Swerea KIMAB &
French Corrosion Institute

General presentation & possibilities to study microbiologically induced corrosion

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Content

Swerea KIMAB in short

- Industry is majority owner
- Approx 180 member companies
- 600 customers
- 180 employees
- Office and laboratories in Kista, Stockholm
- One subsidiary in France (French Corrosion Institute)

!

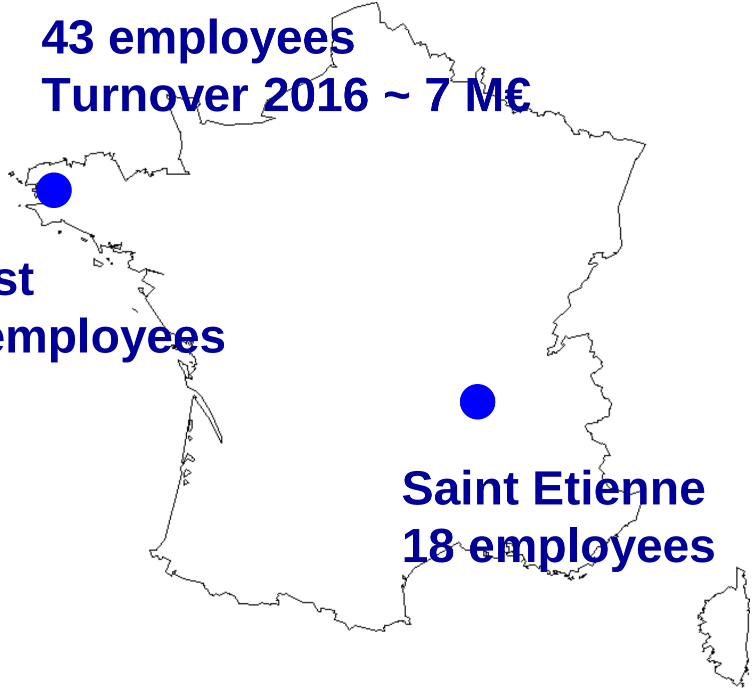
Swerea KIMAB is a non profit research organisation

Swerea KIMAB

Stockholm, Sweden

140 employees

Turnover 2016 ~ 19 M€



Institut de la Corrosion

43 employees
Turnover 2016 ~ 7 M€

Brest
25 employees

Saint Etienne
18 employees

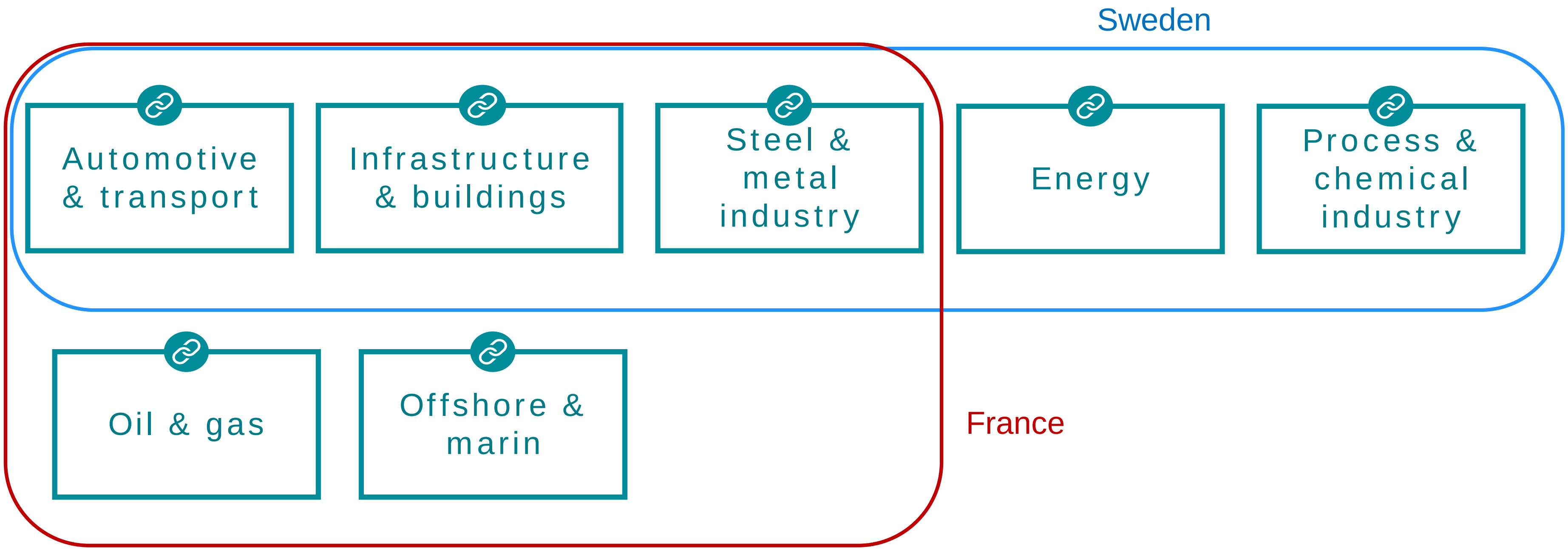
Swerea KIMAB

CORROSION

MATERIAL & PROCESS DEVELOPMENT

PRODUCTION TECHNOLOGY

Our corrosion different segments



Content

swerea
swedish research

MIC: biofilm and corrosion

The biofilm can have a beneficial or detrimental effect on the corrosion properties depending on the bacteria type, some examples:

- *Desulfovibrio desulfuricans (Sulphate reducing bacteria (SRB)), Pseudomonas sp.* and *Bacillus sp.* can accelerate corrosion
- *Bacillus subtilis* can decrease the corrosion of aluminum by secreting polyaspartate and polyglutamate
- *Pseudomonas flava* can decrease corrosion by forming a phosphate film

MIC: biofilm and corrosion

Parameters that influence the effect of the biofilm on the corrosion resistance are:

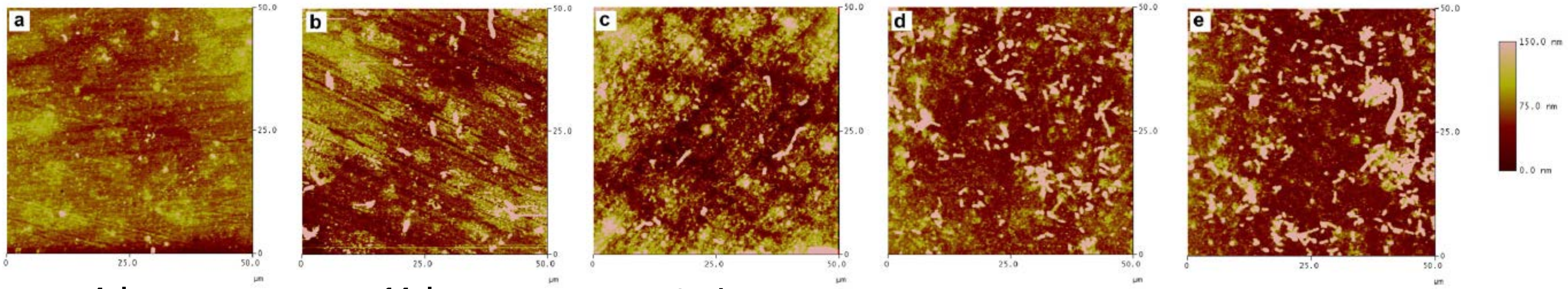
- **Morphology of the biofilm**
  - Porous biofilm: can lead to localized corrosion on the metal surface by trapping harmful components generated by the bacteria and create gradients of dissolved oxygen content, pH and chloride.

- **Temperature**
- **Oxygen content**
- **pH**

AFM for MIC studies

AFM is a potent tool for studying biofilm/substratum interaction, for example:

- **AFM images of stainless steel AISI 316 with desulfovibrio desulfuricans (Sulphate reducing bacteria) biofilm. The proliferation of the biofilms can be seen:**

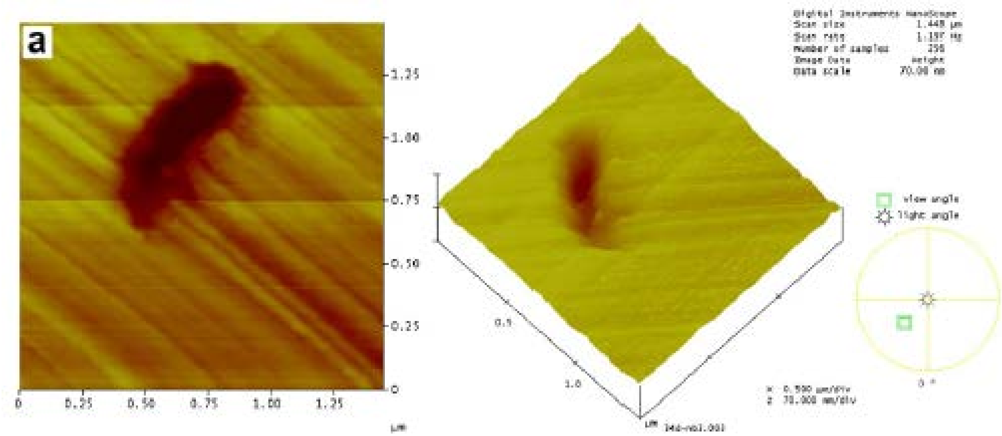


4 days **14 days** **24 days** **34 days** **44 days**

X.sheng et al. Corrosion Science 49 (2007

AFM for MIC studies

Topography map of the surface after removal of the biofilm:



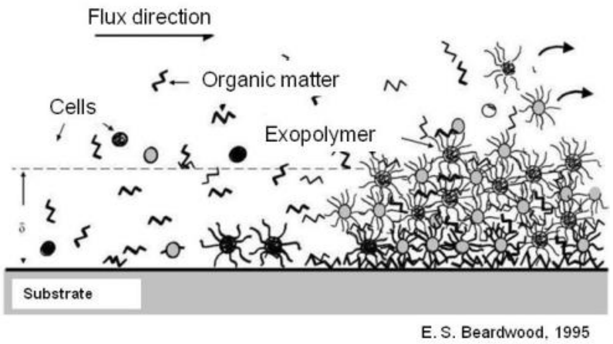
X.sheng et al. Corrosion Science 49 (2007)

SRB can induce faster corrosion on AISI 316.

