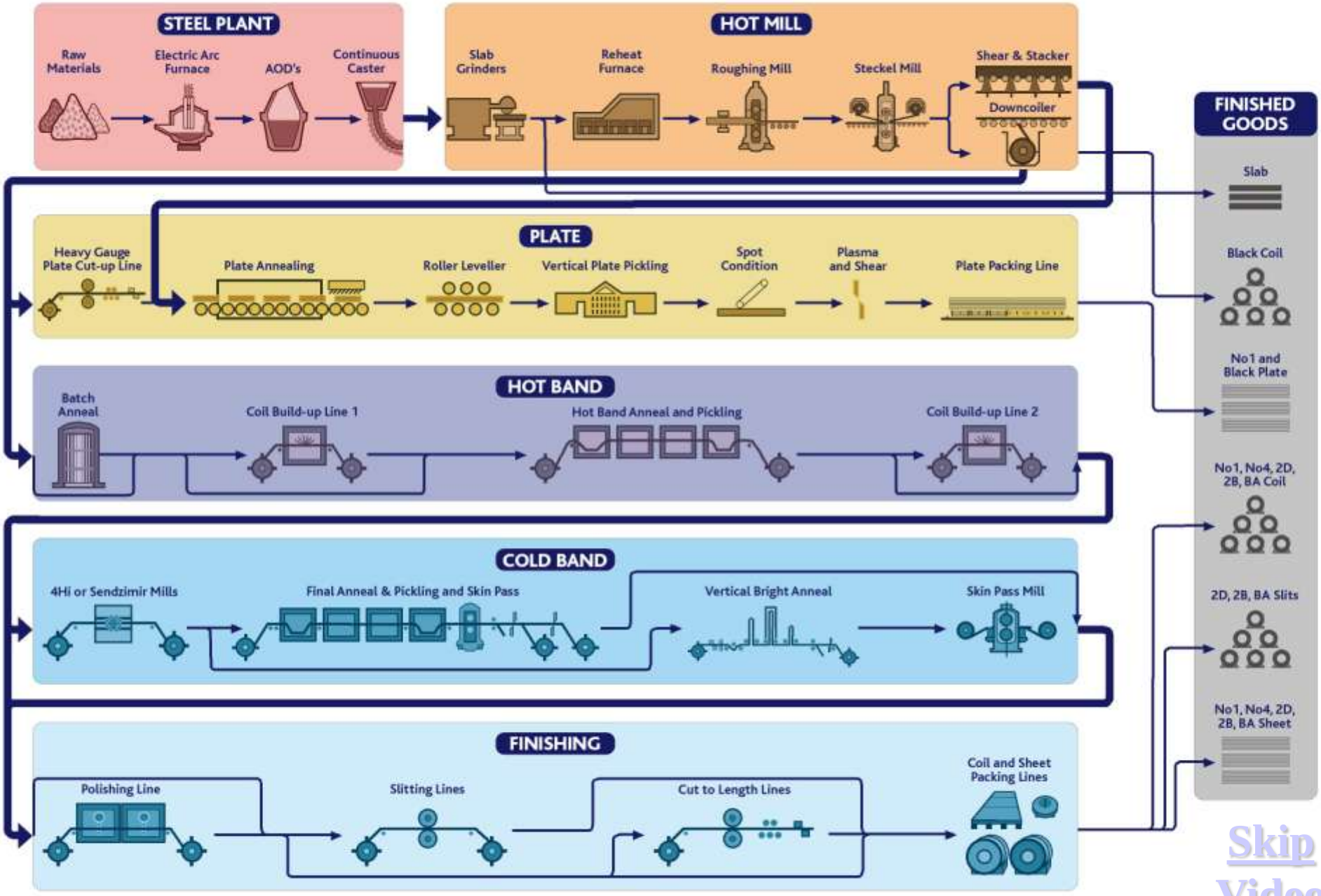
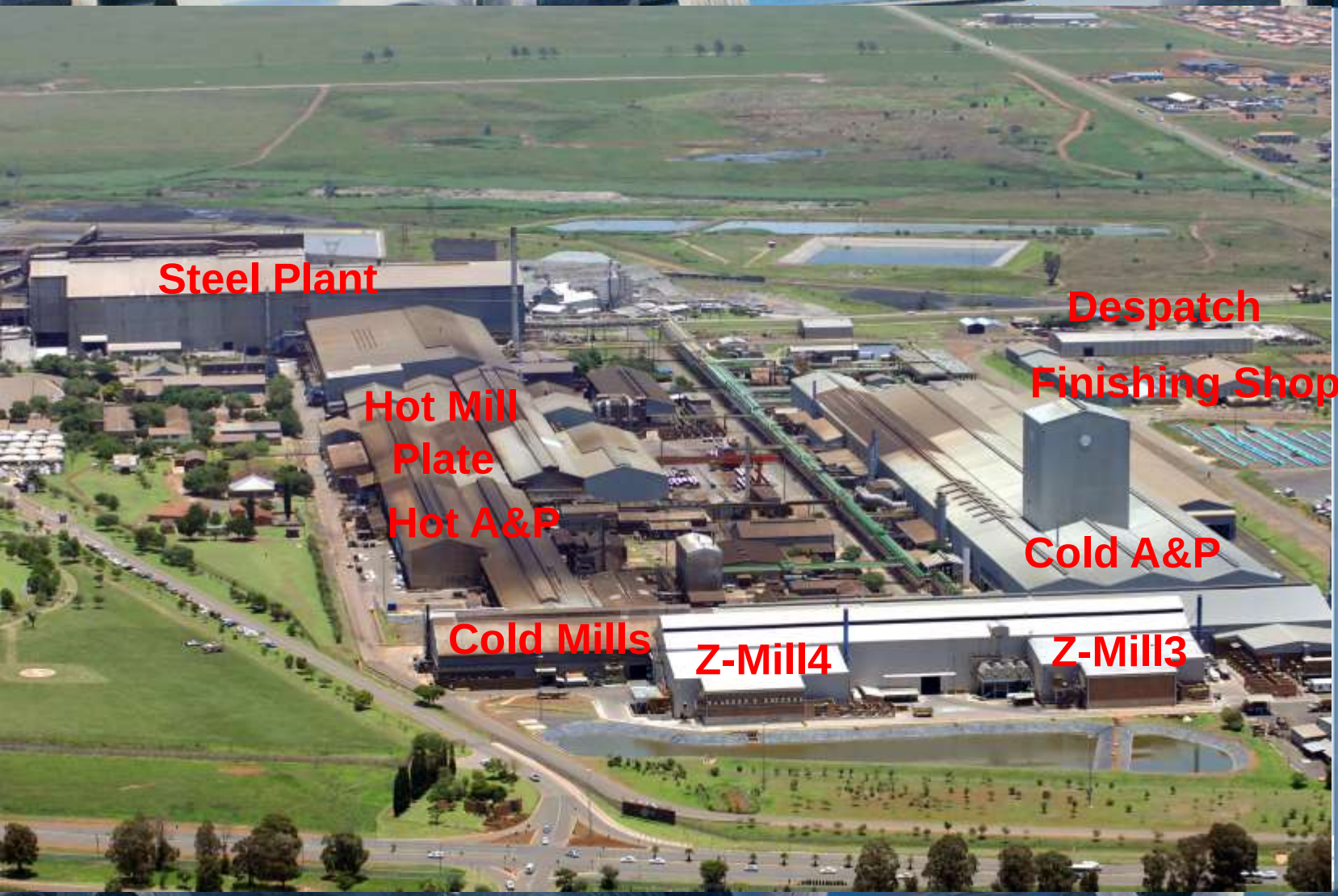

