Saving on corrosion costs: Testing in true environment using electrochemical characterisation

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Saving on corrosion costs

Testing in true environment using electrochemical characterisation

Materials 2015

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Content

- Introduction to the system property Corrosion
- Artificial environment vs True environment
- Applicability of electrochemical characterisation
- Cases

After this presentation you will..

- Understand advantages of electrochemical characterisation
- See it gives you insight in corrosion mechanisms occurring in your system
- Know about possible cost savings related to:
  - Accelerated testing
  - Reduction in time to market
  - Reducing false acceptance or rejection, resulting in:
    - Safety issues
    - Environmental impacts
    - Durability
    - Production losses
    - Maintenance costs

Statements

- €2.2 trillion Global economic cost annually related to corrosion
- Standardised codes are not related to reality

  e.g. A262-14 (Susceptibility to IG attack of aust SS) states:
  - "The presence or absence of intergranular corrosion in this test is NOT necessarily a measure of the performance of the material in other corrosive media/environments."
- Engineers can only design based on general corrosion
- THE corrosion resistant material does not exist
- THE corrosive environment does not exist (neither does non-corrosive)
- Never ask for a corrosion resistant material only

Corrosion is a system property – Two general conditions

High temperature (dry) gas corrosion

- Diffusion driven
- Accelarates at higher temperatus
- Typical above 150-200°C

Mechanisms:

$2Fe + 3O_2 \rightarrow Fe_2O_3$

$Al + 3O_2 \rightarrow Al_2O_3$

Algemeen:

$xMe + yG \rightarrow Me_xG_y$

Electrochemical /wet corrosion

- Electrochemical reaction: Oxidation (anodic) en Reduction (cathodic)
- (Electrical) conductive environment (mostly water)
- Many factors affect corrosion rate
- Typical below approx. <150°C

Mechanisms:

$2Fe + 2H_2O + O_2 \rightarrow 2Fe(OH)_2$

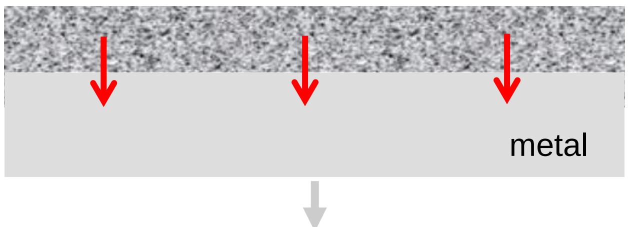
$Fe \rightarrow Fe^{2+} + 2e^-$ (oxidation → anode)

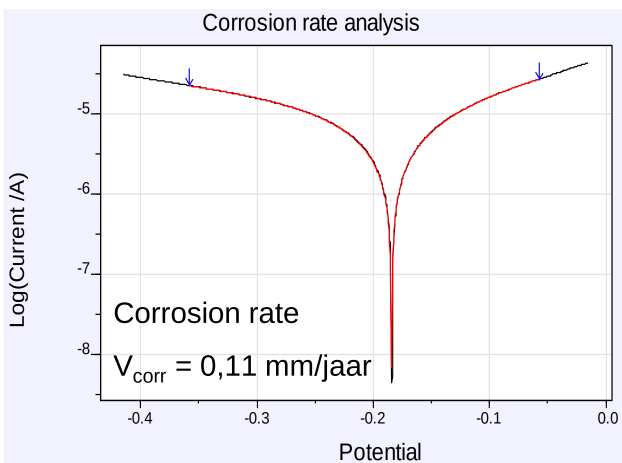
$2H^+ + 2e^- \rightarrow H_2$ (reduction→ cathode)

$O_2 + 4e^- \rightarrow 2O^{2-}$ (reductieon→ cathode

General subdivision electrochemical corrosion

Uniform corrosion



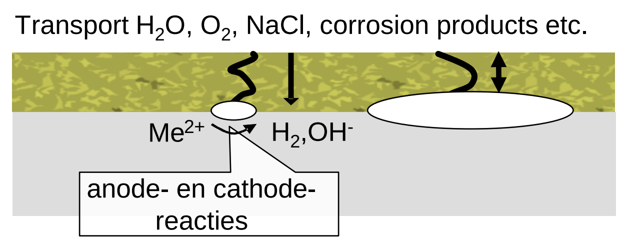


Predictable

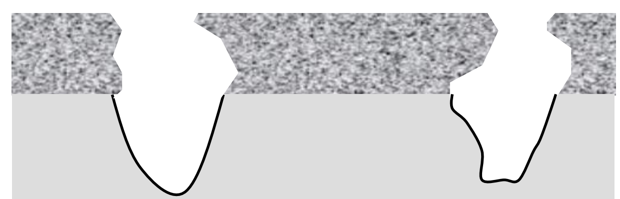
Localised corrosion

Inter-/trans-granular corrosion

Pitting



Coating: barrier-properties?



Uniform corrosieon
Followed by pitting

Not predictiable…

Or is it?

Corrosion is a system property – Parameters acting interactive

- Material (metal)
  - Microstructure
  - Coatings, barriers , joints (brazing / welding/ etc)
  - Residual (tensile) stresses
- Environment
  - Composition, concentrations, alternating environments
  - Fluids and gases, moisture, high temperature gas
- Conditions
  - Temperatures (alternating, level)
  - Mechanical load (static and dynamic stress)
- Use
  - Cleaning
  - Stand Still (process installations)
  - …

Standard test vs electrochemical testing

Standardised tests, e.g. Saltspray test, Kesternich, IG-corrosion test ….. :

- Acceptance tests
- Comparing materials
- Testing of all parameters and processes in one, no clear distinction between: initiation, propagation, acceleration/ retardation …..
- Normalised environments (hardly ever related to actual application)

Electrochemical testing:

- Acceptance tests
- Comparing materials
- Accelareted testing under controlled conditions
- Separate characterisation of; initiation, propagation, acceleration, passivation
- Normalised AND application specific environments

Applications of electrochemical characterisation

$nMe + 2H_2O + O_2 \rightarrow nMe(OH)_2$

$Me \rightarrow Me^{n+} + ne^-$ (oxidation → anode)
$nH^+ + ne^- \rightarrow H_2$ (reduction → cathode)
$O_2 + 2ne^- \rightarrow nO^{2-}$ (reduction → cathode

