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Low-cost Corrosion Protection for Magnesium

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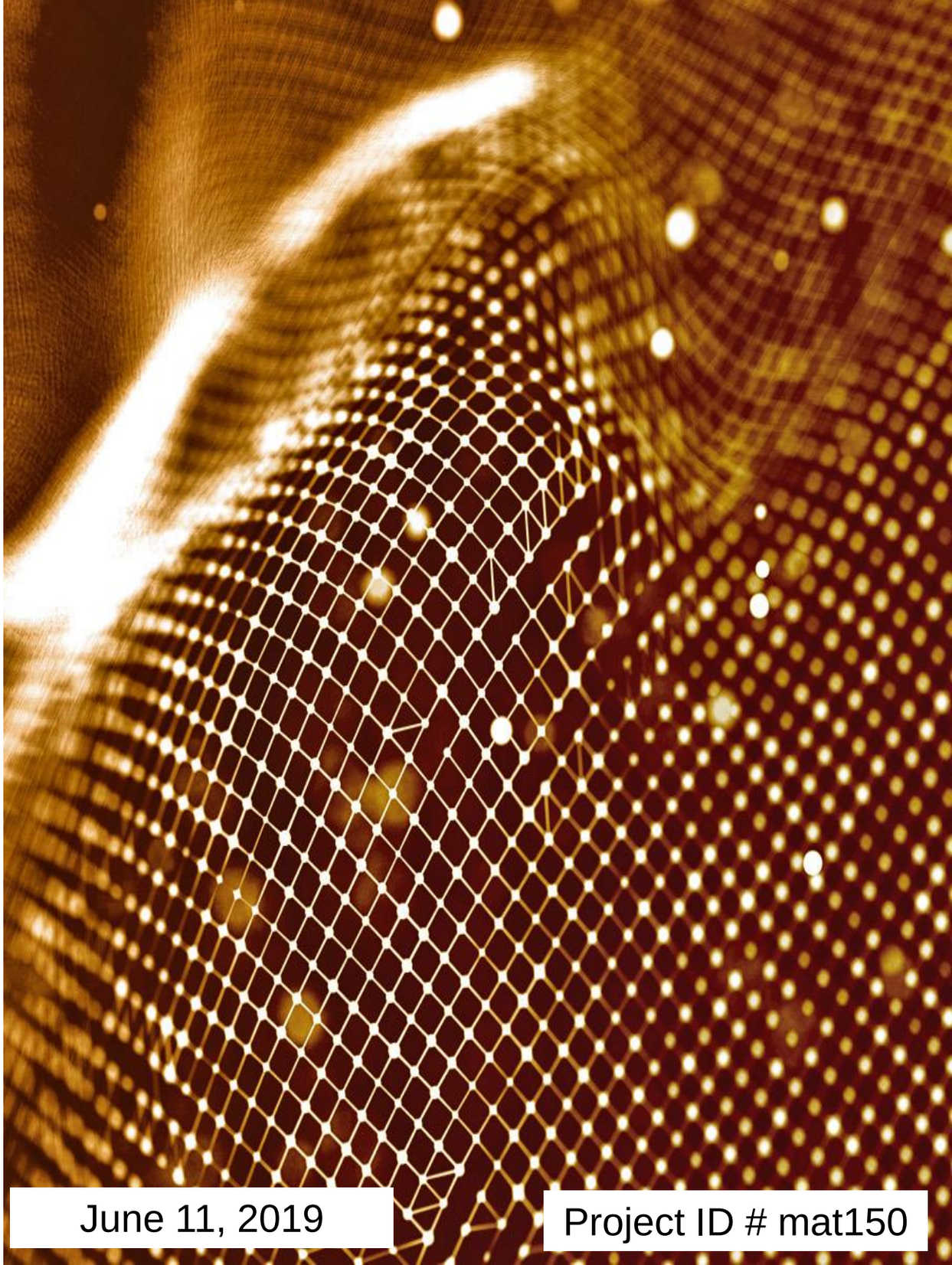

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June 11, 2019

Project ID # mat150

Overview

Timeline

- Start: January 2019
- Finish: January 2020
- % Complete ~25%

Budget

- Total project funding
  - DOE: $ 350K
- Funding since inception
  - $ 350K
- Future funds anticipated
  - $ 0

