

Plasma Electrolytic Oxidation Coatings on Light Alloys for Automotive Applications: Properties, Performance, and Prospects

Vahid Dehnavi^{1,2}, Sridhar Ramamurthy¹, Jeffrey D. Henderson¹, Mohammad Norouzi Banis³, David W. Shoesmith^{1,4}, Jamie J. Noël^{1,4}

¹ Surface Science Western, The University of Western Ontario, London, Ontario, Canada, N6G 0J3

² Department of Chemical & Biochemical Engineering, The University of Western Ontario, London, Ontario, Canada, N6A 5B9

³ Our Next Energy (ONE), Northville, Michigan, United States, MI 48377

⁴ Department of Chemistry, The University of Western Ontario, London, Ontario, Canada, N6A 5B7

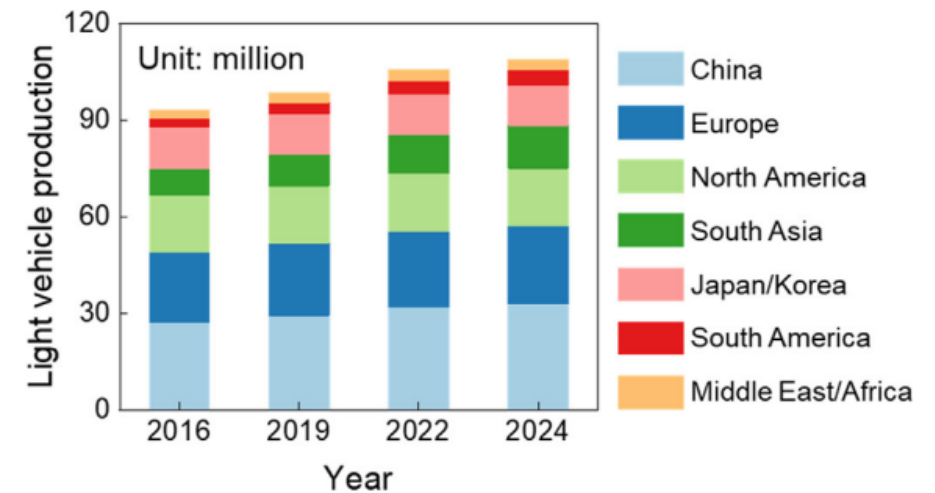
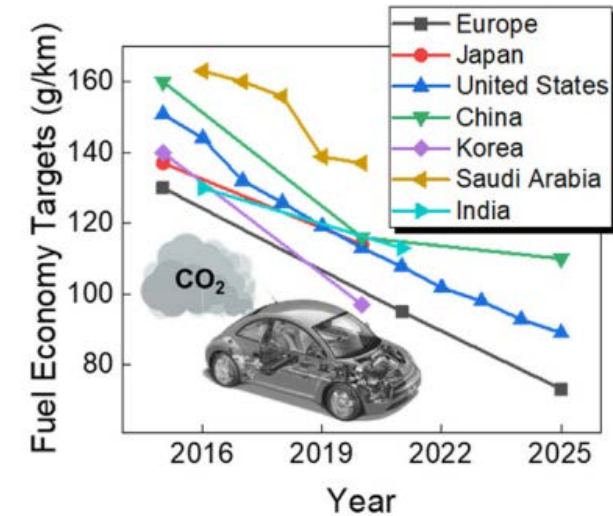
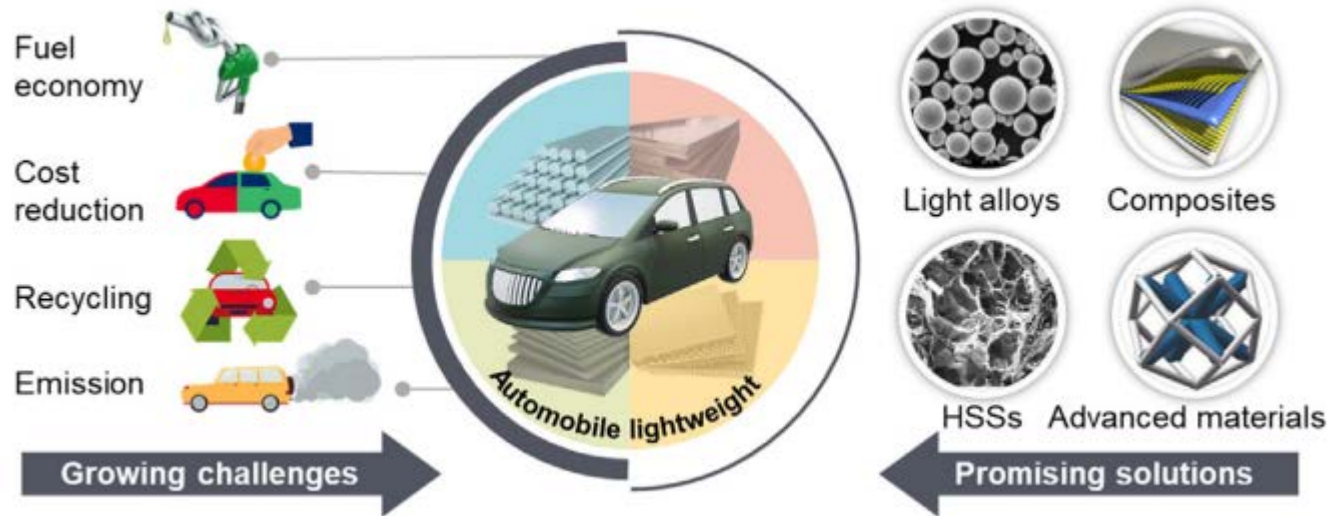
**Southwest Research Institute –
Automotive Corrosion Symposium**

*April 11th – 12th, 2024
Detroit, MI, United States*



Lightweight Materials for Vehicles

Challenges faced by the automotive industry:



Light Metals and EVs

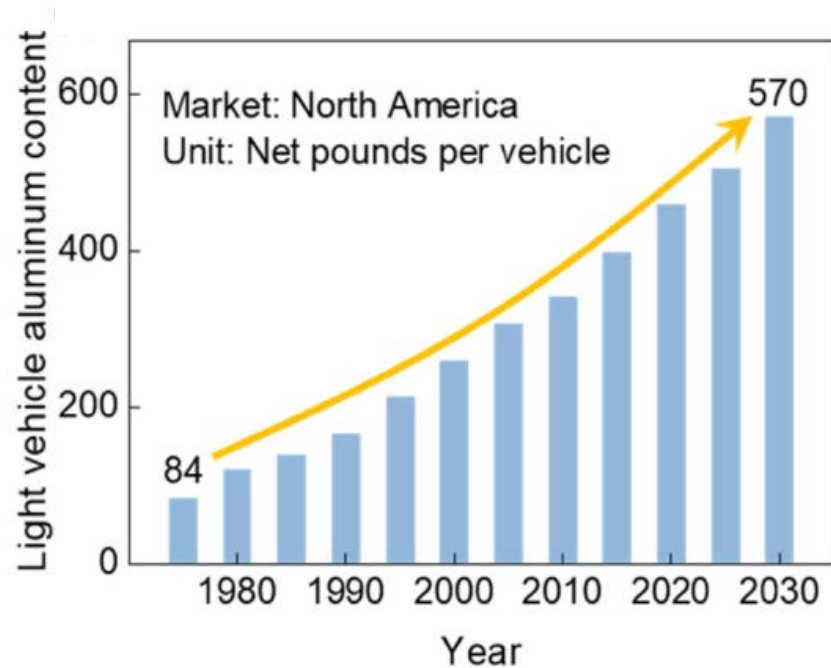
Due to EV specific components and additional aluminum components to compensate the weight increase from the battery, the use of aluminum in new EVs will continue to grow.

“2023 North American Light Vehicle Aluminum Content and Outlook”, The Aluminum Association, April 2023



PPV: Pounds Per Vehicle Averaged on the Total Production (net weight)

Light Metals



W. Zhang & J. Xu, Materials & Design 221 (2022) 110994

Main issues with light metals:

corrosion and **wear resistance**

Wide range of surface finishes:

- Paint coatings
- Metallic and composite coatings
- Powder coating
- Anodizing



Plasma Electrolytic Oxidation (PEO)

- A novel electrochemical surface treatment process
- Creates a functional oxide layer on metals such as Al, Mg, Ti, Zr, Ta and their alloys
- Similar to anodizing, but performed at higher potentials

