BAM
Bundesanstalt für Materialforschung und -prüfung

Sicherheit in Technik und Chemie

27.11.2018

CHALLENGES FOR CORROSION RESISTANCE OF METALLIC MATERIALS IN GEOTHERMAL APPLICATIONS

Ralph Bäßler

Der Geothermie - Corrosion Workshop Kongress 2018

Pertamina: Geothermal Energy Report, Oct 2011

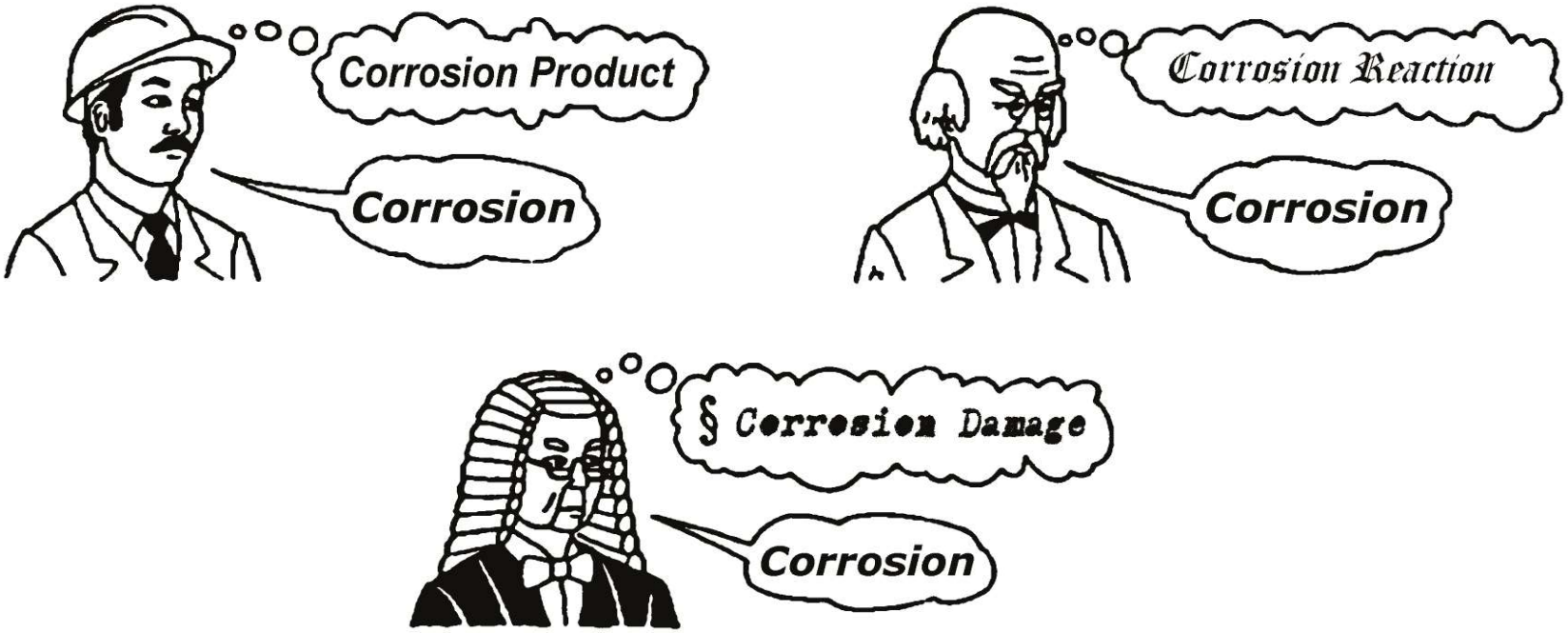
Content

- Corosion in General
  - Term
  - Types
- Corrosion Investigations
  - General
  - Geothermal
- Summary

Corrosion

Terminology

Corrosion is the reaction of a material with the environment, which causes changes of its properties.



Corrosion

Theory

Metal Production by
Supply of Energy

low energetic state (stable)

$$MeO_x \rightleftharpoons Me + x/2\ O_2$$

energy rich state (instable)