Technology Gaps/Barriers

- Lack of corrosion resistant magnesium (Mg) alloys
- Lack of cost-effective, durable protective coatings
- Current technology using organic coatings require multiple steps and chemical baths to improve adhesion and porosity-free coatings
  - Environmental concerns

Partners

- University of Oregon
- University of Iowa

Relevance/Objective

- Corrosion susceptibility limits/prevents greater use of Mg alloys in automotive sector despite its lightweighting potential
- Organic coatings offer corrosion protection but have some challenges:
  - Poor adhesion in the absence of pre-treatment
  - Application of multiple layers to form a porosity-free coating
  - Chemical baths used for coatings are an environmental concern
- Alternative corrosion protection schemes are needed that offer improved corrosion resistance in Mg alloys and overcome the challenges of existing coatings-based approaches
  - PNNL is investigating surface modification approaches for corrosion protection of Mg sheet alloys (AZ31)

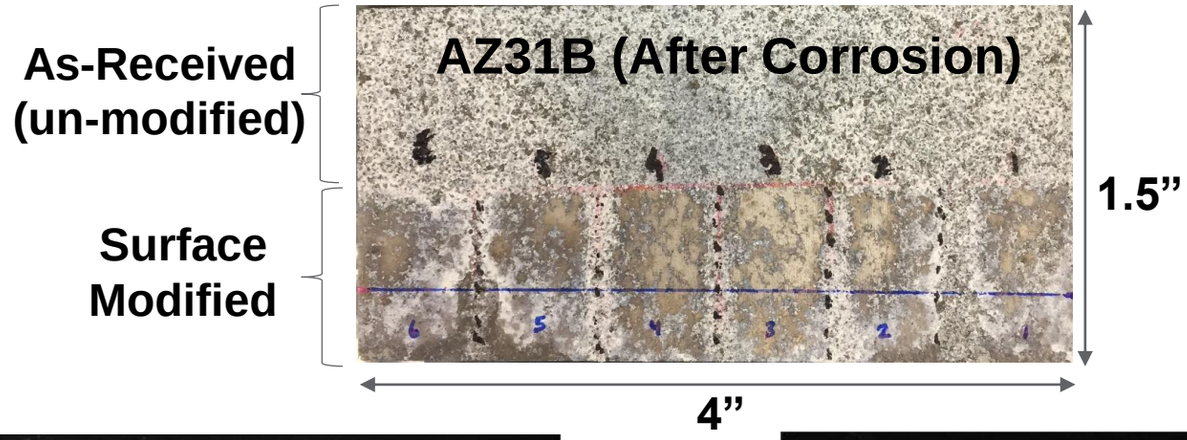
Project Milestones

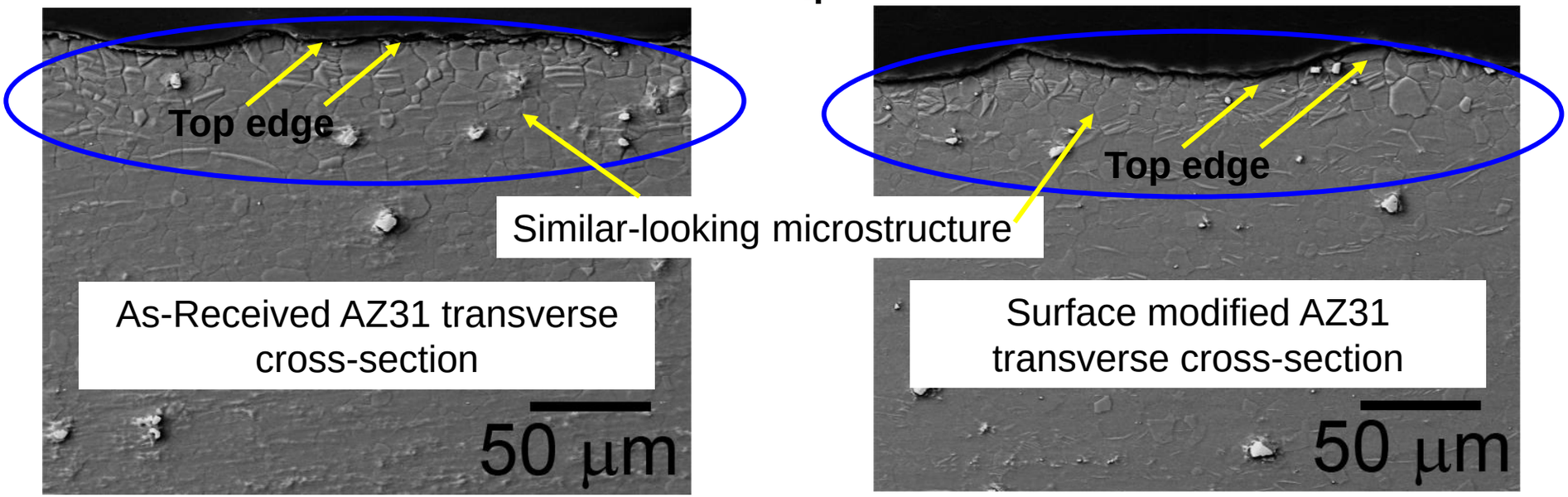
Milestone	Date	Description
M1	03/31/2019	Fabricate surface-modified Mg alloy test coupons ✓
M2	06/30/2019	Perform cross-sectional microstructural characterization of the processed surface to describe elemental and phase distribution
M3	09/30/2019	Compare mass-loss of un-processed and processed samples tested using ASTM B117 test method
M4	12/30/2019	Compare mass-loss of surface-modified samples, prepared with various methods, after testing them using ASTM B117 test method