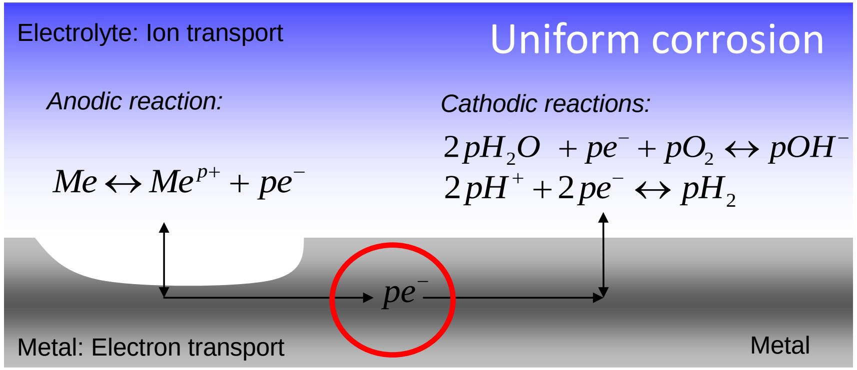
e^- flow = current and potential difference

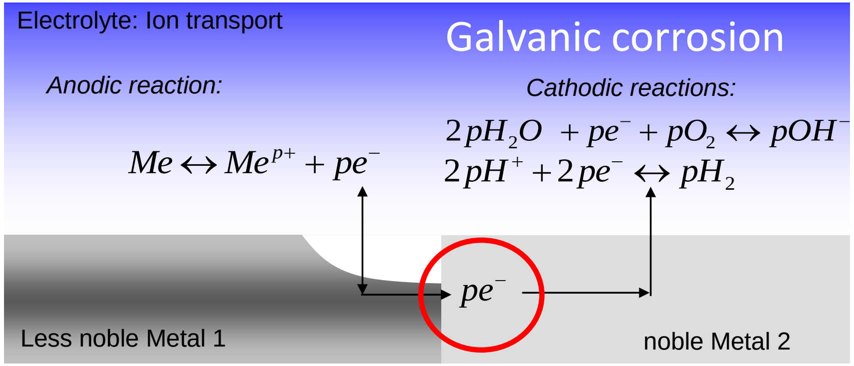
Test		Use	Typical time
OCP	Open Circuit Potential	First scan on stability	10 - 120 min
PC	Polarisation Curve	Corrosion performance & mechanisms	30 - 200 min
EIS	Electrochemical Impedance Spectroscopy	For coatings	2days-2 weeks
SDM	Stepwise Dissolution Method	Accelerated test, different mechanims	6 – 10 hrs
ENM	Electrochemical Noise Measurement	Material/system comparison	1h – 2 days

Electrochemical corrosion

Metal goes into solution under emiting of electrons

- Electrochemical processes
- Electron current measurable
  - Processes can be traced= elektrochemical characterisation
- Enforcing processes
  - Varying potentials
  - Process acceleration
  - Gains insight in both worlds





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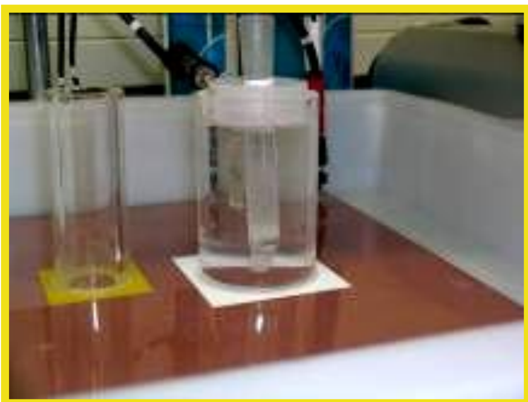
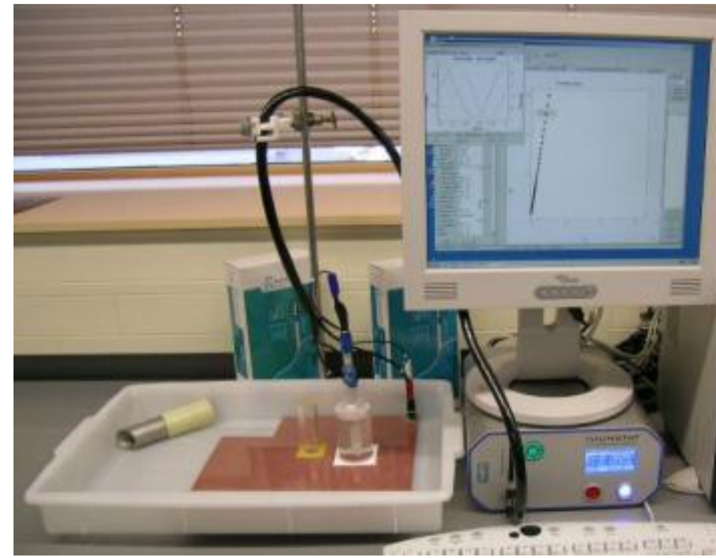
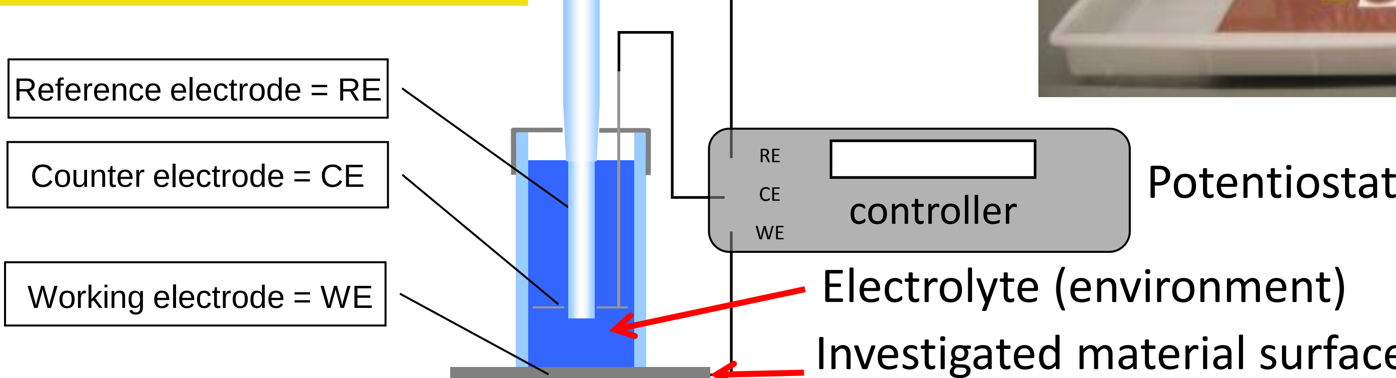
Electrochemical characterisation - principle

