Formulating Functional Films and Coatings IV

Wednesday 8 December 2021

Smart ceramic coatings for corrosion protection

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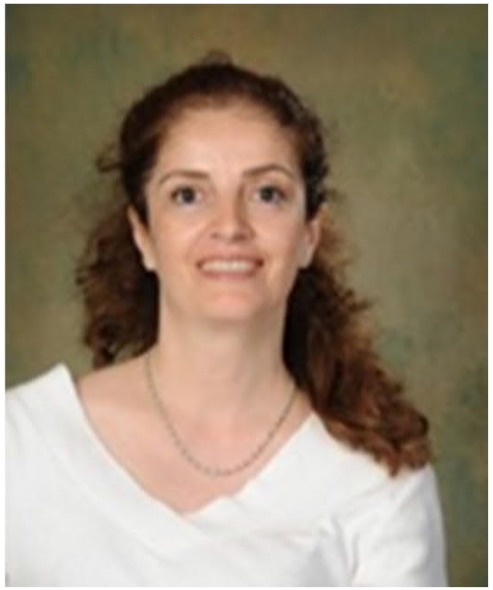
Plasma Electrolysis Research Lab

MANCHESTER 1824

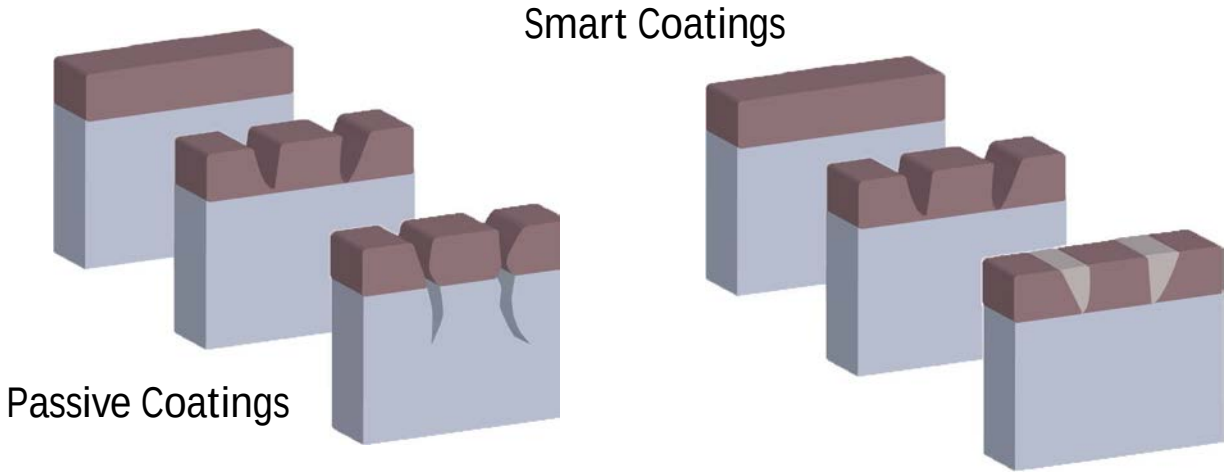
Dr Sepideh Aliasghari

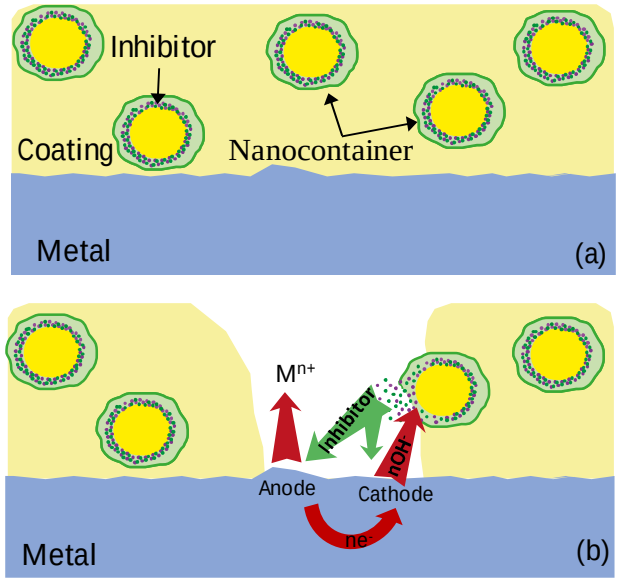


A. Matthews, A. Yerokhin, N. Laugel, S. Aliasghari, A. Rogov, D. Shore, H. Tang , Y. Li, S. Al Abri, Y. Guo

Aims and Objectives

Develop an environmentally friendly coating technology capable of improving the long-term performance of lightweight components used in the transport industry





$$Mg\ (s) \rightarrow Mg^{2+}(aq) + 2e^-$$
$$2H_2O(l) + 2e^- \rightarrow 2OH^-(aq) + H_2\ (g)$$

Achieve the active multi-functionalisation of ceramic coatings by incorporating encapsulated active species to provide corrosion protection and self-healing properties on-demand

Active functionalization

Organic coatings

Ceramic coatings

Anti-corrosion

2

Thermal stability

Mechanical performance

Rigid and inert

Self-healing

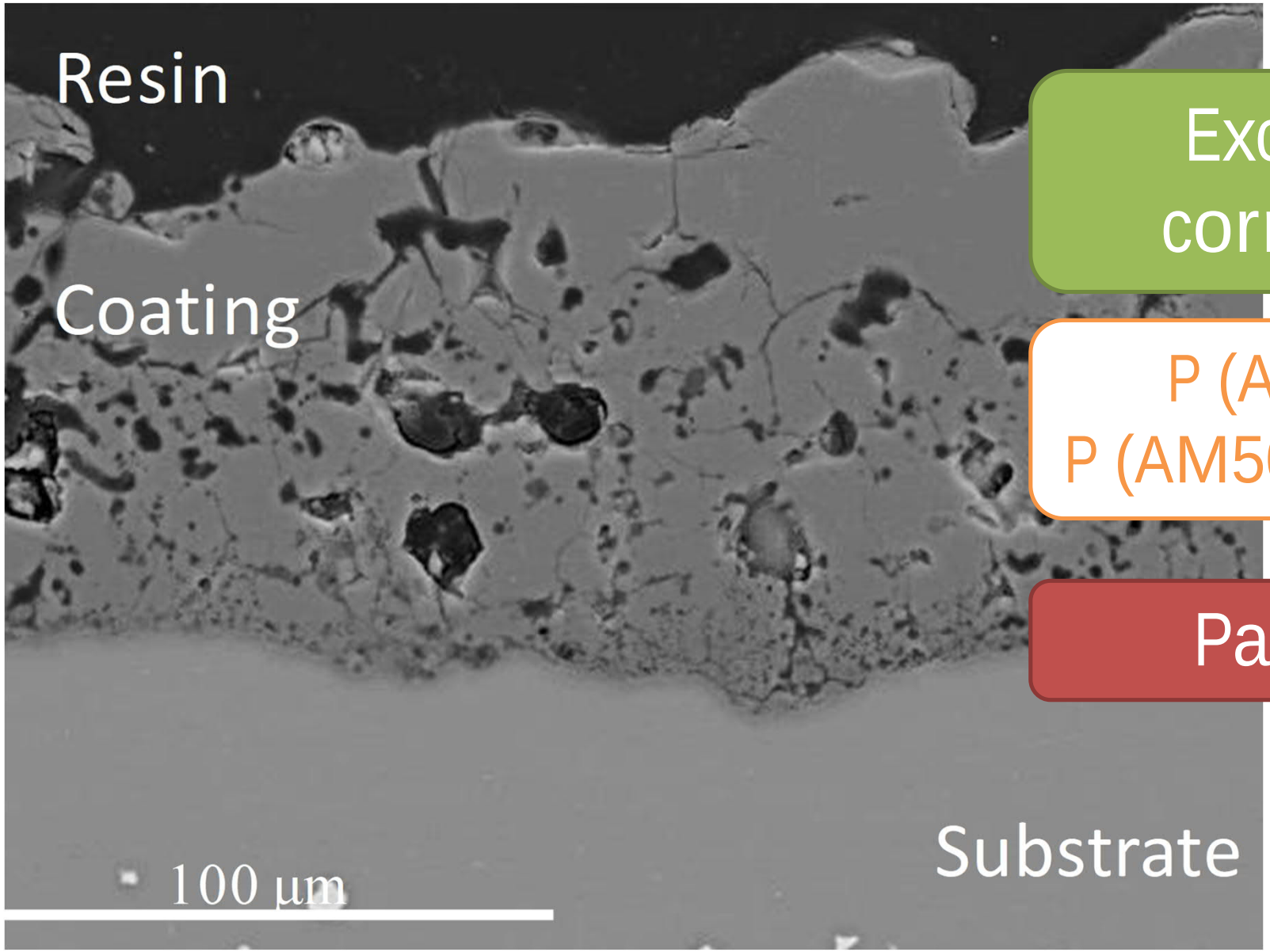
1

Super-hydrophobic

Plasma Electrolytic Oxidation (PEO)

[1] Hanze Ying/Nature Communications 5, 3218 (2014)
[2] Boura/ Prog. Org. Coat., 75 (2012), pp. 292-300
[3] Super hydrophobic coating (UltraTech International, Inc.) https://www.youtube.com/watch?v=IPM8OR6W6WE

Plasma Electrolytic Oxidation (PEO)