Approach

- Material: AZ31 Mg sheet
- Surface Modification: Process in development
  - Laser surface treatment
  - Spot size 500 microns
  - Pulse energy ~100, ~200 and ~300 mJ → ~1, ~2 and ~3W, respectively
- Microstructural Characterization: As-received Mg sheets vs. surface modified sheets using:
  - SEM (Scanning Electron Microscope)
  - GI-XRD (Glancing Incidence X-ray Diffraction)
  - EBSD (Electron Back-scatter Diffraction)
  - TEM (Transmission Electron Microscope)
- Corrosion Characterization
  - ASTM B117 salt fog test for 1500 hours (~ 2 months)
  - Electrochemical tests
- Develop and Test Hypothesis to identify mechanism(s) behind improved corrosion resistance

Technical Accomplishments (January-March 2019)



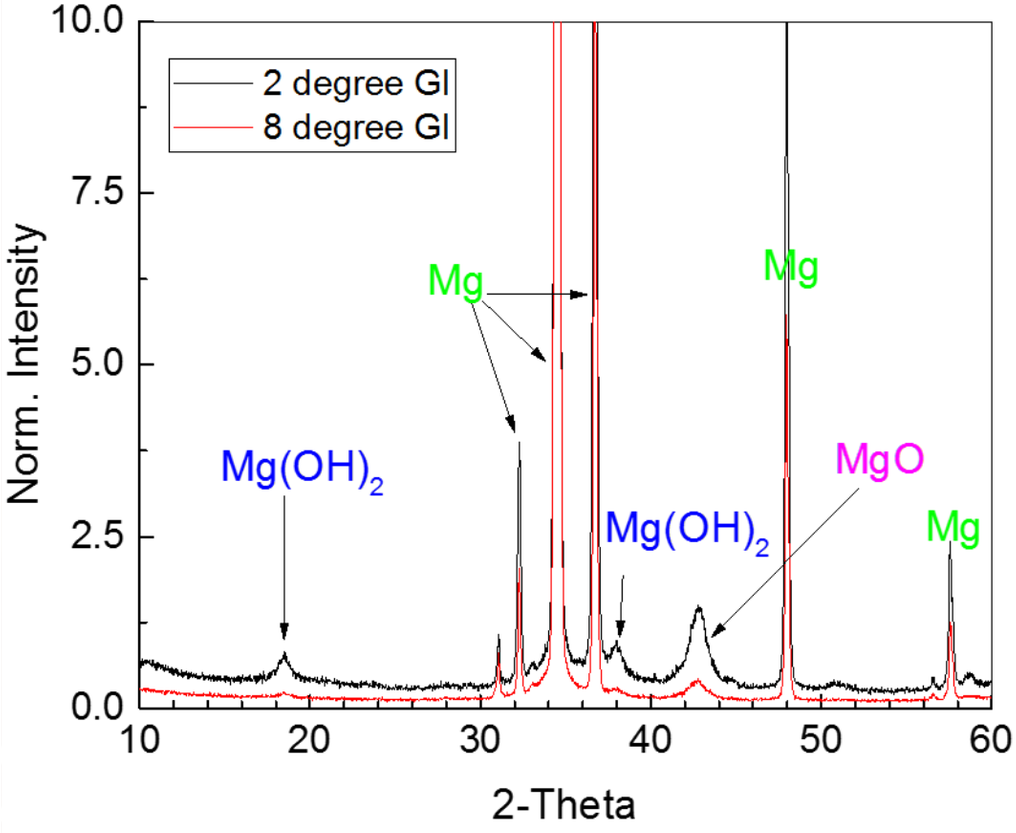


Cross-section SEM

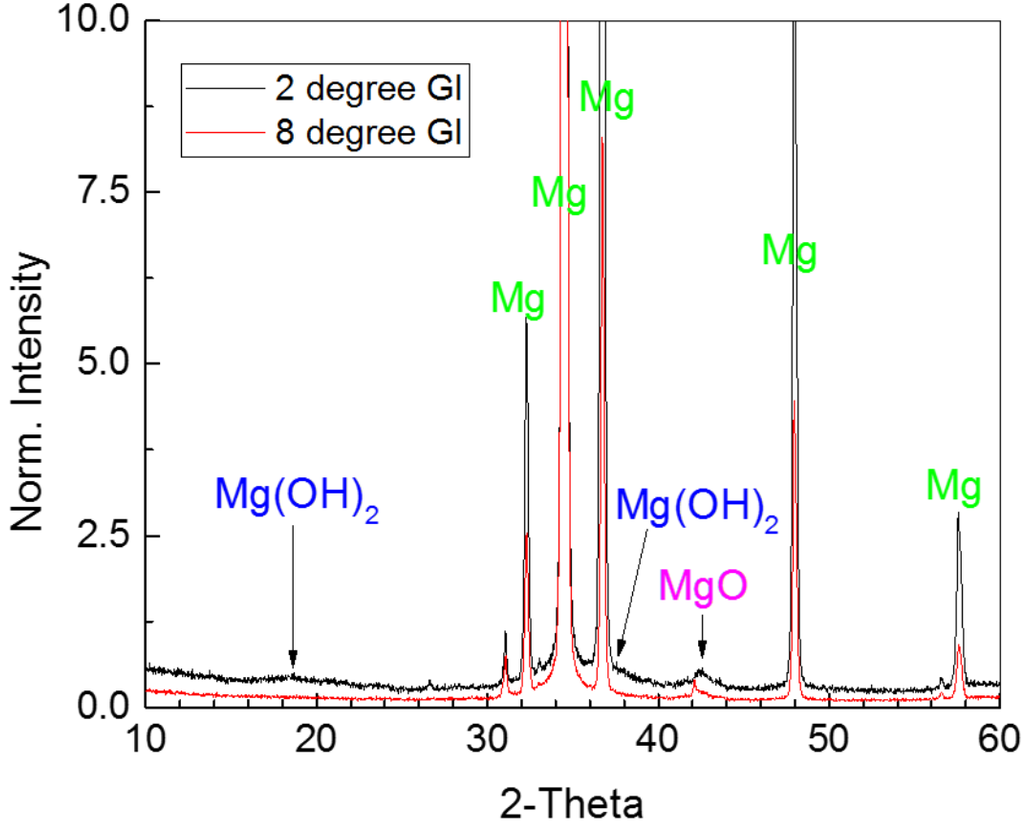
- **Apparent absence of surface coating in surface-modified sample**
- **Similar through-thickness microstructure in as-received and surface-modified samples**

Technical Accomplishments
Glancing Incidence (GI)-XRD

As-received AZ31B



Surface-Modified AZ31B (untested)



- **<u>Presence</u> of magnesium hydroxide ($Mg(OH)_2$ / oxide (MgO) peaks → Corrosion build-up due to atmospheric corrosion**
- **<u>Absence</u> of magnesium hydroxide ($Mg(OH)_2$ / oxide (MgO) peaks → Improved resistance to atmospheric corrosion**

- **GI-XRD confirms improved atmospheric corrosion resistance in surface-modified AZ31B sheet**

Response to Reviewer's Comments

- This project is being reviewed for the first time

Collaboration and Coordination

- University of Oregon
  - Electrochemical testing
- University of Iowa
  - Surface process development

Remaining Challenges and Barriers

- Perform detailed microstructural characterization of surface modified AZ31 sheets before and after corrosion testing
  - TEM
  - XPS (X-ray photoelectron spectroscopy)
- Electrochemical testing of surface modified Mg sheets
- Identify the responsible mechanism for improved corrosion behavior in surface modified Mg sheets

