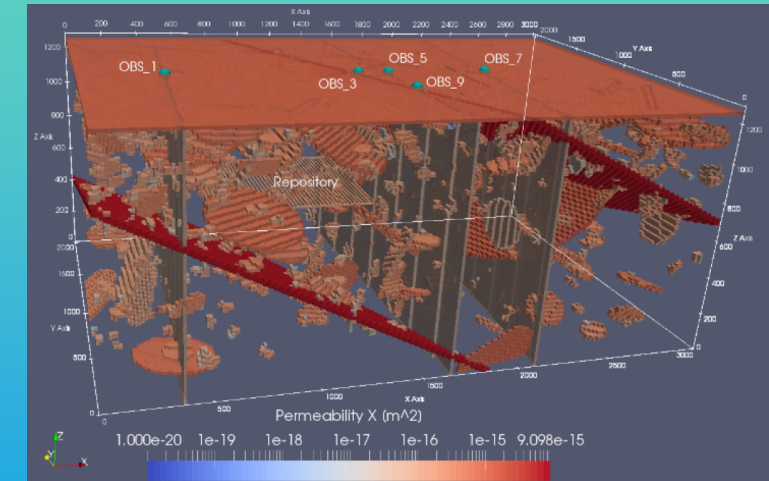




Mitigation & Repair: Initial Corrosion Research of Cold Spray

SFWST
May 12, 2022

Erin Karasz, Rebecca Schaller, Timothy Montoya, and Charles Bryan
Sandia National laboratories

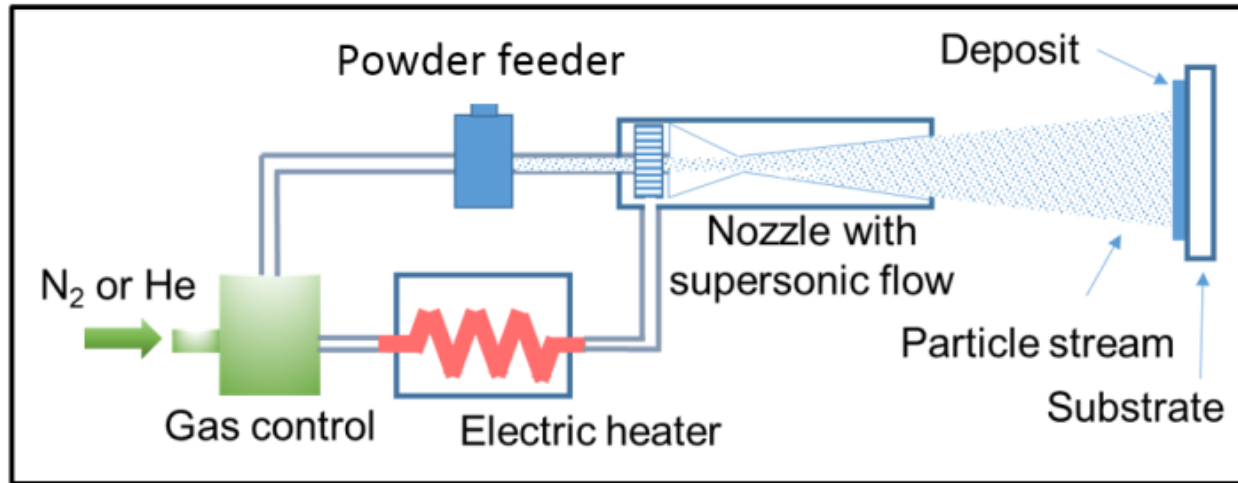
Ken Ross
Pacific Northwest National Laboratories

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Cold Spray Background

Cold Spray:

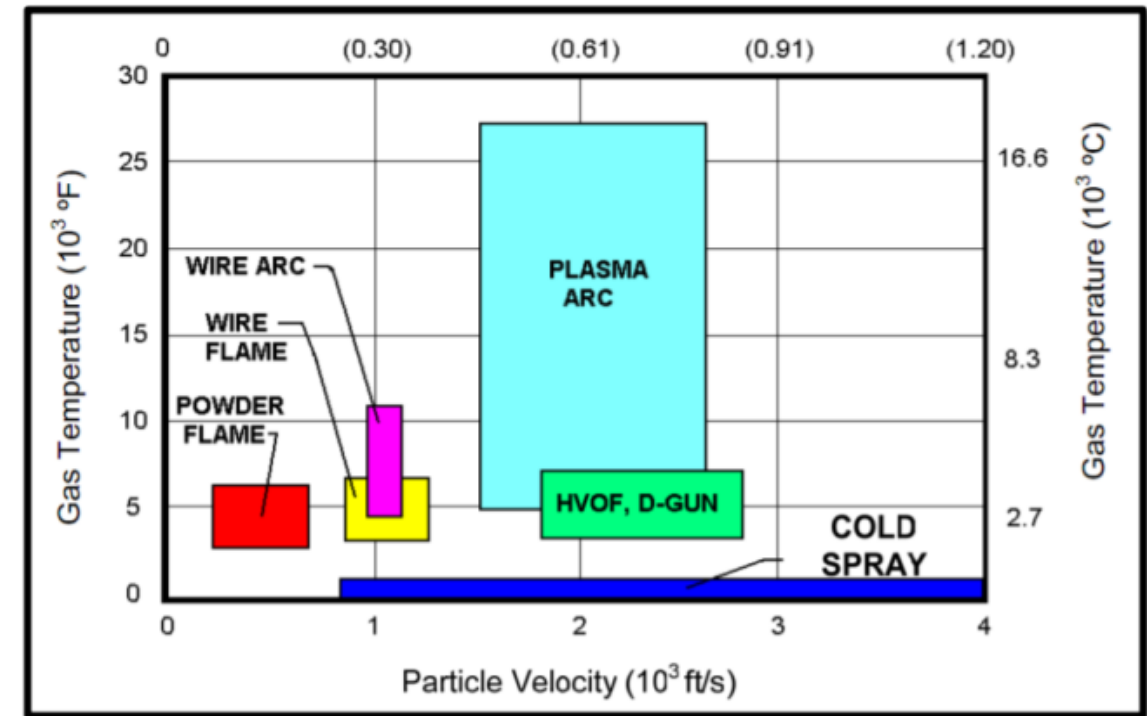
Metal particles accelerated by a stream of inert gas into a substrate. Adhered by plastic deformation.



High-pressure cold spray process. Ken Ross No. PNNL-30299.

Lower temperature helps prevent:

- Temperature-dependent crystalline transformations
- Oxidation
- Vaporization



M. Neshastehriz, 2014, Pennsylvania State University

Canister Coating Scenarios

SNF Canister SCC Prevention/Repair Coating Scenarios

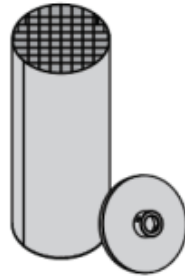
Ex Situ Prevention

Advantages

Unlimited Access
No radiological hazards
Full Coverage Coating

Challenges

Toughest Survability Reqs.
N/A for Existing Canisters



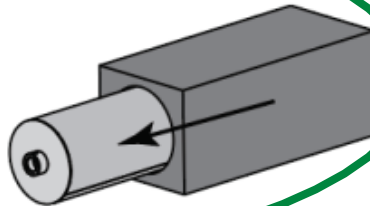
Ex Situ Repair

Advantages

Good Access
Full Coverage Repair
Applicable to Existing Canisters

Challenges

Potential Exposure Risk
Additional Cost of Removal
Few Cleaning/Coating Options



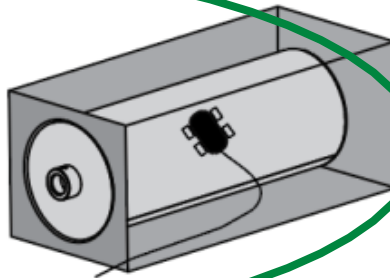
In Situ Repair

Advantages

Applicable to Existing Canisters
Low Exposure Risk
Lowest Survability Reqs.