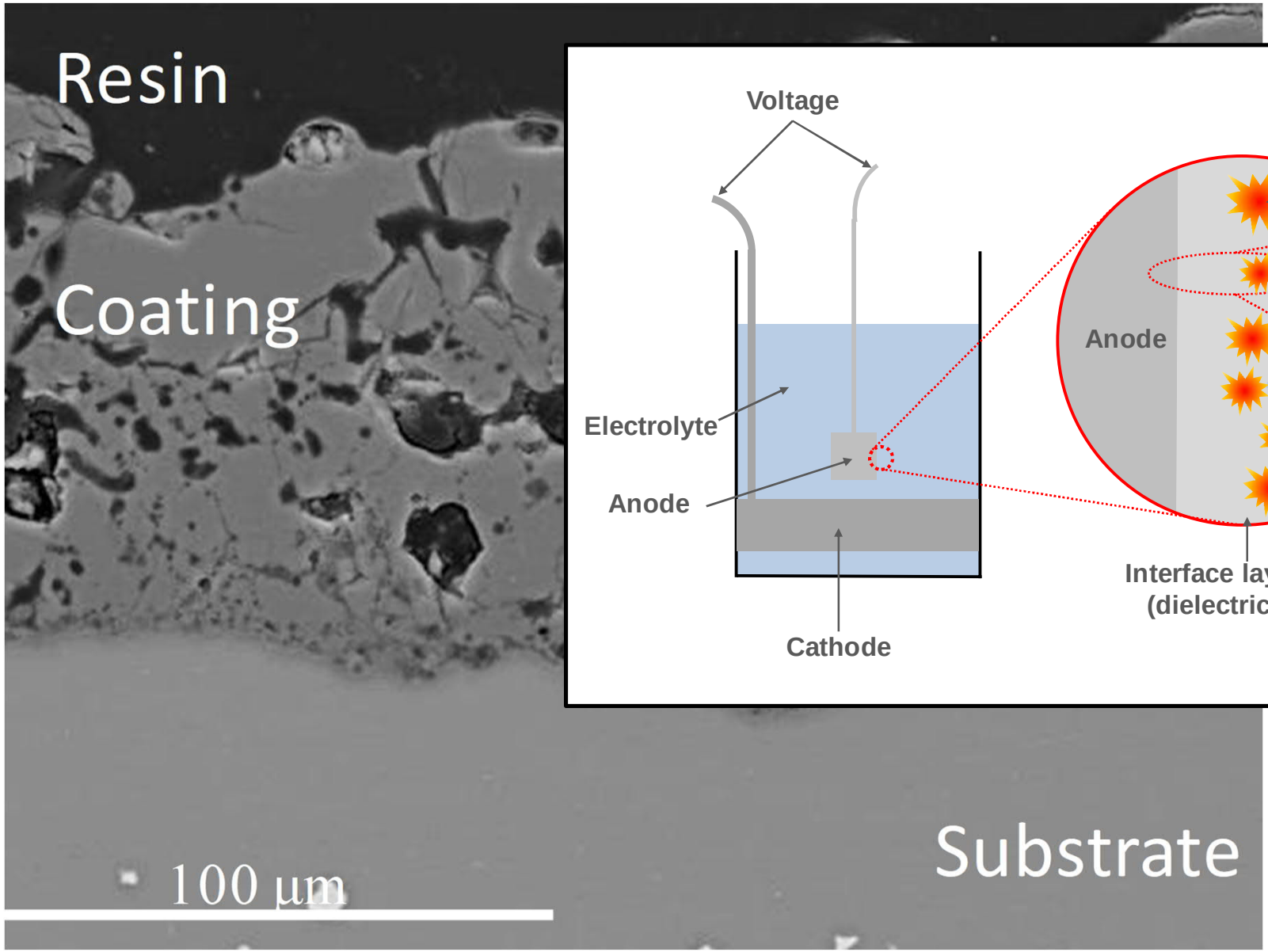
Excellent wear and corrosion properties

P (AM50) = 3.21 mmy^{-1}
P (AM50+PEO) = 0.09 mmy^{-1}

Passive protection

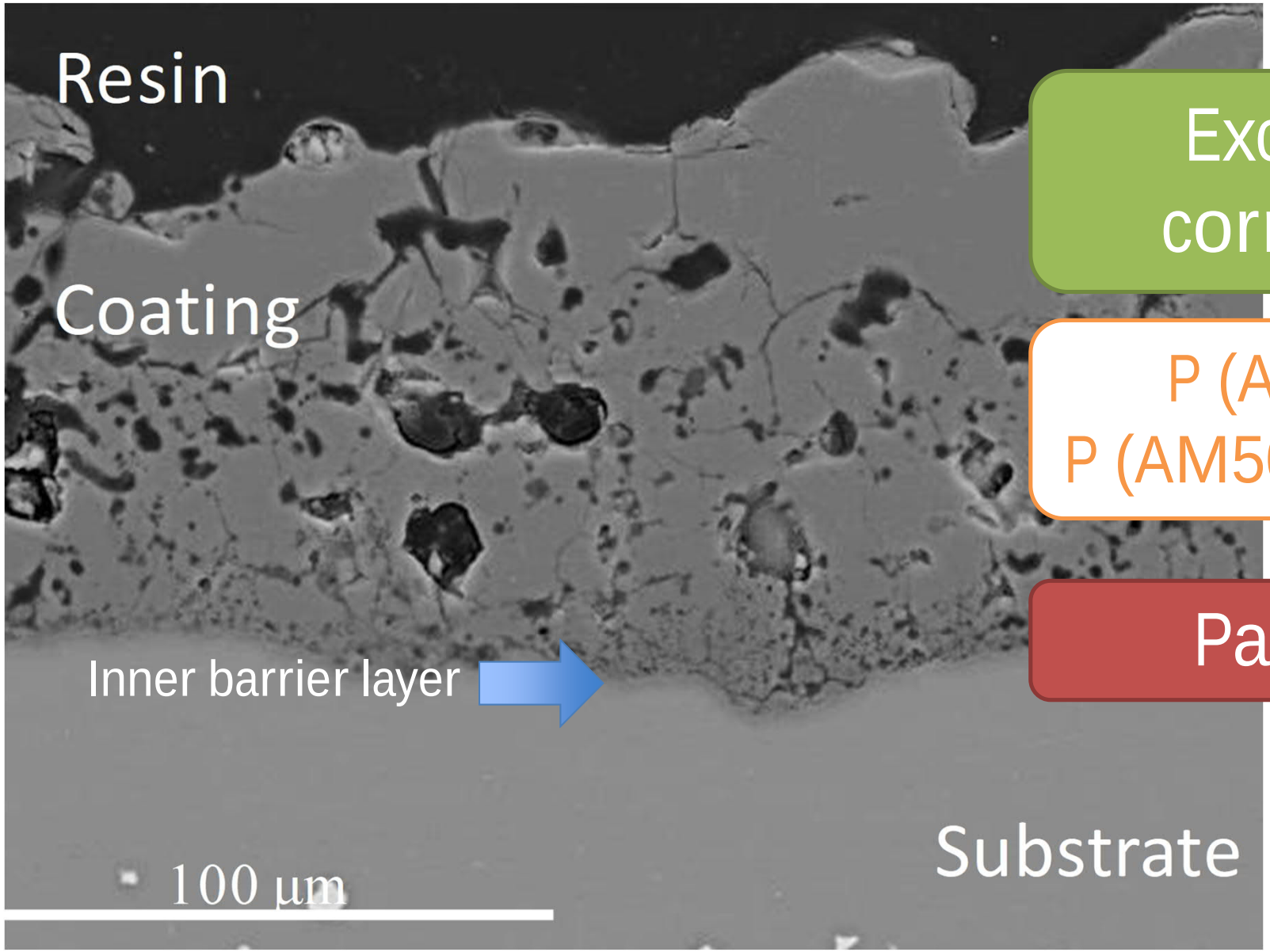
E. Matykina / Applied Surface Science 389 (2016) 810-823

Plasma Electrolytic Oxidation (PEO)



E. Matykina / Applied Surface Science 389 (2016) 810-823

Plasma Electrolytic Oxidation (PEO)



Excellent wear and corrosion properties

P (AM50) = 3.21 mmy^{-1}
P (AM50+PEO) = 0.09 mmy^{-1}

Passive protection

E. Matykina / Applied Surface Science 389 (2016) 810-823

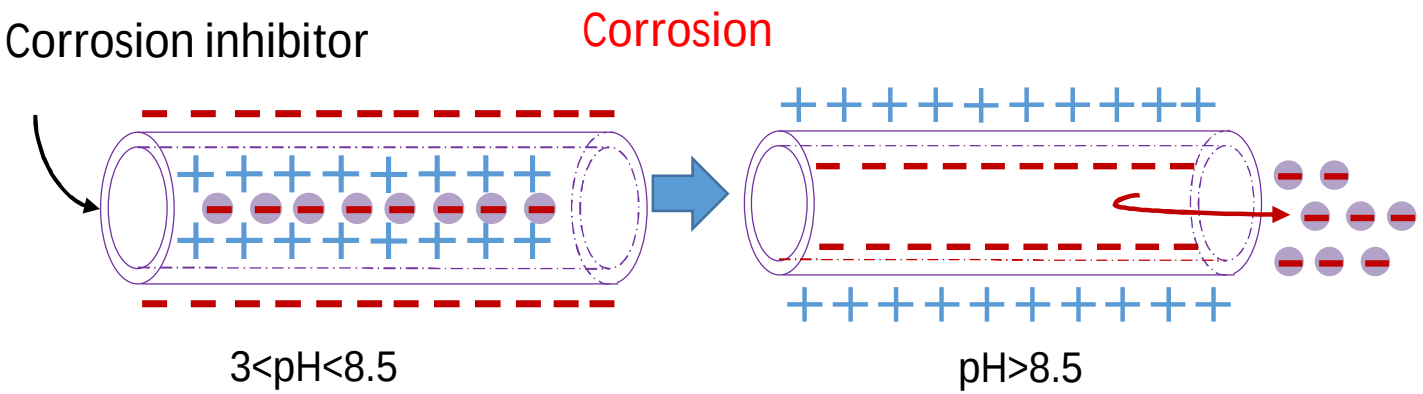
Specific Objective

Functionalization of PEO coatings

Encapsulation of corrosion inhibitors

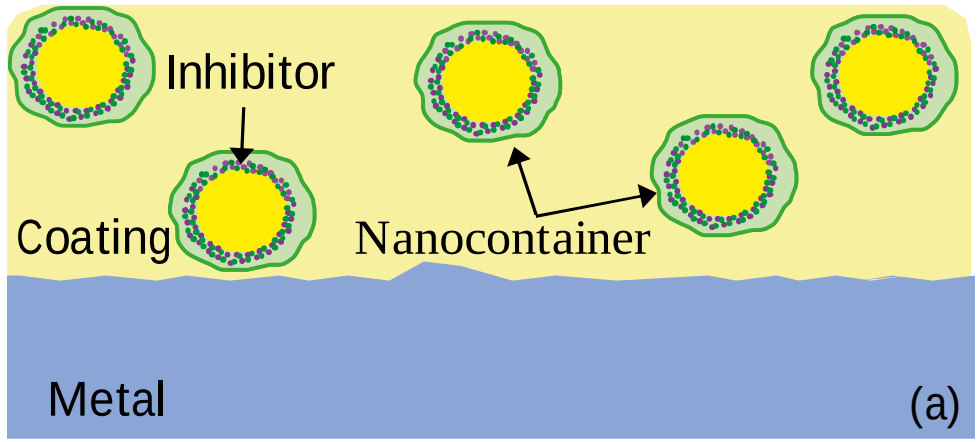
Corrosion protection on-demand

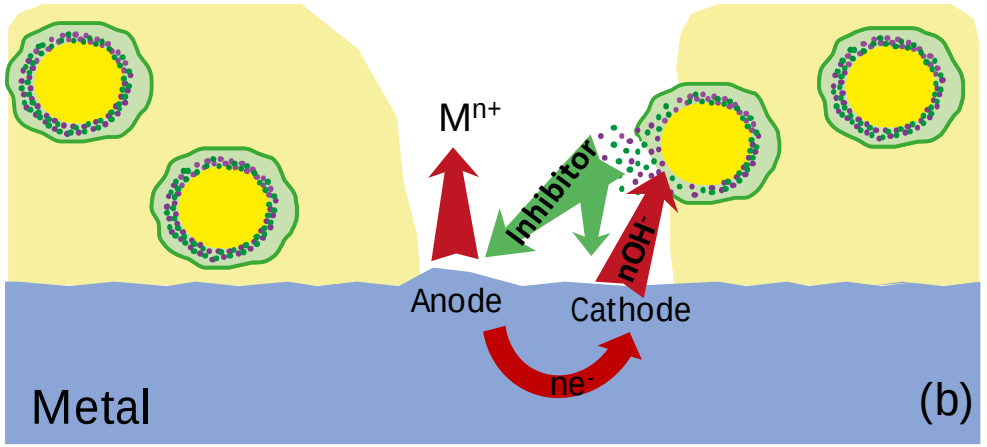
pH sensitive nanocontainers



✔ Self-healing
✔ Control release

Magnesium alloy



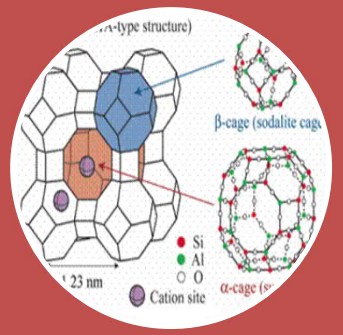


Based on Zheludkevich/Chemistry of Materials, 19 (2007) 402-411

$$Mg\ (s) \rightarrow Mg^{2+}(aq) + 2e^-$$
$$2H_2O(l) + 2e^- \rightarrow 2OH^-(aq) + H_2\ (g)$$