Proposed Future Work

- Identify Mechanism(s) of Corrosion Mitigation:
  - Detailed microstructural characterization
  - Effect of alloying elements, second phase particles
  - Advanced electrochemical testing to correlate microstructure with corrosion behavior
  - In-situ imaging studies

- Work with industry partners:
  - Different Mg-alloy systems
  - Avoidance of pre-treatment step
  - Applicability to castings

Any proposed future work is subject to change based on funding levels

Summary

- Goal of this project is to develop surface modification techniques to improve corrosion resistance of Mg alloys, without the use of conventional chemical baths
  - Simplify corrosion protection package
  - Address environmental concerns
- Initial experimental results confirm that the as-surface-modified AZ31 Mg showed qualitatively greater resistance to atmospheric oxidation relative to un-modified AZ31 sheet

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BACKUP SLIDES

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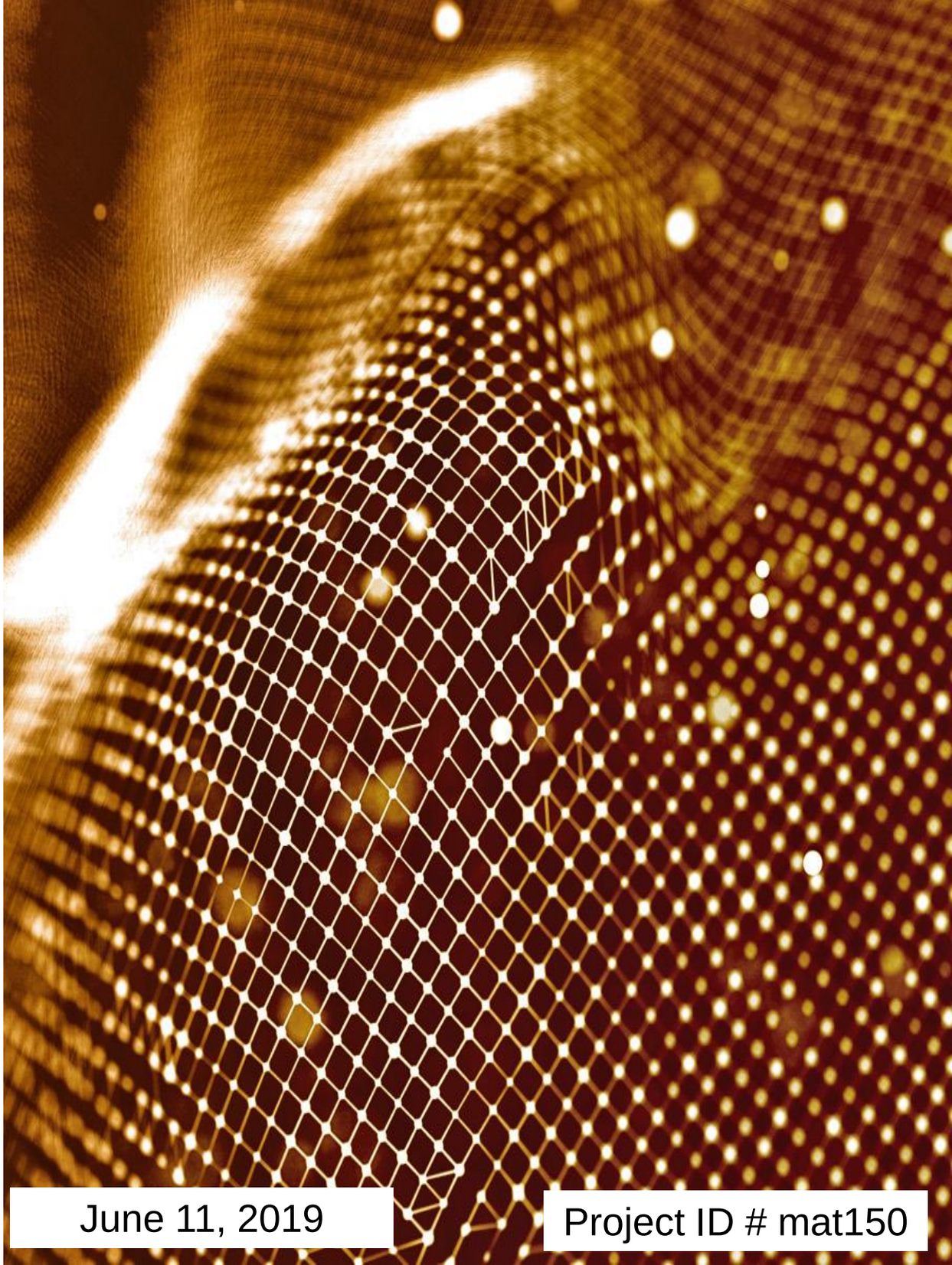