Challenges

Limited Canister Access
Few cleaning/coating options
Partial Coverage Repair



Patch Application:
focus on vulnerable
or damaged areas



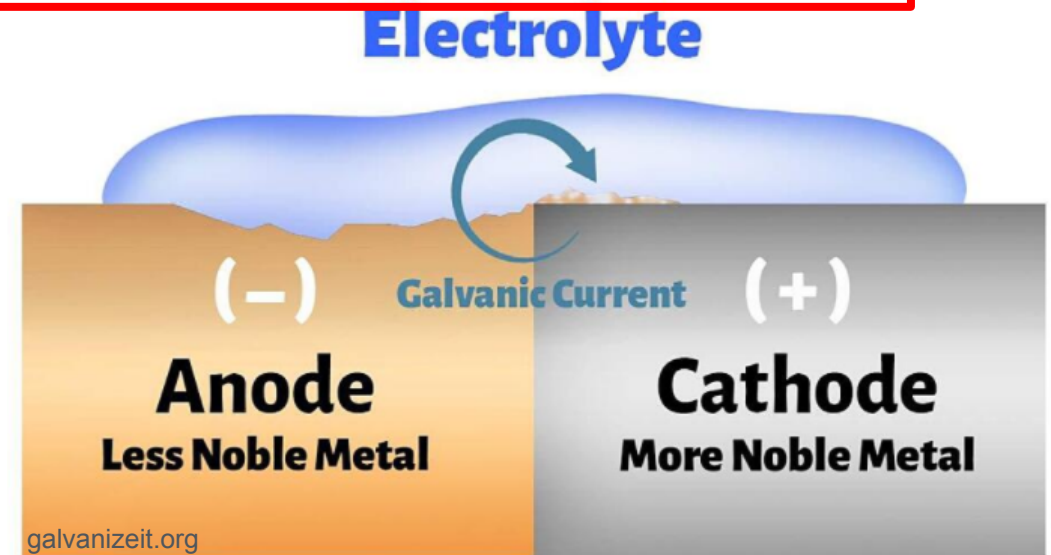
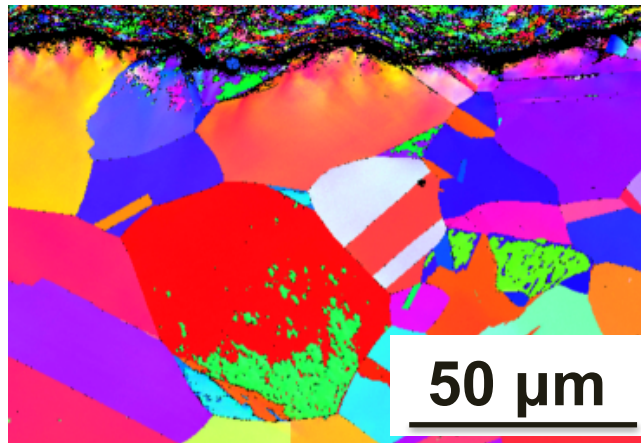
Loading of NUHOMS Storage Cask (TN International, Orano)

Patch Corrosion Concerns

Exposed Junction Between Substrate & Cold Spray

Need to ensure we “do no harm”

- Galvanic Corrosion
- Possible Deformation Layer
- Residual Stresses



Galvanic Corrosion

Try to minimize galvanic corrosion through material selection

Started with Nickel, Nickel Alloys:

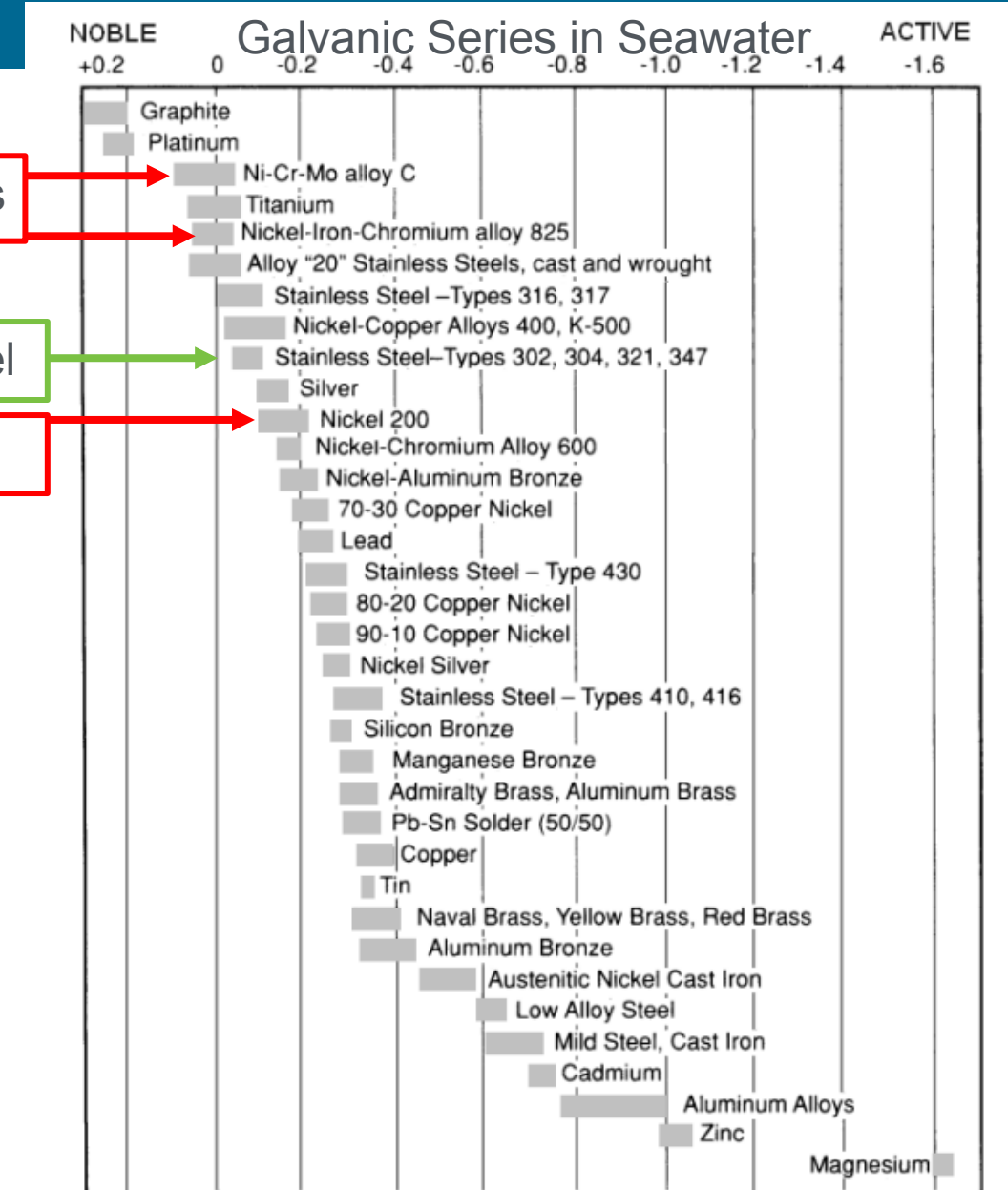
- Historically good galvanic pair with 304
- Good corrosion behavior
- Existing cold spray research

- Commercially Pure Nickel (Ni)
- Inconel 625 (Inc)
- Super C (SC)

Nickel Alloys

304 Stainless Steel

Nickel



Cold Spray Samples

Interface:

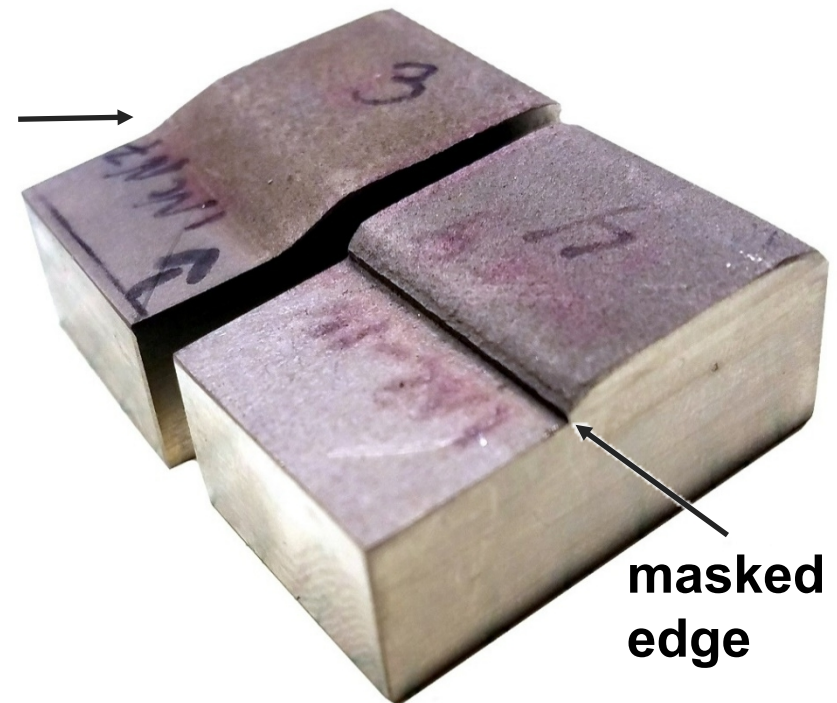
- Blended
- Masked

- Affects Coating Coverage at Interface
- Residual Stresses

Accelerating Gas:

- Nitrogen
- Helium
- Affects Porosity
- Cost/Sustainability

blended edge



Ross, Kenneth A., et al. *Assessment of Cold Spray Technology for Nuclear Power Applications*. No. PNNL-30299. Richland, WA (United States), 2021.