Corrosion

Corrosion

Aspects

Not every corrosion reaction causes a

Corrosion Damage

Impairment of functionality of a structural member

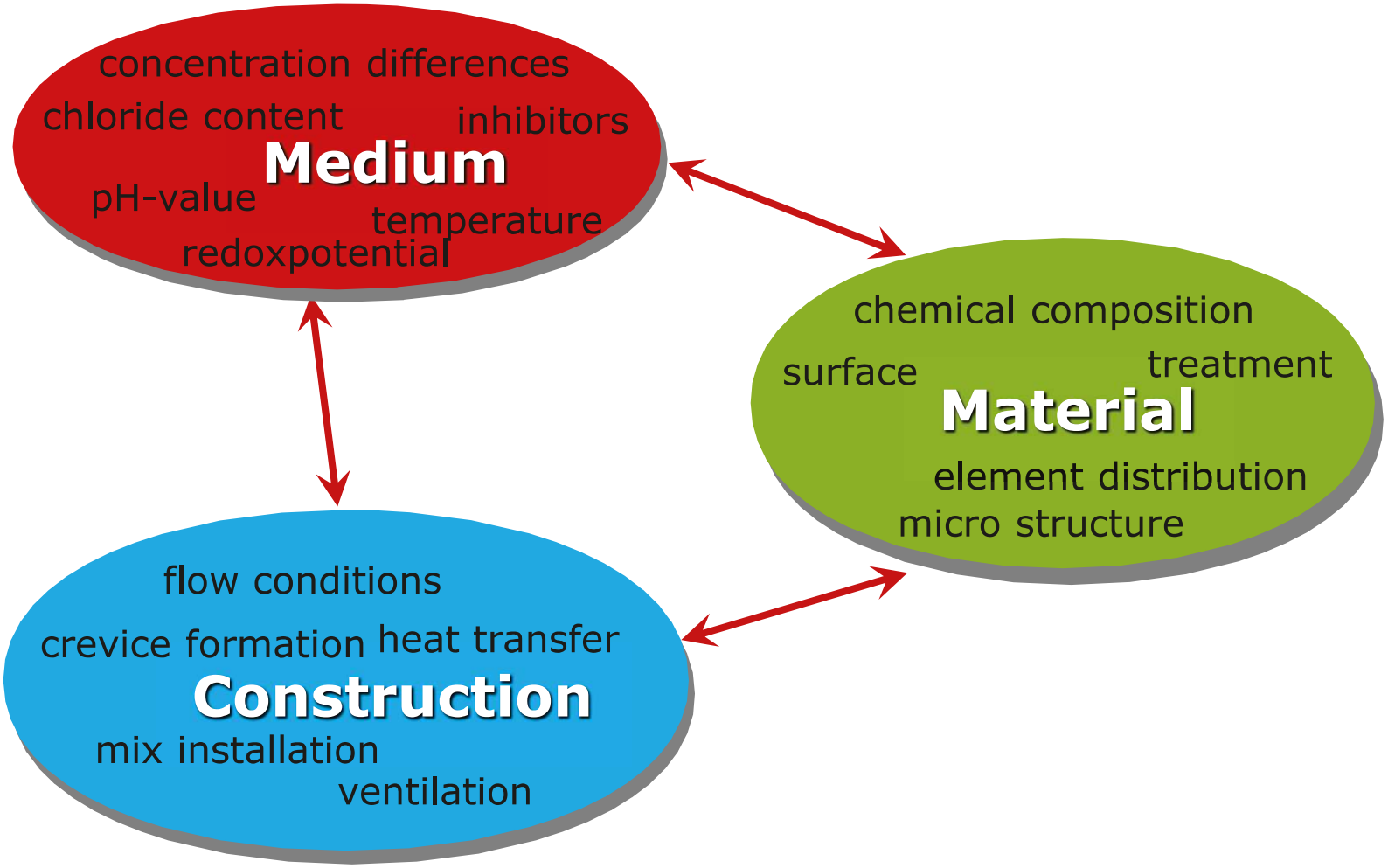
- stability
- load bearing capacity
- flexibility
- tightness
- visual effect

Impairment of environment

corrosion damage causes
direct and indirect following costs.