Pitting could occur due to a depletion of elements (Fe/Ni ratio) in the passive film beneath the bacteria.

SRB produces hydrogene sulfide, which can enhance the dissolution of Fe.

MIC in natural seawater

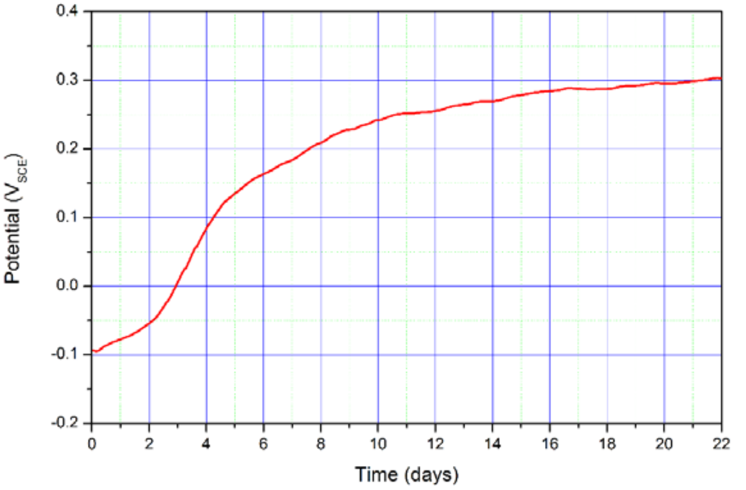


- ❑ Biofilms naturally forms on surfaces exposed in natural seawater.

- ❑ The practical consequences of biofilms on stainless steel

→ **Potential ennoblement of stainless steel** (risk of localized corrosion)

→ **Increase the cathodic reduction of oxygen** (higher risk of corrosion propagation)

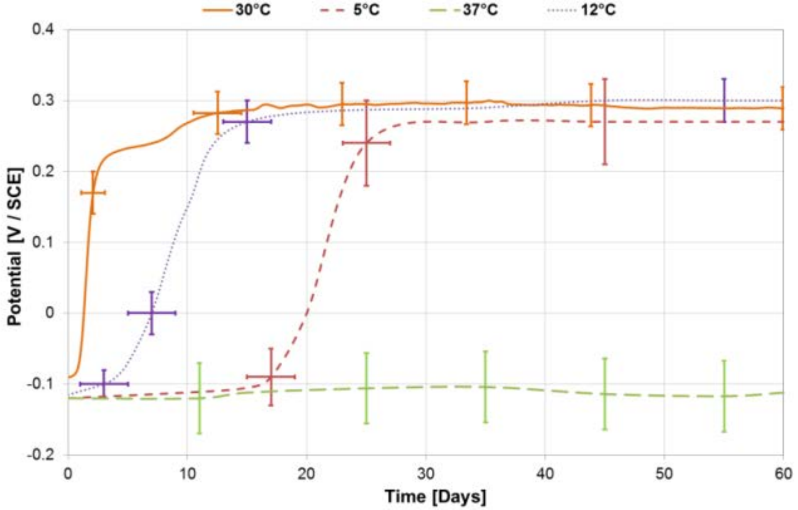


MIC in natural seawater

RESULTS: EFFET OF TEMPERATURE IN TEMPERATE SEAWATER *BiofoulCORR JIP*

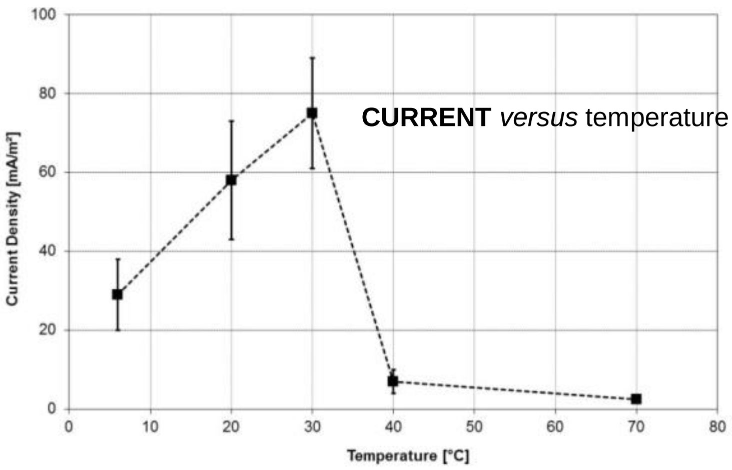
Joint Industry Program on the effect of TROPICAL BIOFILMS on Crevice Corrosion of stainless steels *(including Sandvik)*