Methodology

Active functionalization of PEO coatings



Selection

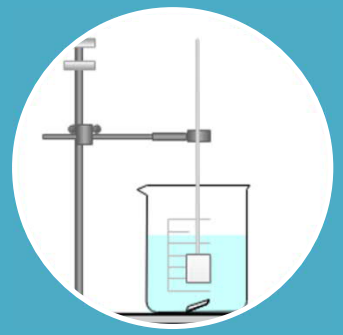
nanocontainers

Encapsulation

corrosion inhibitors

Synthesis

of the coating



Functionalisation
post-treatment

Step I → Step II → Step III → Step IV

Step I: Selection of the nanocontainer

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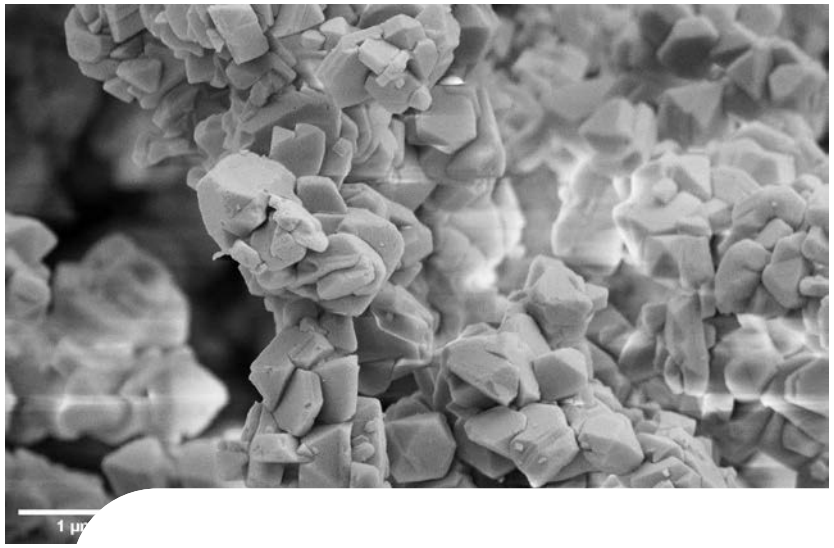
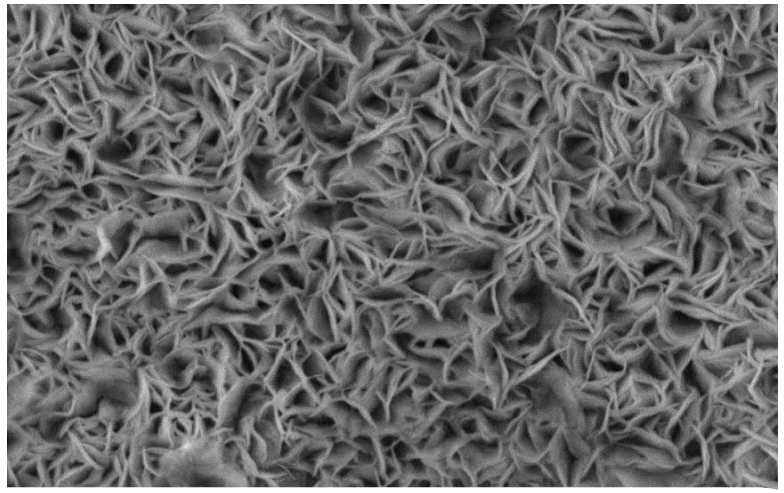
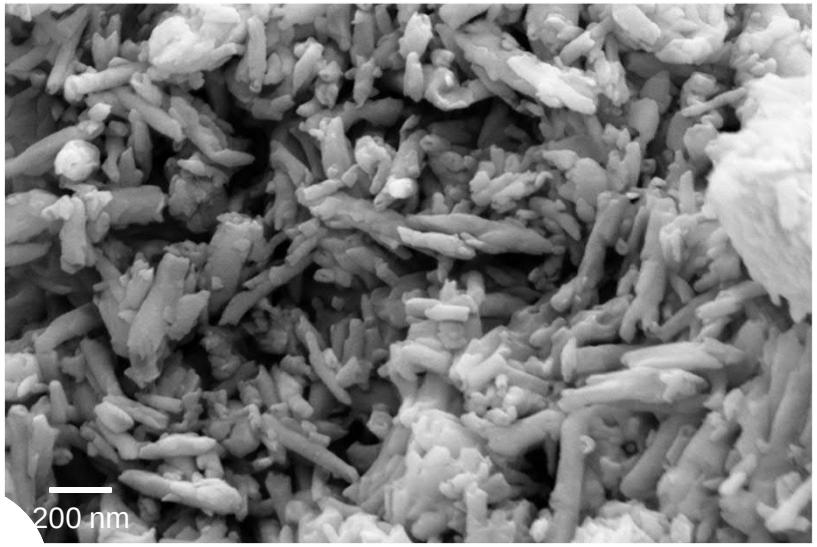
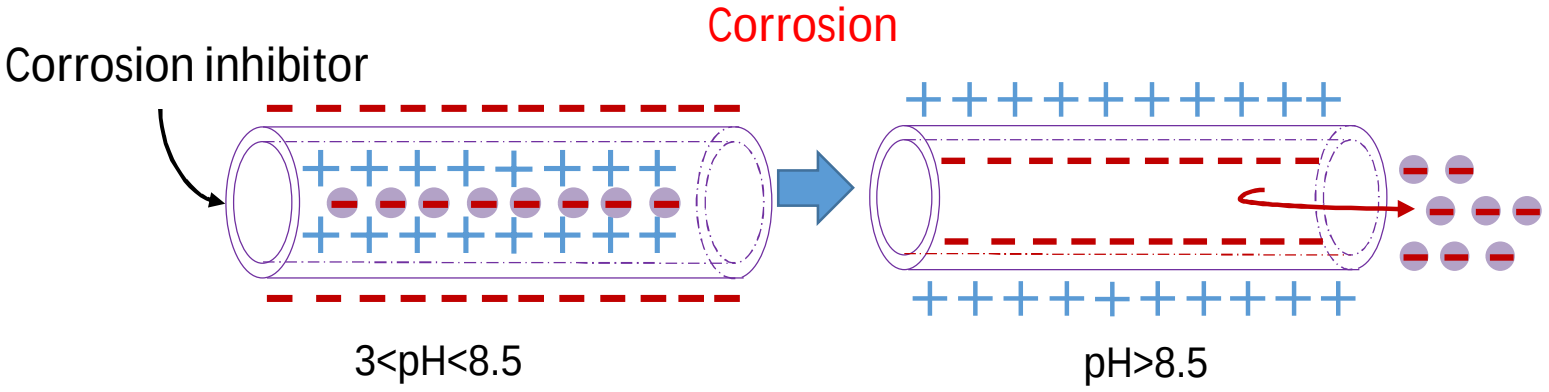
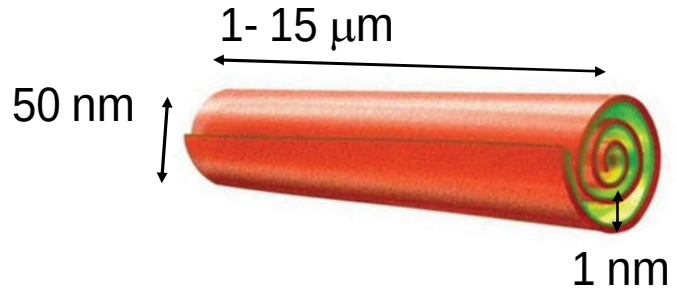
Zeolites | Layered Double Hydroxides (LDH) | Halloysite Nanotubes (HNT)



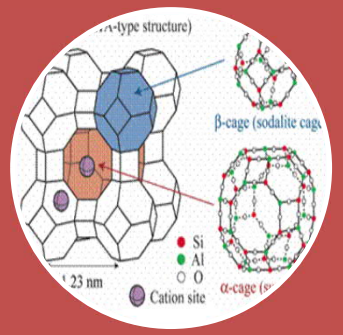








Active functionalization of PEO coatings



Selection

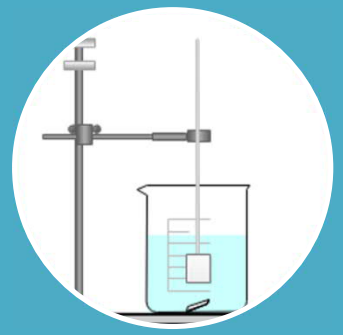
nanocontainers

Encapsulation

corrosion inhibitors

Synthesis

of the coating



Functionalisation
post-treatment

Step I

Step II

Step III

Step IV

Step II: Encapsulation

Corrosion inhibitors

Vanadate salt (NH_4VO_3)

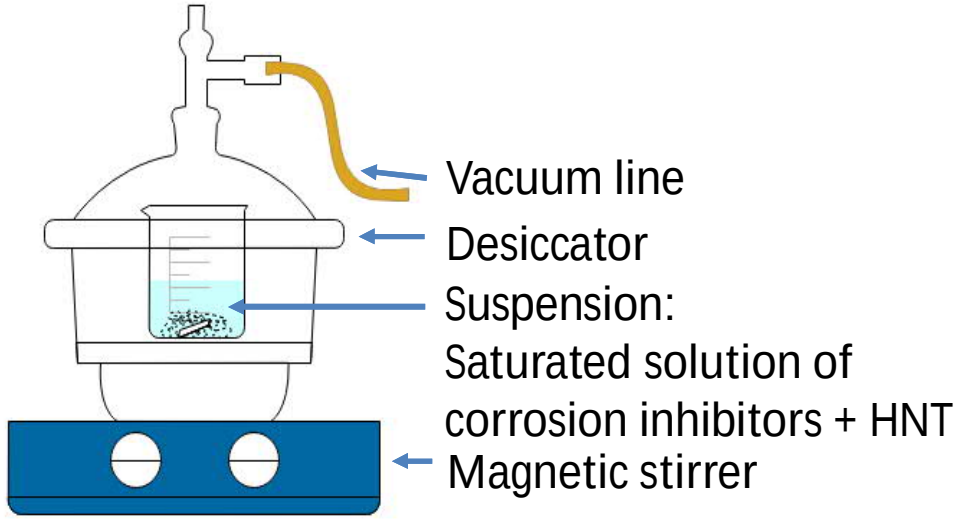
Molybdate salt $(NH_4)_6Mo_7O_{24}\,4\,H_2O$)