Corrosion

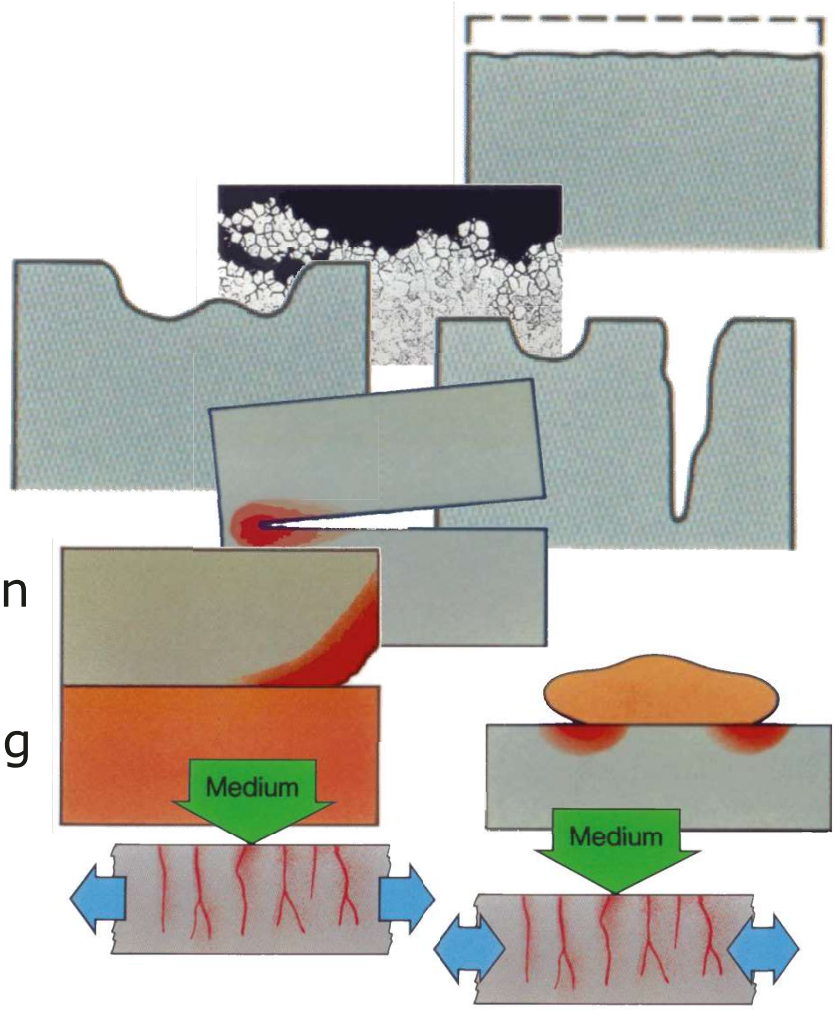
Theory – System Property



Corrosion

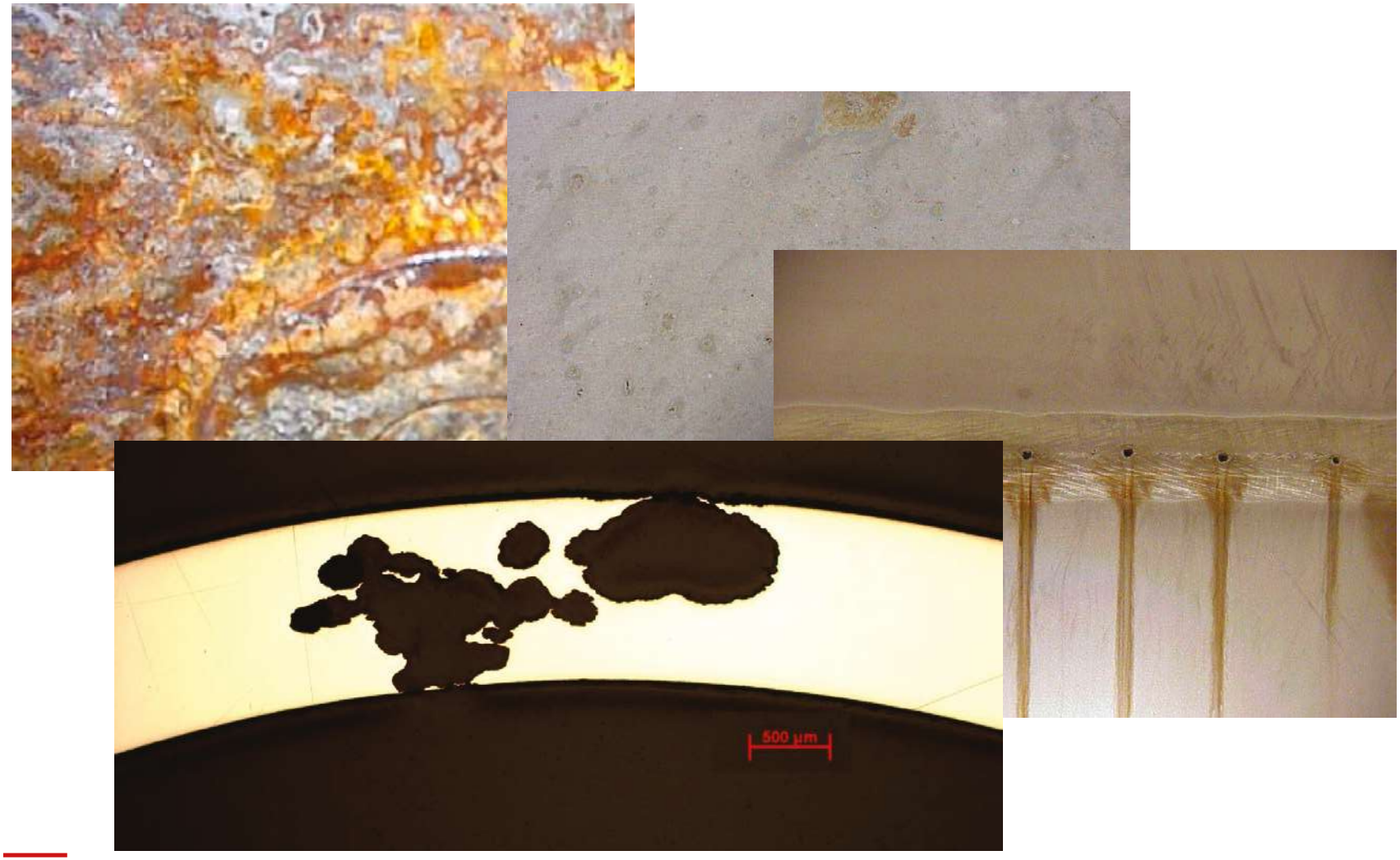
Types

- Uniform Corrosion
- Intercrystalline Corrosion
- Localized Corrosion
- Pitting Corrosion
- Crevice Corrosion
- Bimetallic Corrosion
- Microbiologically Induced Corrosion
- Stress Corrosion Cracking
- Torsion Induced Corrosion Cracking



Corrosion

Types – uniform, localized (pitting)



Corrosion

Underneath coatings

GfKorr, Schadensatlas 2006 auf http://www.corrosion-failures.com

Corrosion

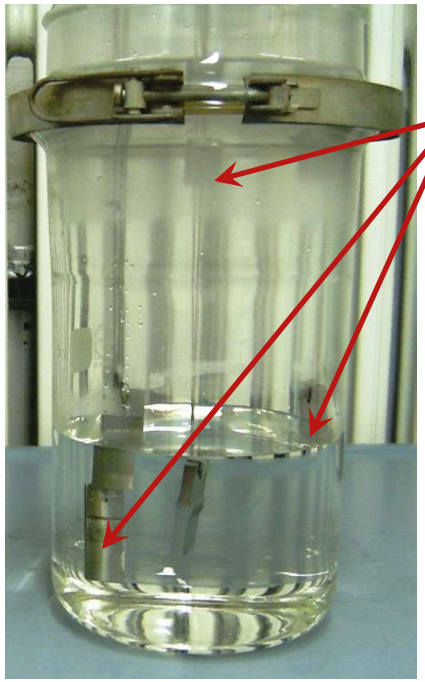
Failure Cases Reportd from Iceland

- Broken at 1600 m
  Severely corroded
- Corrosion rates above acceptable limits for K55, T95 and 13Cr
- Superaustenite, Superduplex and Ni-alloys all measured with corrosion rates below the acceptable limit
- Superaustenite and Superduplex least affected by corrosion

Karlsdottir et al. Corrosion Testing Down-Hole in Sour High Temperature Geothermal Well in Iceland, NACE Corrosion Conf. 2013

Testing

specimen



exposure receptacle

climate chamber

Testing

Assessment

Appearance

Measured Value

Threshold

uniform → mass loss

localized → intrusion depth

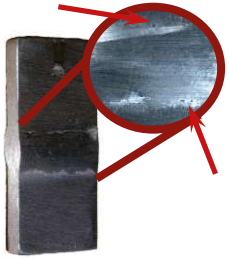
mass loss → ≤ 0.3 mm/a

intrusion depth → ≤ 0.3 mm/a

yes

no

Pitting



yes

Suitability

no

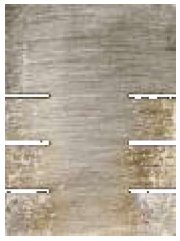
yes

Testing

Visual and Massloss Basing Parameters

Corrosion Types

- uniform and localized corrosion
- crevice corrosion as well as
- stress corrosion cracking