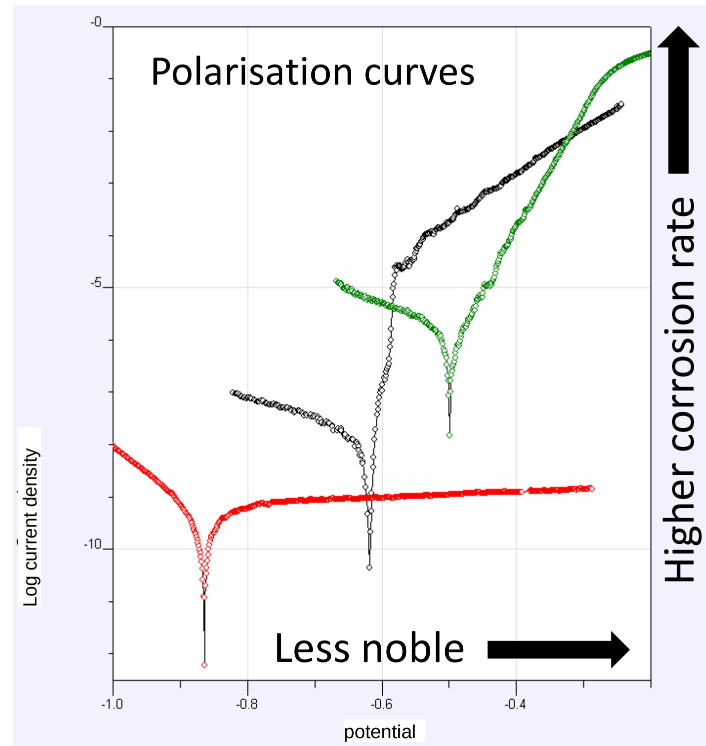






Electrochemical characterisation – PC

- Conditions comparible to practice
  - Elektrolyte: similar to real conditions
  - Varying temperatures
- Insight in actual corrosion mechanisms
  - Simulation of reality
  - Local processes can be predicted
- Extreme sensitive measurement
- Variation in testing
- Accelerated test possibel
- Strong reduced testing times: 30 min – 1 week