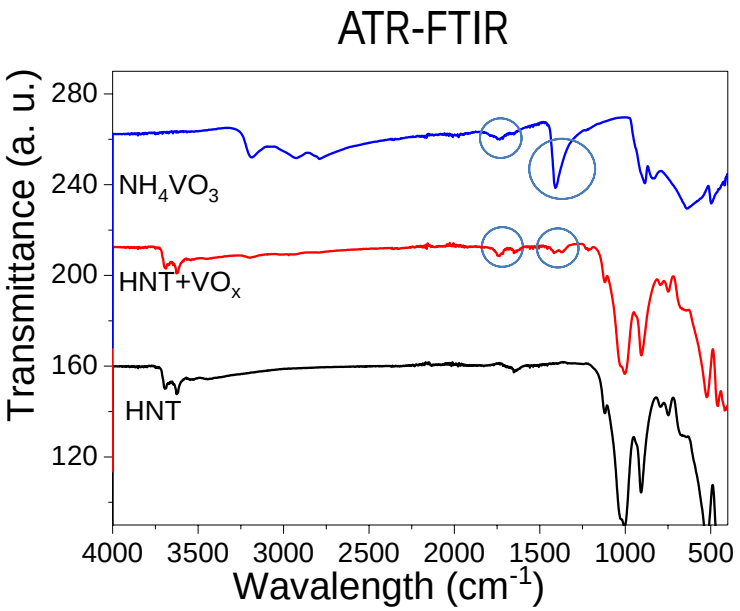
8-Hydroxyquinoline

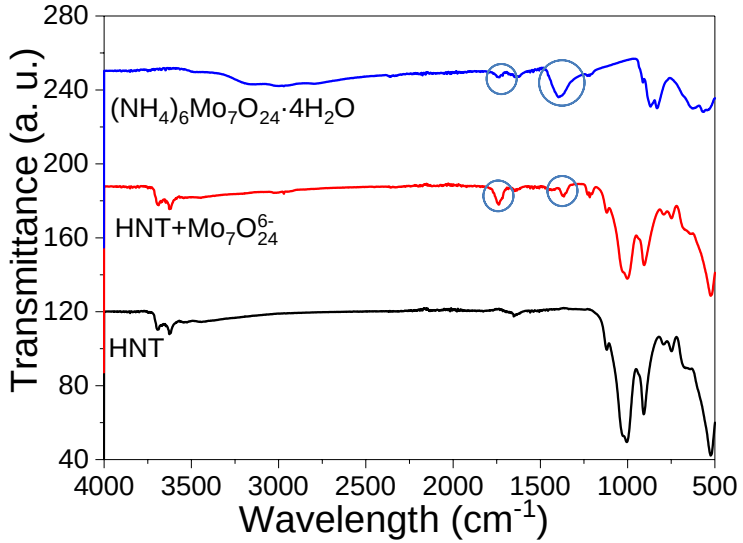
pH

Time

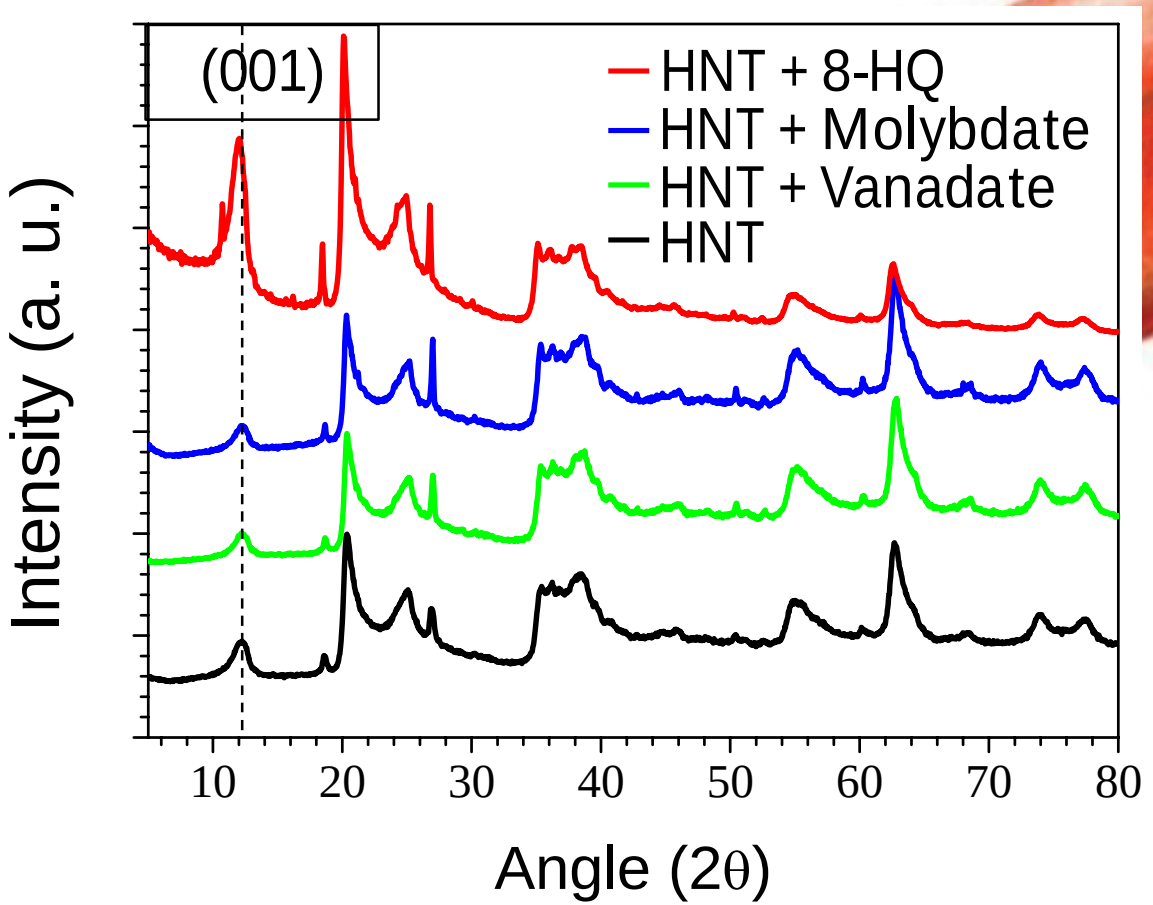
Vacuum-induced capillarity

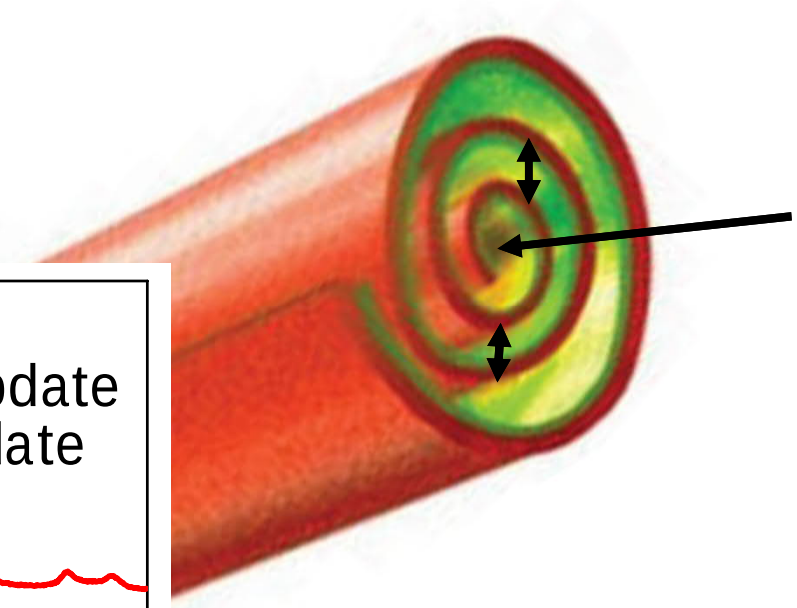




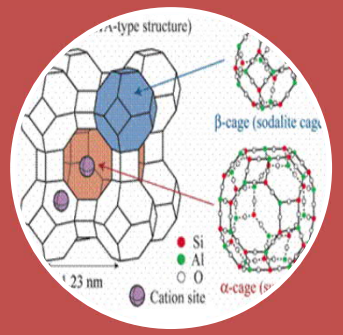


Step II: Encapsulation





Active functionalization of PEO coatings



Selection

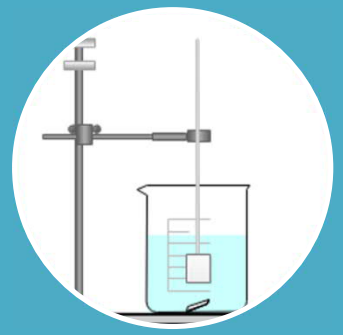
nanocontainers

Encapsulation

corrosion inhibitors

Synthesis

of the coating



Functionalisation
post-treatment

Step I

Step II

Step III

Step IV

14

Step III: Synthesis of PEO coating

Single-step process

Direct functionalisation during PEO synthesis

Double-step process

Synthesis of the coating followed by functionalisation treatment