POTENTIAL *versus* temperature in BREST



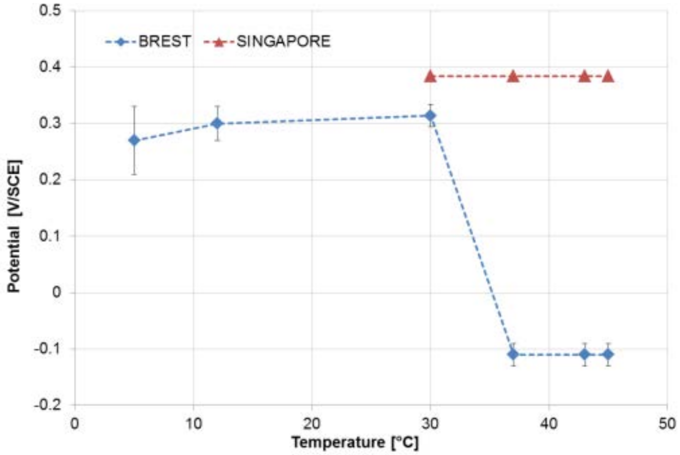
- ❑ Potential ennoblement at ≈ +300 mV from 5°C to 30°C
- ❑ (occurs faster with temperature → bacterial activity)
- ❑ No potential ennoblement at 37°C in Brest (temperate seawater)

CURRENT *versus* temperature in BREST



Many similar studies [Corr. of SS versus biofilming conditions in natural seawater]

MIC in natural seawater



Very different behavior in **TROPICAL** seawater **when heated**

↓

Potential ennoblement still occurs at 46°C

↓

Expected higher corrosivity in heated TROPICAL Seawater

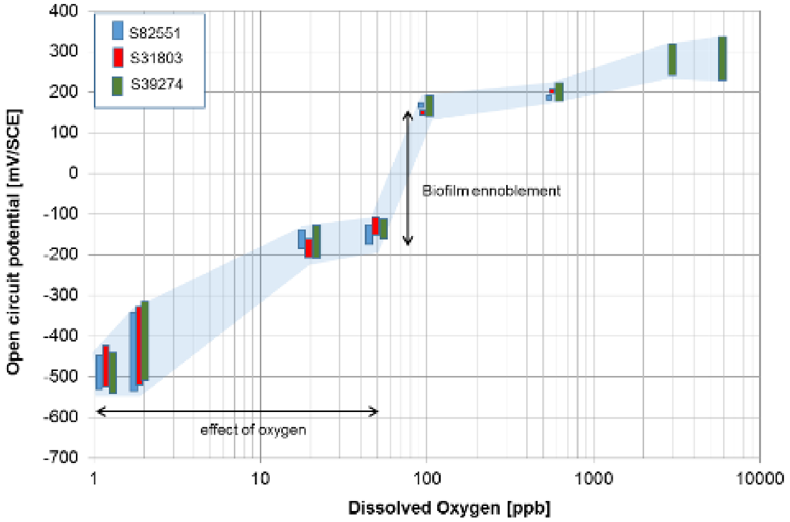
BiofoulCORR JIP

Critical Temperature for optimal ennoblement seems connected to a delta Temperature from Ambient

"average ambient +15 to 18°C"

MIC in TREATED seawater

Effect of OXYGEN on MIC risk



No potential difference between the 3 tested alloys

At **DOC>70-100 ppb**, signicant potential increase to 200-300mV/SCE

↓

INCREASE CORROSION RISK

Study for Statoil & Sumitomo (published at NACE & EUROCORR)

The potential increase to values >200mV/SCE in natural seawater is due BIOFILM formation

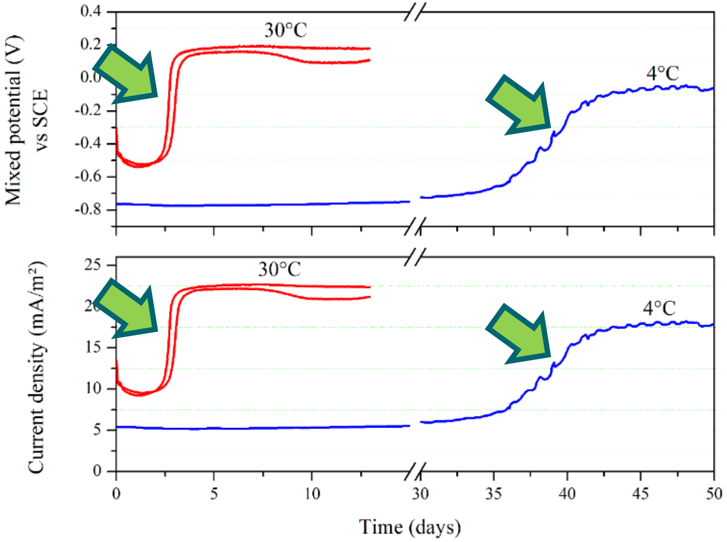
From these results BIOFILM is not active on OCP when DOC<50ppb in renewed seawater (confirmed by several studies at IC)

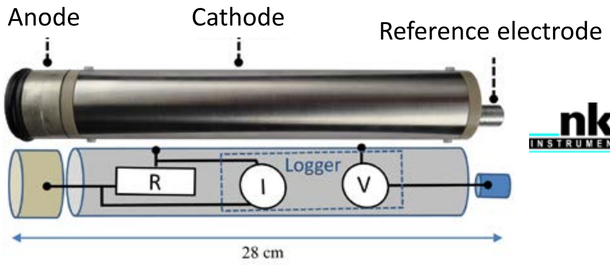
MIC in DEEPSEA water

Development and use of BIOFILM SENSORS

Effect of natural seawater biofim on open-circuit potential and current

Biofilm growth





Have been used successfully in deepsea water (<2000m) to evaluate MIC risk & Crevice corrosion risk of stainless steels in these environments (Joint Industry Program, **including SandvikMT**)