STEEL PLANT
Raw Materials
Electric Arc Furnace
AOD's
Continuous Caster
HOT MILL
Slab Grinders
Reheat Furnace
Roughing Mill
Steckel Mill
Shear & Stacker
Downcoiler
PLATE
Heavy Gauge Plate Cut-up Line
Plate Annealing
Roller Leveller
Vertical Plate Pickling
Spot Condition
Plasma and Shear
Plate Packing Line
HOT BAND
Batch Anneal
Coil Build-up Line 1
Hot Band Anneal and Pickling
Coil Build-up Line 2
COLD BAND
4Hi or Sendzimir Mills
Final Anneal & Pickling and Skin Pass
Vertical Bright Anneal
Skin Pass Mill
FINISHING
Polishing Line
Slitting Lines
Cut to Length Lines
Coil and Sheet Packing Lines
FINISHED GOODS
Slab
Black Coil
No1 and Black Plate
No1, No4, 2D, 2B, BA Coil
2D, 2B, BA Slits
No1, No4, 2D, 2B, BA Sheet

Skip Video

Aerial Photograph



Hot Water Tanks

* **Historically**
  - 316L or 304L used
    - Stress Corrosion Cracking
  - 444 used extensively in Japan and Scandinavia
    - Fabrication difficulties
  - 441 used in South Africa
    - Pitting if fabrication and design substandard
    - Fabrication difficulties
  - 3CR12 used in South Africa
    - Pitting if fabrication and design substandard
    - Weld HAZs tend to pit

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Hot Water Tanks

* **Material Selection**
  - Corrosion resistance
  - Formability
  - Weldability
  - Strength

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Hot Water Tanks

* **Material Selection**
  - Corrosion resistance
    - Stress Corrosion Cracking

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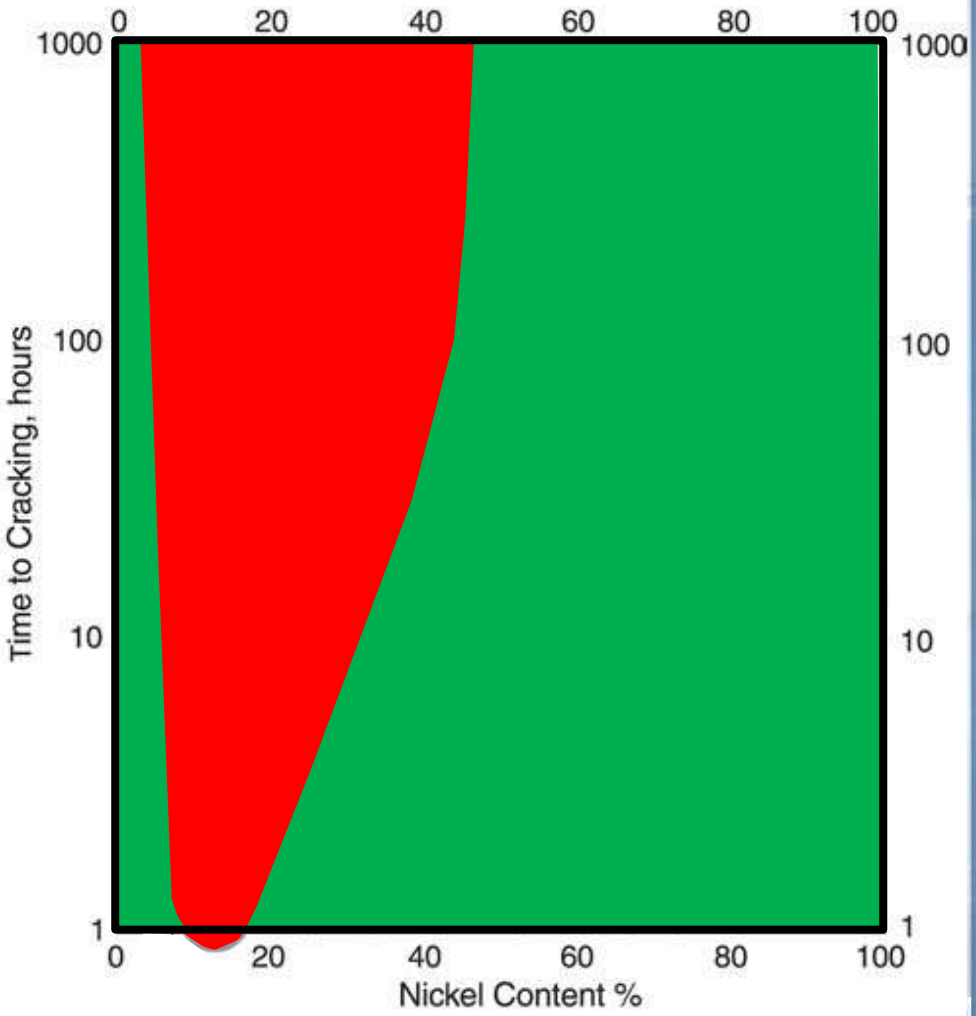
Stress Corrosion Cracking