Step III: Synthesis of PEO coating

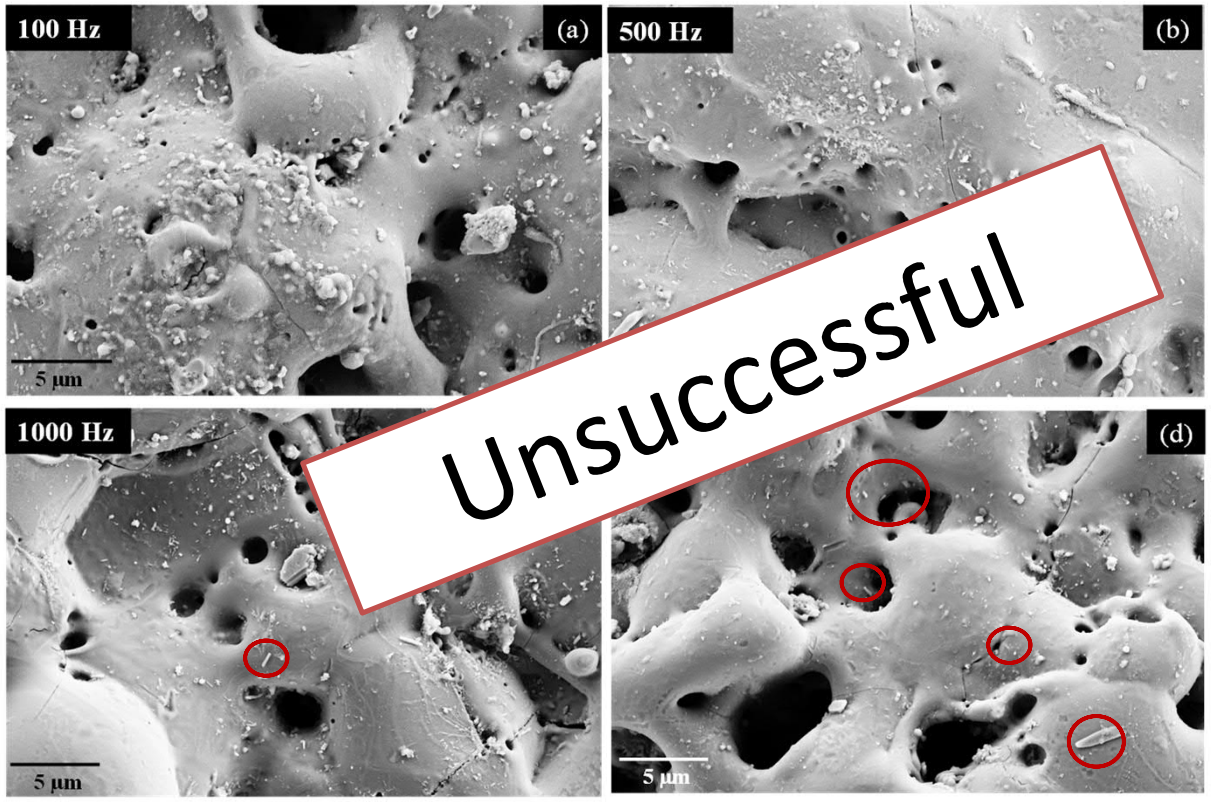
Single-step process

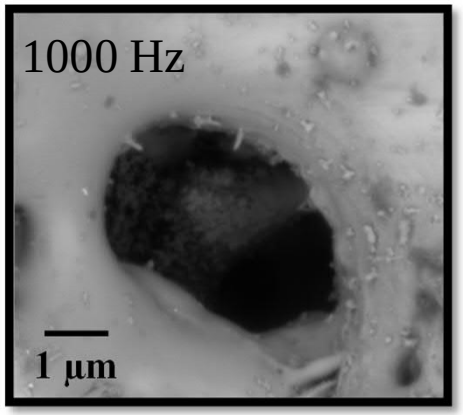
AM50

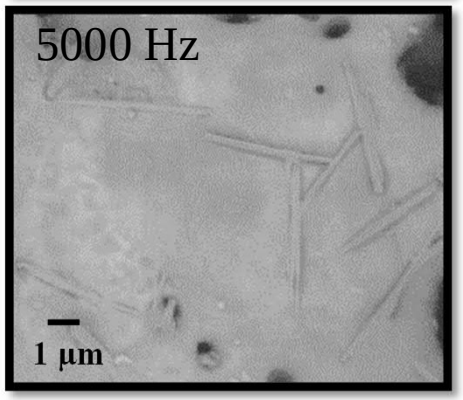
12 g/L Na_2SiO_3
2 g/L KOH
4 g/L NaF
10 g/L HNT

i= 40 mA/cm^2
t= 5 min
δ=10 %
f=100-5000 Hz

Reactive **Partially Reactive**







Partially Reactive **Non Reactive**

↑Frequency ↑ Number of ↓ intense micro-discharges

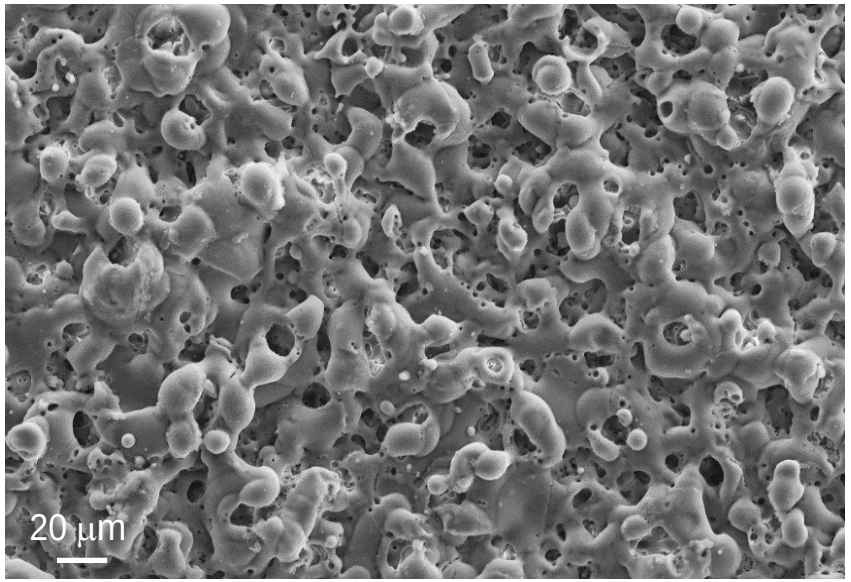
Step III: Synthesis of PEO coating

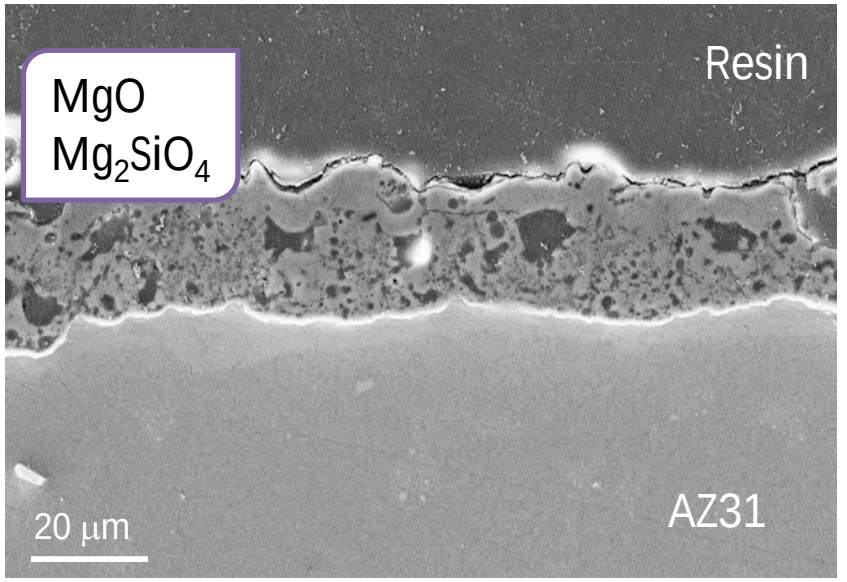
Double-step process

Electrolyte

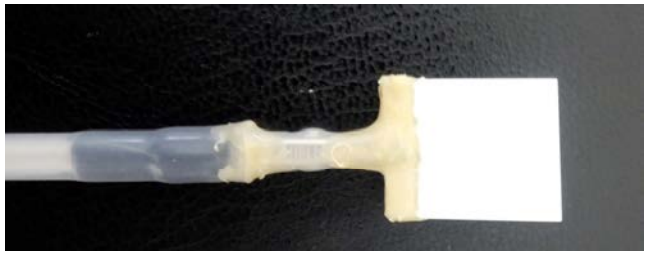
12 g/L Na_2SiO_3
2 g/L KOH
4 g/L NaF

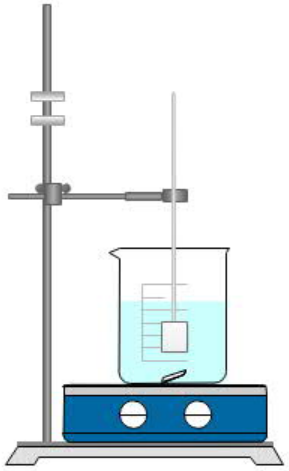
i= 40 mA/cm^2
t= 10 min
δ=10 %
f=5000 Hz