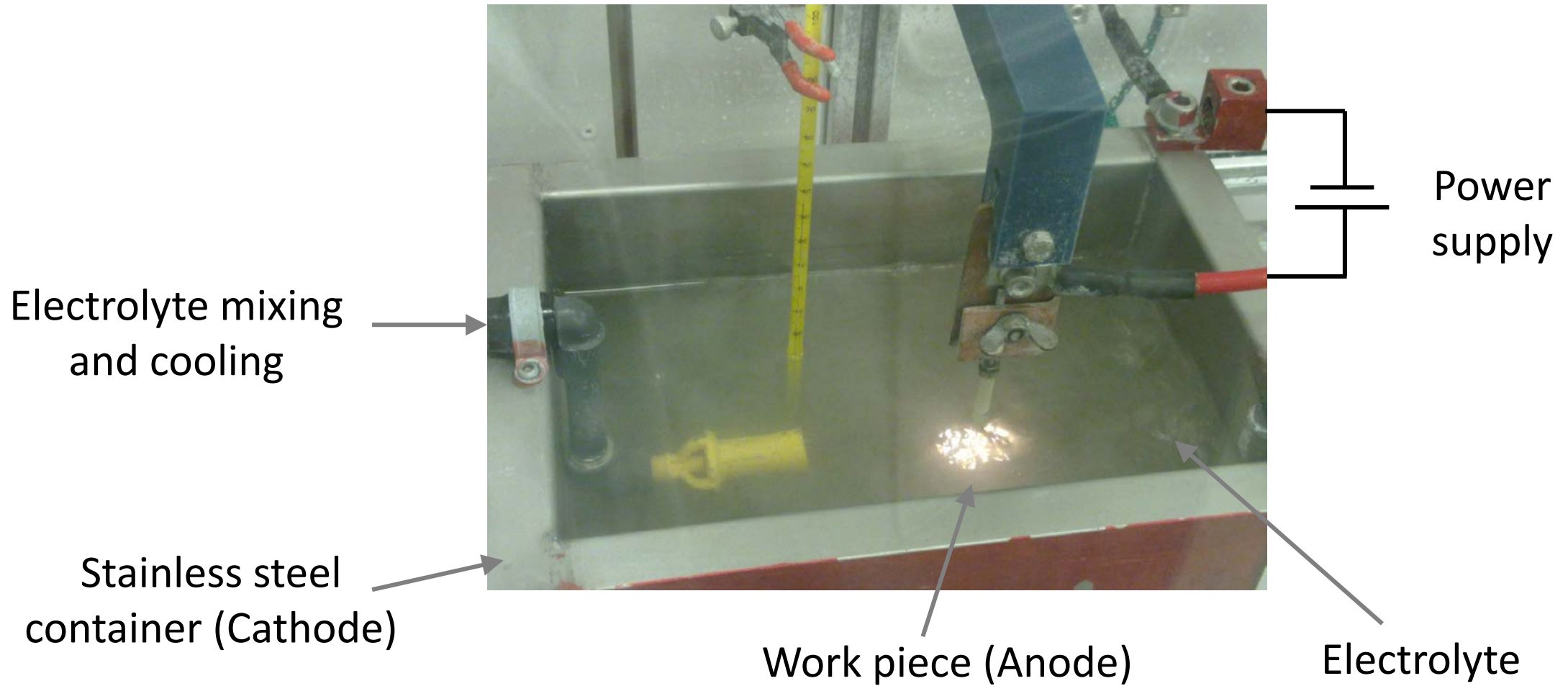
PEO coatings characteristics:

- Compact
- Thick (up to 200 μm)
- Hard
- Electrically and thermally insulating
- High adhesion to the substrate metal
- An environmentally friendly technology



PEO coating on aluminum

PEO Process Setup



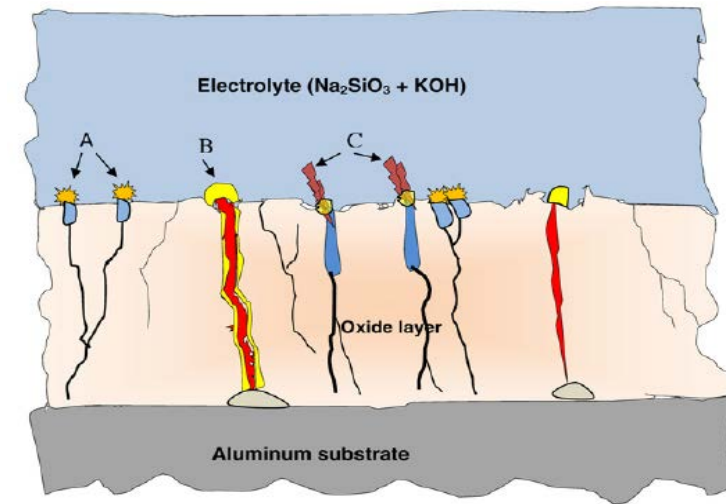
PEO in Action



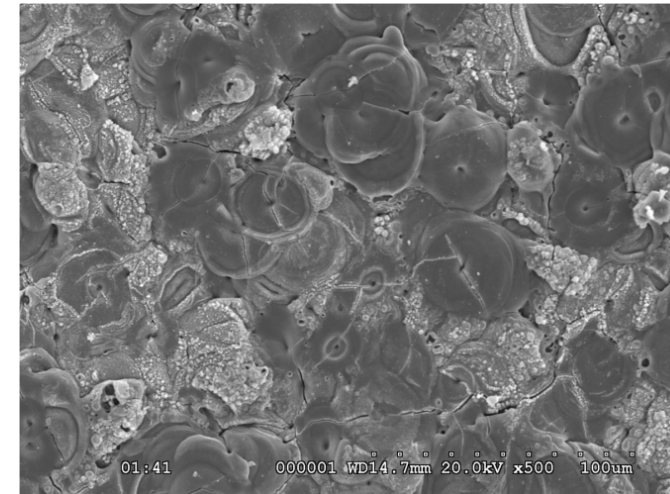
Micro-discharges during PEO

Micro-discharges play a key role in PEO

- A-type: gas discharges in surface holes
- C-type: gas discharges in relatively deep holes
- B-type: dielectric breakdown in a strong electric field through the oxide layer.

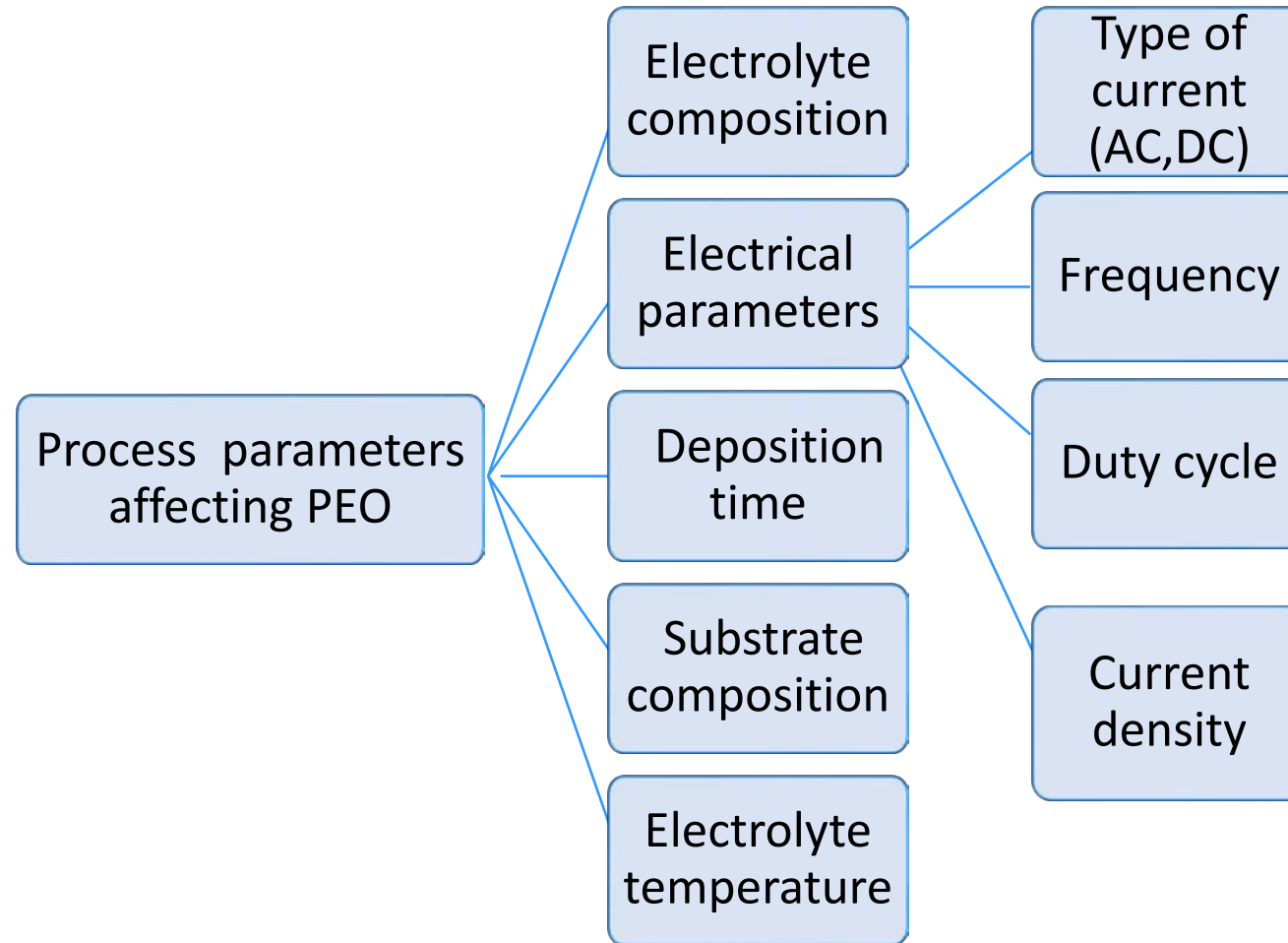


Hussein et al., J. Vac. Sci. Technol. A Vacuum, Surfaces, Film. 28 (2010) 766–773.