Susceptibility to Chloride Stress Corrosion Cracking Boiling 42% $MgCl_2$ Test



SCC 304 Solar HWT

Hot Water Tanks

* **Material Selection**
  - Corrosion resistance
    - Stress Corrosion Cracking
      - Austenitics are prone
      - Ferritics and duplexes are resistant

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Hot Water Tanks

* **Material Selection**
  - Corrosion resistance
    - Stress Corrosion Cracking
    - Pitting Resistance

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Pitting Resistance

* **PRE to Predict Pitting Resistance**
  - PREcs = 1.1Cr + 2.2Mo + 24N -1.5Mn +0.25Ni
    - 304L or 2001, 2101, 441, 434 and 436
    - 316L or 2304, 444
    - 2205 much better than 316L
  - Choose suitable stainless steel based on
    - Environment (water quality, chlorides and temperature)
    - Fabrication practices

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Hot Water Tanks

* **Material Selection**
  - Corrosion resistance
  - Formability
    - Austenitics = 40% elongation, Rm – Rp = 320MPa
    - Duplex = 25% elongation, Rm – Rp = 250MPa
    - Ferritics = 20% elongation, Rm – Rp = 200MPa

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Hot Water Tanks

* **Material Selection**
  - Corrosion resistance
  - Formability
  - Weldability
    - Austenitics – no limitations
      - Tough welds
    - Duplex – controlled heat input, use filler and N shielding
      - Tough welds
    - Ferritics – low heat input, thin gauges,
      - Brittle welds

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Hot Water Tanks

* **Material Selection**
  - Corrosion resistance
  - Formability
  - Weldability
  - Strength
    - Austenitics – 250MPa
    - Duplexes – 500MPa
    - Ferritics – 250MPa

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Hot Water Tanks

* **Material Selection Conclusion**
  - Duplexes are material of choice
  - Best combination of properties
  - Choose duplex to suit environment

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History of Duplexes

* **First duplex in 1929 in Sweden**
  - Type 329 developed after 1945
* **Patent granted in France in 1935**
  - Uranus 50 and became 2404
* **Second generation duplexes in 1980s**
  - **2205** (PRE 35) – 50% of duplex use
  - Lean duplexes such as **2304** and **2001** (PRE<30)
    - 2304 was first and most well known lean duplex
    - 2001 Armco patent in 1988 for automotive applications
    - 2101 Outokumpu patent in 2002
  - Super duplexes (PRE>40)

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Columbus Duplexes

* **First produced duplex in 1980s**
  - SAF 2205 under license from Sandvik
* **Lean Duplexes**
  - R&D started in 1990
    - 160 lab heats, hot rolled and annealed plates
    - Doctoral thesis in 1995
      - Alloy same as 2101 without 1% nickel
        - Patent
        - Production
        - Prototype trials – mining industry in South Africa

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Columbus Duplexes

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  - R&D started in 1990
    - 160 lab heats, hot rolled and annealed plates
    - Doctoral thesis in 1995
      - Alloy same as 2101 without 1% nickel
  - Production of tried and tested grades in 2005
    - Already in all relevant specifications
    - Already have applications history
    - Successfully produced around the world

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Columbus Duplexes

* **Rationale for Columbus duplex range**
  - 2205 as this is 50% of the duplex market
  - 2304 as 316 equivalent
  - 2001 as 304 equivalent

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Columbus Duplexes

* **What is 2001?**
  - Patented in the USA in 1988 by Armco
  - Marketed as Nitronic 19D
    - Good toughness
    - Good ductility
    - Good corrosion resistance
    - Good SCC resistance
    - Strength
    - Good forming and drawing characteristics
    - Ease of welding

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Columbus Duplexes

* **What is 2001?**
  - Patented in the USA in 1988 by Armco
  - Marketed as Nitronic 19D
  - Developed for automotive industry
    - Automotive modular frame
  - Major application undersea oil umbilical tubing

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Hot Water Tanks

* **Extensive Lab Benchmark Testing**
  - Columbus Metallurgical Laboratory
  - Acerinox Europa R&D+I Laboratories
  - Mintek Research Laboratories
* **Columbus Duplexes for Hot Water Tanks**
  - Extensive fabrication record
  - Hot water tank application history