Step IV: Functionalisation post-treatment

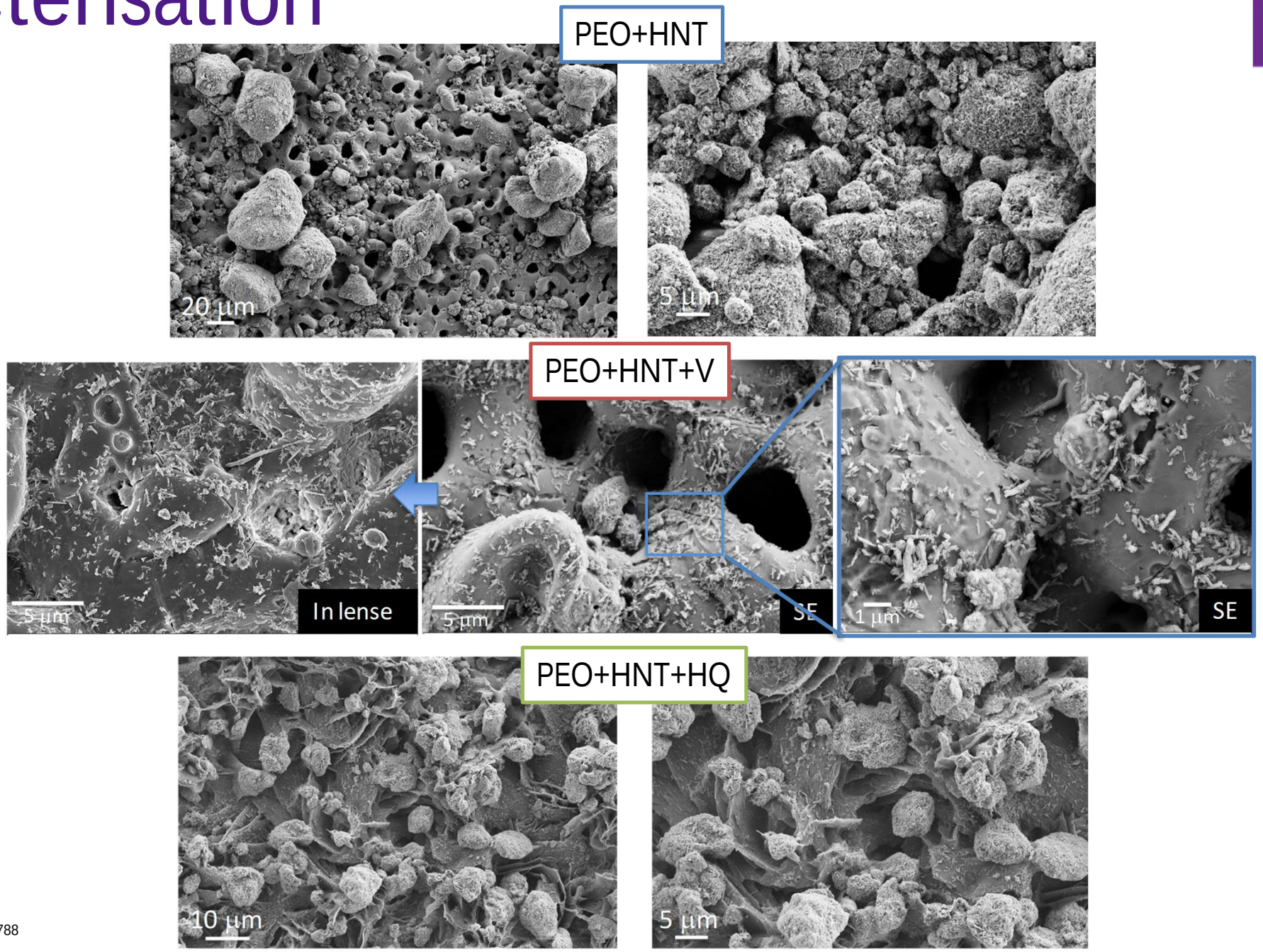




Immersion

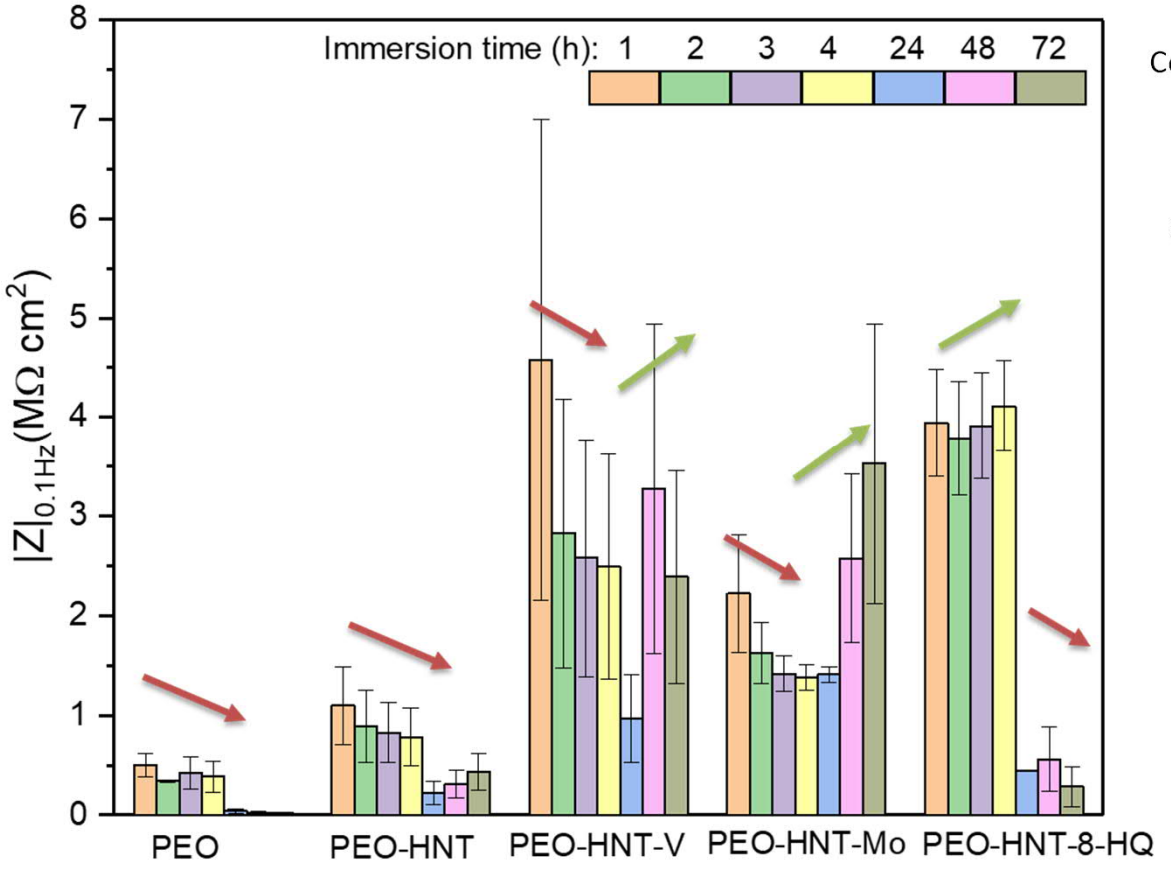
20 g/ L corrosion inhibitor-loaded HNT
10 min
pH 7-7.5

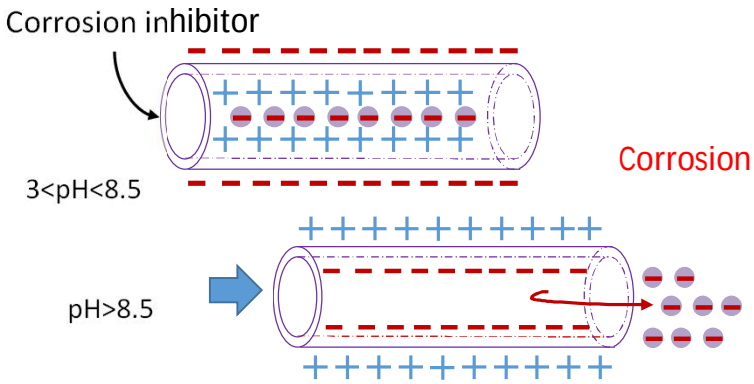
Characterisation

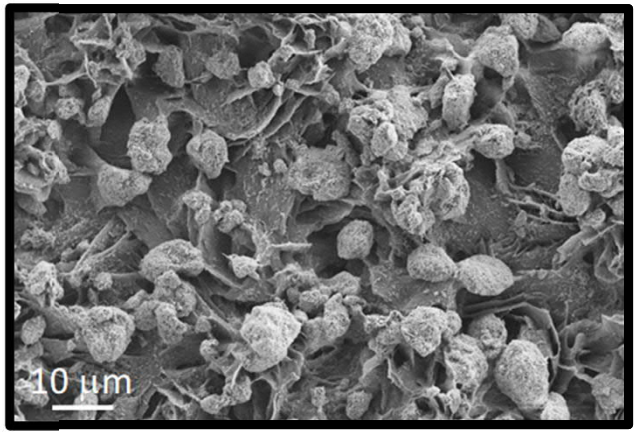


Electrochimica Acta 299 (2019) 772e788

Evaluation of the Corrosion Resistance: Electrochemical Impedance Spectroscopy (EIS)







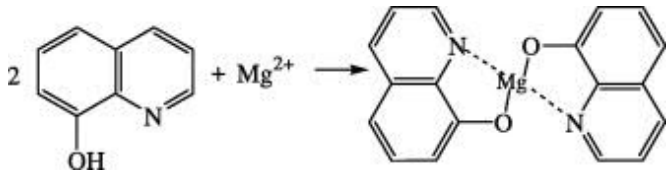
Vanadates
HVO_4^{2-} (tetrahedral)
Anodic type inhibitor
Adsorption/precipitation

pH dependant

Molybdate
$HMoO_4^-/MoO_4^{2-}$
Cathodic type inhibitor
Adsorption/precipitation

8-HQ
Mixed type inhibitor
Precipitation

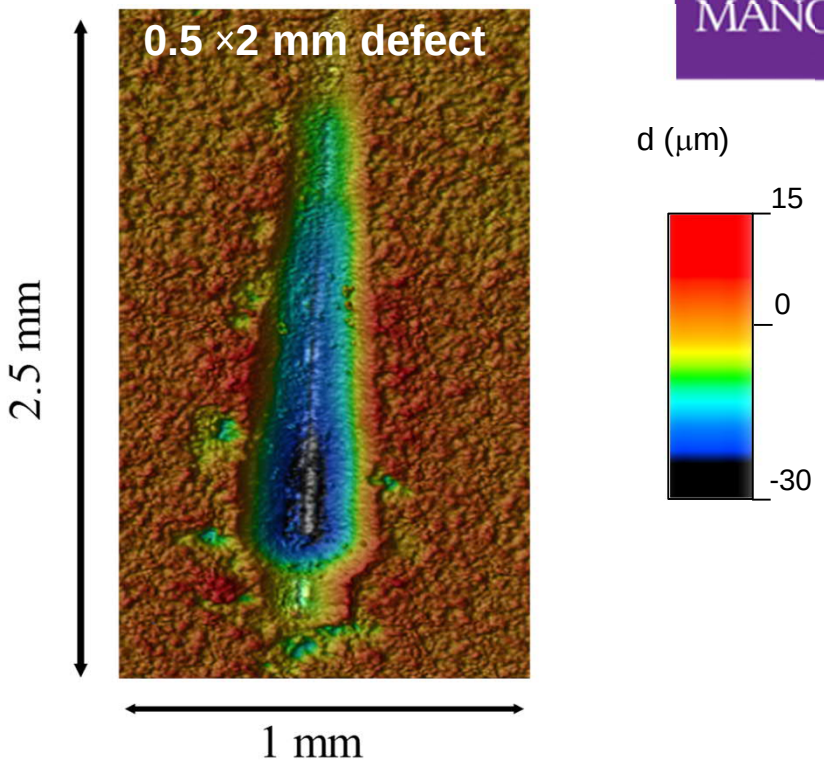
$$Mg\,(s) \rightarrow Mg^{2+}(aq) + 2e^-$$
$$2H_2O(l) + 2e^- \rightarrow 2OH^-(aq) + H_2\,(g)$$



NaCl 0.5 wt. %

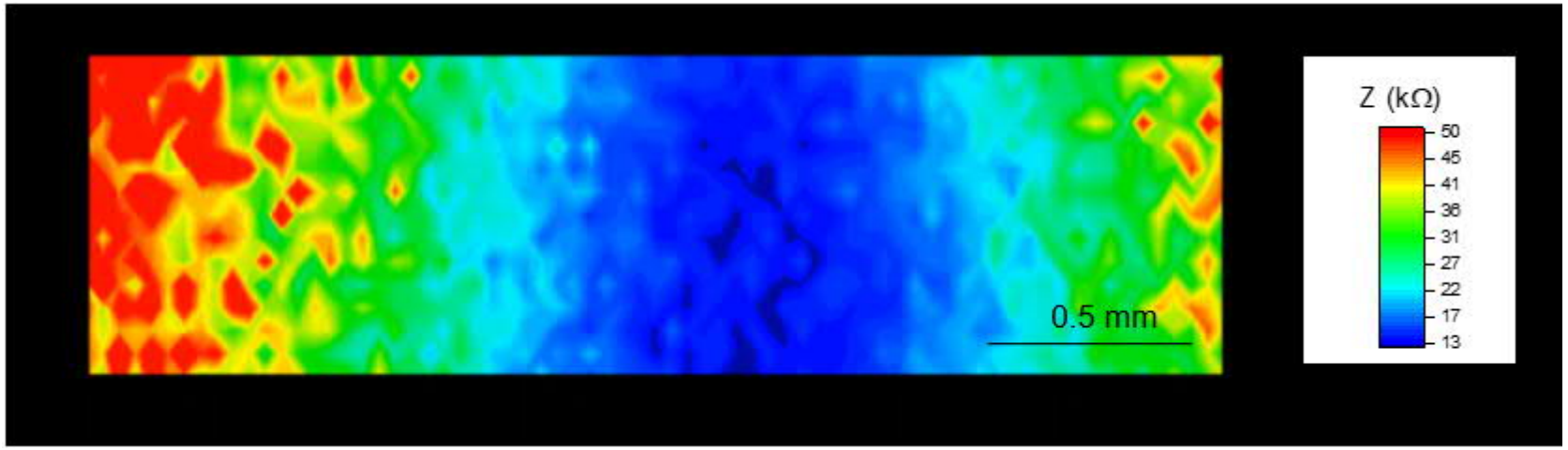
ACS Appl. Mater. Interfaces 2020, 12, 30833–30846