CREVICE ASSEMBLIES for CORROSION TESTS

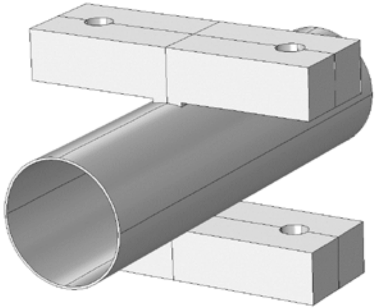
CREVCORR tubes

Two types of “CREVCORR” assemblies :

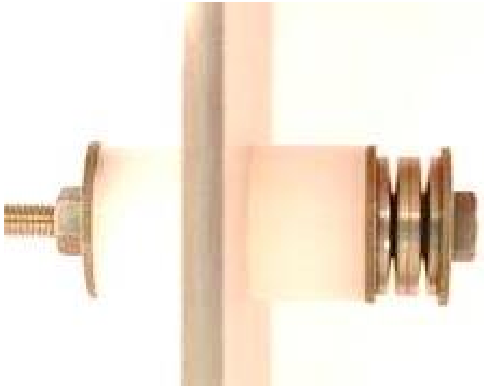
- **Usual geometry** used for the crevice former set-up on tube
- **New geometry** for tubes develop at IC
    - Crevice former in PVDF with the same curvature as the tube
    - Bolt, nuts and disc springs in titanium (Gr2)
    - Applied pressure on the tube surface : 3 and 20 N/mm² (MPa)

Usual Crevcorr

New Crevcorr

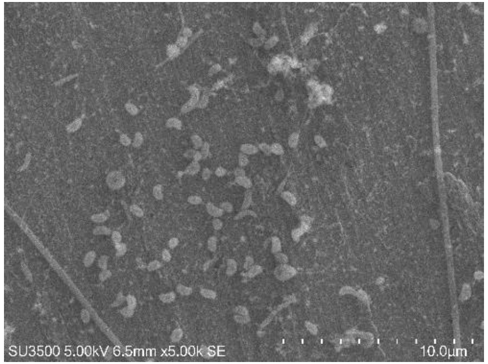


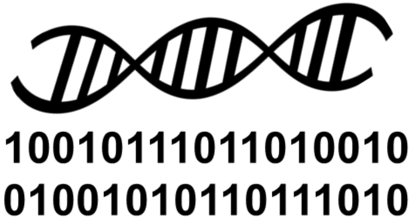
CREVCORR plate

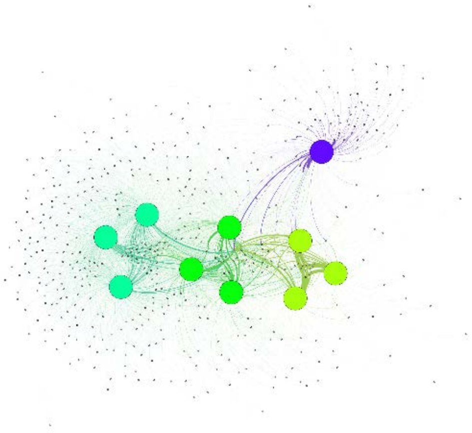


Fundamental investigation of seawater Biofilms

pHD – thesis on **Electrochemical and molecular characterization of electro-active biofilms on stainless steel in seawater**

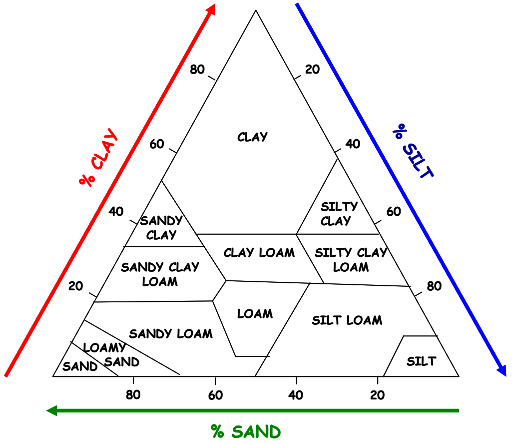






Correlation between bacteria nature (DNA/RNA sequencing) and their effect on stainless steels

MIC in anaerobic SOILS



Study = application for Nuclear Waste Storage Program with Andra

Objective is to develop and investigate experimental protocols to evaluate and characterize the risk of Microorganism Influenced Corrosion (MIC) for carbon steel, under the simulated service conditions of an HA waste disposal application (**Deep Ground environment**, with filler material in contact with Callovo-Oxfordian clayey rock).

For this purpose, microbiological investigations are performed in the relevant environment, and a methodology for corrosion testing in the presence of these bacteria is tested and evaluated.