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Material Selection for HWT

- Standard tests cannot predict fitness for purpose
  - Must replicate real life
    - Immersion testing
      - 6% $FeCl_3$ (ASTM G48, practice A) at 18°C
      - Reducing environment (stagnant, silt, scale)
    - Critical Pitting Temperature
      - 3.5% $FeCl_3$
      - 250ppm chlorides
    - Cyclic potentiodynamic polarization (CPP)
      - 3.5% NaCl at 30°C – PRE vs. PREcs
      - Potable water with 250ppm chlorides at 65°C
    - Salt Spray
      - 5% NaCl (ASTM G85) – fabrication effects

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Material Selection for HWT

* **6% $FeCl_3$ (ASTM G48, A) at 18°C**
  - To test pitting and crevice corrosion
    - University of Sheffield
    - Full results not available

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Material Selection for HWT

* **Corrosion Resistance in reducing acids**
  - To test stability of passive layer
    - Immersion weight loss in sulfuric acid
    - Stability important
      - Deaerated or stagnant conditions
      - Silt deposits
      - Scaled tanks

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Material Selection

* **Sulfuric acid at room temperature**
  - 2001 similar to 316
  - 2001 iso-corrosion curve double 2101 at 20°C

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Water Corrosion

* **2001, 2101, 444 in 250ppm chlorides**
  - Electrochemical pitting scans (CPT)
    - 300mV (potable water)
      - All had CPT > 80°C
    - 700mV (chlorinated seawater)
      - 444 = 38°C
      - S32001 = 34°C
      - S32101 = 44°C