Localised Electrochemical Impedance Spectroscopy (LEIS)



ARTIFICIALLY DAMAGED PEO COATING WITH INHIBITORS

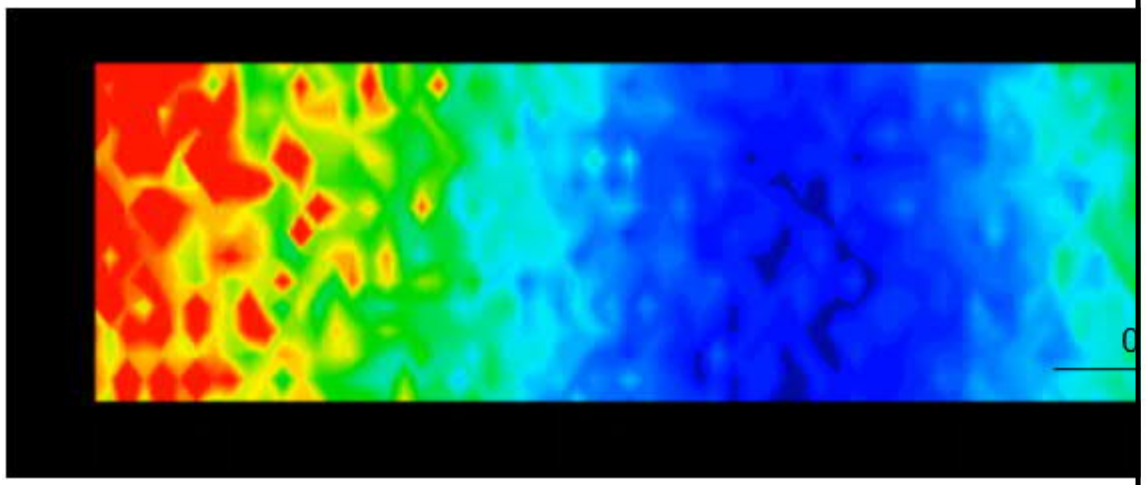
0-35 h

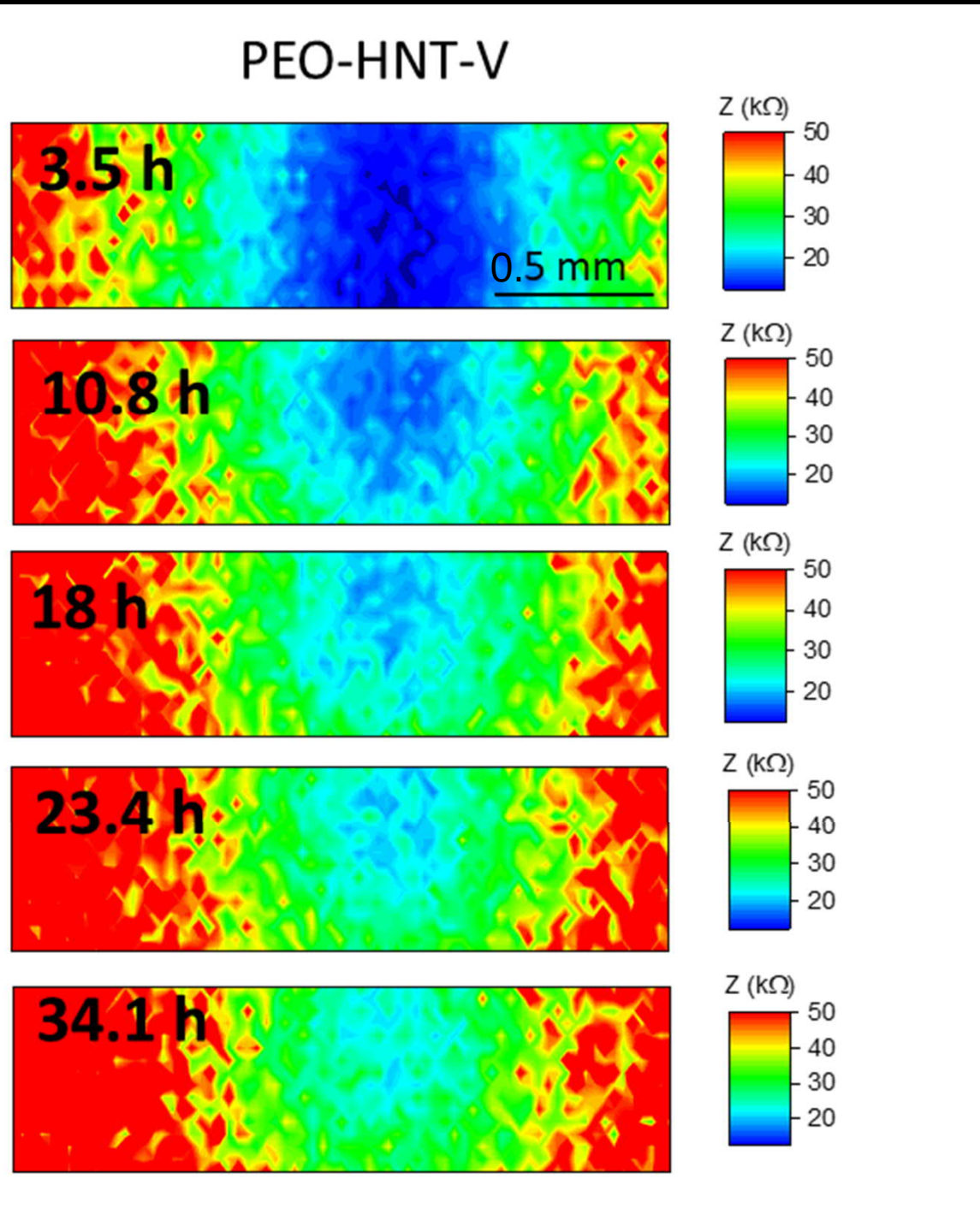


Localised Electrochemical Impedance Spectroscopy (LEI

ARTIFICIALLY DAMAGED PEO COATING WITH INHIBITORS

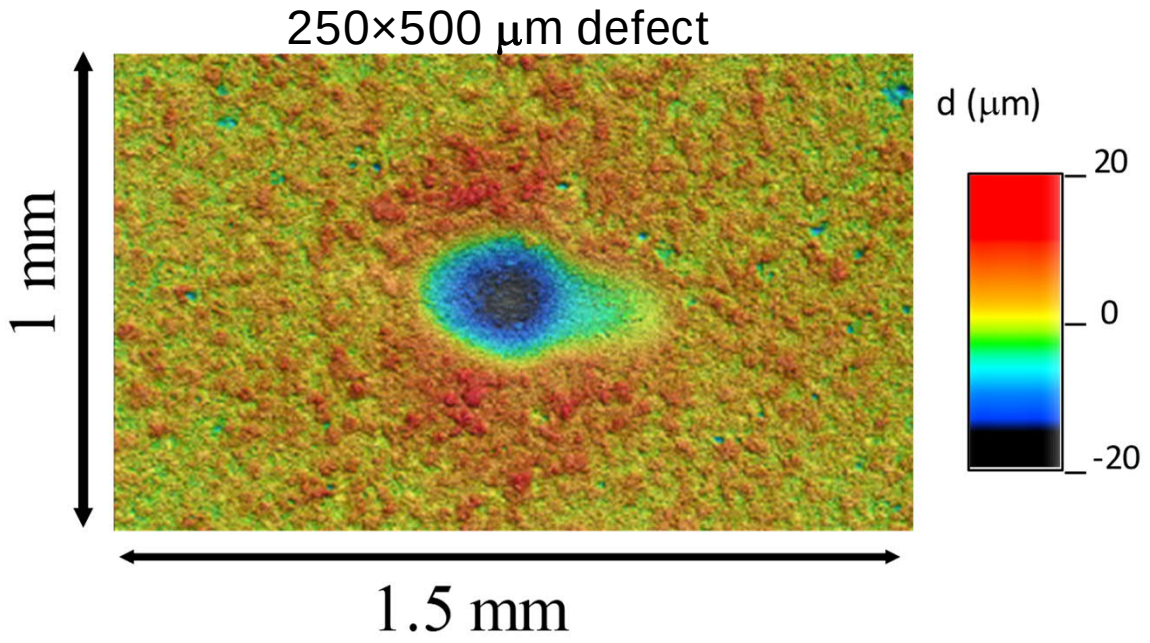
0-35 h



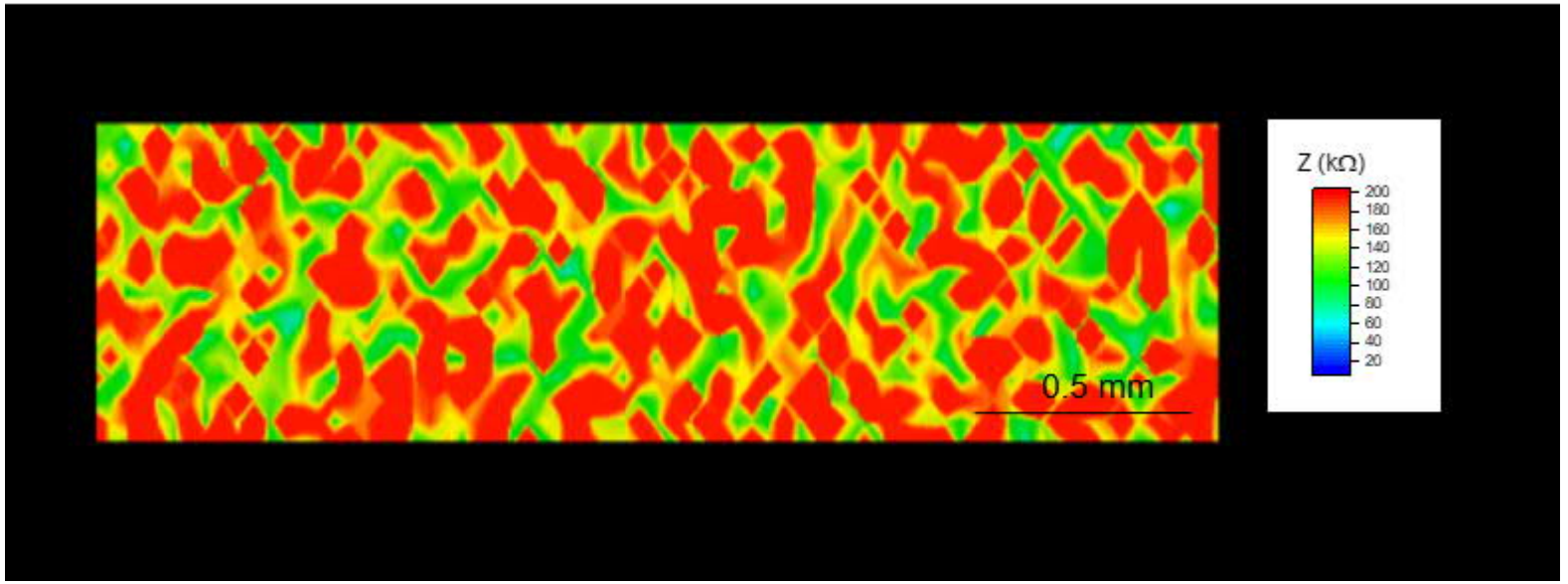


Localised Electrochemical Impedance Spectroscopy (LEIS)