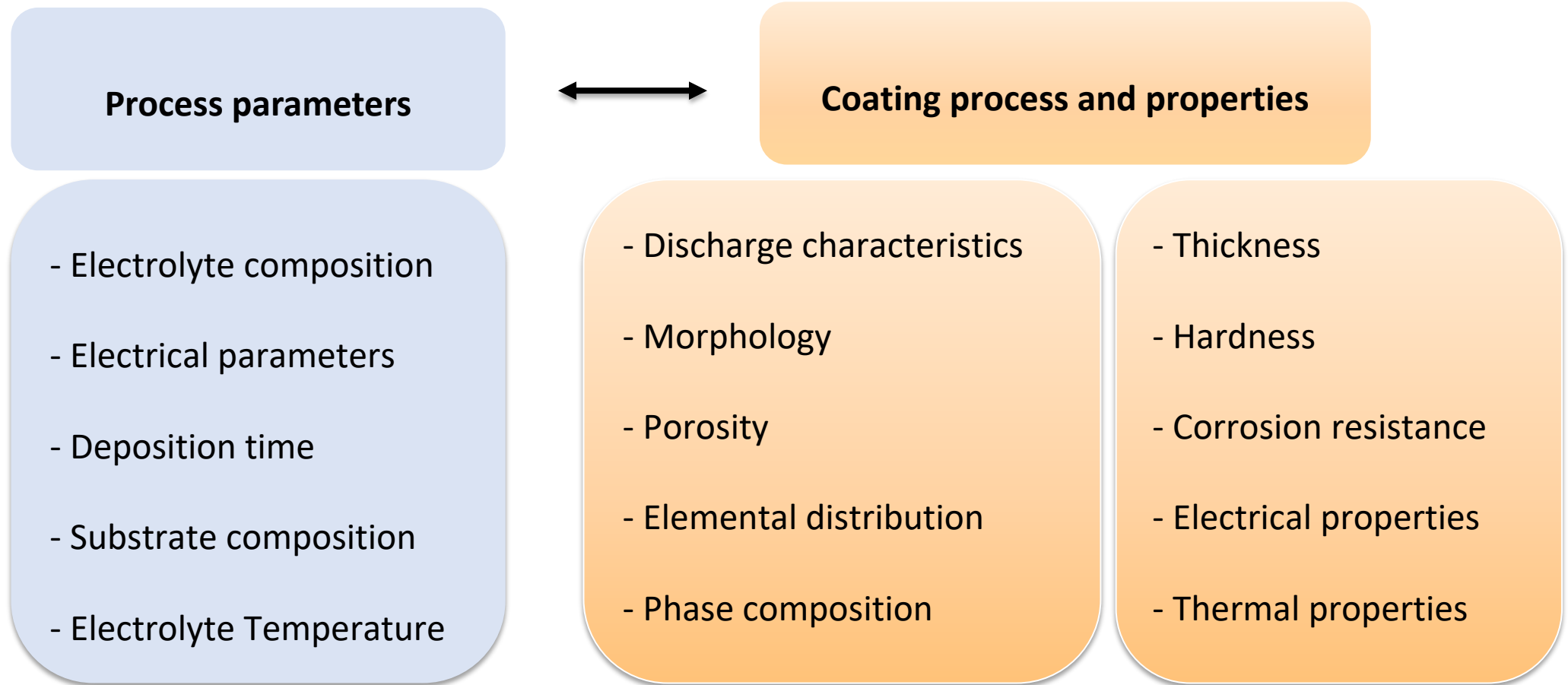


SEM image of PEO coating on an aluminum alloy

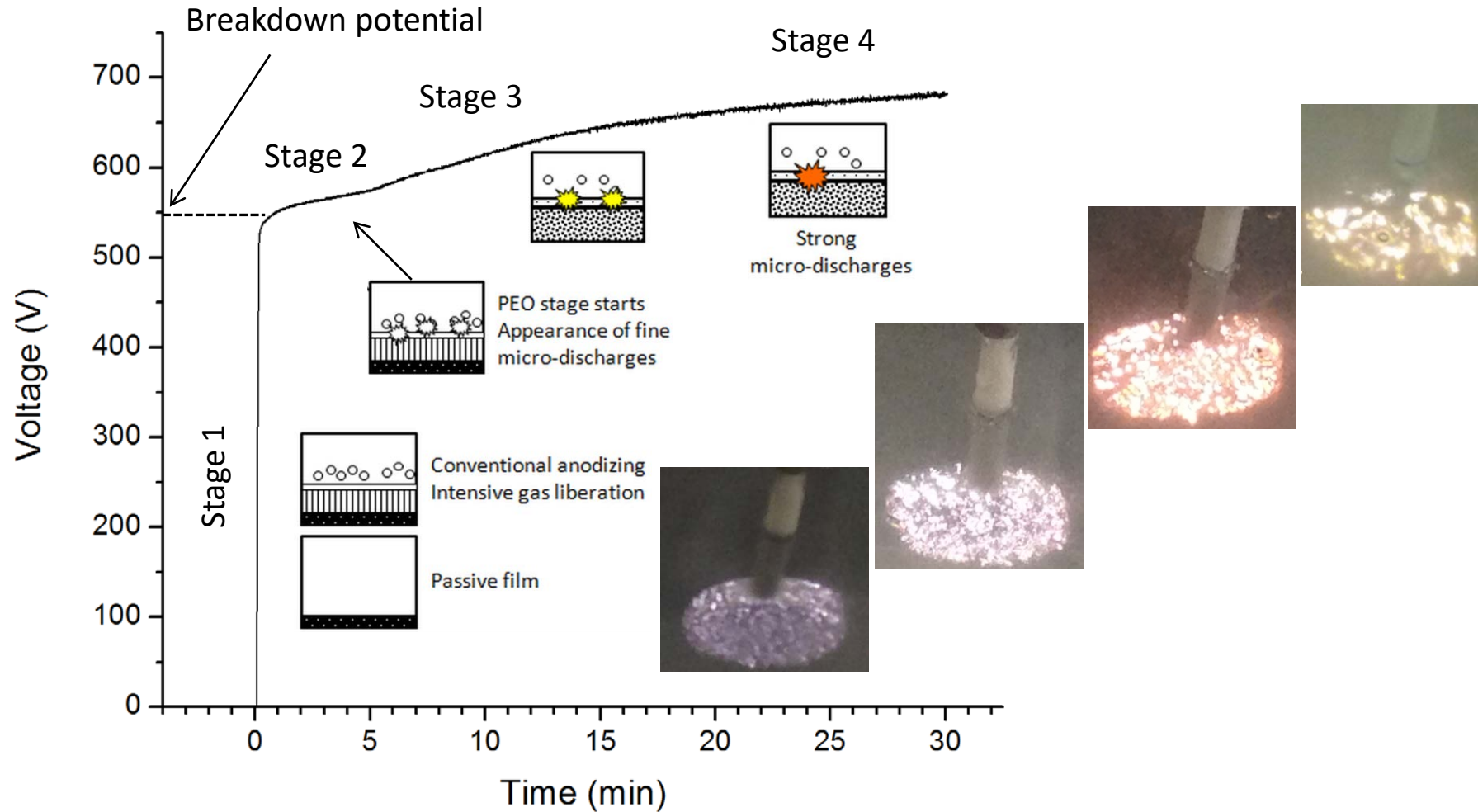
Parameters Affecting the PEO Process



Designing PEO Coatings



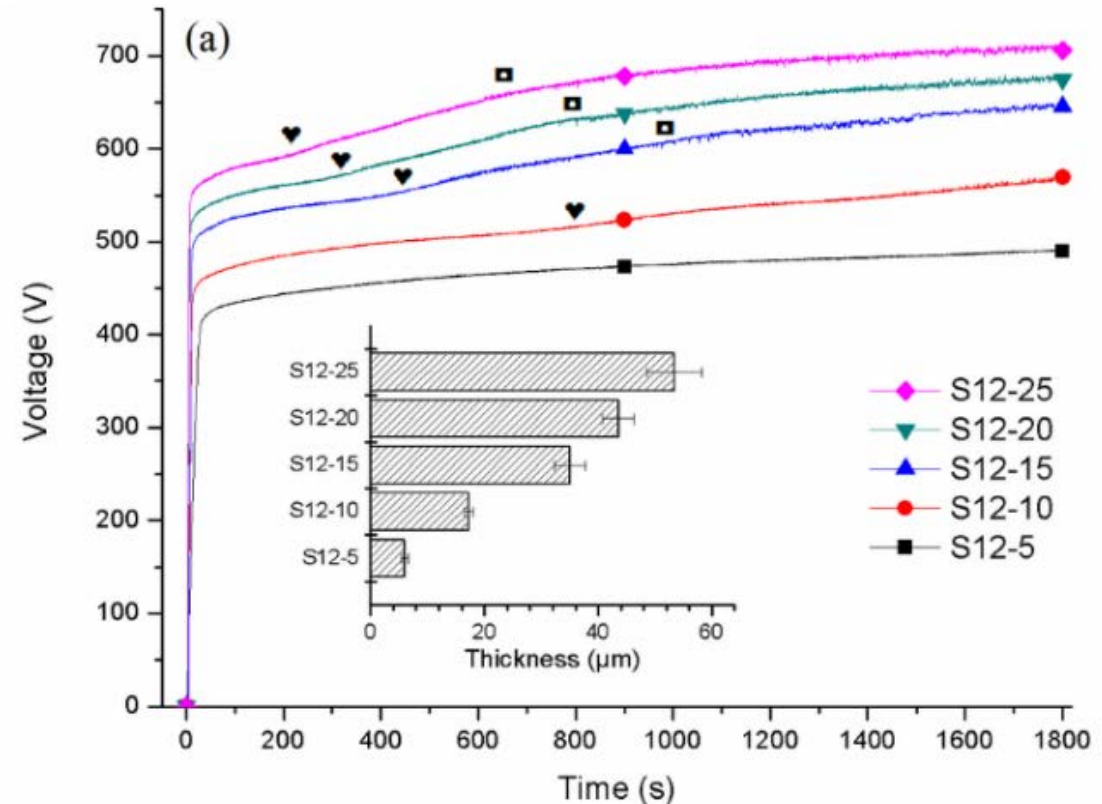
Different Stages during PEO



Controlling Micro-discharges

PEO on 6061 Aluminum

- Frequency: 1000 Hz
- Duty cycle (D_t): 20%
- Current density: $J=5\text{-}25\text{ A/dm}^2$