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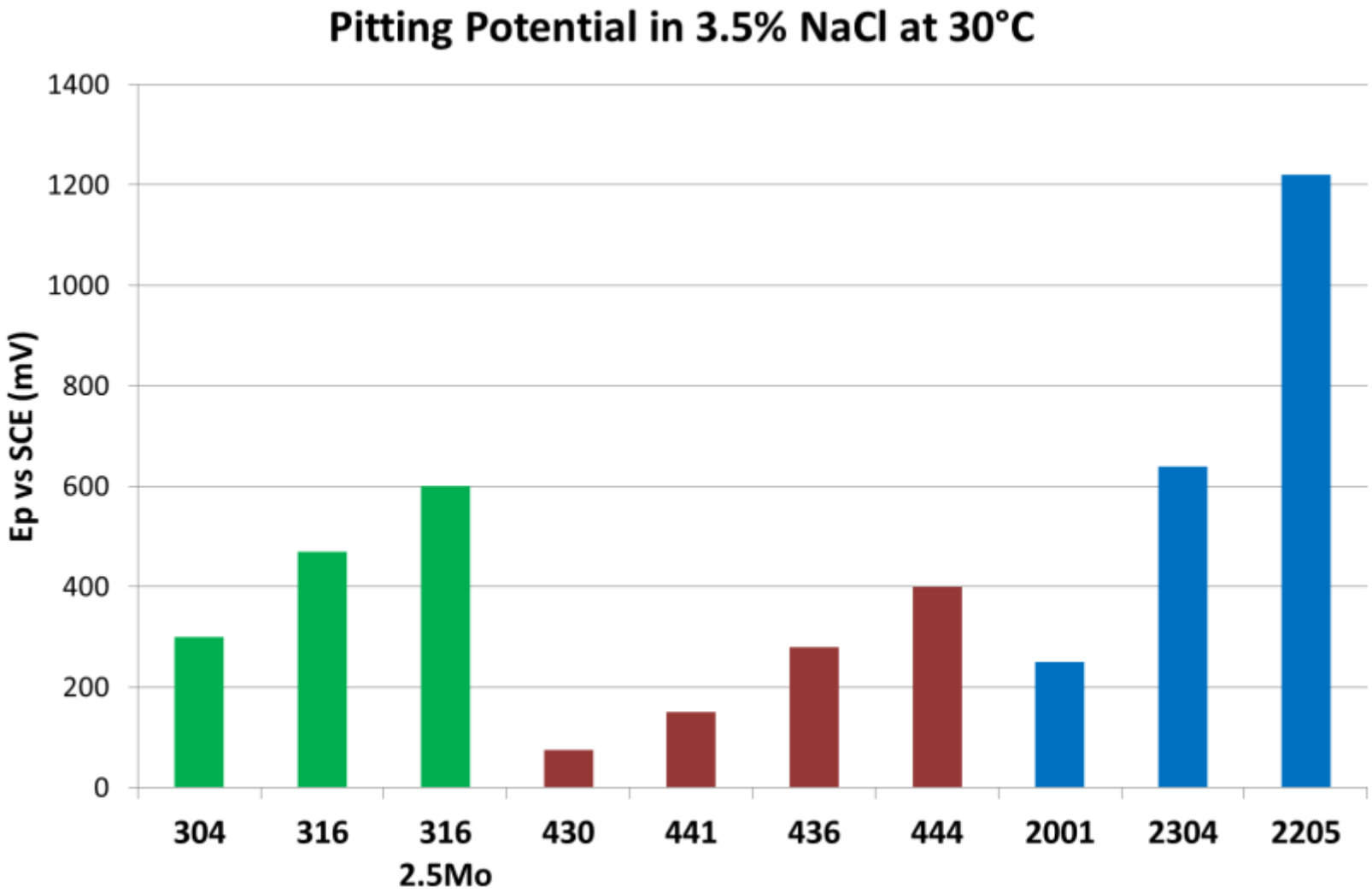
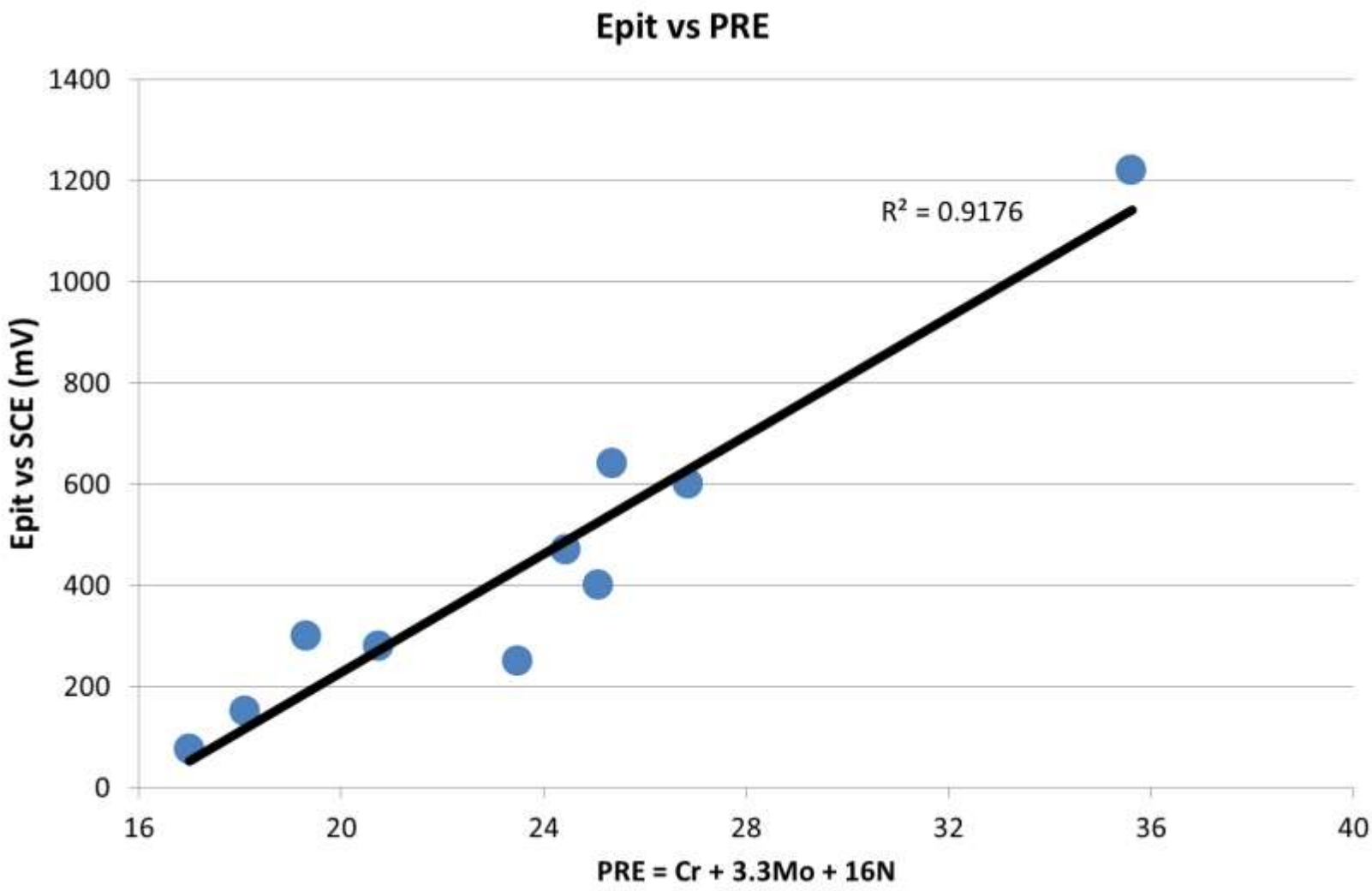
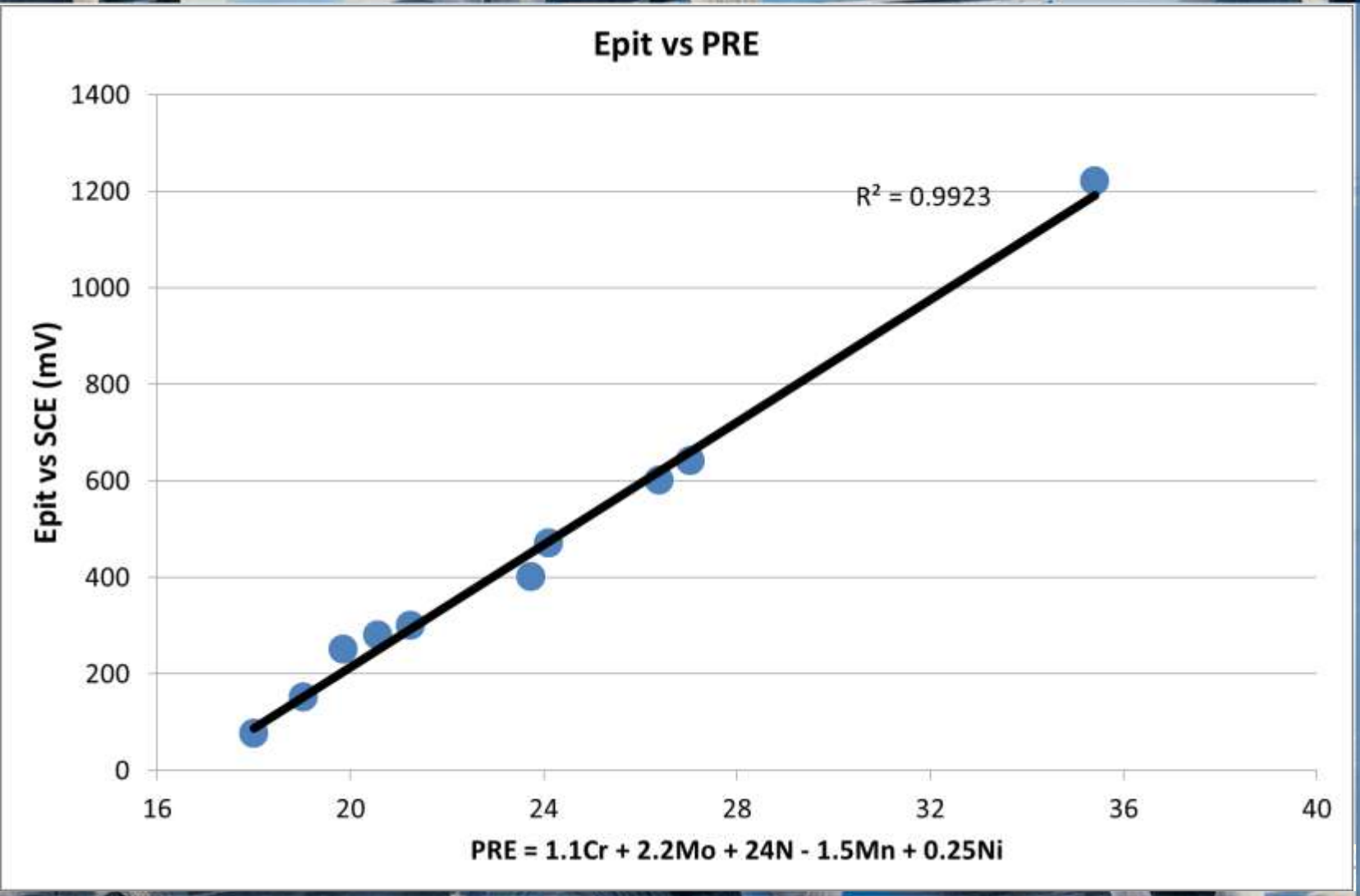
Pitting Resistance