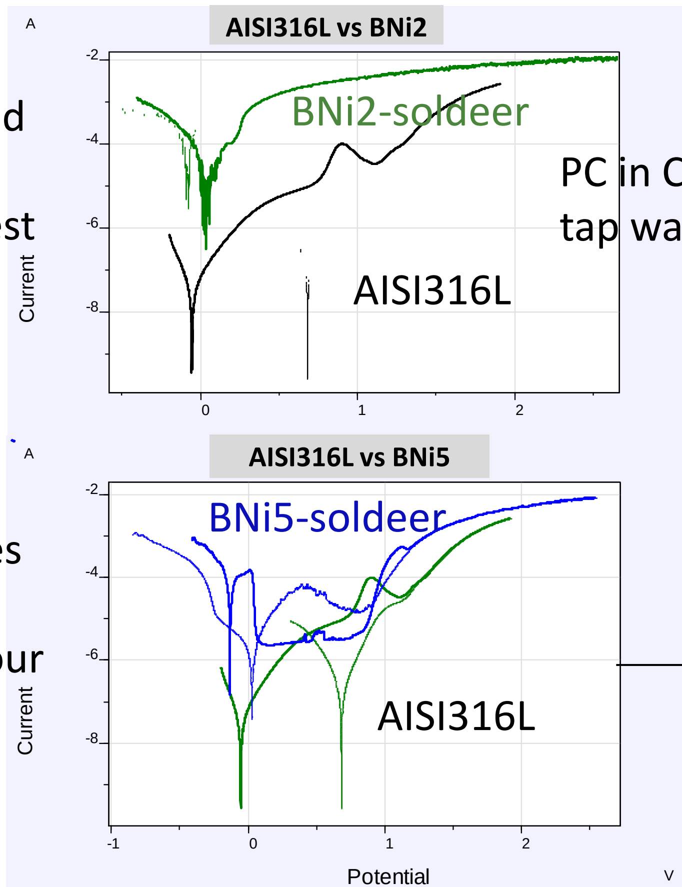


Check between occurring corrosion in practice and electrochemical test

Case 1: PC, SDM, (ENM) Comparing brazing materials

False accepted in salt spray test

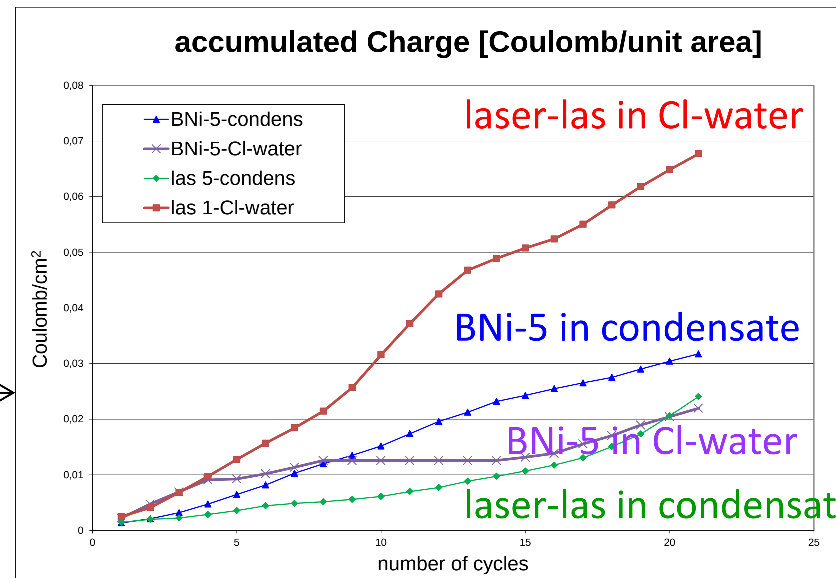
PC indicates similar behaviour



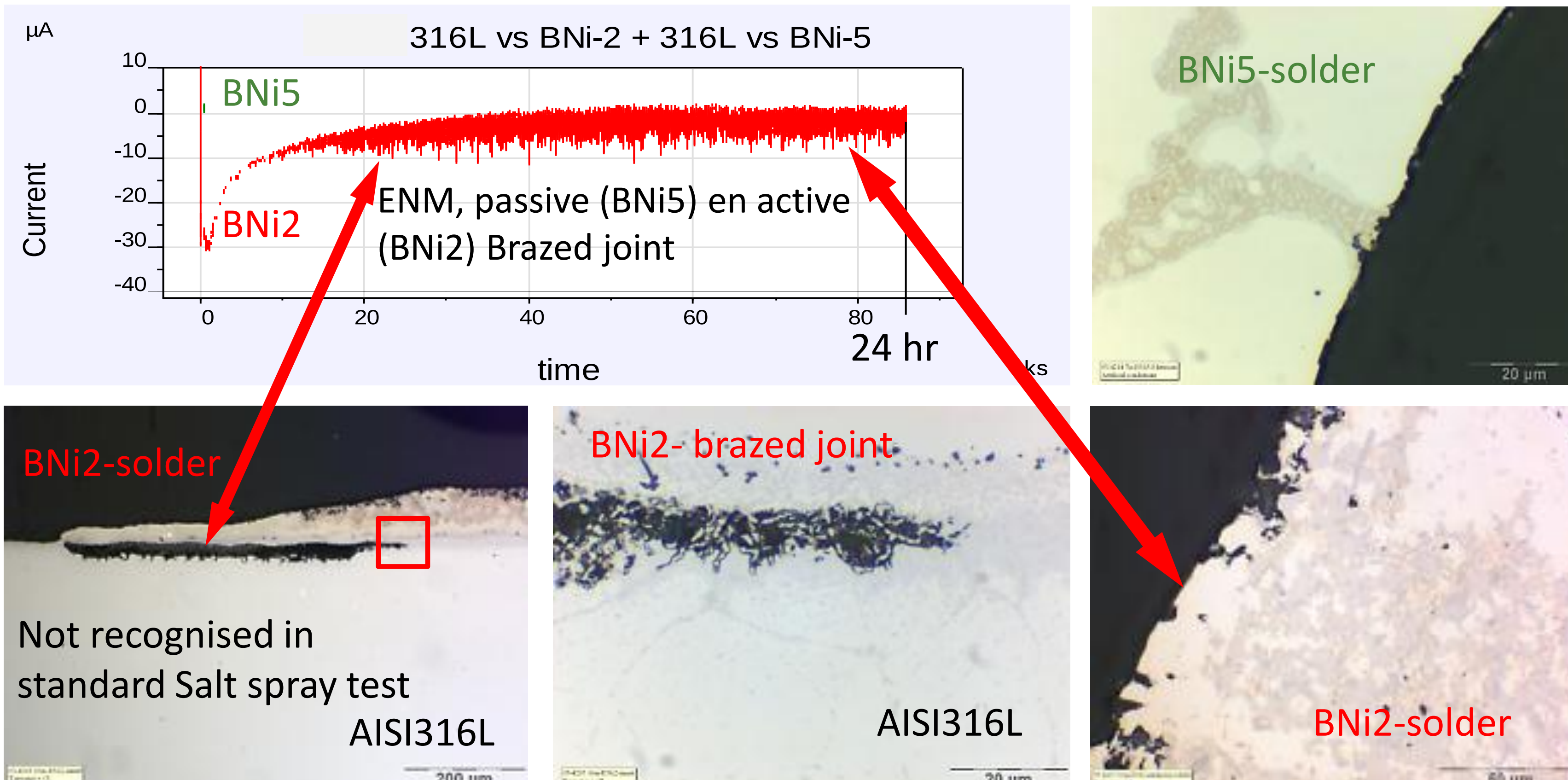
PC in Cl-containing tap water @60°C

Brazing joints: 2 types applied on SS AISI316L

SDM: Stepwise Dissolution Method (accelarated test)



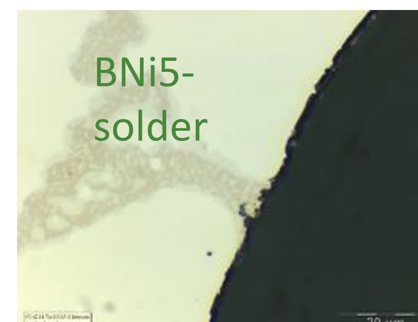
Case 1: (PC, SDM,) ENM
Comparing brazing materials



Case 1: (PC, SDM,) ENM
Comparing brazing materials

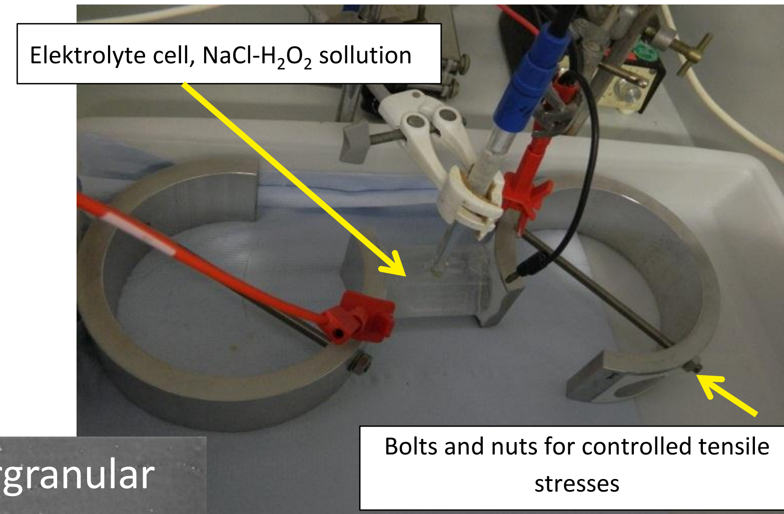
Conclusions:

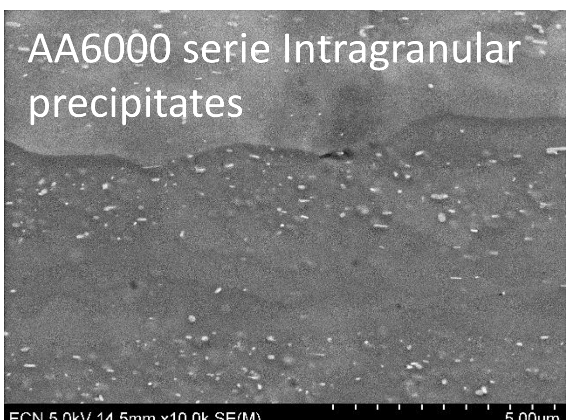
- Selected material combination correct for required function and lifetime
- First indication on performance within 2 hours
- Confirmation within 10 hours (per combination)
- Local corrosion processes identified and false acceptance avoided
- **Joining technique now accepted by costumer (initial refused due to false acceptance in Salt spray resulting in high costs and credibility loss)**



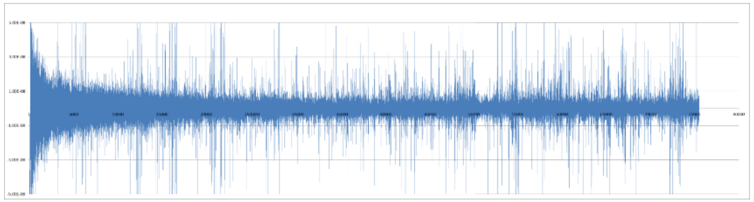
Case 2: Stress corrosion measurement using ENM

Fast comparison of SCC susceptibility of two Al-alloys

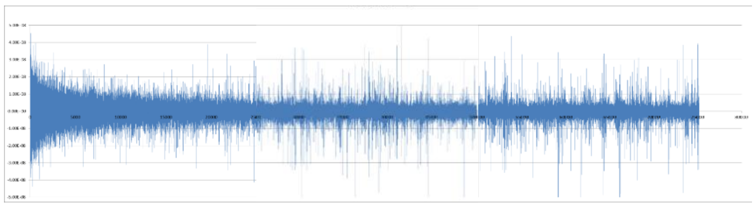




Case 2: Stress corrosion measurement using ENM



AA6000 series
Unloaded



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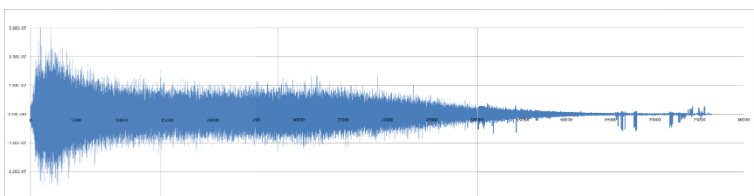

AA7000 series
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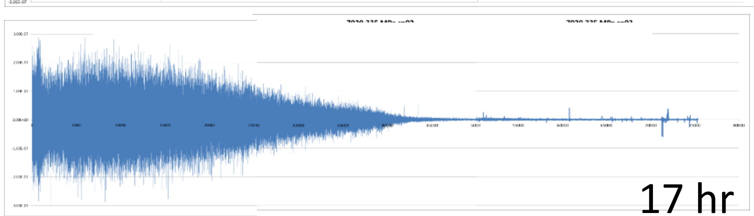

AA7000 series
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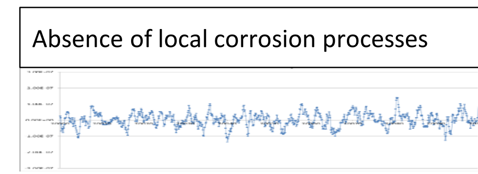
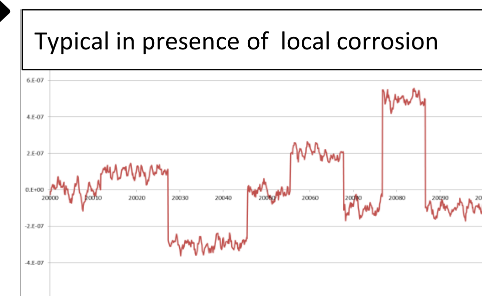
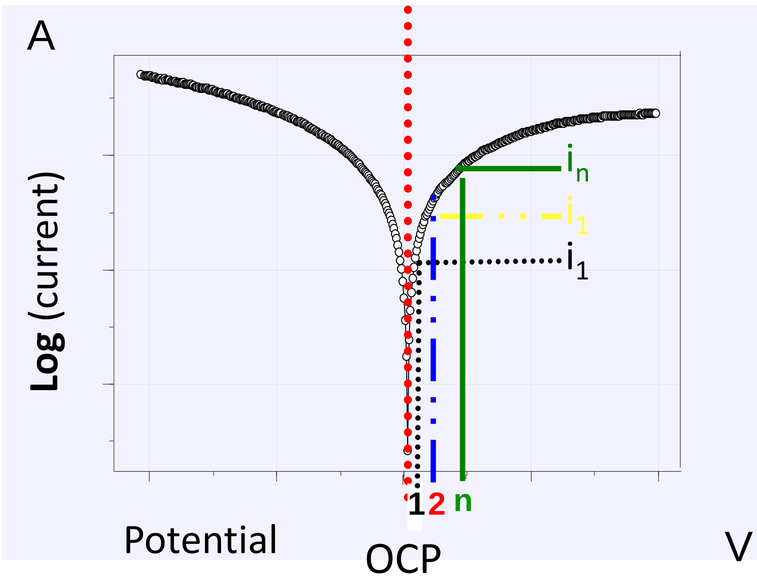
Conclusions:
- Both not susceptible
- AA7000 passivates faster, but starts more active (precipitates)
- No local corrosion (e.g.pitting)





Case 3: SDM (Accelerated test) Measurement principle

Stepwise Dissolution Method (SDM)



- Stap wise raise of potential to $OCP_{0..n}$ by ΔE
- Accelerated corrosion test
- All corrosion processes accelerated individually
- Different corrosion mechanisms seperated
- Results in 6-8 uur

Case 3: SDM (Accelerated test) organic primer on aluminium

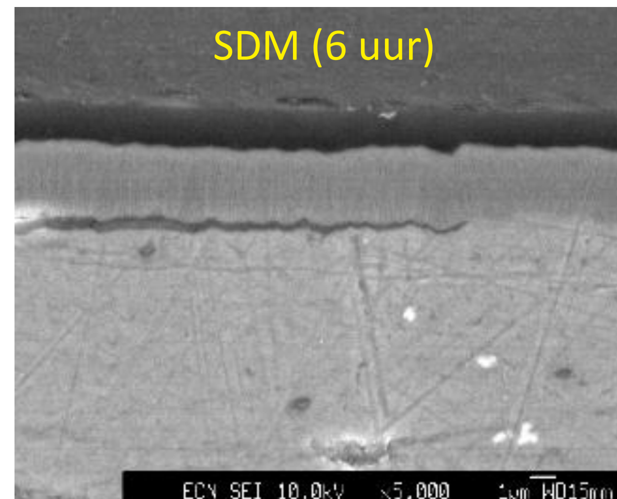
Comparible corrosion processes in Salt Spray Test (BLC) en SDM – Corrosion progresses at the substrate-anodised layer interface.