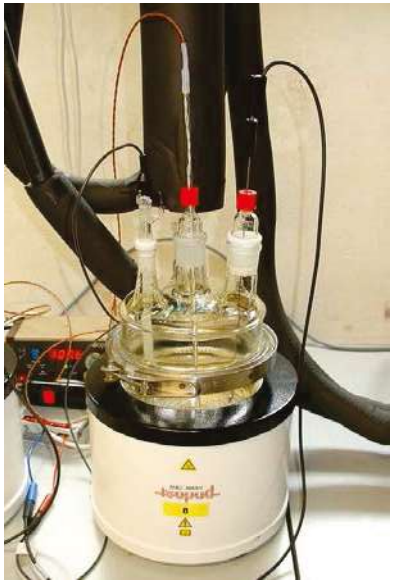
Temperatures

- below
- above

boiling point

Testing

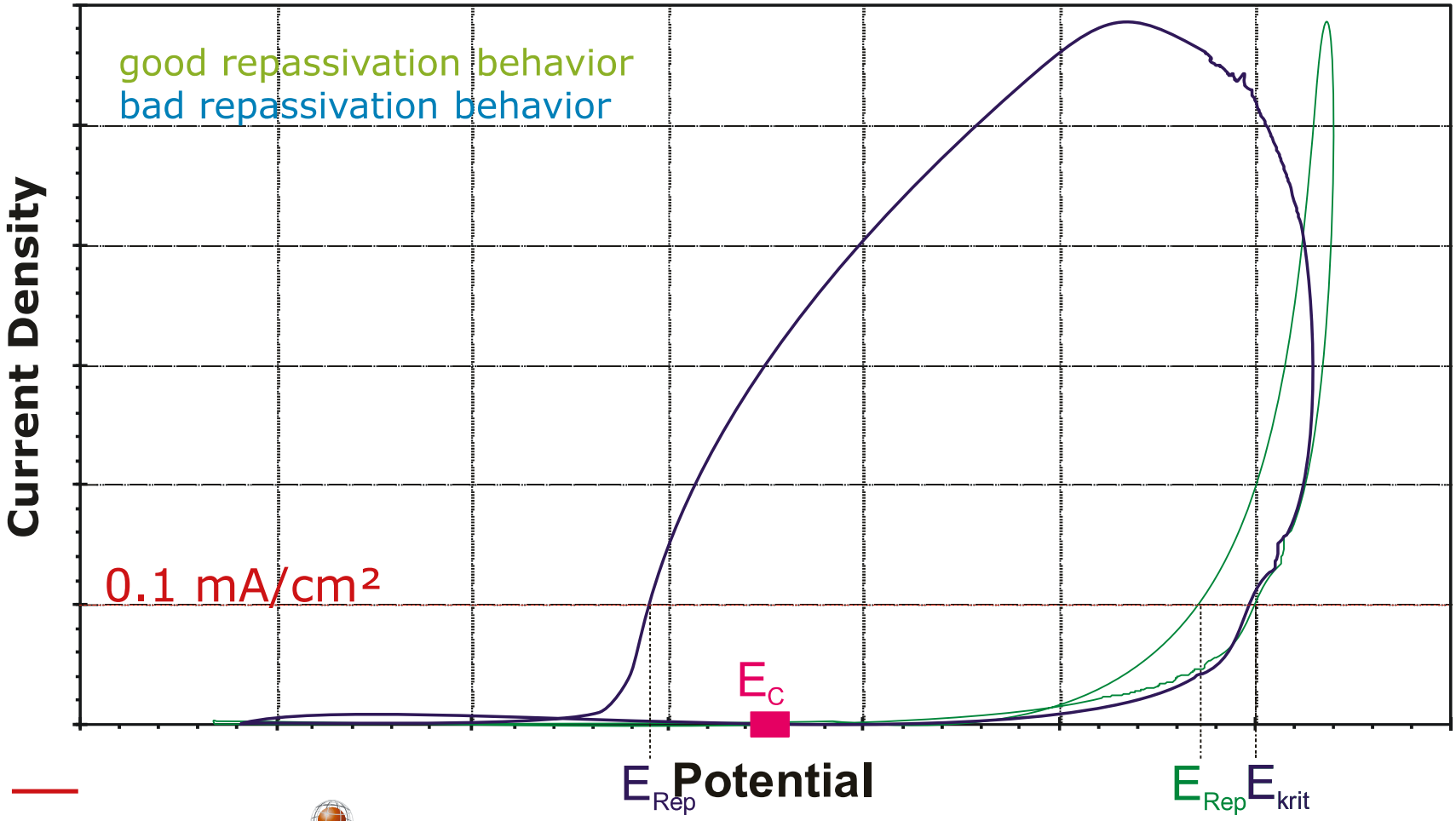
Electrochemical Methods



- **Potential Measurements**
  - Free Corrosion Potential (OCP)
  - Redoxpotential
- **Potentiodynamic Measurements**
  - critical pitting potentials
  - repassivation potential
- **Potentiostatic Measurements**
  - anodic polarization (crevice, pitting)
- **Impedance Spectroscopy**
  - layer properties
  - electrode processes

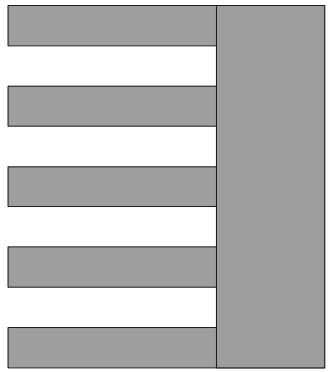
Electrochemical Corrosion Investigations