Content

1. Swerea KIMAB & IC in brief
2. Experience related to MIC
3. Discussion
4. Corrosion – domains of expertise (appendix)
5. Relevant experimental techniques, methods, equipments (appendix)

Scientific Work for Industrial Use
www.swerea.se

Competence area - material

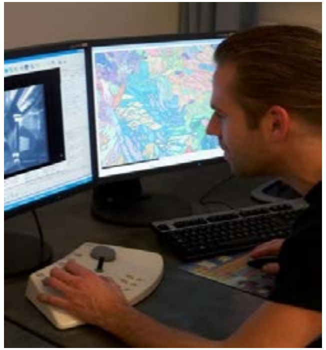
Material analysis

Process monitoring

Stainless steels

Powders and AM

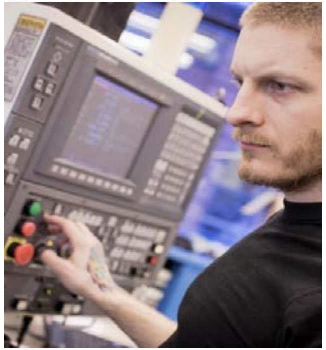
Low alloy steels and casting



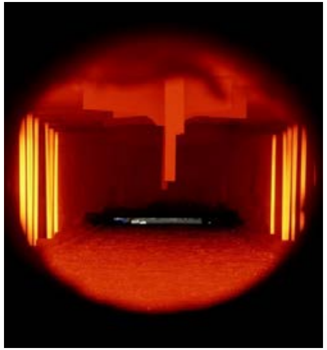
Competence area - production

Joining

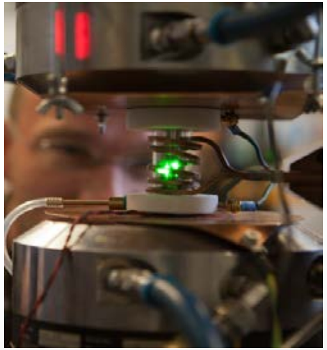
Metal machining



Heat treatment



Mechanical testing



Virtual methods

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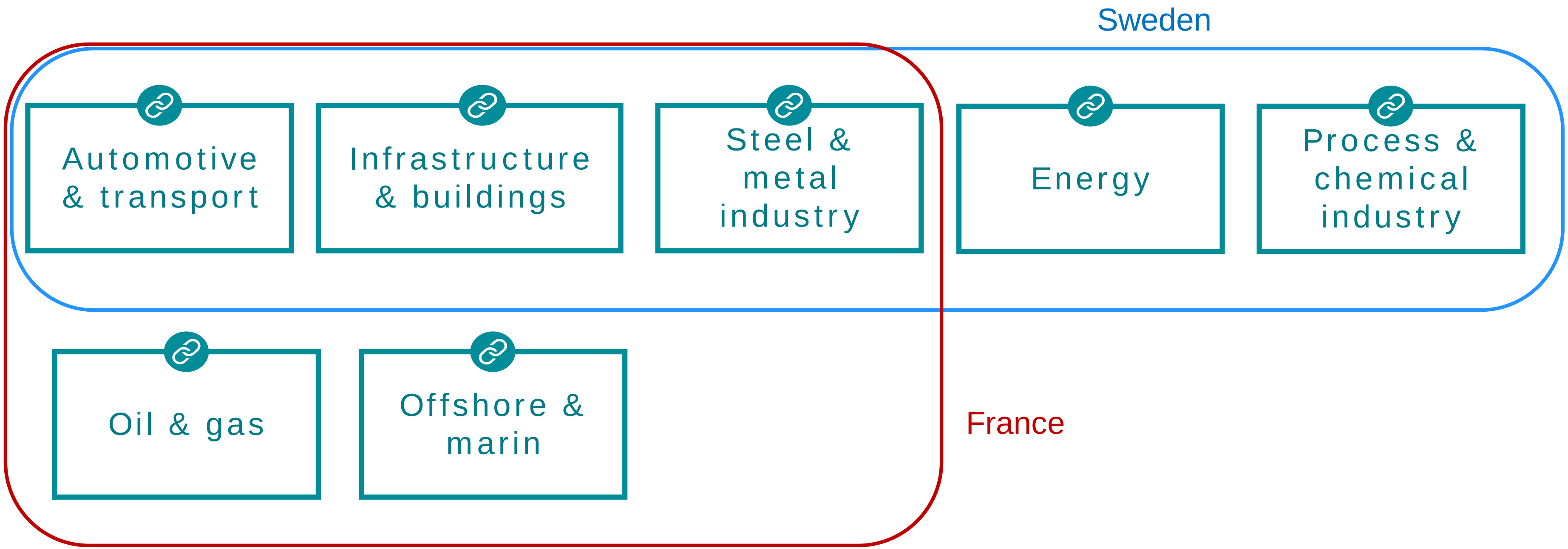
Our corrosion different segments



Automotive & transport

- Corrosion testing of automotive materials
- Mobile and stationary field testing
- Corrosion testing and evaluation of coatings
- Corrosion of multimaterial lightweight structures
- Corrosion testing of materials used in the aerospace industry
- Hydrogen embrittlement of advanced high-strength steels
- Testing of materials for biofuels

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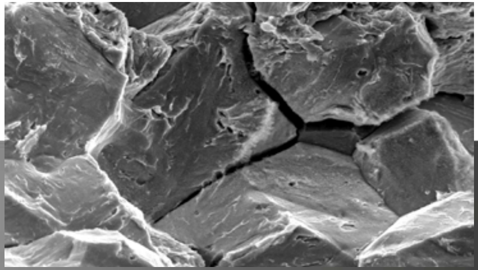
Infrastructure & buildings