Pitting Resistance



Pitting Resistance



Pitting Resistance

* PRE to Predict Pitting Resistance

- PRE
  - PRE = Cr + 3.3Mo + 16N
    - Ignores beneficial effect of nickel
    - Ignores detrimental effect of manganese
  - PREcs = 1.1Cr + 2.2Mo + 24N – 1.5Mn + 0.25Ni
    - Ni increases passive layer Cr:Fe ratio
    - Mn decreases pit initiation (MnS inclusions)
      - High Mn duplexes drops PRE by 4

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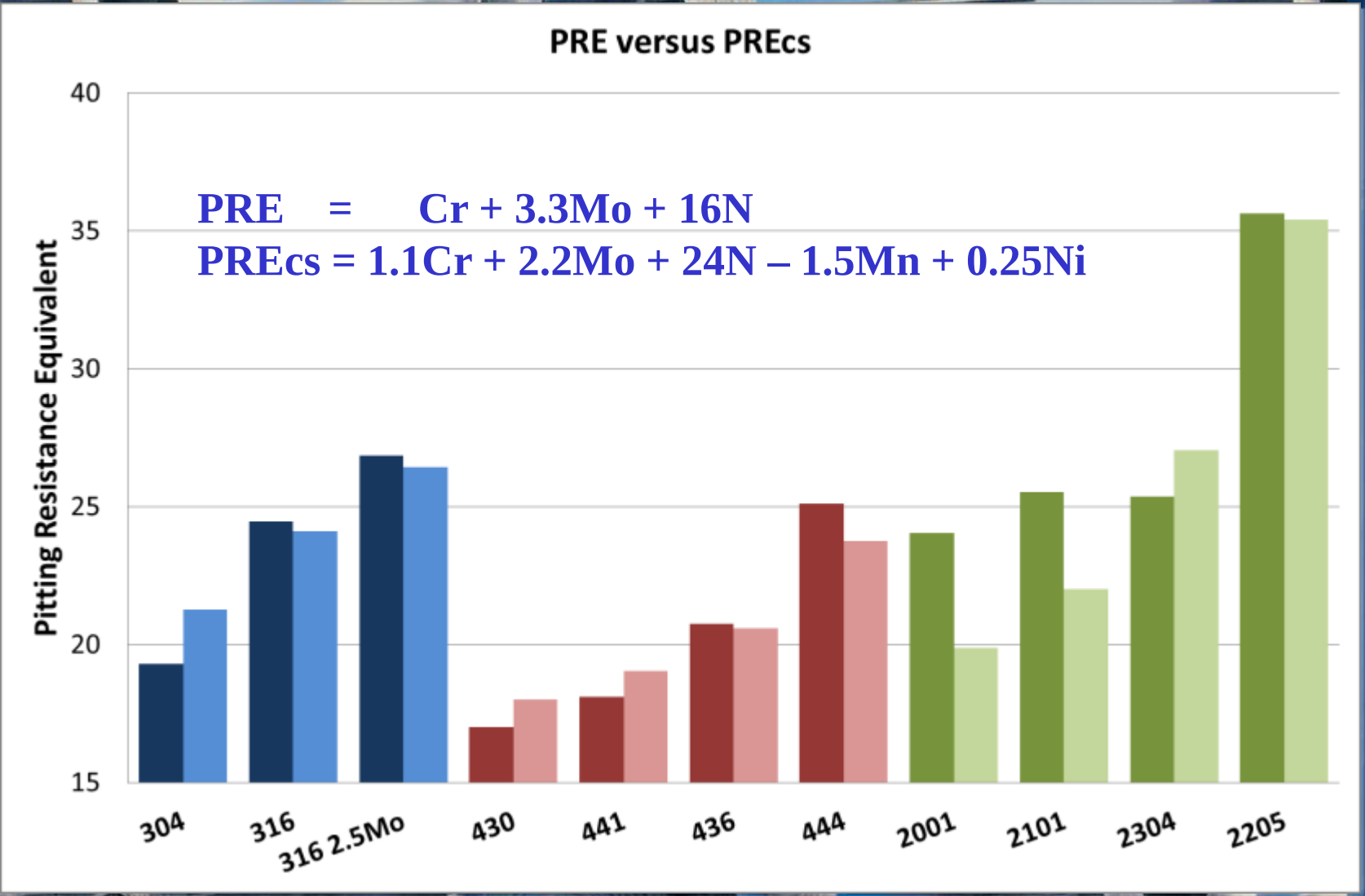
Pitting Resistance