Exposure side

Inbedding mass

Anodised layer

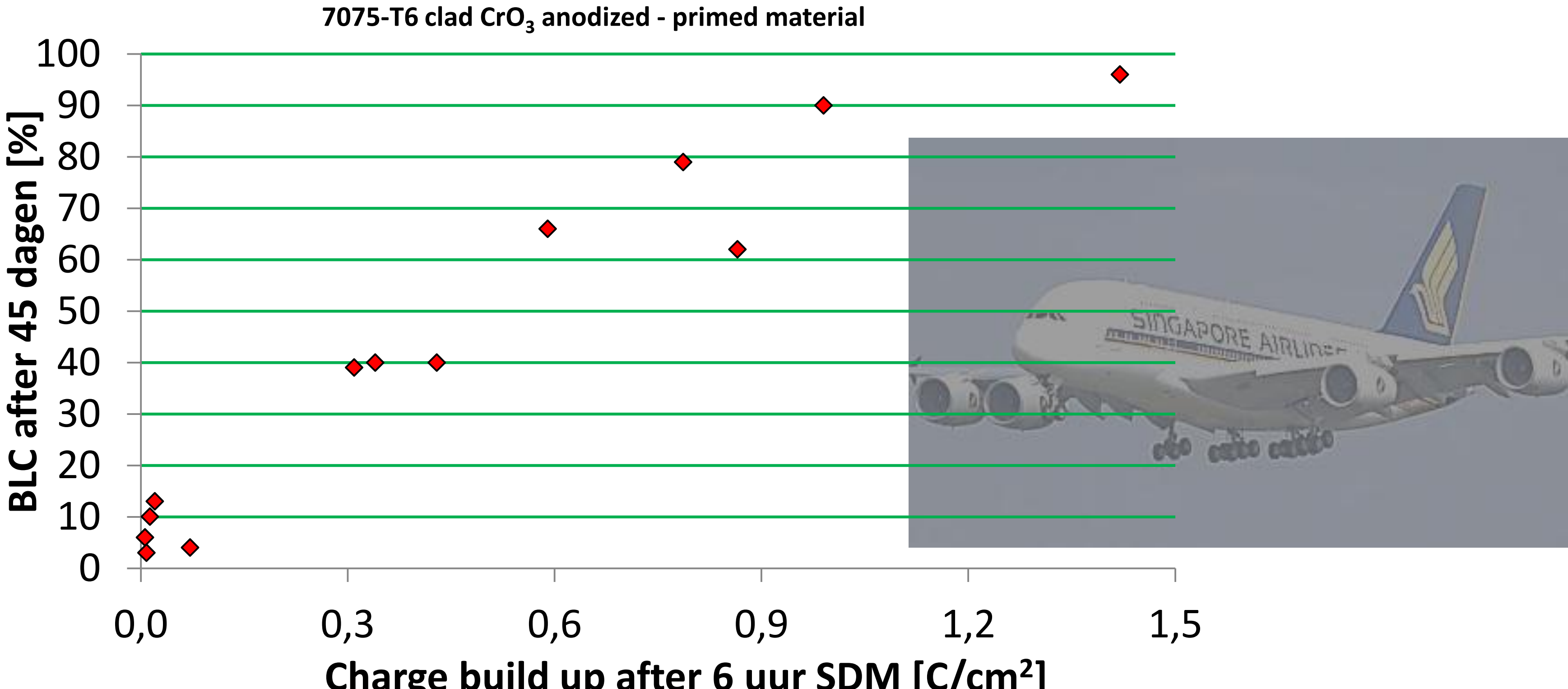
aluminium substrate



Confirmation of corrosion failure mechanism→ validation

Case 3: SDM (Accelerated test) organic primer on aluminium

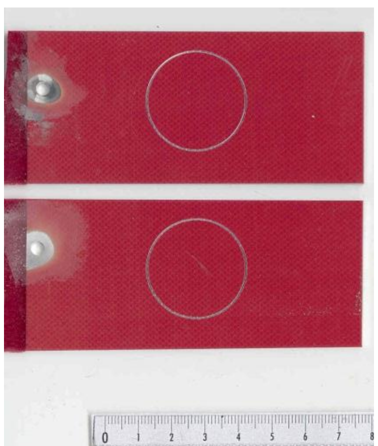
Stepwise Dissolution Method (SDM) vs. Salt Spray Test (BLC)

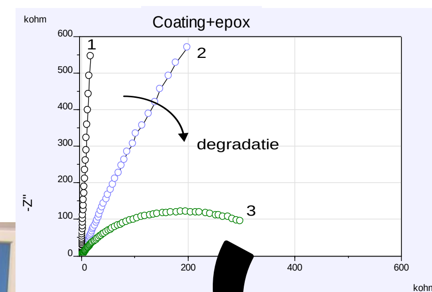


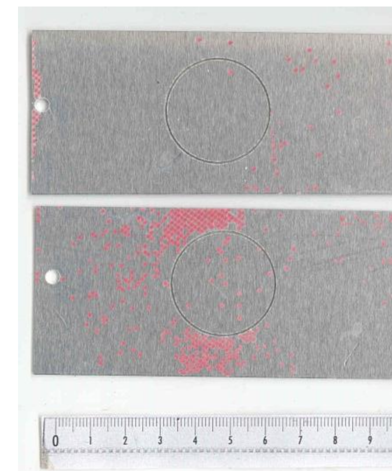
Case 3: SDM (Accelerated test) organic primer on aluminium

Resulted in:

- Reduction in testing cost by a factor of 10
- Faster acceptance of production
- Faster production procedure development and optimisation (results in 6 hours)







Case 4: PC & SDM (Accelerated test) On Brass, Copper, Nickel, C-steel – water system