ARTIFICIALLY DAMAGED
PEO COATING WITH
INORGANIC INHIBITORS

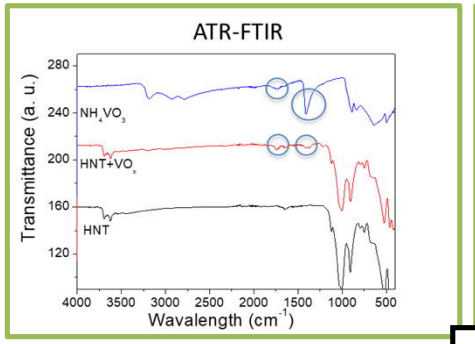


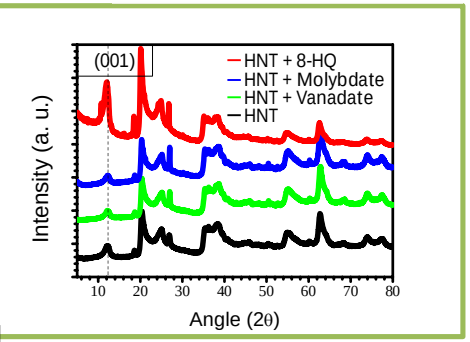
0-35 h



Summary

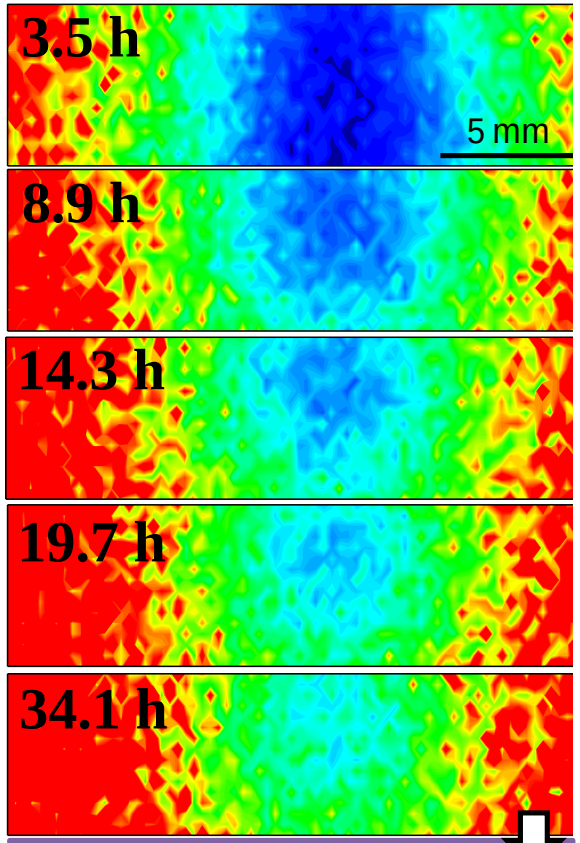
HNT were successfully loaded with three corrosion inhibitors



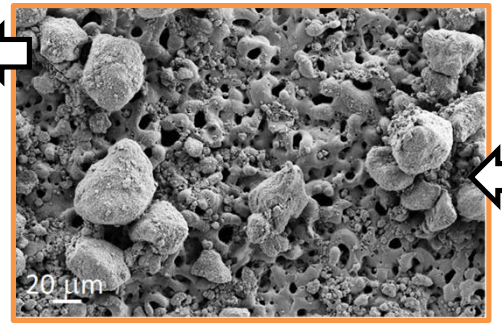


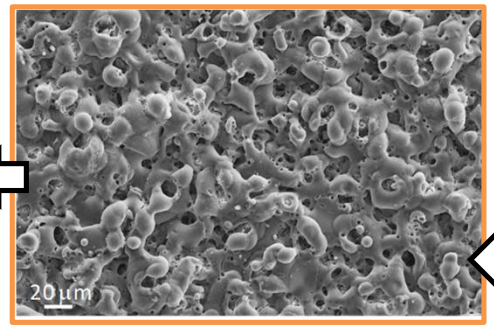
Synthesis and Functionalisation of PEO coatings

Corrosion response



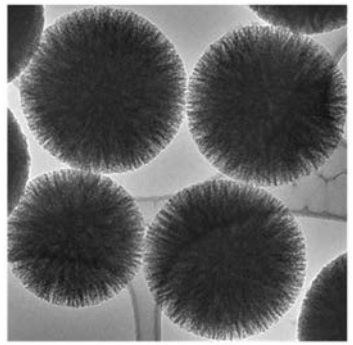
Smart properties



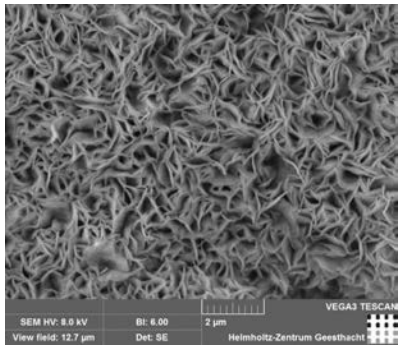


Future work

Nano-containers



Fibrous Silica

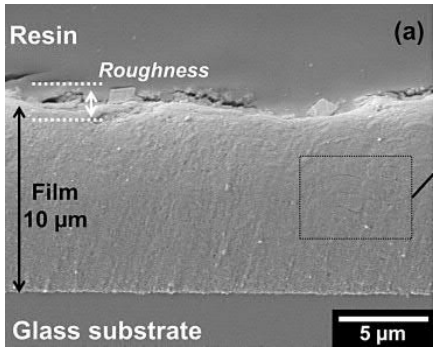


LDH

Deposition techniques

Aerosol Deposition Method

- Room temperature
- Spraying technique
- Powder precursor
- Uniform functionalisation



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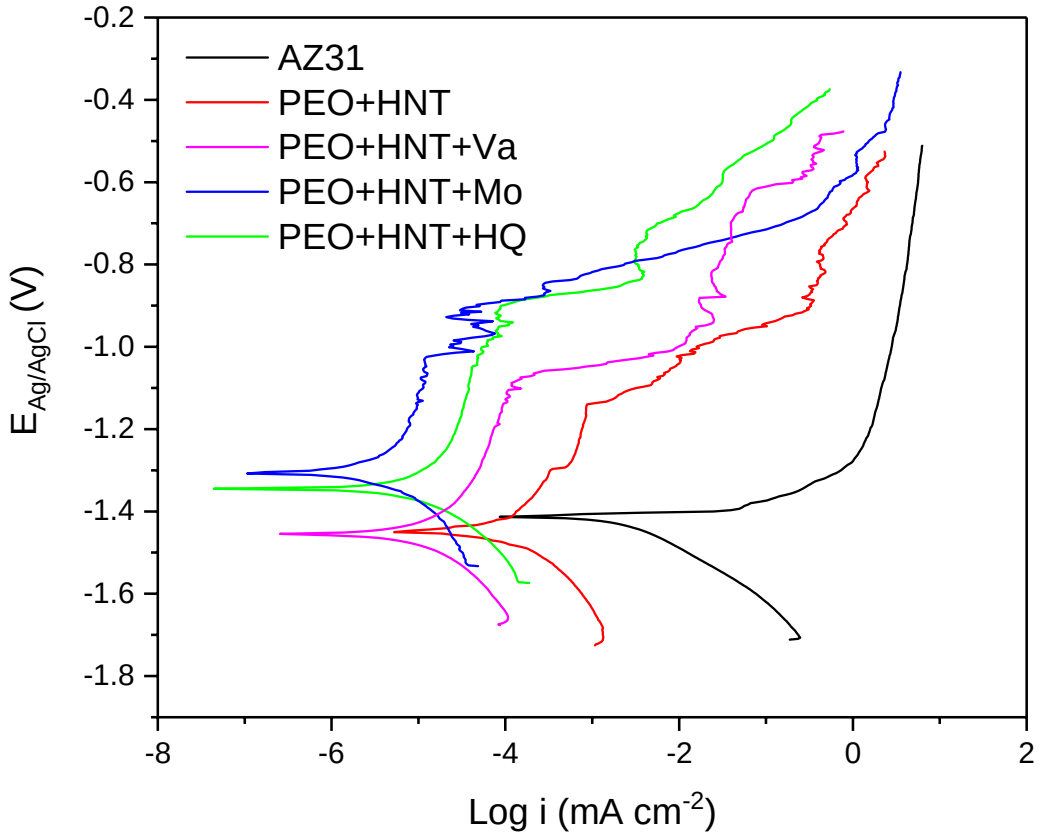
Evaluation of the Corrosion Resistance: Potentiodynamic polarisation



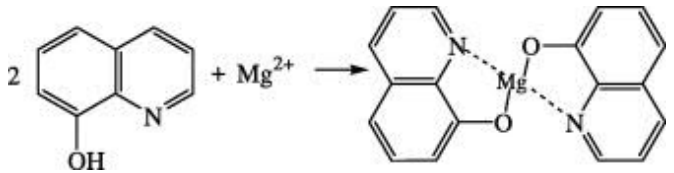
	E_{corr} ($mV_{Ag/AgCl}$)	E_{bd} ($mV_{Ag/AgCl}$)	E_{bd}-E_{corr} ($mV_{Ag/AgCl}$)
AZ31	−1432 ± 25	−1432 ± 25	0
PEO-HNT	−1302 ± 11	−1262 ± 42	40 ± 53
PEO-HNT	−1401 ± 66	−1181 ± 52	220 ± 118
PEO-HNT-V	−1454 ± 1	−1075 ± 5	379 ± 6
PEO-HNT-Mo	−1306 ± 1	−926 ± 2	381 ± 1
PEO-HNT-HQ	−1350 ± 8	−900 ± 12	450 ± 20

pH dependant

Vanadates
HVO_4^{2-} (tetrahedral)
Anodic type inhibitor
Adsorption/precipitation

Molybdate
$HMoO_4^-$/MoO_4^{2-}
Cathodic type inhibitor
Adsorption/precipitation

8-HQ
Mixed type inhibitor
Precipitation



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