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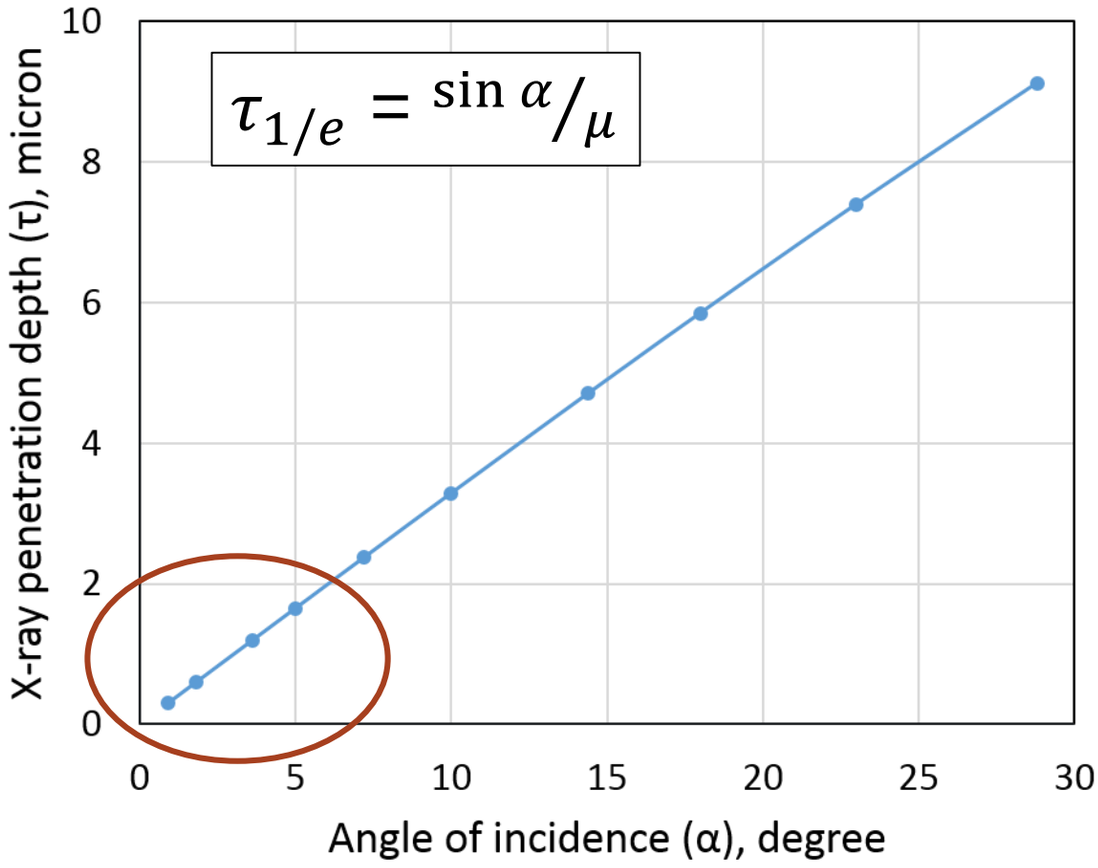
Glancing Incidence(GI)-XRD

- The incidence X-ray beam enters the sample at a very low angle of incidence (1-5°), and thus the structural information contained in the resulting diffractogram stem primarily from the top surface region (tens to hundreds of nm thickness)
- For the current study, we have applied GI-XRD in order to investigate the very top surface region in processed Mg alloy to find out if any new phase is forming that provides the improved corrosion performance



$\tau_{1/e}$ = Characteristic distance for which the x-ray beam is attenuated to 1/e of its initial value
α = Angle of incidence
μ = X-ray attenuation coefficient

For small angle of incidence, X-ray penetration depth remains limited to hundreds of nm to a few microns, which is useful for surface characterization

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Thank you