- Corrosion in soils
- Development of sensors for corrosion monitoring
- Cathodic protection and heavy organic coatings
- Corrosion of steel reinforcement in concrete
- Water & sewage (plastic pipes for water distribution, disinfection, welding and inspections, relining)
- Consulting, inspection, failure selection and corrosion protection

Steel & metal industry

- Fundamental knowledge about corrosion mechanisms
- Development and standardization of test methods
- Advanced localized electrochemical techniques
- Understanding and modeling of the interaction between material and solution
- Relation microstructure – corrosion properties
- Hydrogen embrittlement
- Corrosion properties of coil coated materials and stainless steel
- Corrosion issues related to welding of stainless steel and weld oxides



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Energy

- Combustion & gasification
- High temperature corrosion
- Nuclear industry & nuclear waste storage
- Energy storage (corrosion in batteries, electrochemistry)
- Corrosion in molten salts
- Corrosion in wind power plants
- Pilot plant for polymers in flue gas stacks

Process & chemical industry

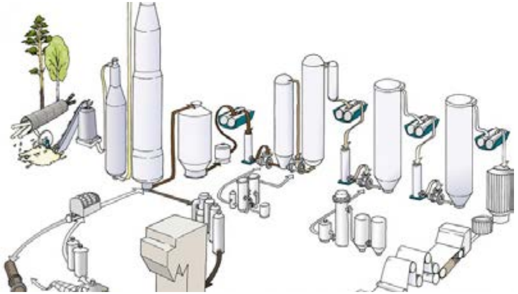
Polymeric and metallic material in corrosive environment

- Pulp & paper industry
- Chlor/alkali
- Chemical industry
- Steel industry pickling

Laboratory techniques to investigate corrosion

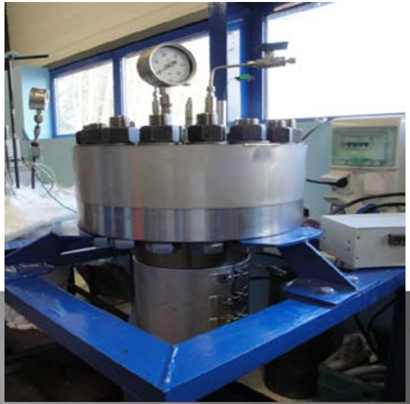
- In different solutions and gases
- At high temperatures
- At elevated pressures

FIELD exposures and expertises



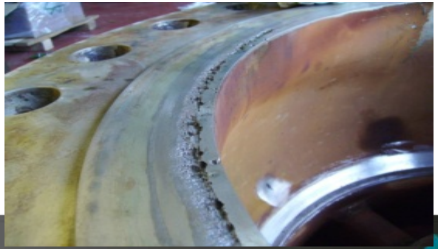
Oil & Gas Production

- Corrosion properties of materials and equipments in sour environments (e.g. containing H_2S)
- Corrosion resistance of materials in super-critical CO_2 environments
- Development of new testing methods
- Design of fit-for-purpose testing devices
- Fatigue corrosion in sour environment
- Testing at High temperature and High pressure (up to 300 bar)
- Testing in explosive atmosphere
- Industrial segments :
  - ✓ Oil & Gas (predominately)
  - ✓ Chemical engineering / Energy



Offshore & marine corrosion

- Corrosion properties of stainless steel and Ni based alloys in seawater (and aqueous media)
- Corrosion properties of copper and copper alloys in seawater
- Fatigue corrosion in seawater
- Cathodic protection in seawater
- Modeling



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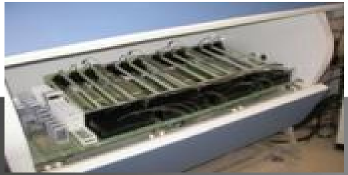
Testing Facilities: outdoor at Brest

- **Natural flowing seawater**
  - Immersion, tidal zone, splash ..
  - Temperate area (Atlantic ocean) / Tropical zone (Singapore)
- **Natural seawater regulated** from 4°C to 90°C
  - Chlorination regulation system,
  - Oxygen control, pollution, etc.
- ***In-situ* corrosion monitoring**
  - Measurements of electrochemical potential, current and cathodic protection
- **From lab to full scale experiments**
  - Heat exchangers, umbilicals, connectors, chlorination full units, pumps….
- **Cathodic disbonding test**
  - ISO 15711

Testing Facilities: indoor (France & Sweden)

- **Fatigue Corrosion**
  - **In seawater:** hydraulic assist power machines (+/- 25kN)**,** tensile-compression; 4 points bending device; 10kN. Titanium chambers for chloride-containing media, temperature 5°C to 80°C, dissolved oxygen control, possibility to polarize specimens
  - **In atmosphere:** a unique tool enabling fatigue cycles in an accelerated corrosion test. Performances: 0-3.5 kN ; 0-5 Hz, with or without cycle
  - **Rotary bending; Alternative bending** (Saint Etienne)