Corrosion Testing

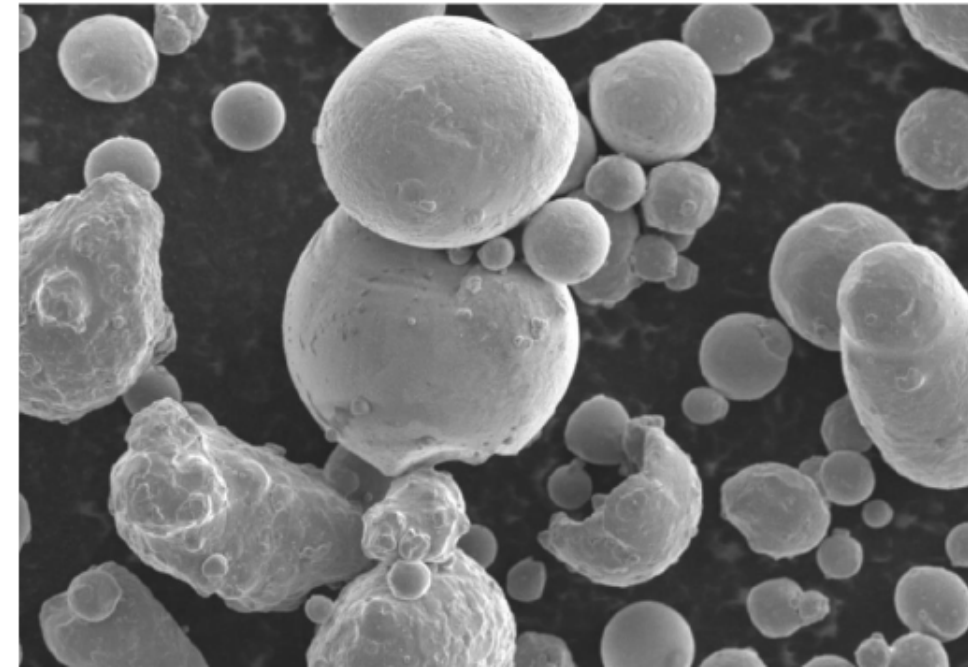
Rapid Assessment of Influencing Factors

Accelerated Testing:

- Electrochemical Potentiodynamic Scans
- Ferric Chloride

Relevant Conditions:

- Atmospheric Exposures (preliminary)



316L stainless steel powder

Expedited Electrochemical Testing

Assess electrochemical & corrosion properties of the cold spray

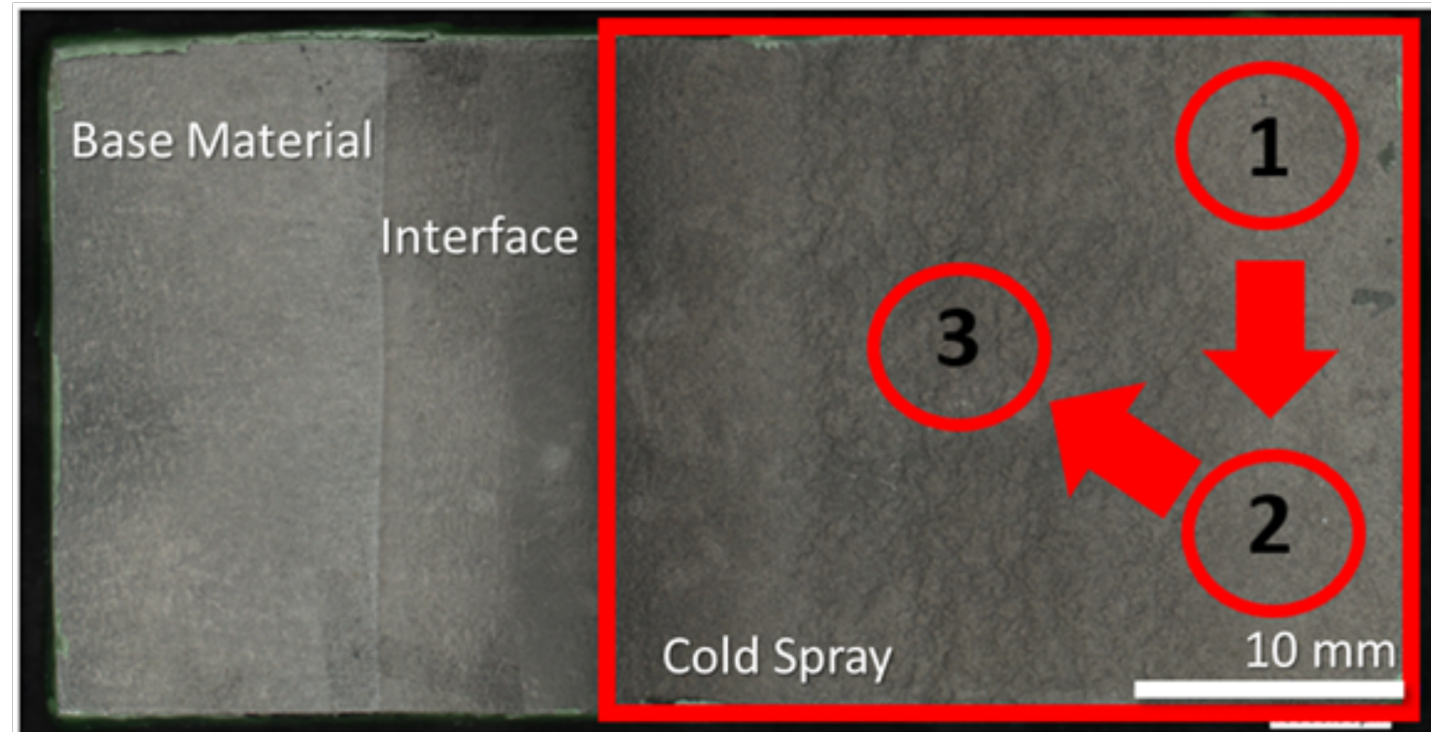
Tested 3 spots per sample (compare to substrate)

Finishes:

- As-Sprayed
- Ground (600, 1200 grit)