PRE = Cr + 3.3Mo + 16N

PREcs = 1.1Cr + 2.2Mo + 24N – 1.5Mn + 0.25Ni

Material Selection

* **PREcs**
  - Literature
    - Difference of 2 is considered insignificant
  - Only useful as alloy ranking
    - Can not predict relative performance in specific conditions
      - 304, 441, 436, 2101 and 2001 similar
      - 2304 better than 316, same as 316 (2.5%Mo)
      - 2205 exceptionally good PRE

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Material Selection for HWT

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      - 250ppm chlorides
    - Cyclic potentiodynamic polarization (CPP)
      - 3.5% NaCl at 30°C – PRE vs. PREcs
      - Potable water with 250ppm chlorides at 65°C

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Water Corrosion

* **S32001, S32101, 444**
  - Cyclic polarisation scans
    - Maximum operating conditions for hot water tank
      - 65°C
      - 250ppm chlorides

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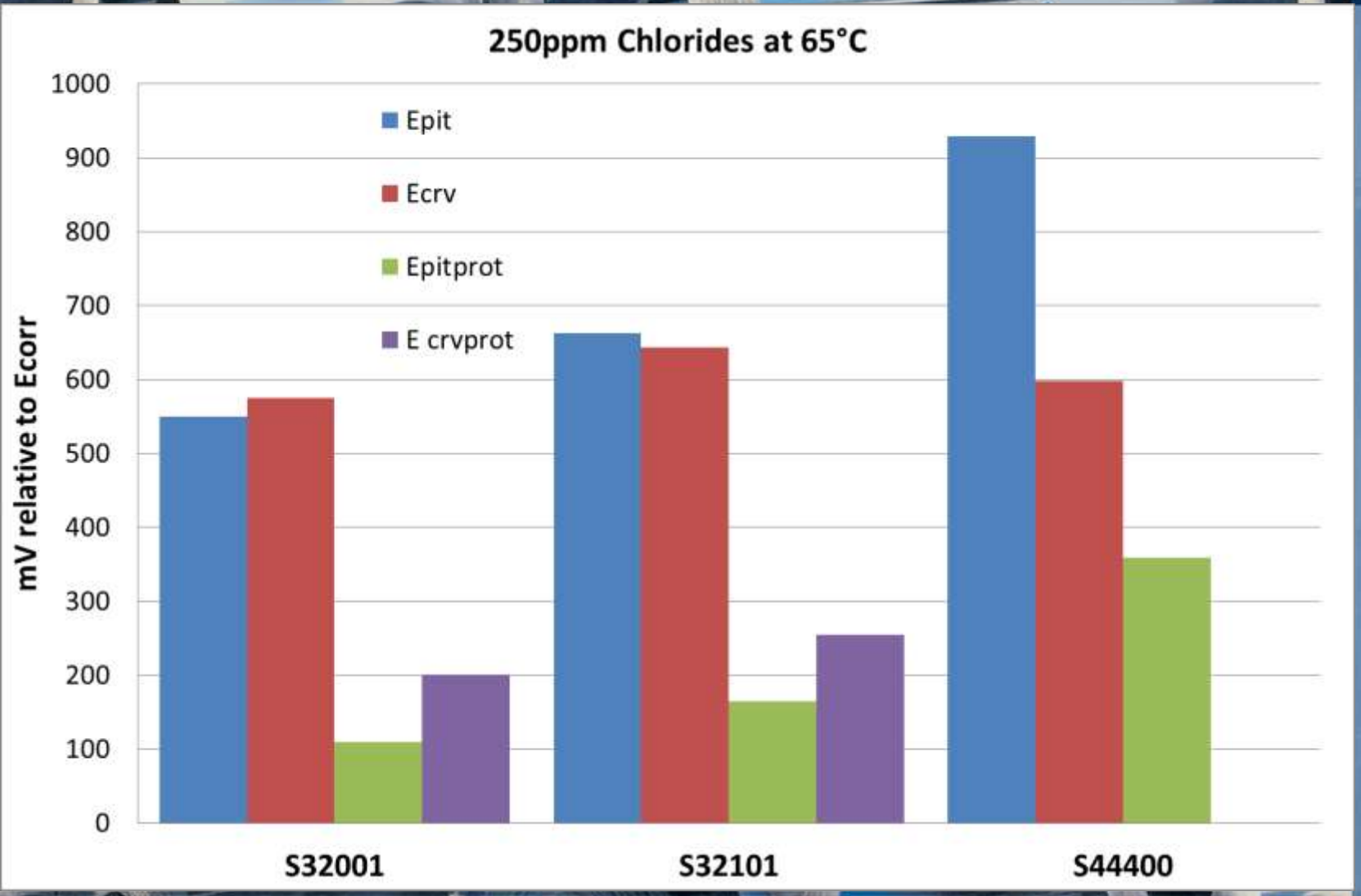
Cyclic Polarisation Scan



Water Corrosion

* **Cyclic Polarisation Scans** (250ppm Cl, 65°C)
  - All three alloys are unlikely to pit or crevice
  - 2001 and 2101 versus 444
    - Large hysteresis loop
      - Repassivation is difficult
    - All had low corrosion rates of 0.002mm/yr