- **Stress corrosion cracking tests (Saint Etienne)**
  - **Static:** 4 points bending devices
    Constant load tensile tests (limited to 40 bar)
    C-rings ; Other loading methods (U-bends, spring loaded specimens) ; Fracture mechanics specimens DCB, CT, WOL
  - **Dynamic:** SSRT, Slow-strain-rate tensile tests (limited to 40 bar)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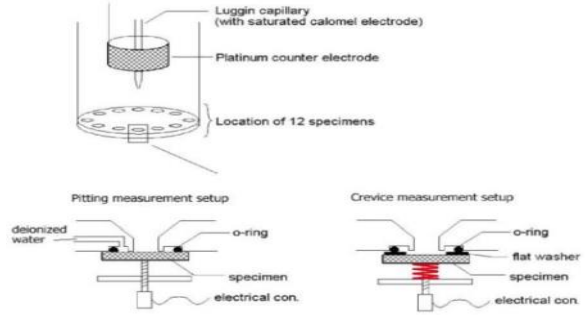
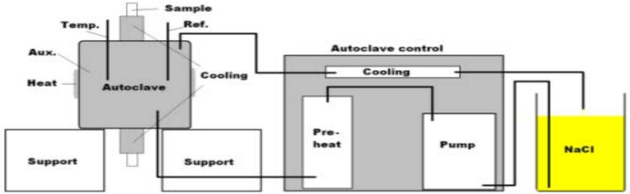
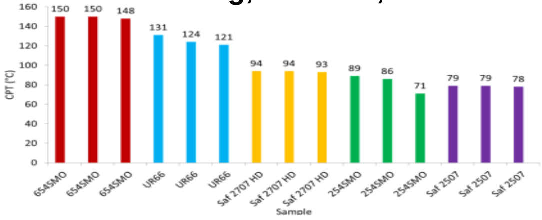
Methods used to investigate the corrosion resistance





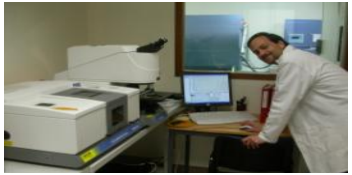
- Immersion test in different solutions
- Immersion test at higher temperature and pressure
- Electrochemical measurements

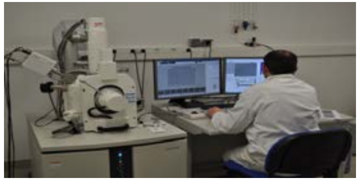
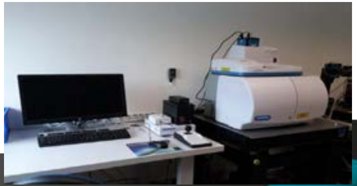
Autoclave testing, 1M NaCl, 700 mV SCE



Methods of Investigations (France)

- Paint adhesion testing
- Colour and gloss measurements
- Contact angle measurements
- Electrochemical techniques: Potentiostats, scanning Kelvin probe
- Optical and metallographic microscopy and image analysis
- Light confocal profilometry
- Infrared spectroscopy and micro-spectroscopy
- Raman spectrometry
- Ion chromatography
- SEM/EDS/WDS
- (AFM/SKPFM, XPS and SIMS)
- Hydrogen analyser
- Fluorescence X spectrometer



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Methods of Investigations (Sweden)

Electrochemical DC and AC techniques

SKP (IC)

Local electrochemistry; SVET:

- Surface reactivity
- Oxide film properties
- Corrosion behavior

FT-IR:

- Molecular and phase analysis
- Thin film analysis
- Metal / polymer interfaces
- FTIR-imaging
- Tribo corrosion; Surface and tribo films

XRD:

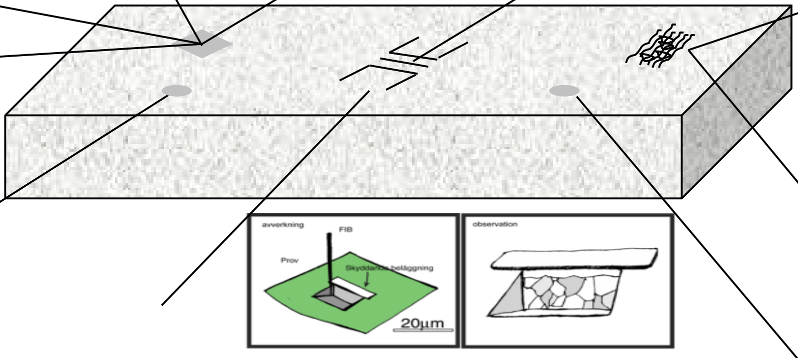
- Phase analysis
- Residual stresses
- Thin film analysis

TEM-EDS/EELS:

- Elemental analysis
- Grain boundaries
- Recrystallization
- Inclusions, dislocations etc.

Stylus

- Surface roughness



SEM-EBSD/EDS/WDS:

- Microstructure
- Residual stresses
- Grain sizes
- Elemental analysis

Confocal microscope

Surface structure

- Surface roughness
- Wear measurements

ICP-MS / OES:

- Wet chemistry method
- Elemental analysis
- LA-ICP-MS (solids and surfaces)

BIB / FIB-SEM:

- Cross sectional analysis in desired areas
- Analysis of cross section and top surface
- FIB: Sample preparation for TEM study

GD-OES:

- Elemental analysis
- Depth analysis at very high resolution

Scanning Vibrating Electrode Technique

- Used for study in-situ corrosion phenomena.
- Measurements of DC current density distribution over the surface scanned in a solution.
- Resolution up to 5 µm.
- Possibility of testing in different conducting solutions.