Electrolyte: 0.6 M NaCl

1 hour Open Circuit Potential
Potentiodynamic Scan 0.167 mV/s



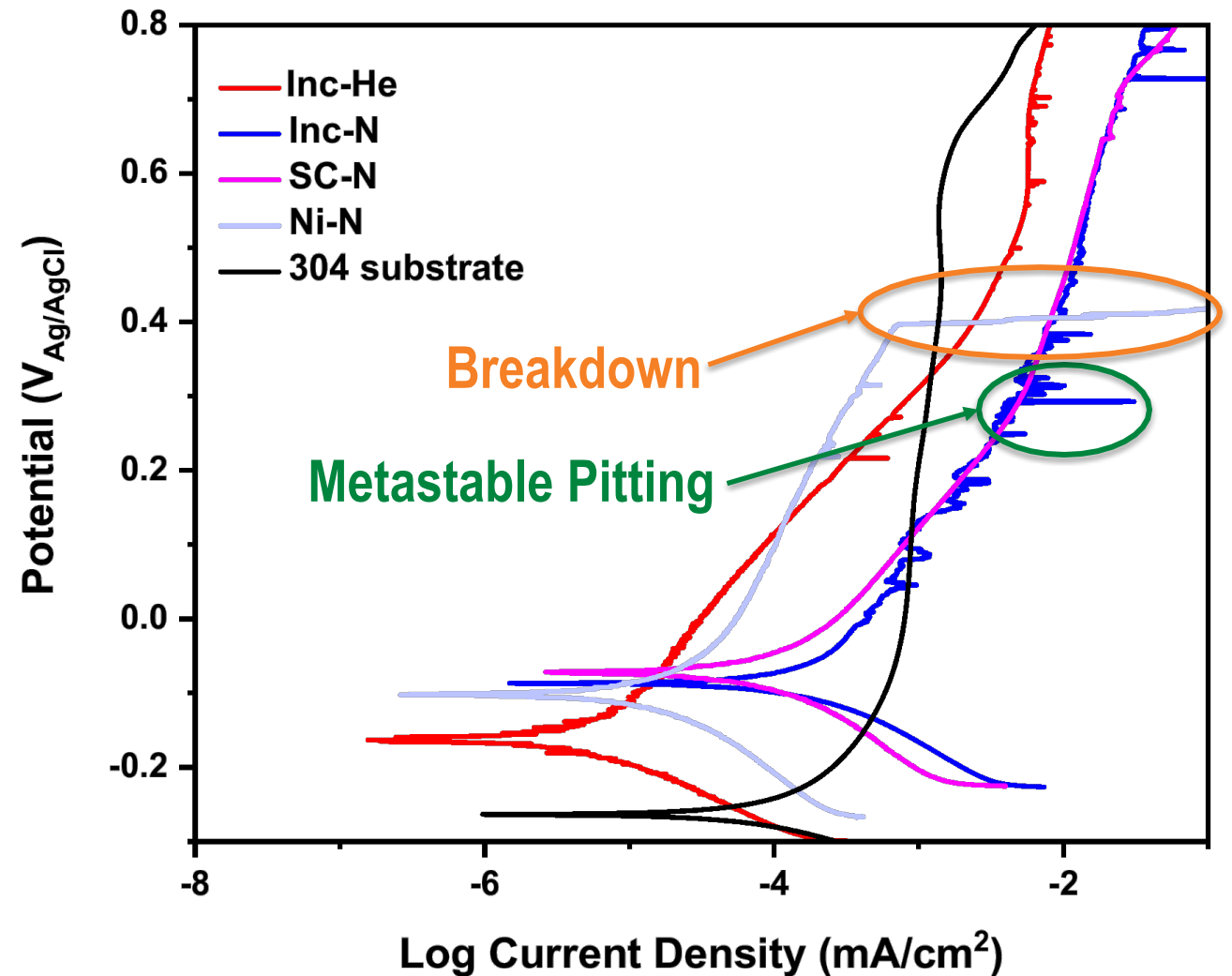
Potentiodynamic Scans: As Sprayed

- Ni breakdown very early in scan
- Metastable pitting

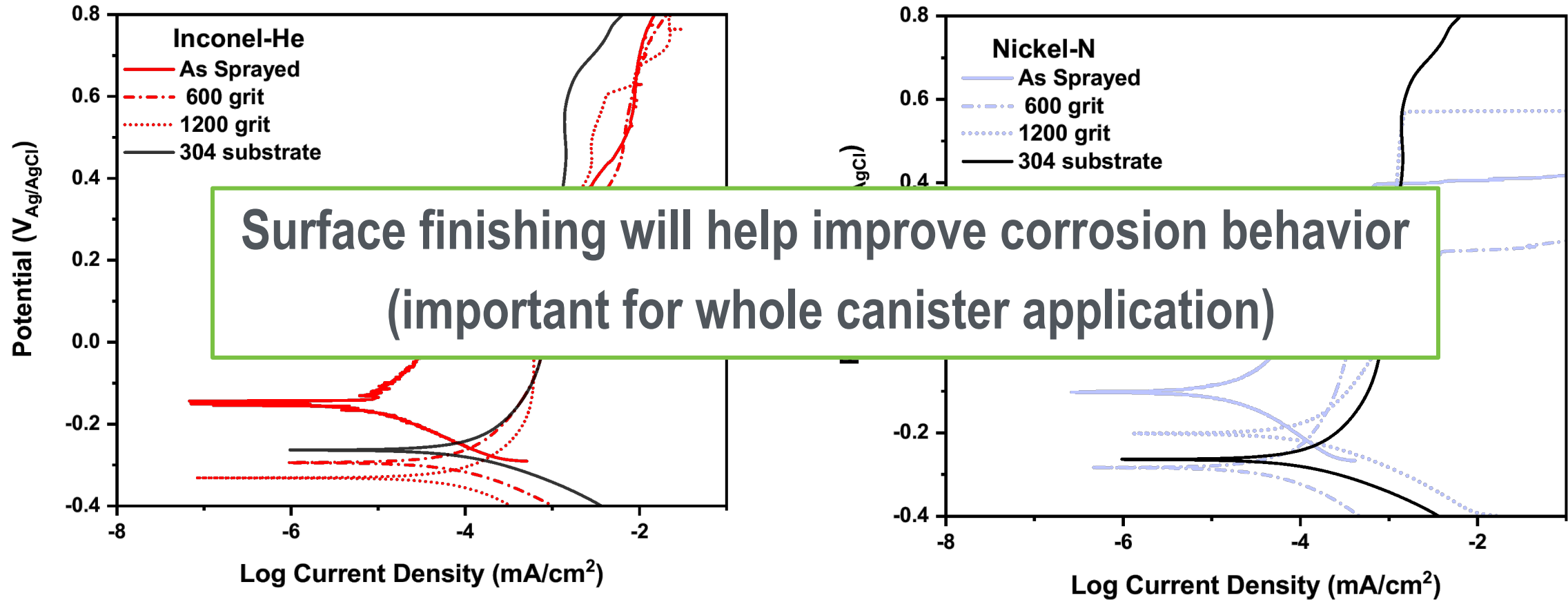
Passive Current Density

- Lower- Ni & Inc-He
- Higher- SC & Inc-N

Sample	Porosity (%)	S _a (μm)
SC-N	5.51 ± 0.44	16.7 ± 0.5
Inc-He	1.21 ± 0.20	15.7 ± 0.5
Inc-N	5.79 ± 0.18	17.2 ± 0.6
Ni-N	3.78 ± 0.59	18.5 ± 0.6



Potentiodynamic Scans: Surface Finished



- Nickel breakdown very early in scan
- Polishing reduces metastable pitting
- Polishing removed native oxide, higher initial passive current density & changes OCP (expected)

Accelerated Ferric Chloride Testing

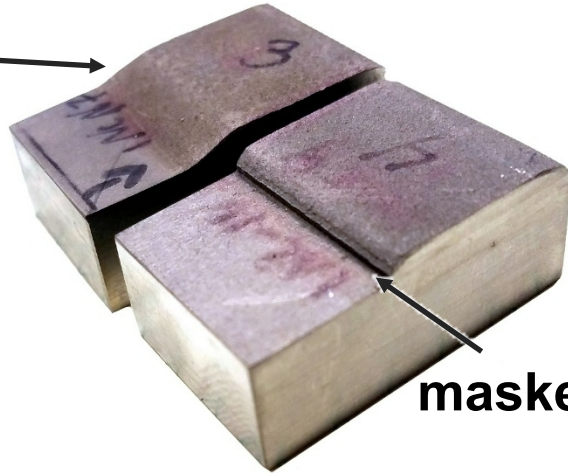
Bottom & sides of samples were coated for full immersion