Potentiodynamic Measurements - Critical Potentials

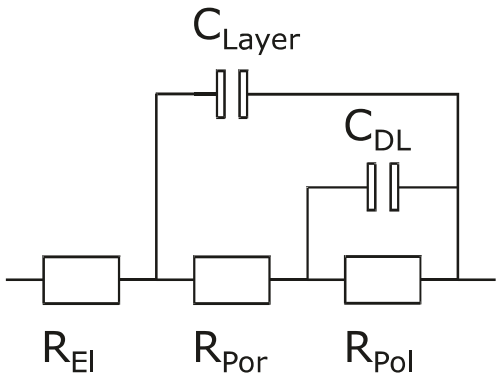


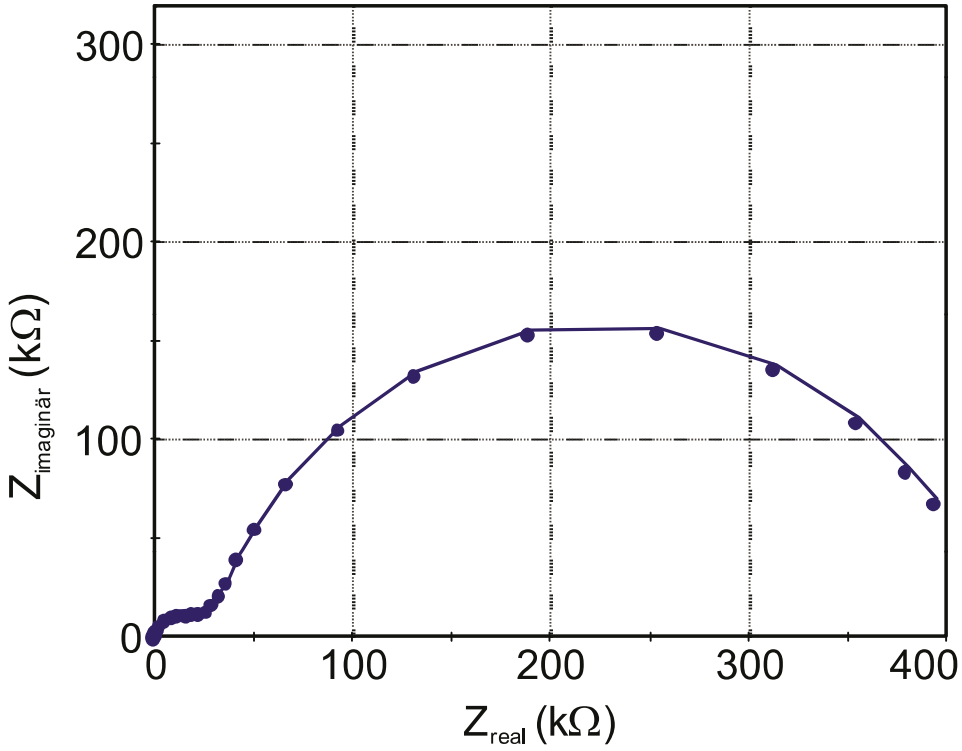
Electrochemical Corrosion Investigations

Impedance Spectroscopy



electrolyte | porous oxide-layer | base material





Testing

Materials

- **C-Steels**
  - P23MnCrTi5/1 (Grade L 80)
  - P29CrMo44/V1 (Grade Q 125)
- **Cr-Steel**
  - 25CrMo4 (A29)
- **Ni-Alloys**
  - NiCr23Mo16Al (2.4605)
  - NiMo23Cr8Fe (2.4710)
- **Stainless Steels**
  - X1NiCrMoCu32-28-7 (1.4562)
  - X2CrNiMnMoNbN25-18-5-4 (1.4565)
  - X2CrNiMo-22-5 (1.4462)
  - X2CrNiMoCuWN25-7-4 (1.4501)
  - X2CrNiMo17-12-2 (1.4404)
- **Ti-Alloys**
  - TiMo0.3Ni0.8
  - TiAl6Sn2Zr4Mo6

Testing

Geothermal Waters

	Content [g/L]												pH
	Cl^-	SO_4^{2-}	HCO_3^-	Ca^{2+}	Mg^{2+}	K^+	Na^+	NH_4^+	Fe^{2+}	Pb^{2+}	Sr^{2+}	SiO_2	
NDB	166	0.05	-	56.5	0.5	3.1	38.7	0.2	-	0.2	1.55	-	5.6
ORG	102	1.5	-	10.9	1.9	3.7	47.9	-	0.25	-	0.5	0.15	6
MB	0.175	0.025	0.4	-	0.011	0.16	0.15	0.05	-	-	-	-	8.1
SBY	1.5	0.02	0.015	0.2	-	0.25	0.6	-	-	-	-	-	4

Results

Materials Suitability – Exposure Tests

Results

Materials Suitability – Exposure Tests, Crevice Corrosion

X1NiCrMoCu32-28-7 (1.4562)

X2CrNiMnMoNbN25-18-5-4 (1.4565)