Coating Phase Composition

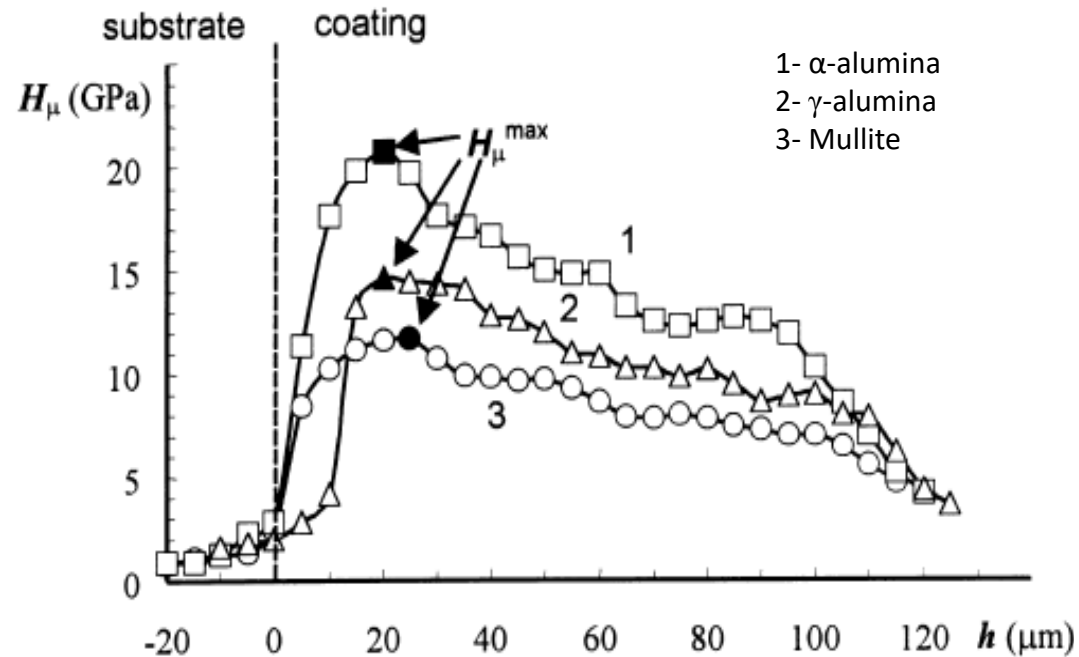
The phase composition of coatings affects their:

- Mechanical properties
- Physical properties
- Tribological behaviour

PEO coatings on aluminium alloys:

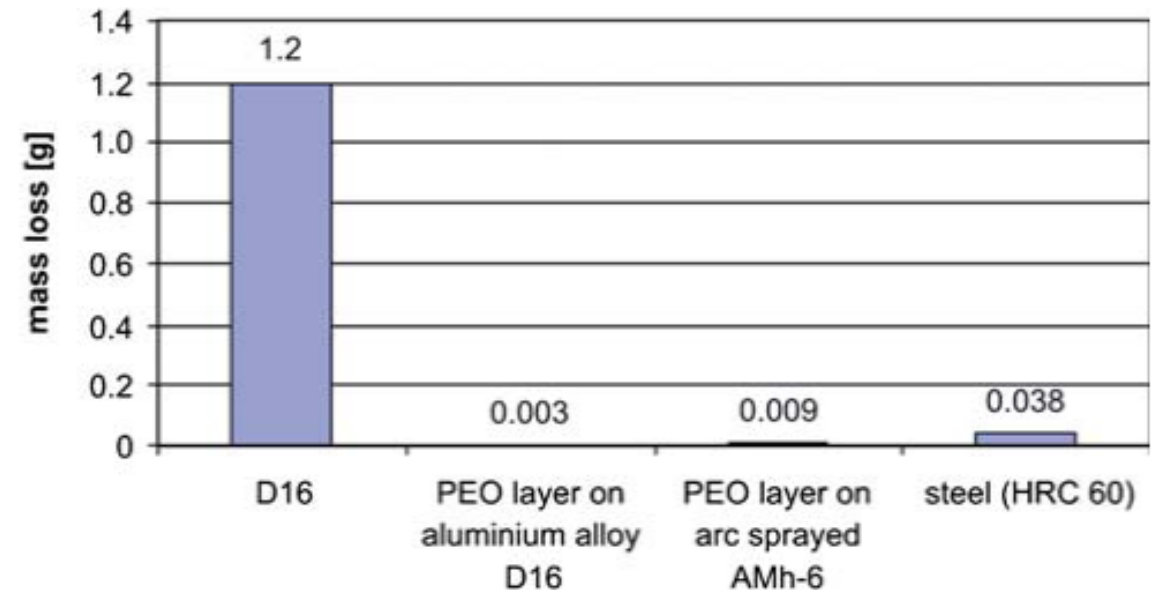
- Al_2O_3 allotropic forms (α , χ , η , δ , κ , θ , γ , ρ)
- $\alpha\text{-Al}_2\text{O}_3$: Rhombohedral structure, thermodynamically stable, $T_m=2050\text{ }^\circ\text{C}$
- $\gamma\text{-Al}_2\text{O}_3$: Cubic structure, metastable
- $\gamma\text{-Al}_2\text{O}_3 \rightarrow \alpha\text{-Al}_2\text{O}_3$ (Phase transformation 800 - 1200 $^\circ\text{C}$)
- Mullite ($(3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2)$): Good thermal shock resistance, low thermal conductivity

Coating Phase Composition



Hardness of PEO coatings with different phase compositions

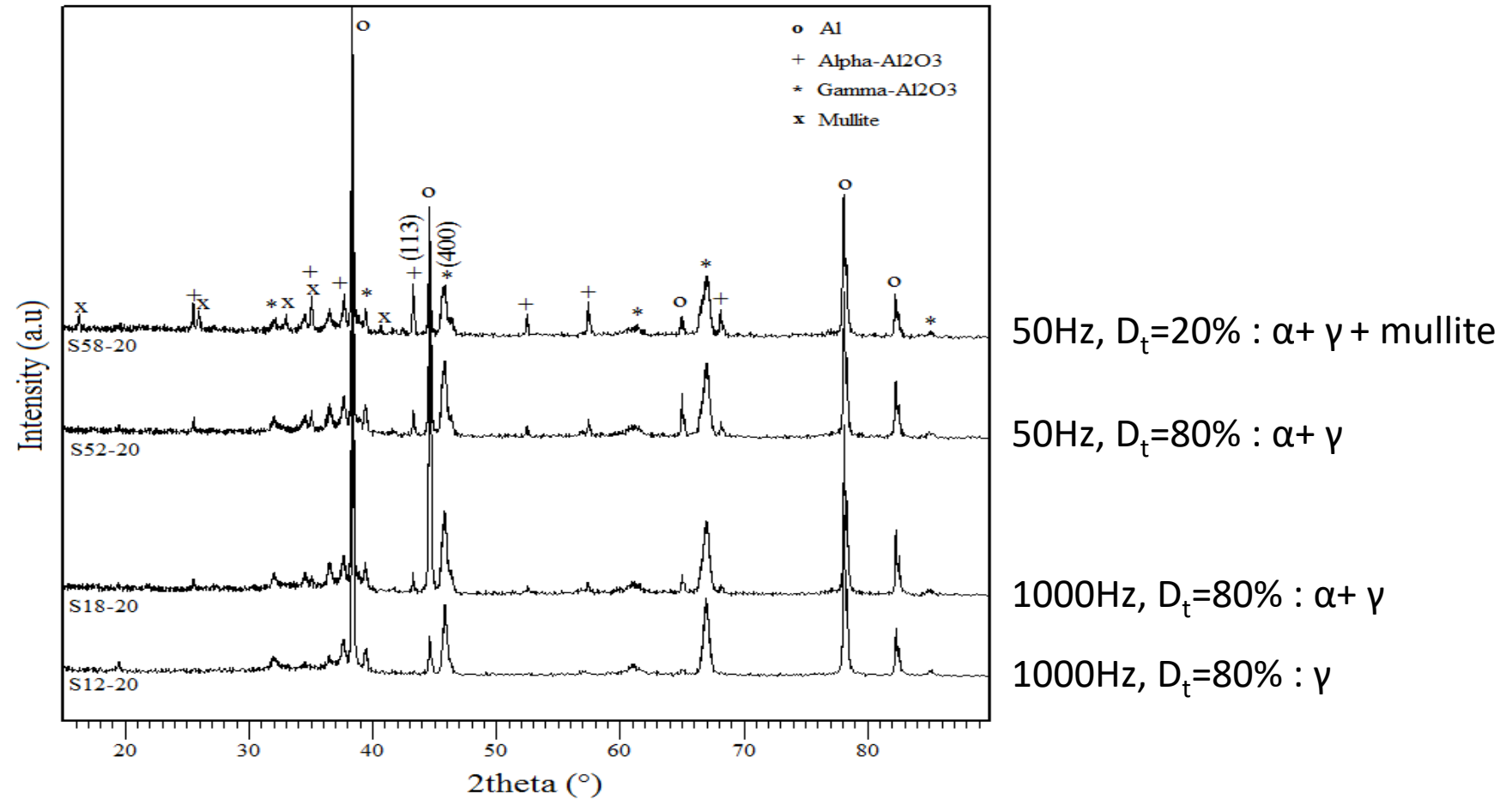
A.L. Yerokhin et al., *Surface and Coatings Technology* 122 (1999)