ASTM G48 Method A

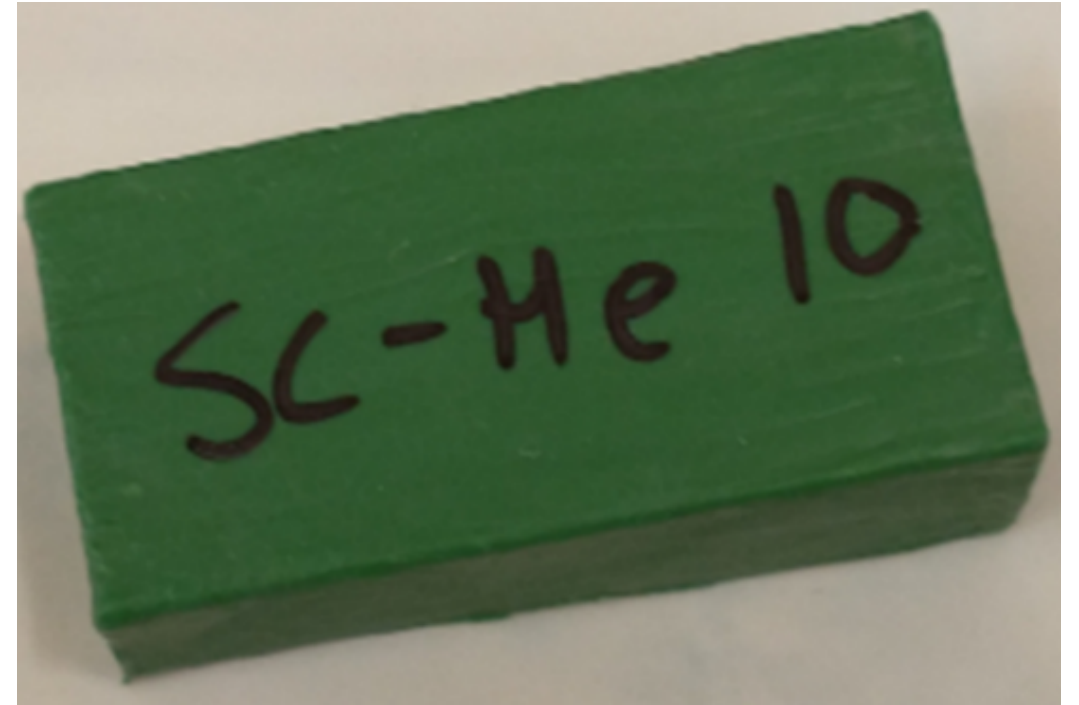
6% by mass ferric chloride solution

72 hours at 22 °C

blended edge

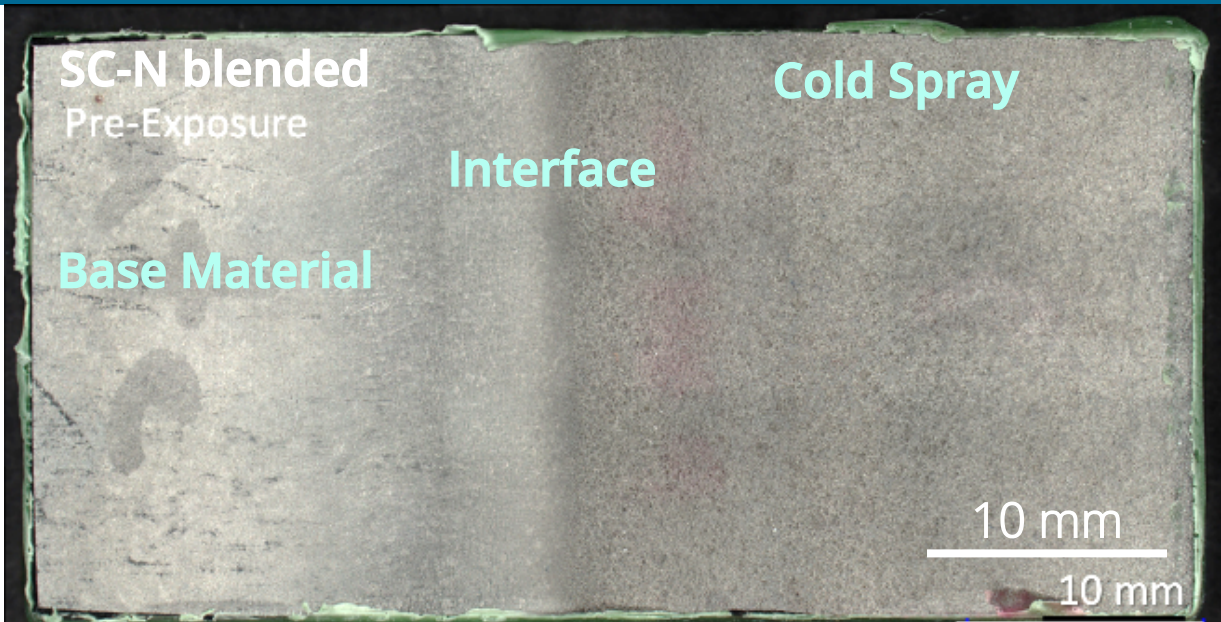


masked edge

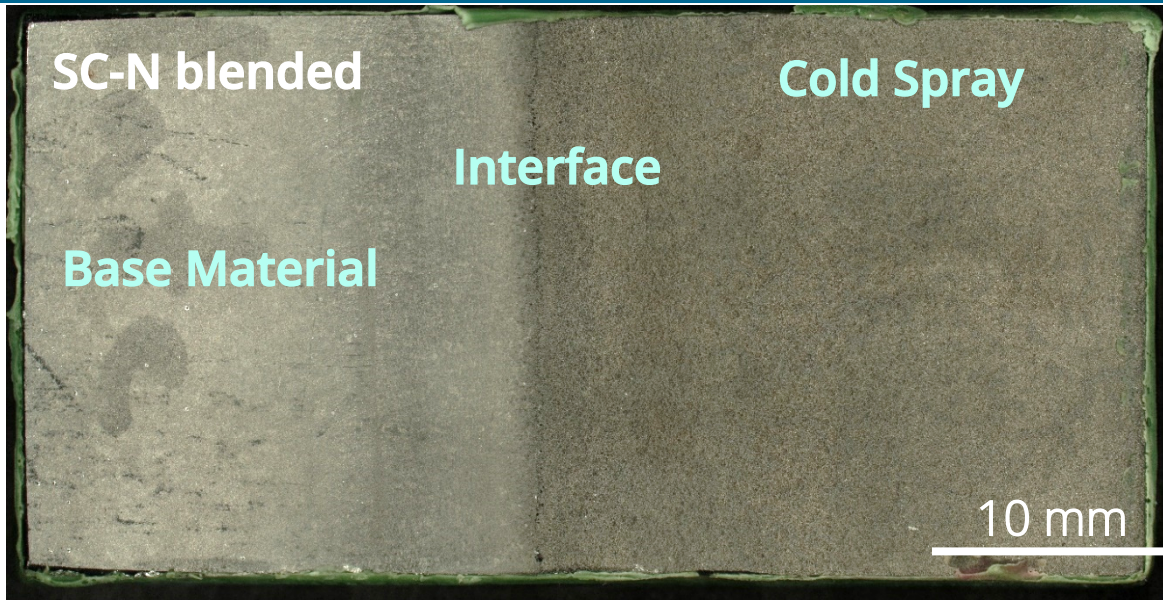


- Accelerated pitting test
- Evaluate potential galvanic couple influences
- Evaluate interface-type impact