Results

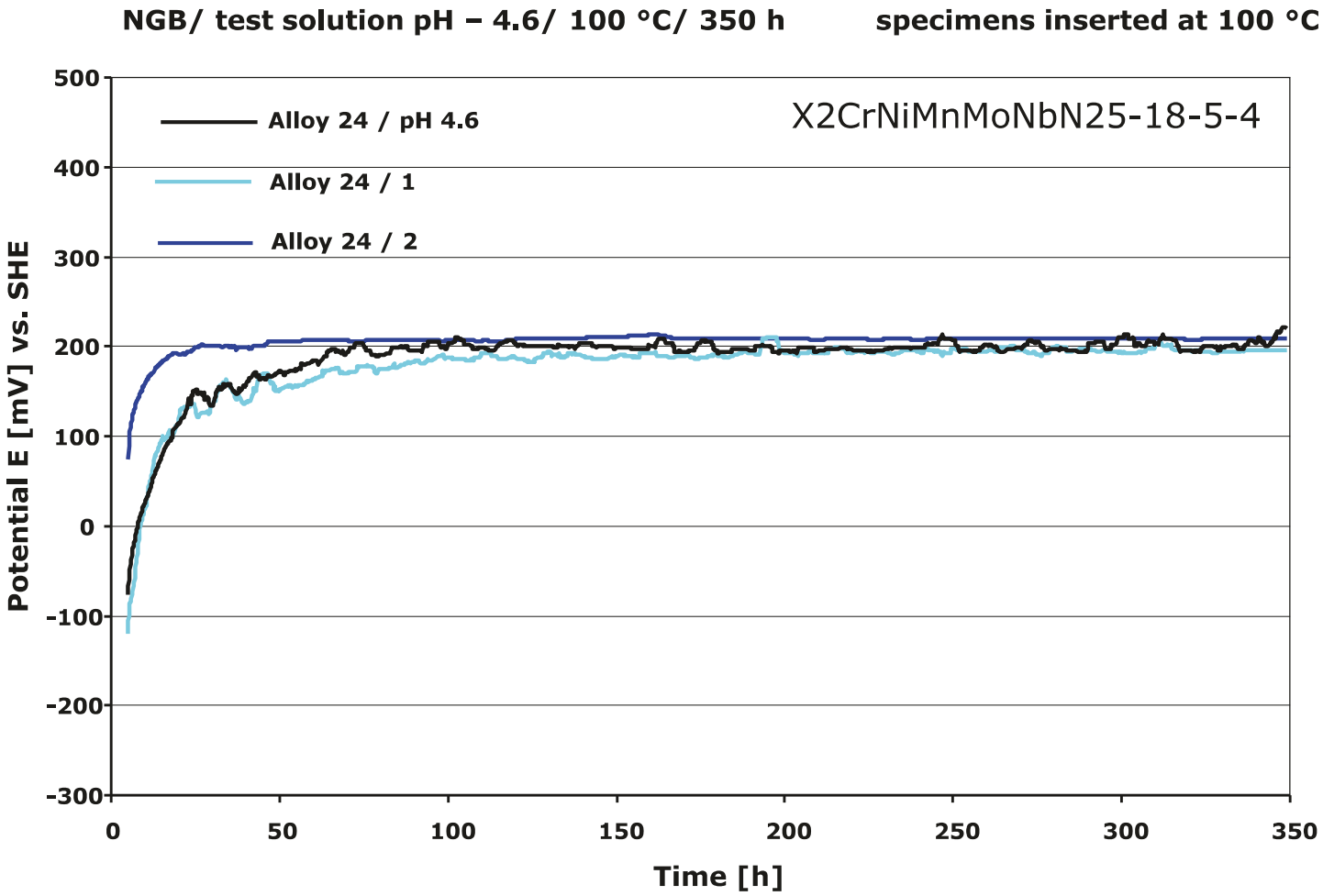
Materials Suitability – Exposure Tests, Stress Corrosion Cracking

X1NiCrMoCu32-28-7
(alloy 31, 1.4562)

X2CrNiMnMoNbN25-18-5-4
(alloy 24, 1.4565)