Mass loss during wear test.
Load:1.5 kg, Duration:30 min

Vasyl Pokhmurskii et. al., *Journal of thermal spray technology*, Vol 16 (5-6)Dec 2007

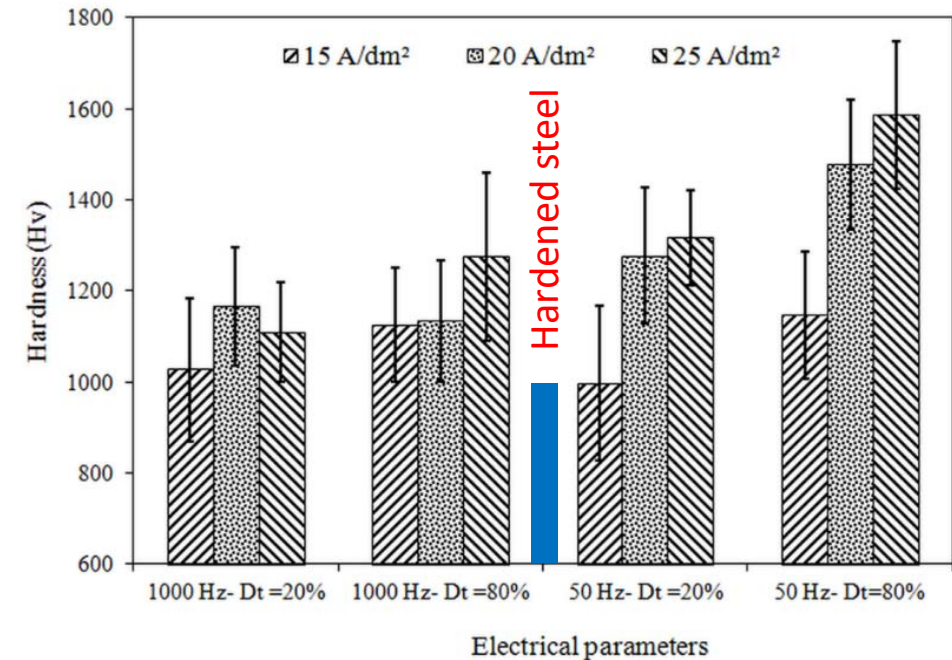
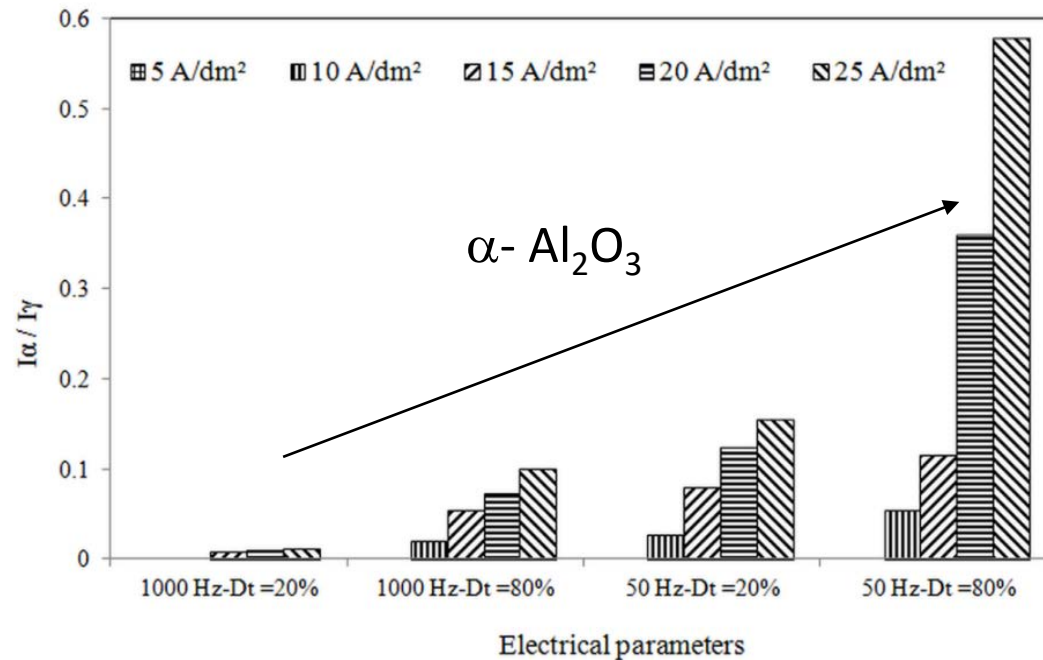
Controlling Coating Phase Composition



X-ray diffraction patterns of PEO coatings on 6061 Al substrates formed at $J=20 \text{ A/dm}^2$.

Controlling Coating Phase Composition

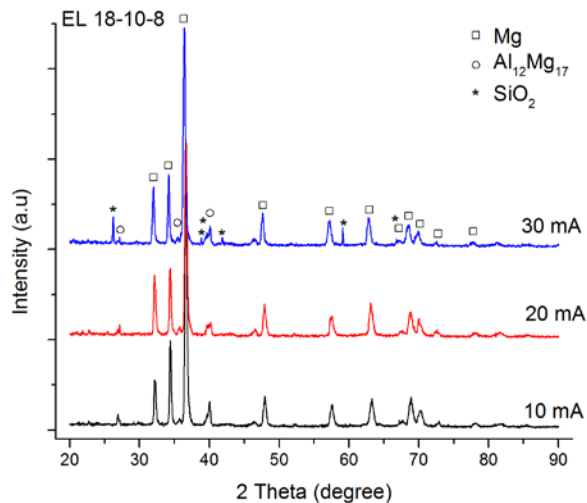
Controlling phase composition with electrical parameters (6061 Aluminum)



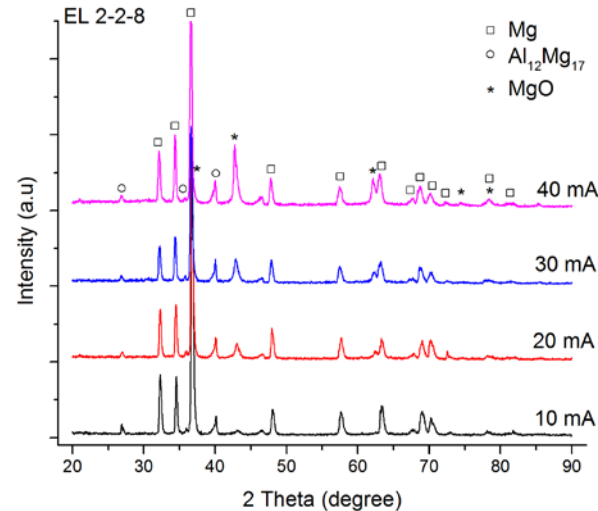
Controlling Coating Phase Composition

Controlling phase composition with electrolyte composition (AM60 magnesium)

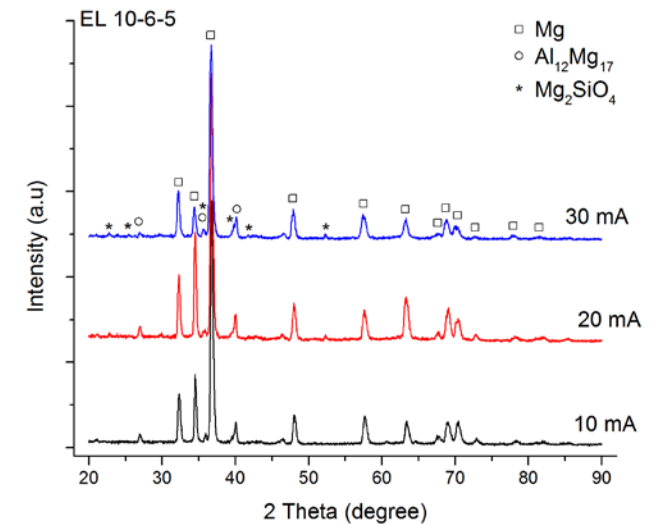
SiO_2



MgO



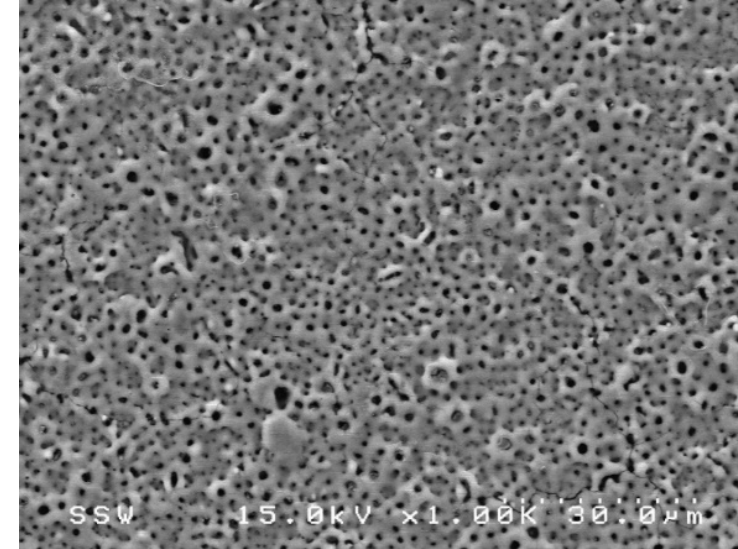
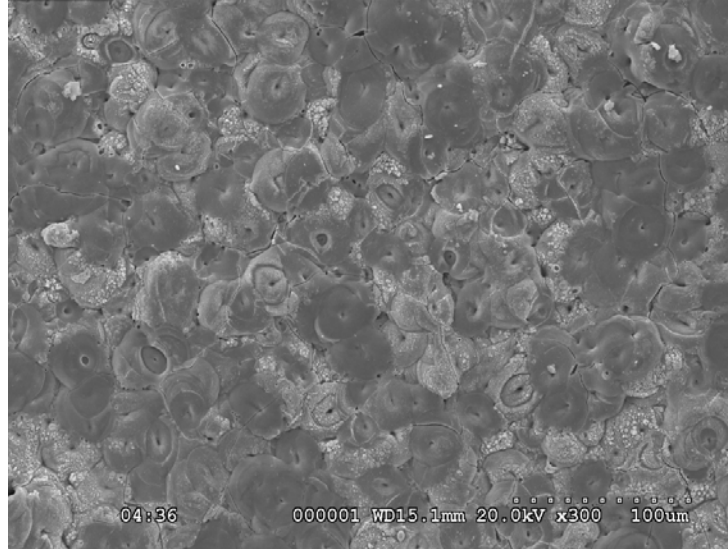
Mg_2SiO_4