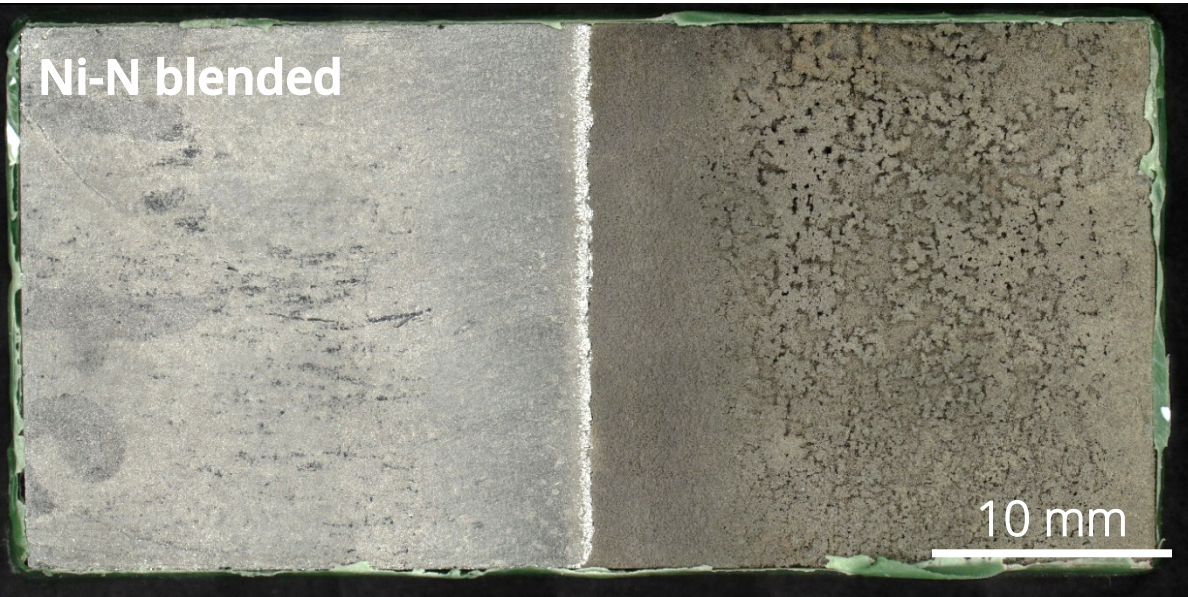
Material Selection



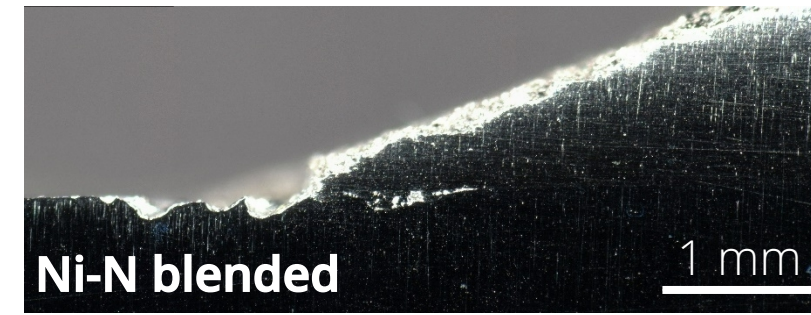
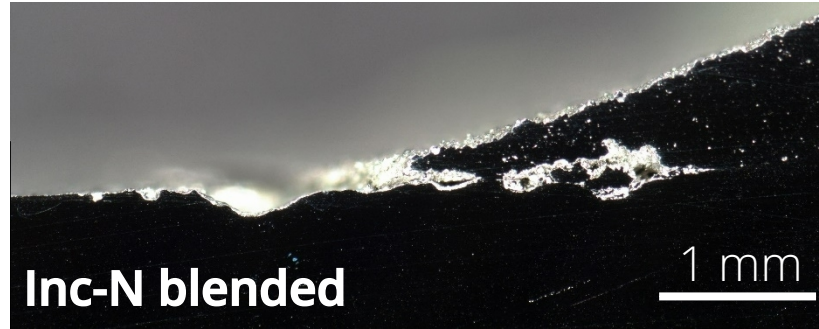
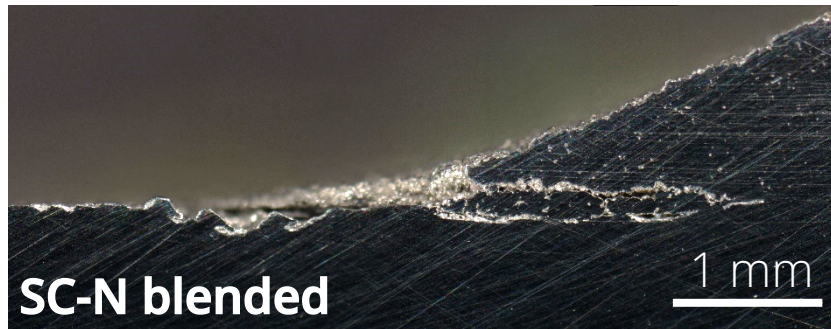
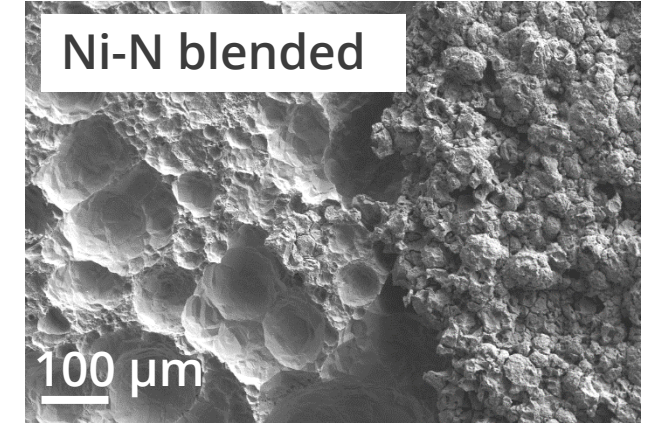
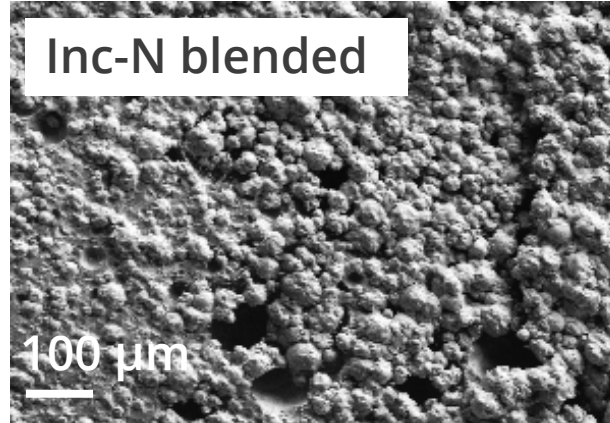
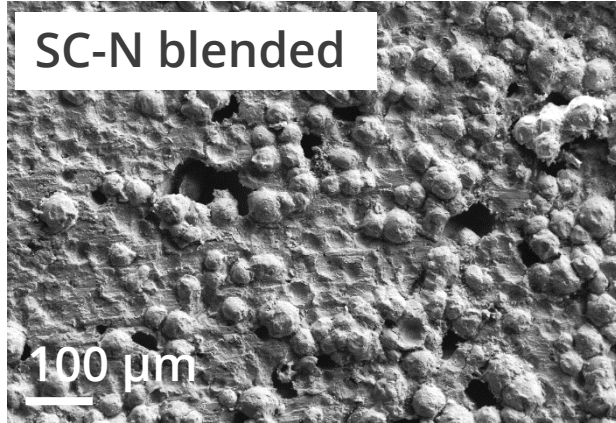
Material Selection



- Ni shows lots of damage in the cold spray & at the interface
- Inc-N & SC-N damage is harder to see



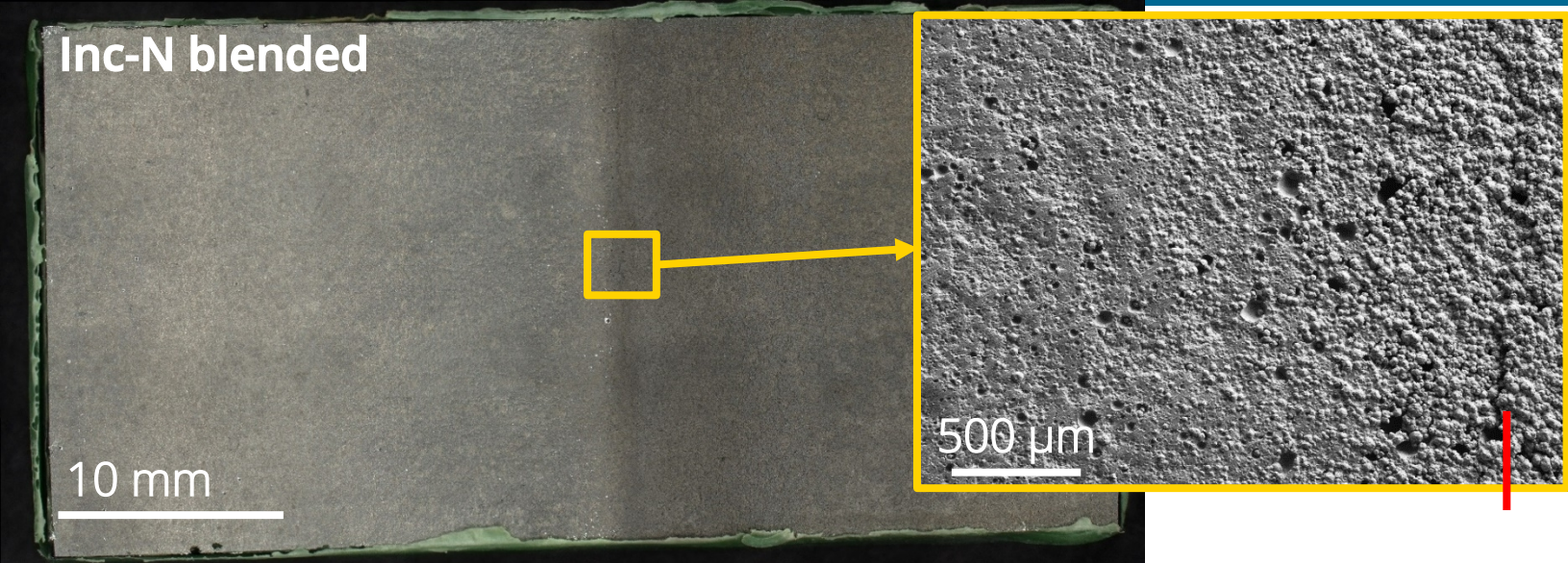
Material Selection



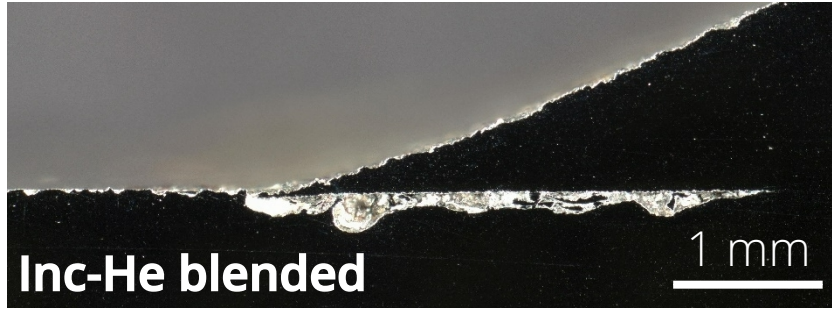
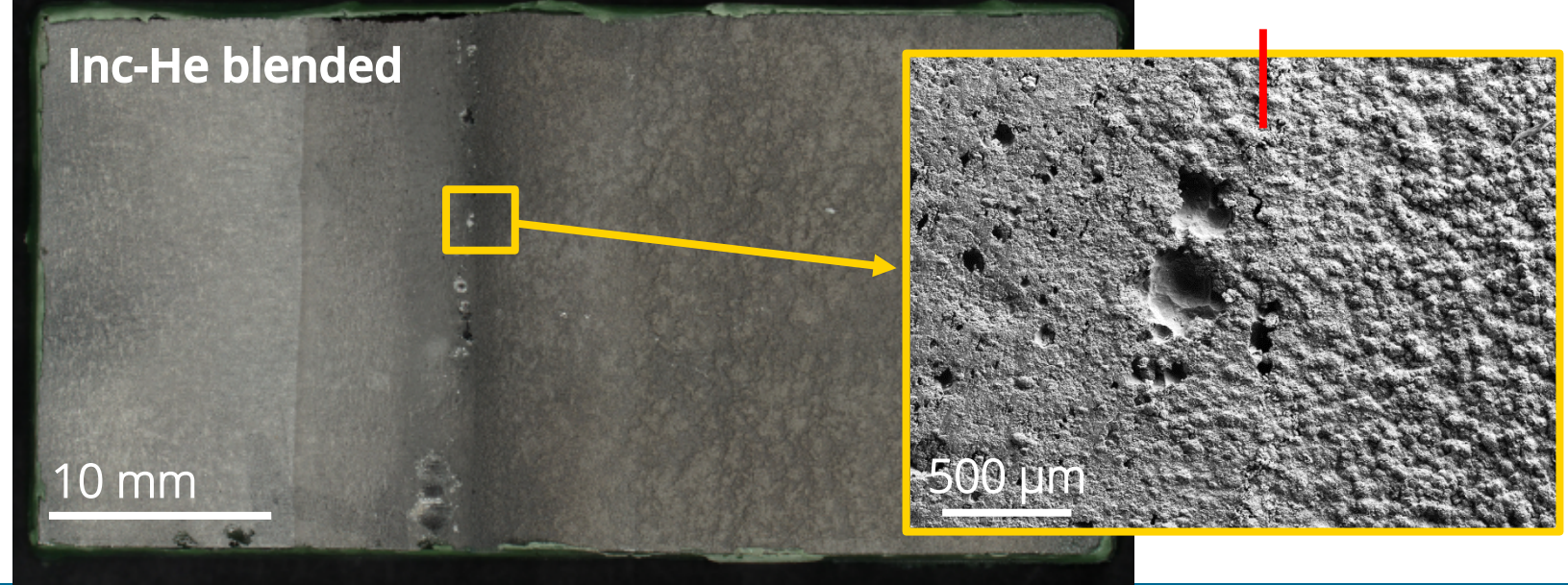
Sample	Porosity (%)	S_a (μm)
SC-N	5.51 ± 0.44	16.7 ± 0.5
Inc-N	5.79 ± 0.18	17.2 ± 0.6
Ni-N	3.78 ± 0.59	18.5 ± 0.6