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Water Corrosion

* **Salt Spray S32001, S32101**
  - Fabricated water tanks subjected to salt spray
    - No significant differences
    - Corrosion occurred at
      - Welds
      - Cut edges
      - Crevices

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Water Corrosion

* **Salt Spray S32001, S32101**
  - Good fabrication critical
    - Restore passive layer by Pickling and passivation
      - Welds and weld discolouration
      - Grinding or polishing
      - Exposed cut edges
    - Ensure good design
      - Eliminate crevices
      - Eliminate stagnant areas
  - Fabrication more important than steel difference

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Water Corrosion

* **Not just chlorides and temperature**
  - Corrosivity also determined by
    - pH
    - Sulphates
    - Alkalinity
    - Hardness
    - Conductivity
    - Total dissolved solids
    - Ionic strength

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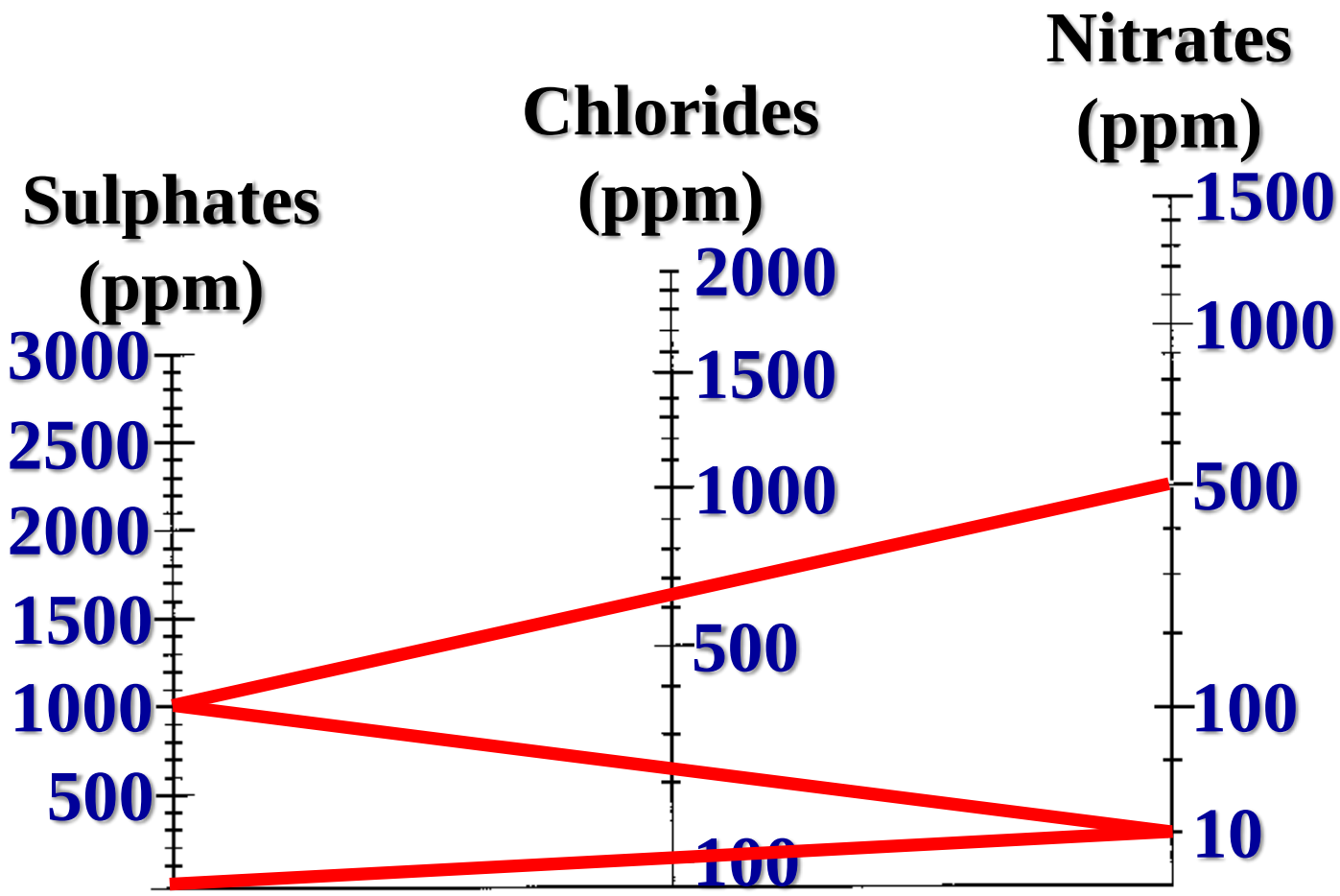
3CR12 Pitting Resistance



Potable Water Corrosion (65°C)

Max Cl^- (ppm)	Austenitic	Ferritic	Duplex
CONs	SCC Strength	Fabrication Strength	
PROs	Fabrication	SCC	SCC Strength
50ppm		3CR12	
150ppm	202	430, 439	
300ppm	304L	441, 434, 436	2101, 2001
700ppm	316L	444	
1 250ppm	316L (2.5Mo)		2304
5 000ppm			2205

Stainless Steels for Hot Water Tanks

* **Duplex is the Obvious Choice**
  - Strength, SCC resistance, fabricability
  - Which type
    - Operating conditions?
      - 2001 vs. 2304 vs. 2205
    - How good is the fabrication?
      - Poor fabrication demands 2304 or 2205
    - Ease of forming?
      - 2001, 2304, 2205 easier, less springback and memory than 2101
        - Due to lower nitrogen content gives less work hardening
* **2001, 2304 or 2205?**

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