Coating Morphology

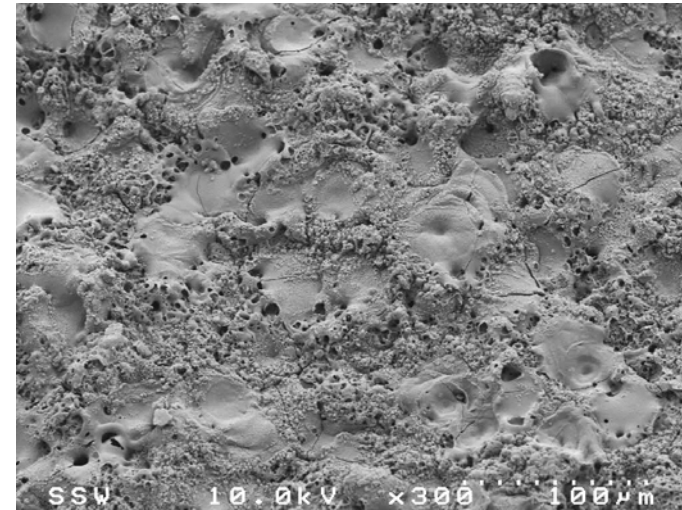
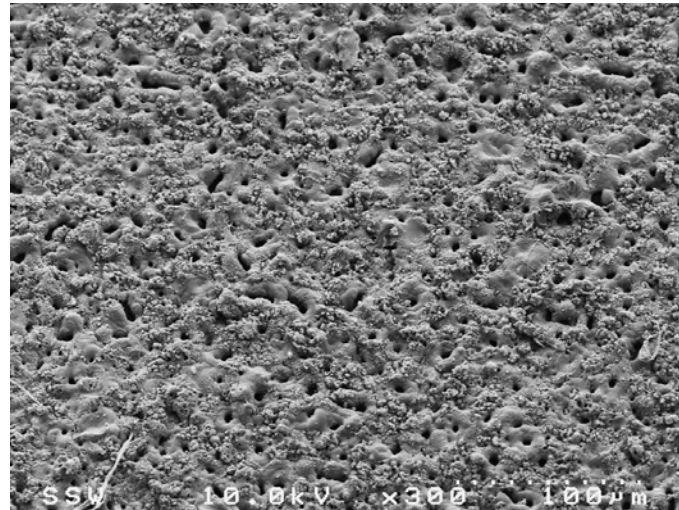
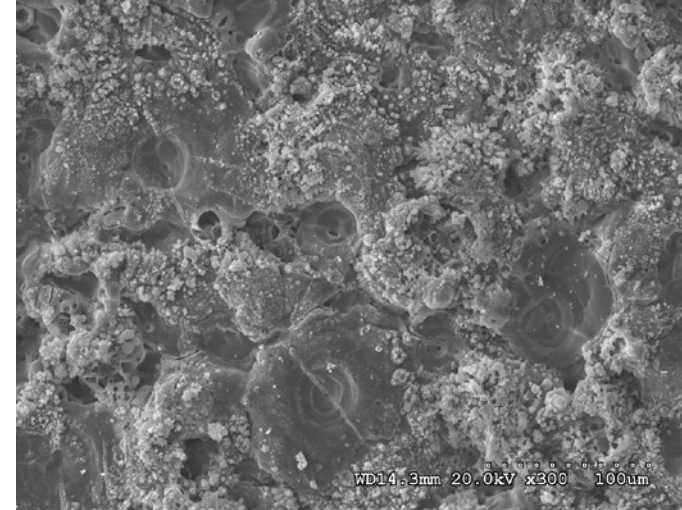
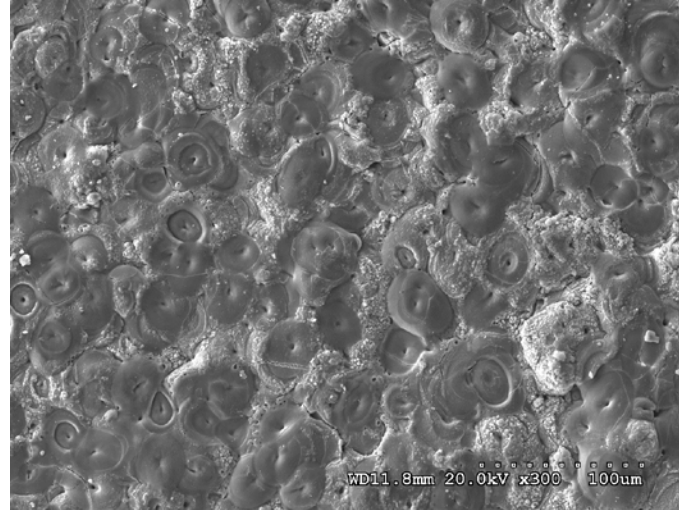
Coating morphology affects coating properties:

- Protective coatings: no open pores
- Paint adhesion : surface porosity favourable
- Catalysts: high surface area



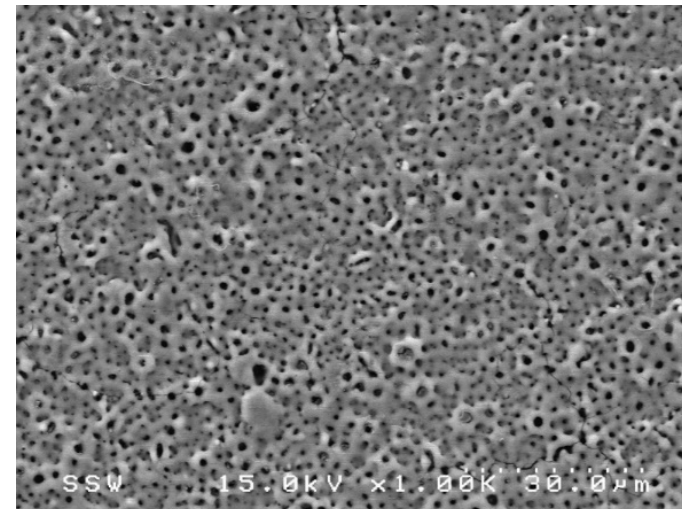
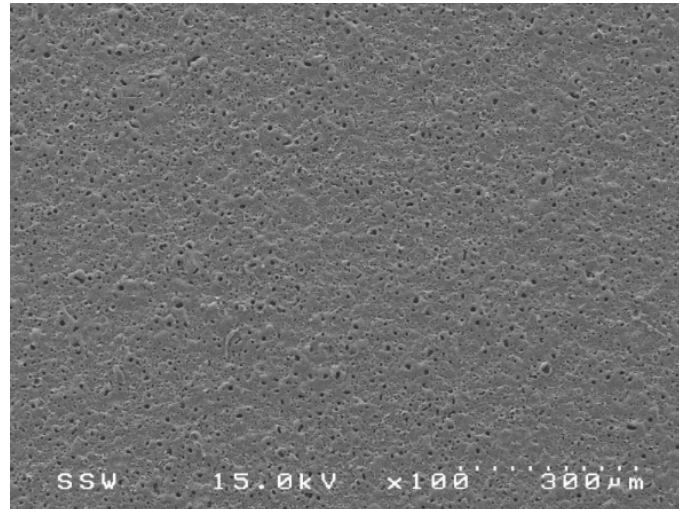
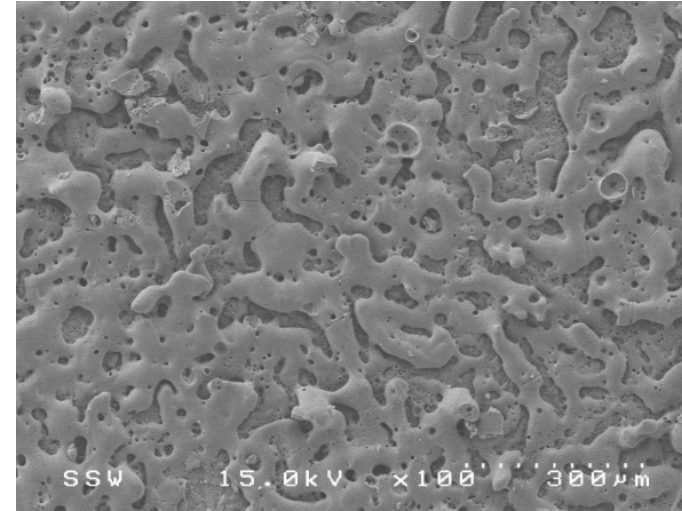
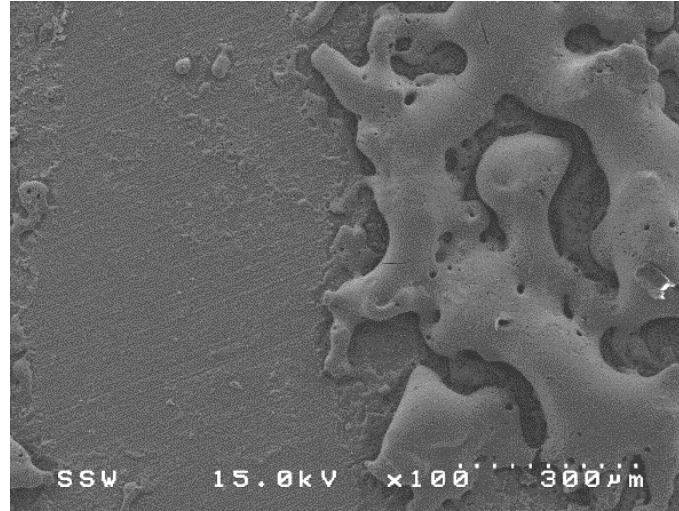
Controlling Coating Morphology