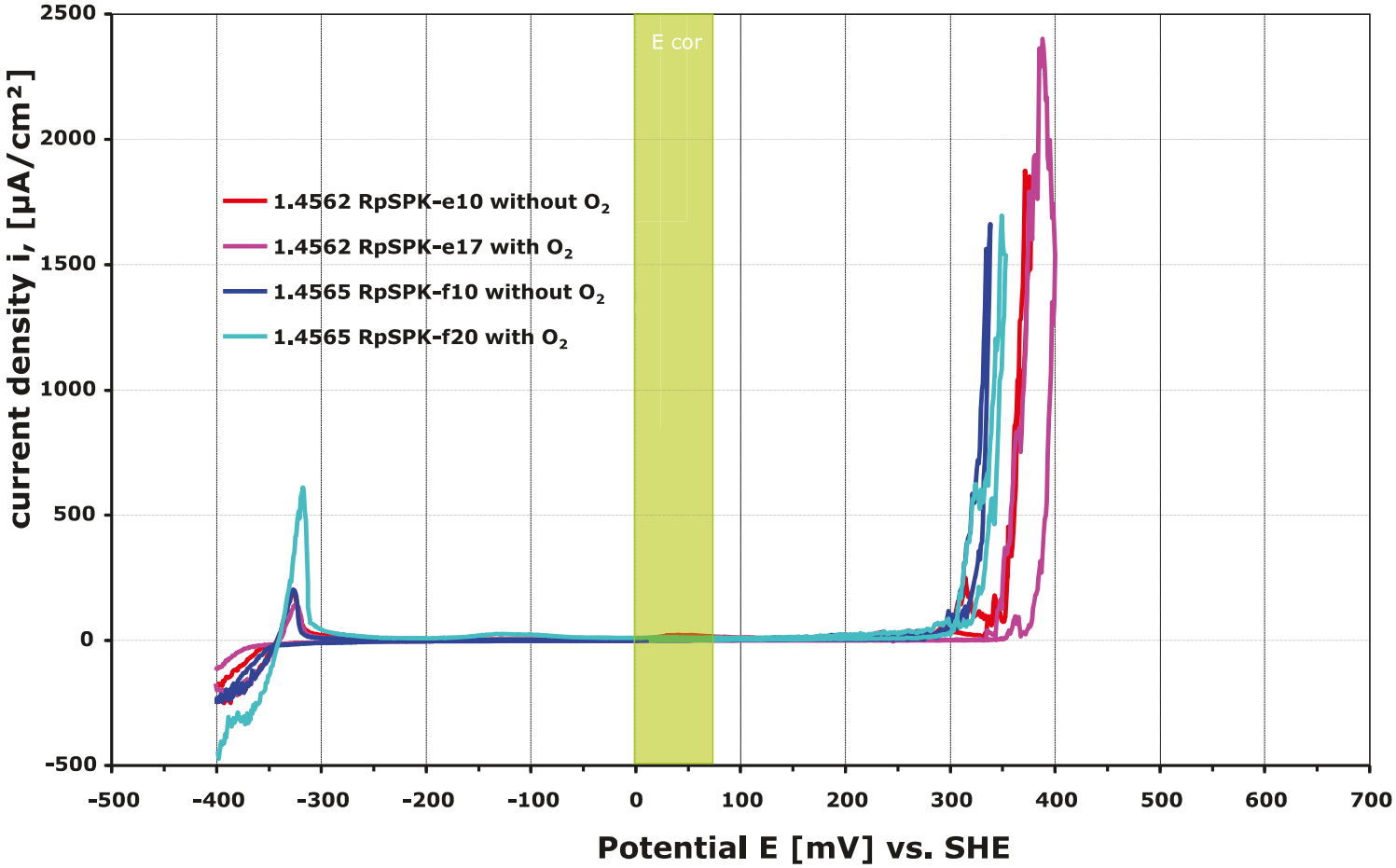
Results

Materials Suitability – Electrochemical Tests - OCP



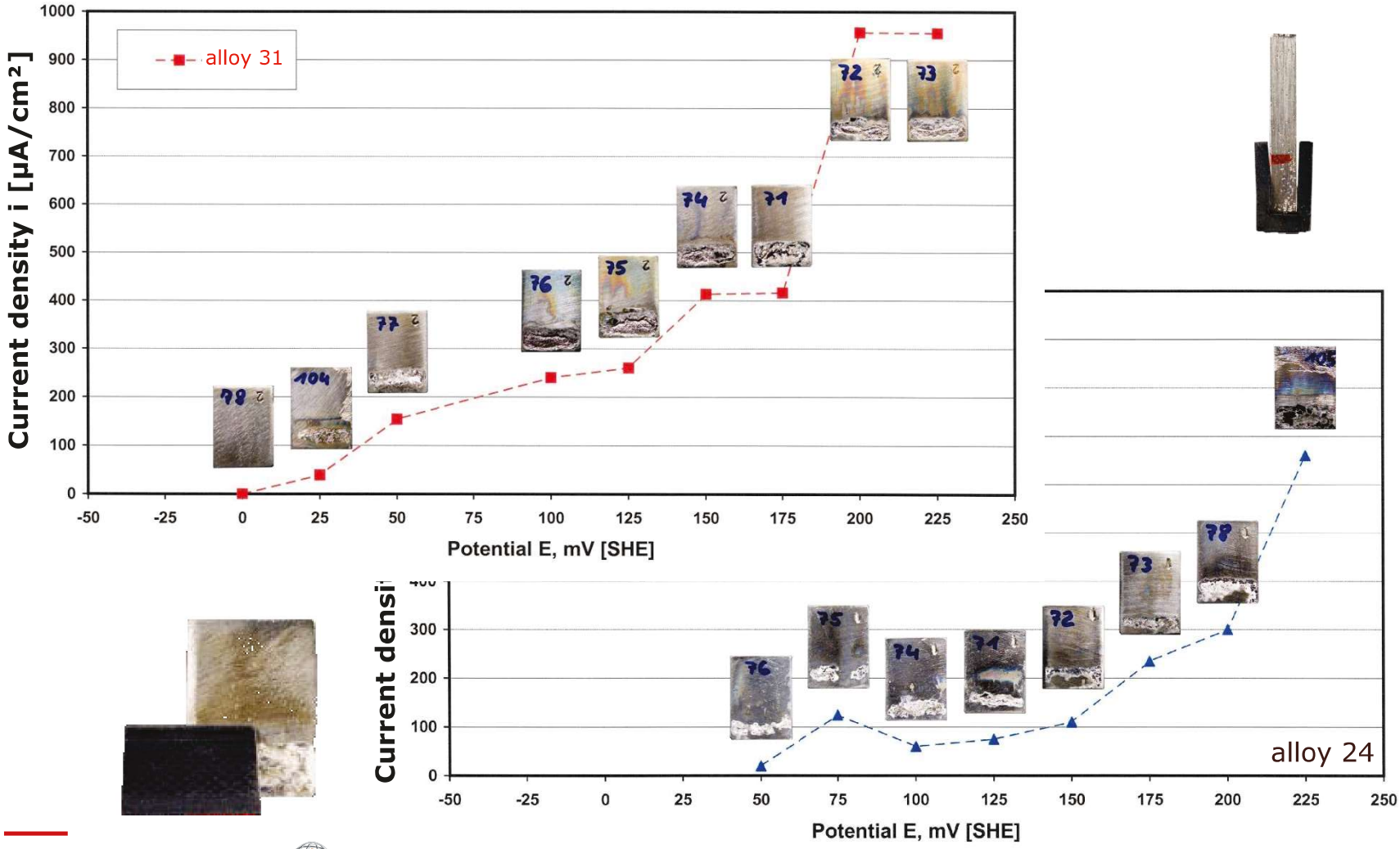
Results

Materials Suitability – Potentiodynamic Electrochemical Tests - CDP



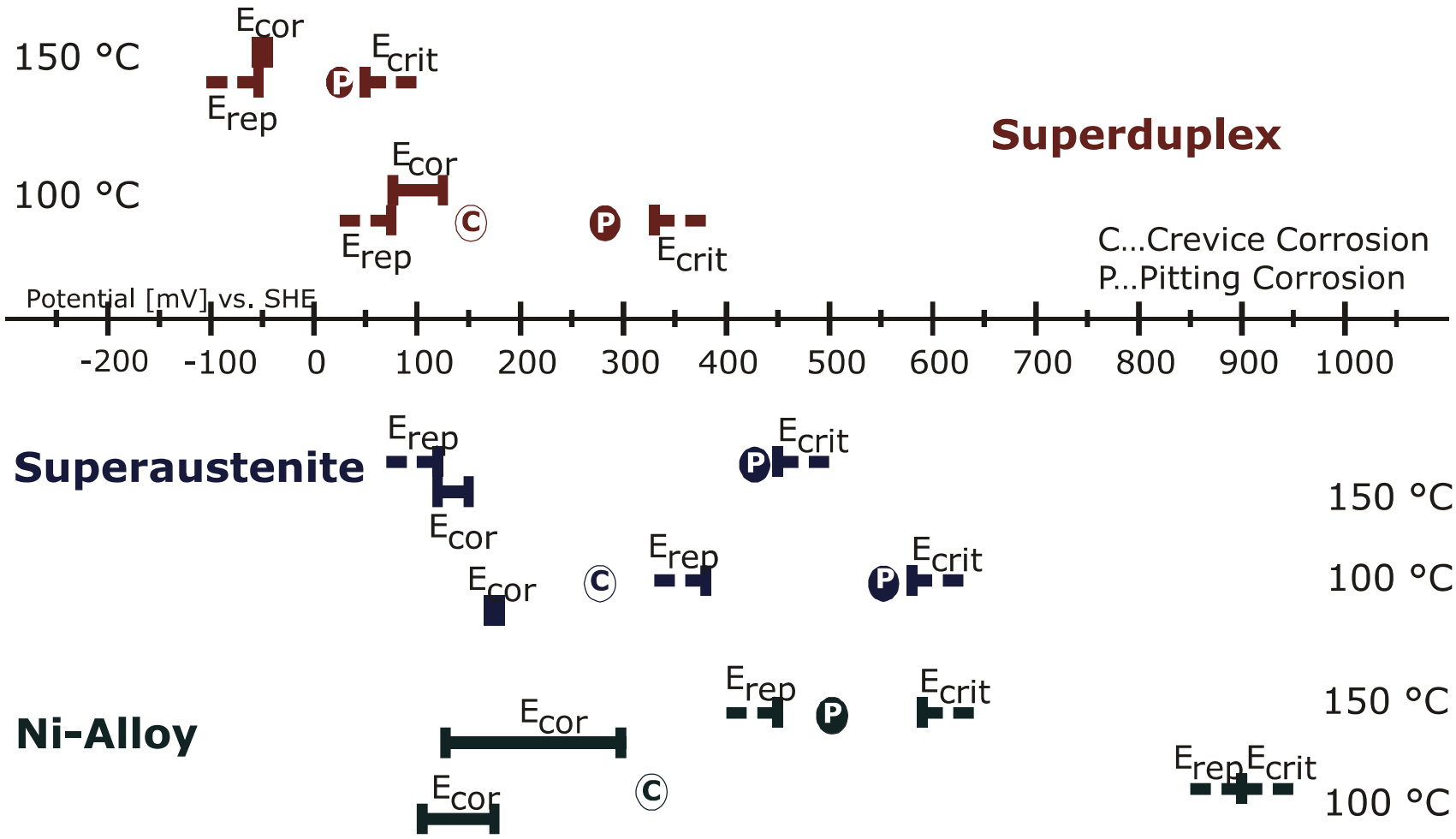
Results

Materials Suitability – Electrochemical Tests – Crevice Corrosion



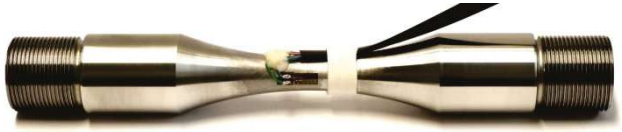
Results

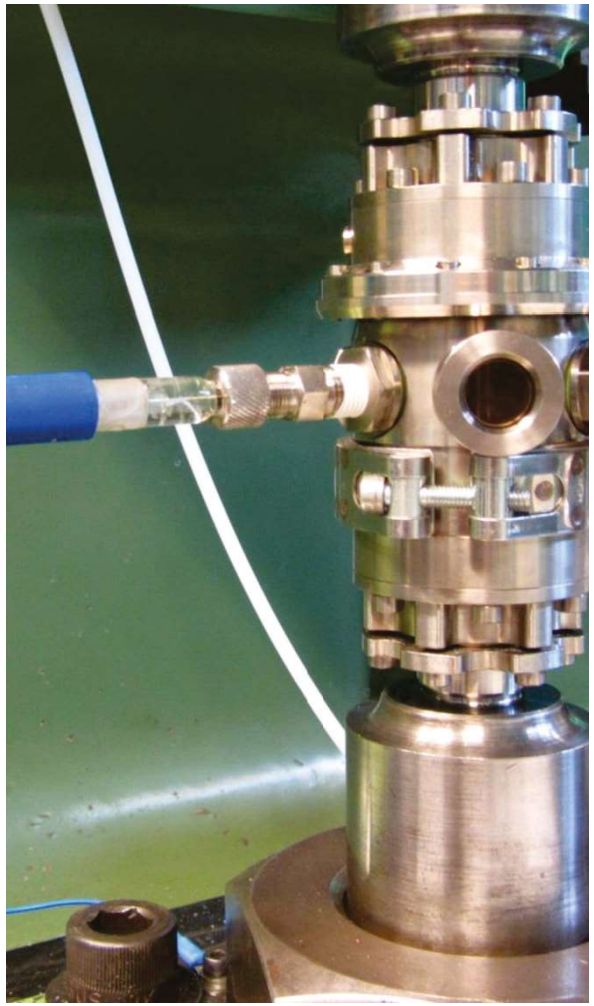
Materials Suitability – Electrochemical Tests – Potential Survey



Results

Mechanical Properties





M. Wolf · *Eurocorr 2012*

Results

Materials Suitability

- **Carbon-Steel**

  in low-saline brines:
  - uniform corrosion below the threshold value
  - susceptible to localized corrosion (pitting/crevice corrosion at 150 and 175 °C)
  - slightly susceptible to crevice corrosion at 100 °C

  ↳ **suitable with strong limitations**

  in high-saline brines:
  - uniform corrosion above the threshold value
  - susceptible to localized corrosion (pitting/crevice corrosion at 150 °C)

  ↳ **not suitable**

Necessity,
of using high-alloyed materials

Results

Materials Suitability

- **Duplex-Steel (1.4462) and Superduplex (1.4501)**

  in high-saline brines
  - susceptible to localized corrosion (crevice, pitting)

  ↳ **not suitable**

  in low-saline brines
  - no signs of any kind of corrosion

  ↳ **suitable**

1.4501

1.4462

- **Superaustenite (1.4562)**

  in low-saline brines:
  - no sign of any kind of corrosion

  ↳ **suitable**

  in high-saline brines:
  - susceptible to localized corrosion (crevice, pitting) at 150 °C
  - slightly susceptible to crevice corrosion at 100 °C

  ↳ **suitable with strong limitations**

1.4562

Bäßler et al. NACE Corrosion Conf. 2009 - 2013

Results

Materials Suitability

- **Ni-alloy (2.4605)**

  in highly saline brines:

  - no signs of corrosion

  ↳ **suitable**

2.4605

- **Ti-alloys**

  in highly saline brines:

  - no signs of corrosion

  ↳ **suitable**

Ti Grade 12

Results

Summary

Highly saline geothermal brines require high alloyed materials, for safe long-term operation!

Any questions, comments, remarks?

Ralph.Baessler@BAM.de