Porosity associated with attack in cold spray layer

Gas Selection



Sample	Porosity (%)
Inc-N	5.79 ± 0.18
Inc-He	1.21 ± 0.20



Masked vs Blended: Ni-N

Ni-N masked

10 mm

100 μ m

Ni-N masked

1 mm

Ni-N blended

10 mm

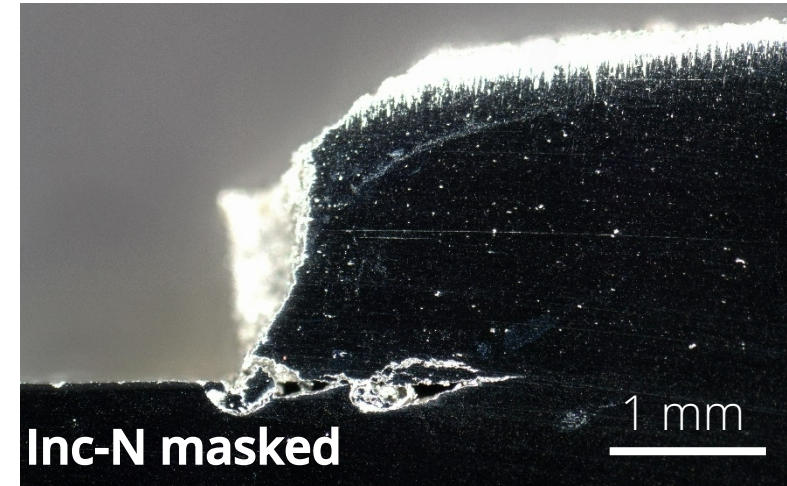
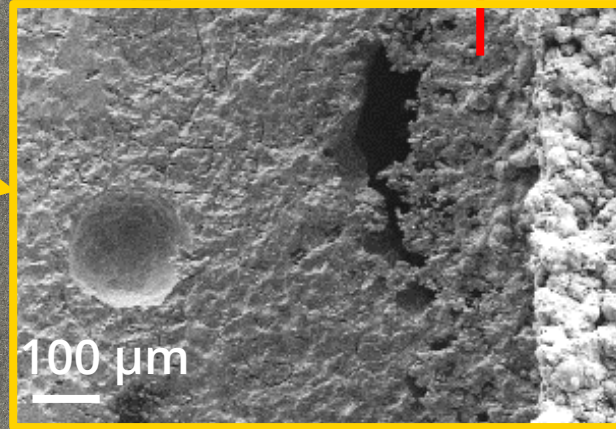
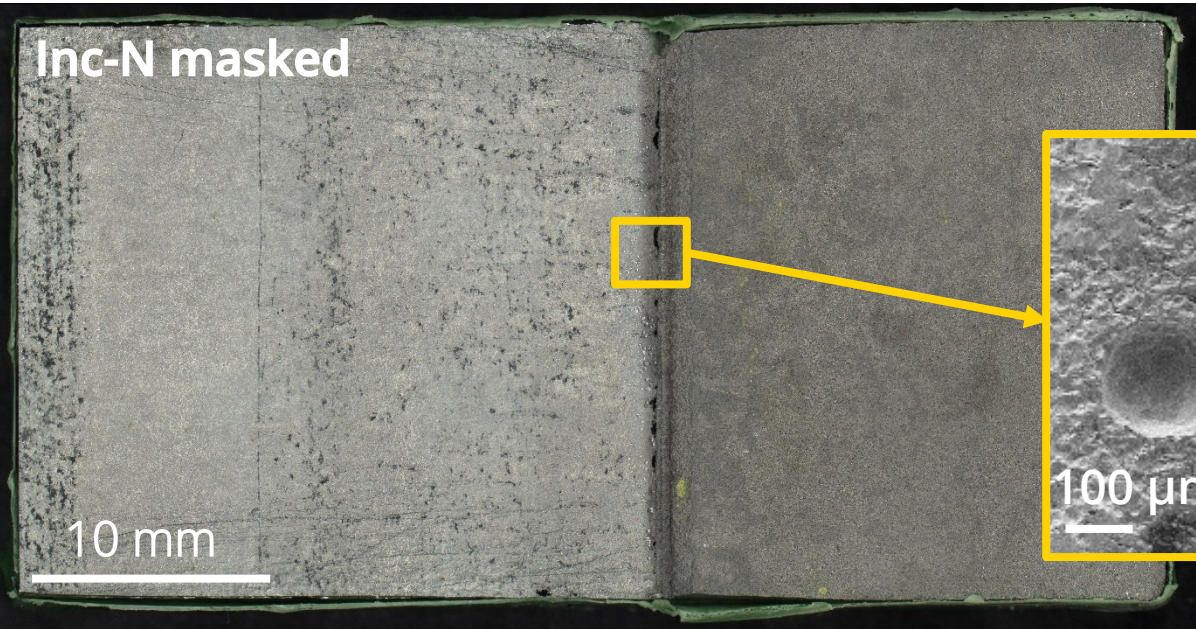
100 μ m

Ni-N blended

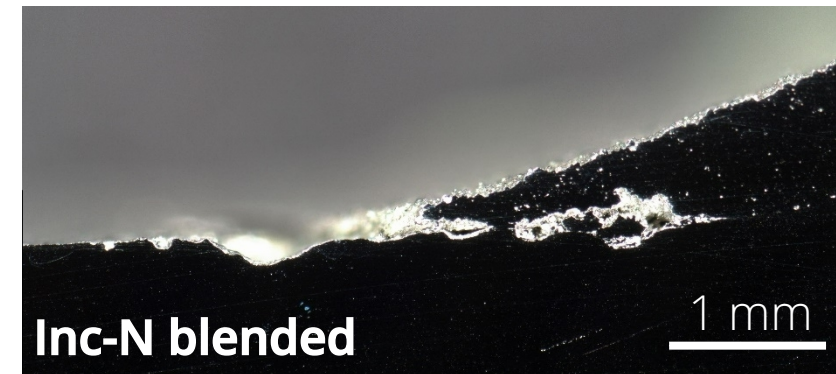
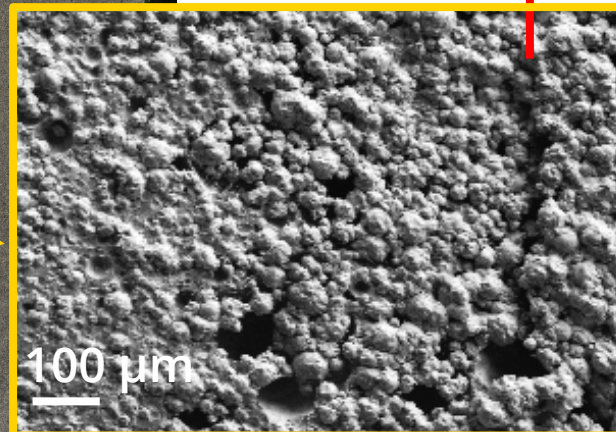
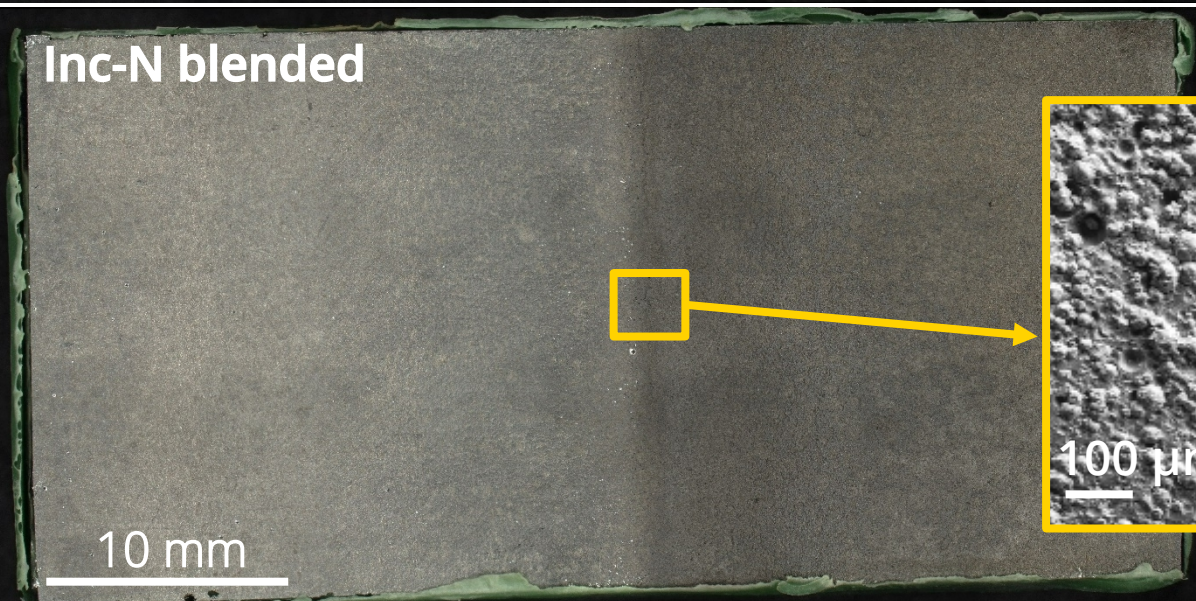
1 mm