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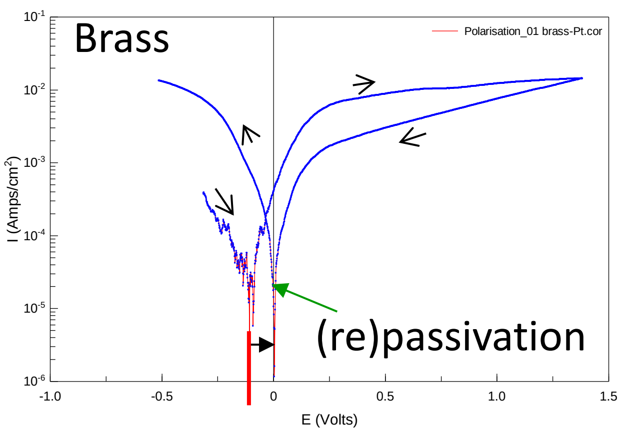
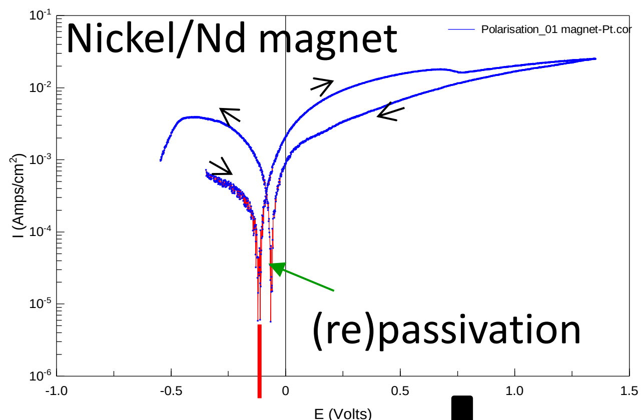
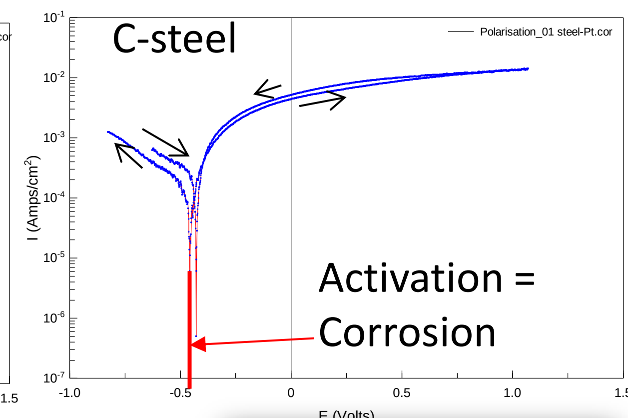
Question: What is the effect if a Ni-Cu-Ni coating on a Nb-magnet is left out?
In a system with brass, C-steel (Nb-magnet), and nickel in chlorinated tap water at RT







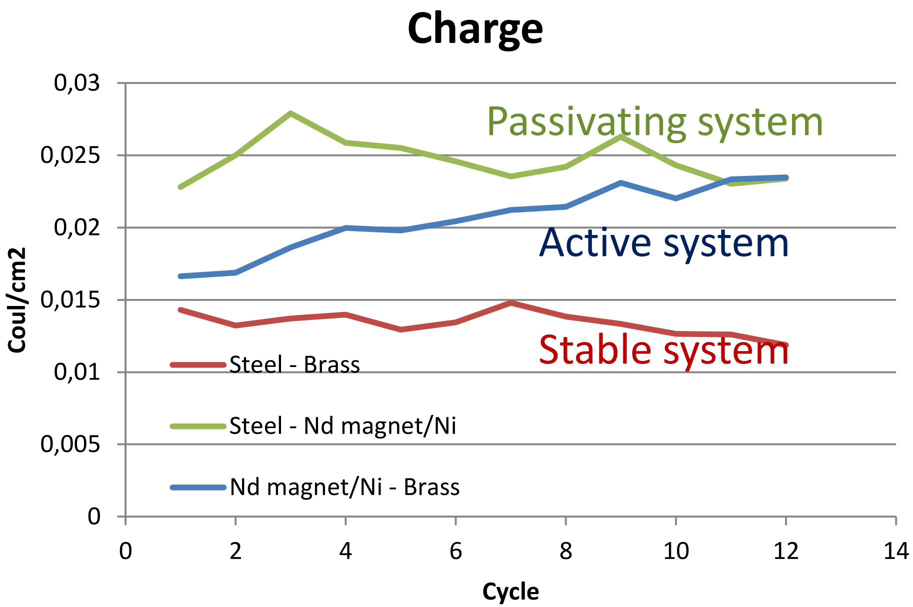
PC at:
- 10°C
- 250ppm Cl tap water

Nobel

Brass	-0,12 V
Nickel coated Nb-magnet (Ni)	-0,15 V
C-steel	-0,43 V

SDM: Nickel less noble than Copper → preferential corrosion
Nickel shows pin holes!

Case 4: PC & SDM (Accelerated test) On Brass, Copper, Nickel, C-steel – water system

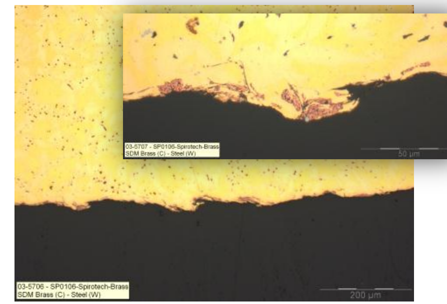


Conclusion:

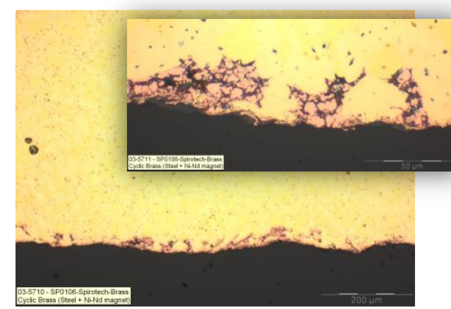
- Omitting the Ni(-Cu-Ni) coating results in enhanced corrosion of Nd-Magnet (C-steel)
- Indication for performance within 2 hours

Validation:

Comparing exposition and SDM test



SDM test:
Brass vs C-steel
Results: 10hrs



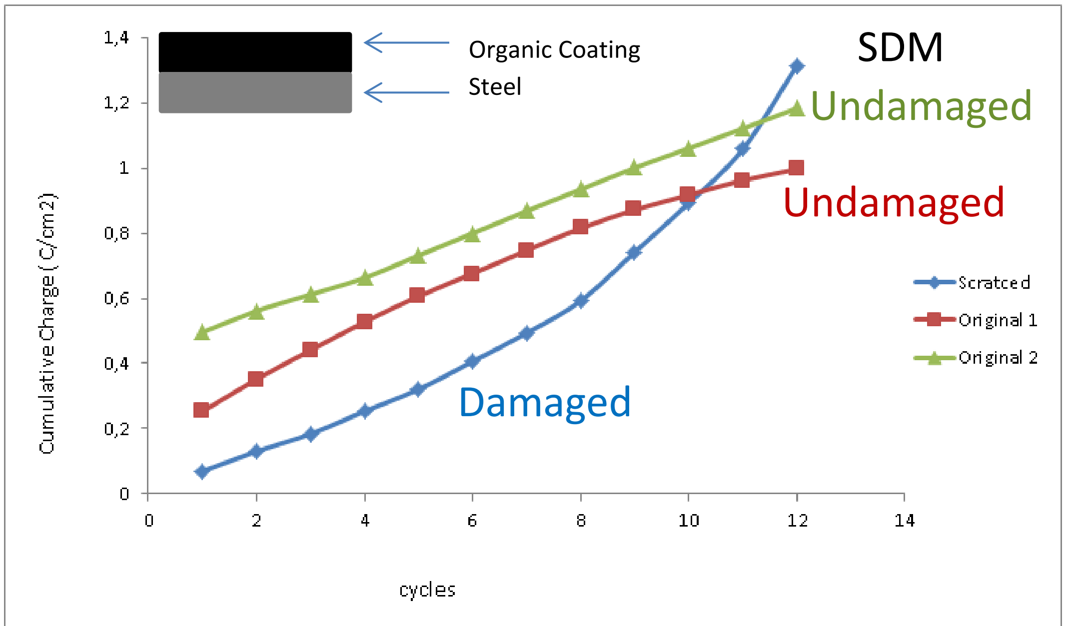
Exposition:
Brass vs C-steel
Results: 2 months

Both dezincification ➔ same mechanism

Case 5: EIS and SDM measurement Characterisation of coatings

Problem: Corrosion of coated C-steel component

Question: Qualification of organic coating vs Aluminised substrate and effect of (mechanical) damage

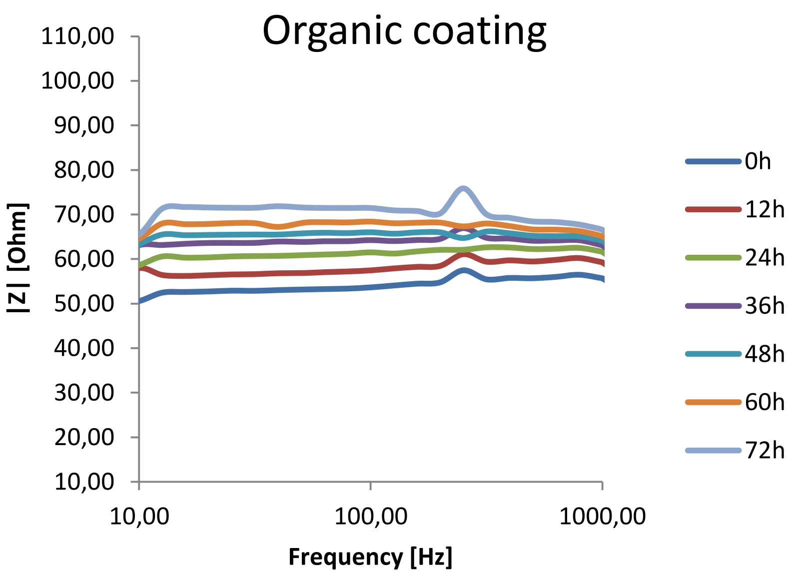


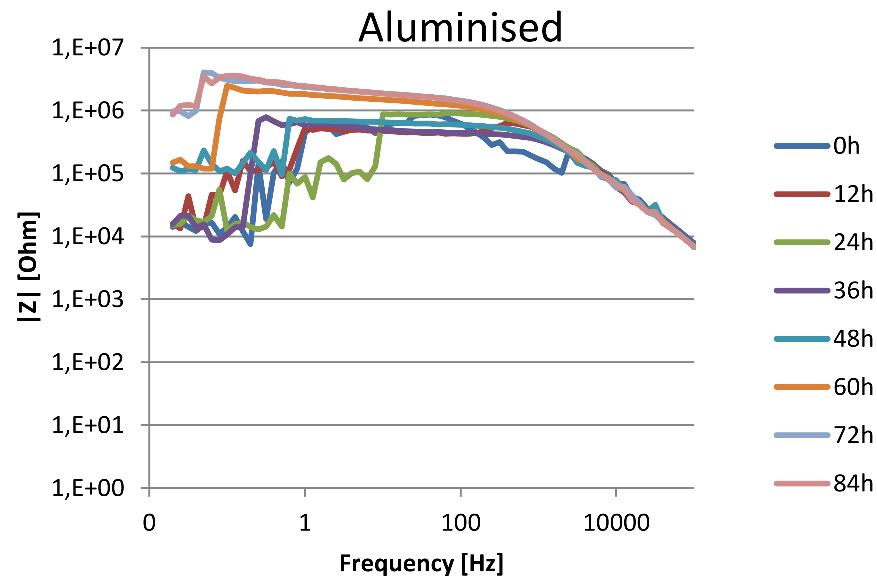
Undamaged: straight climbing line → electrochemical stable behaviour → relative protective layer

Damaged: exponential climbing line → electrochemical active behaviour → corrosion

Case 5: EIS and SDM measurement Characterisation of coatings

Damaged organic coating vs aluminised substrate





Low resistance → High electrochemically active → corrosion
Constant over time

High resistance →low electrochemically active → low corrosion
Increases over time → repair of defect

Summary & conclusions

- Electrochemical characterisation:
  - Identifies corrosion processes
  - Reduces risk for false acceptance or rejection
- Validation with respect to corrosion mechanisms required (e.g. metallographic examinations)
- Generally faster insight in corrosion performance
- True system can be evaluated (Environment-Material-Temperatures)
-

Thanks for your attention

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