6061 Aluminum



Controlling Coating Morphology

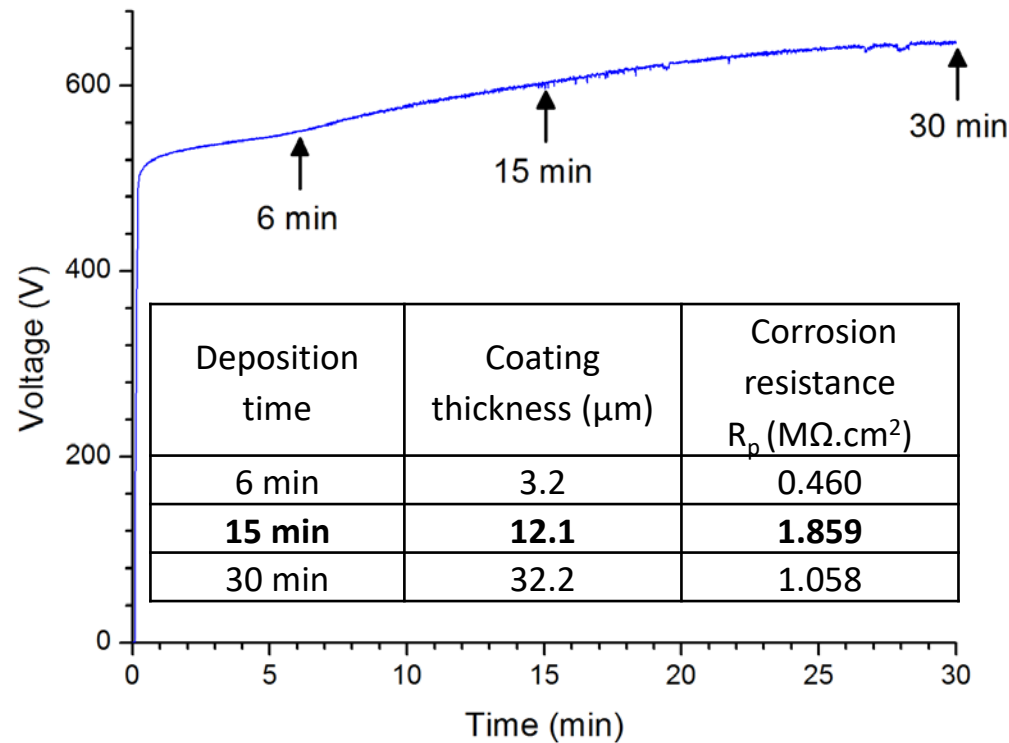
AM60 magnesium



Controlling the Corrosion Resistance

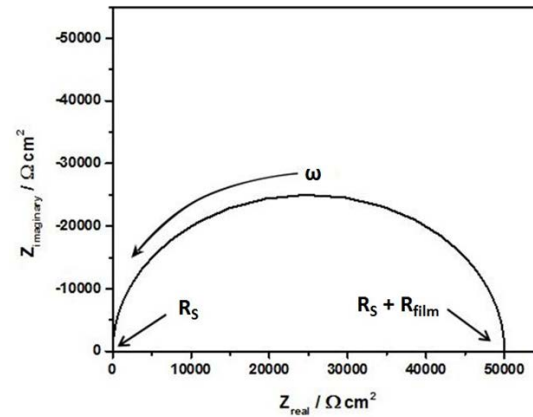
- Protective coatings: high corrosion resistance
- Biodegradable coatings: controlled corrosion rate

6061 aluminum

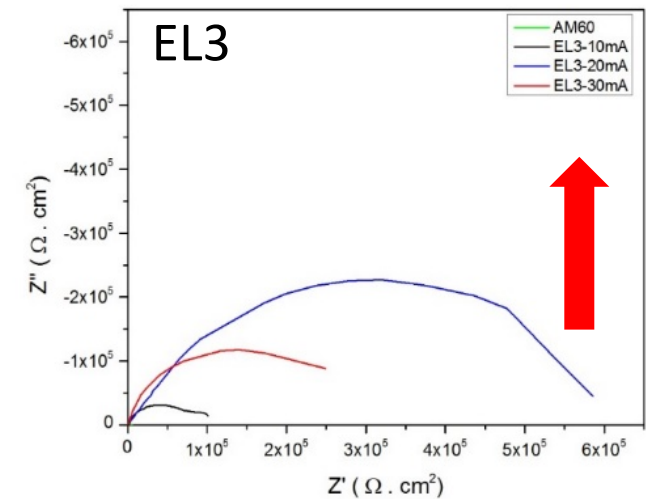
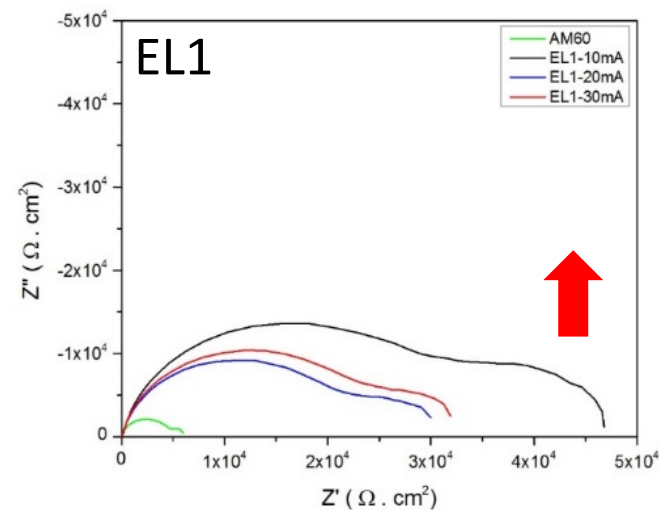
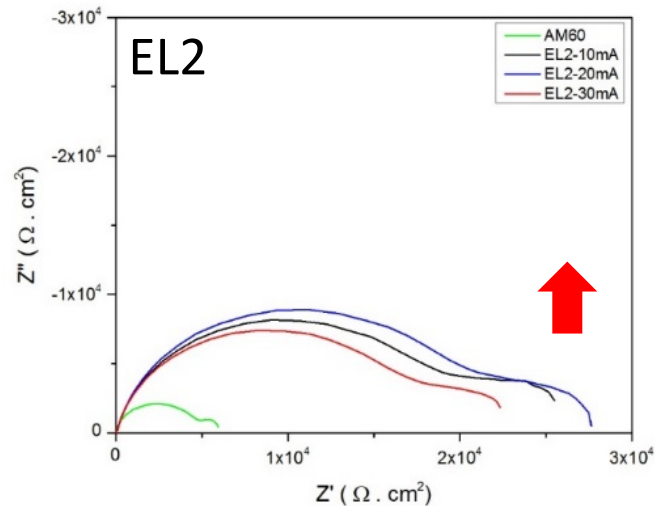


Controlling the Corrosion Resistance

AM60 magnesium



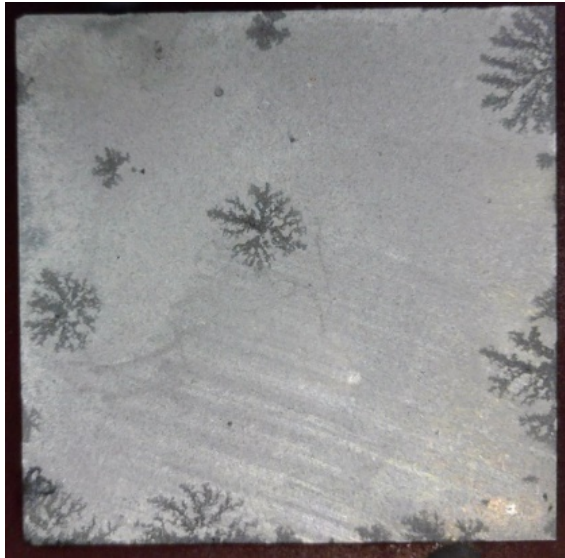
$$R_{\text{film}} \propto \frac{1}{\text{Corrosion Rate}}$$



Controlling the Corrosion Resistance

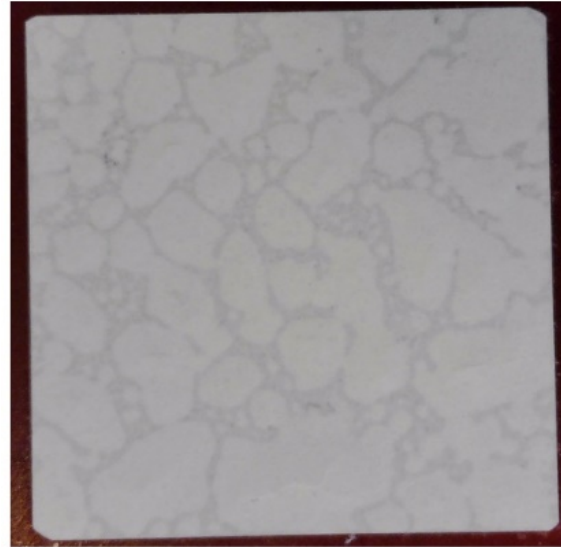
Samples were polarized to +500 mV vs E_{corr} after 8 hrs of immersion in 0.5 wt% NaCl

Uncoated AM60 Mg

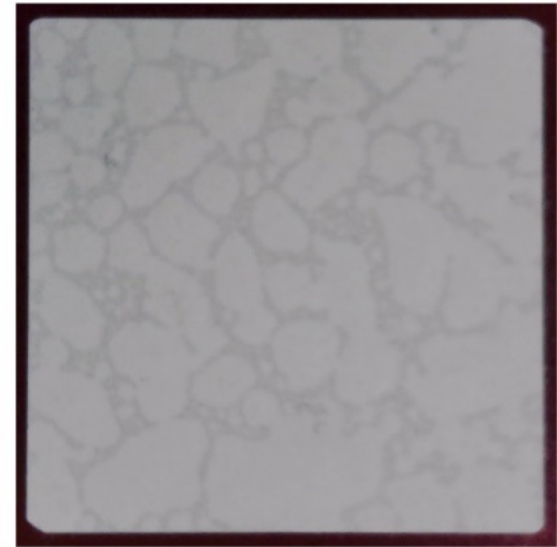


After test

PEO coated AM60 Mg



Before test

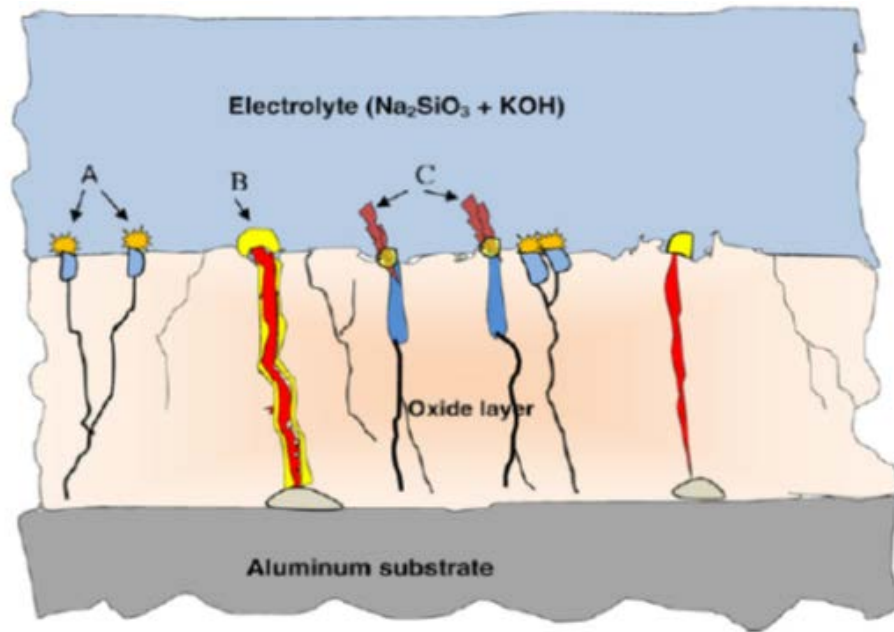


After test

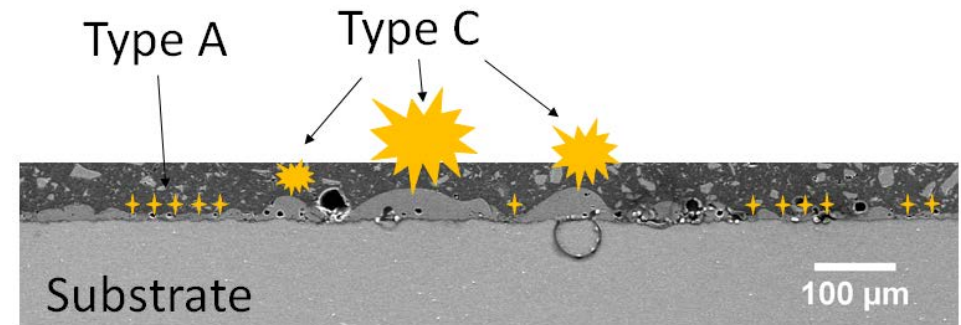
Composite Coatings

- Incorporation of nano-particles
- Improving coating properties (hardness, wear resistance)
- New applications for PEO coatings
 - Catalytically active structures
 - Antibacterial properties (addition of silver nanoparticles)
 - Self-lubricating coatings (addition of graphite)

Controlling the incorporation of Nano-particles

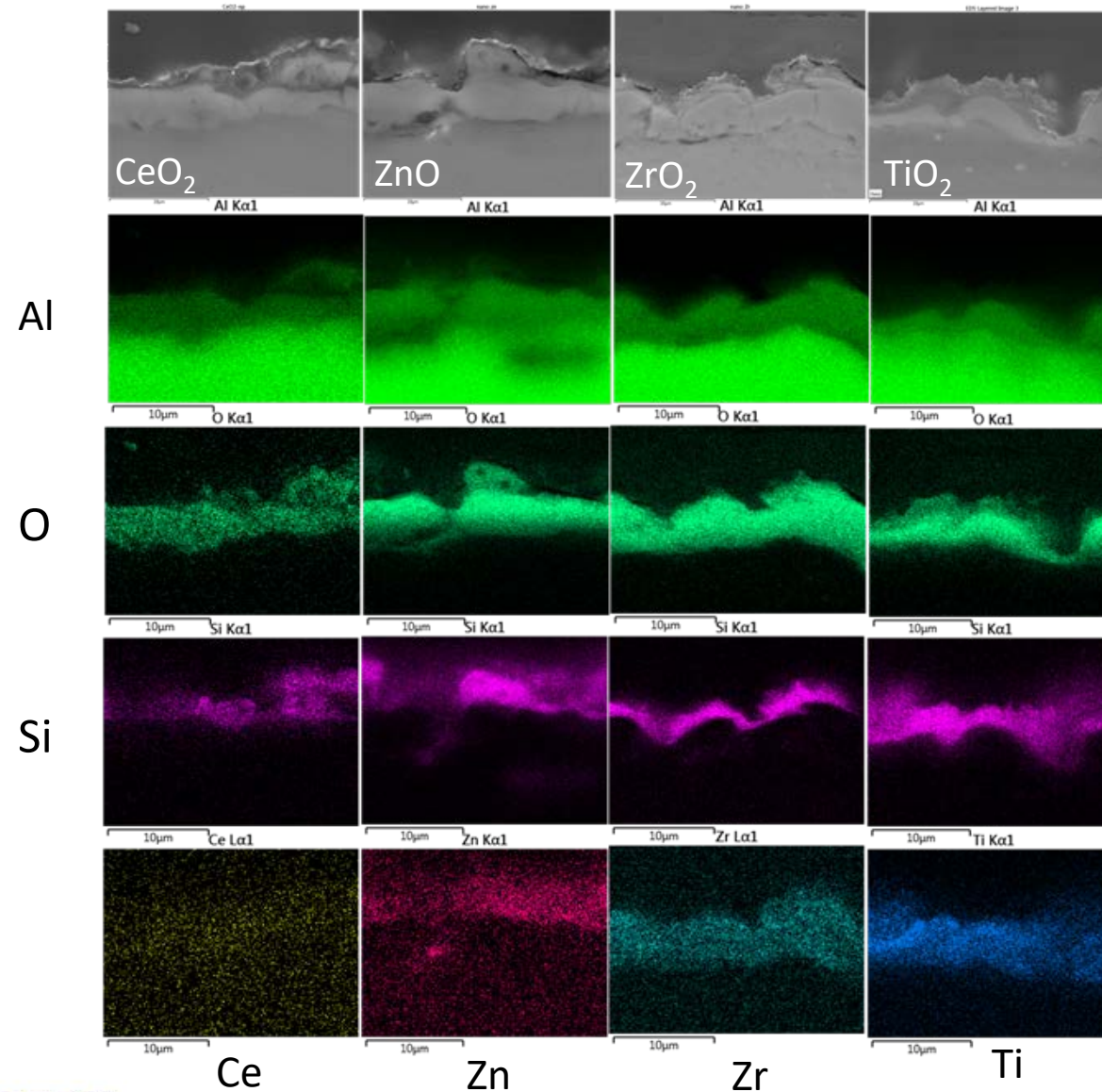


Hussein et al., J. Vac. Sci. Technol. A Vacuum, Surfaces, Film. 28 (2010) 766–773.



Dehnavi et al. / Journal of Magnesium and Alloys 6 (2018) 229-237

PEO coatings with Nano-particles on 6061 Al



M. Vakili, V. Dehnavi, J.J Noel, D. W, Shoesmith, unpublished data

Summary

- PEO is a surface treatment process capable of producing coatings with a wide range of properties.
- Notable properties of PEO coatings include high wear resistance, strong corrosion protection, high hardness, and excellent adhesion to the metallic substrate.
- The PEO process is a flexible coating process.
- Proper selection of process parameters would enable us to design coatings with tailored properties for specific applications.

Thank you

vdehnavi@uwo.ca