Masked vs Blended: Inc-N

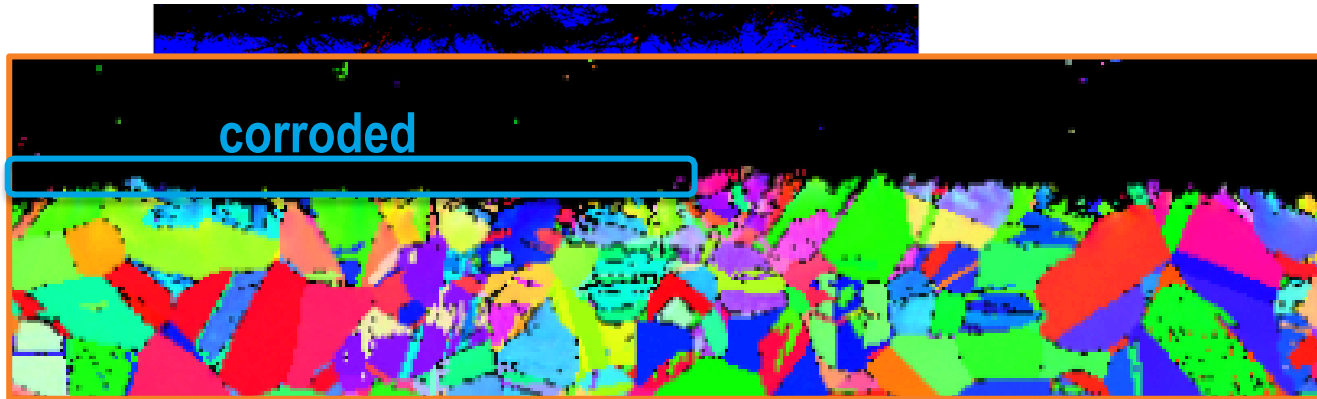
Inc-N masked



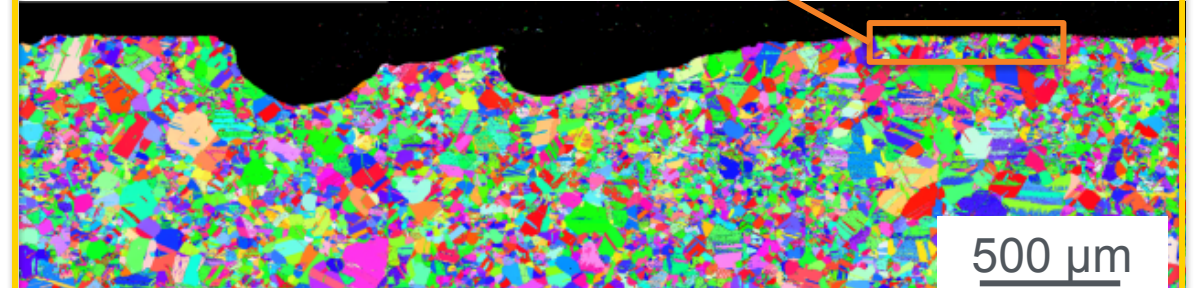
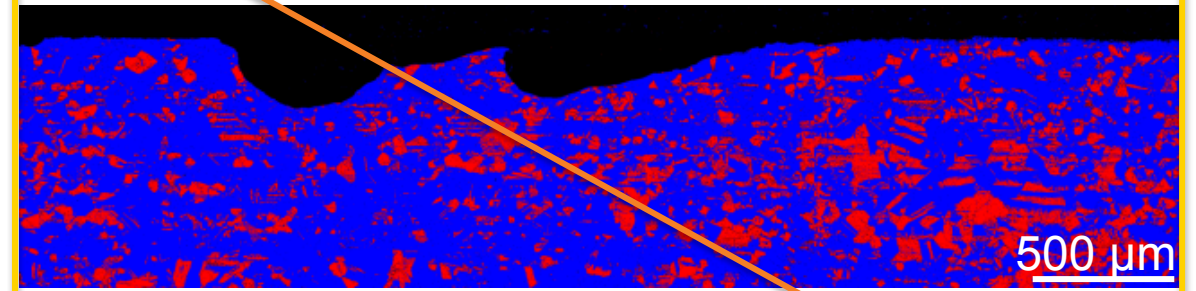
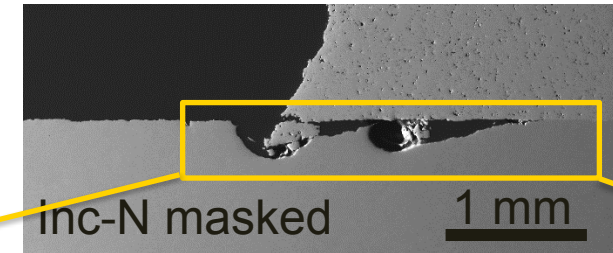
Inc-N blended



Corrosion in Deformation Layer

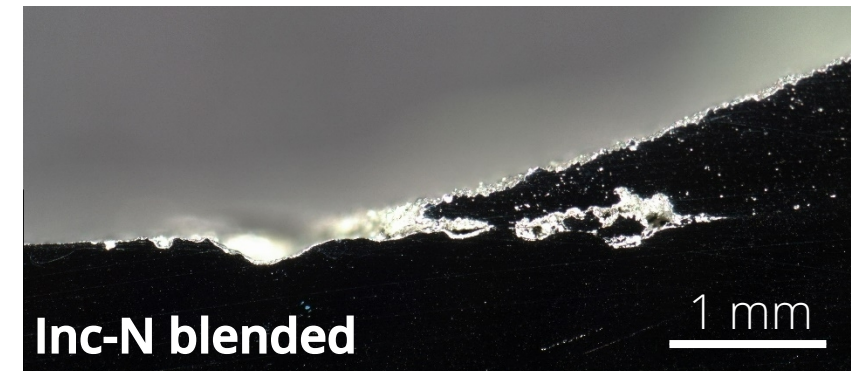
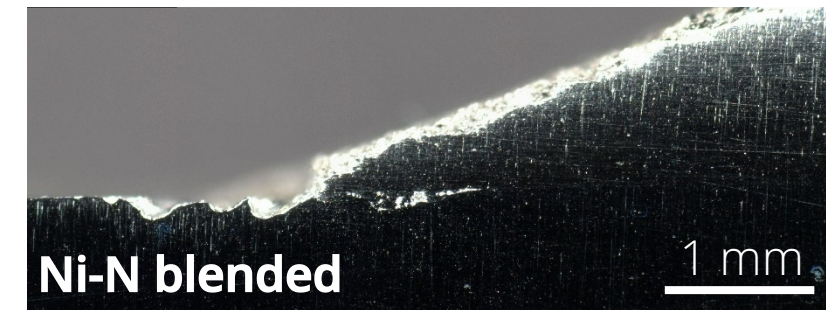
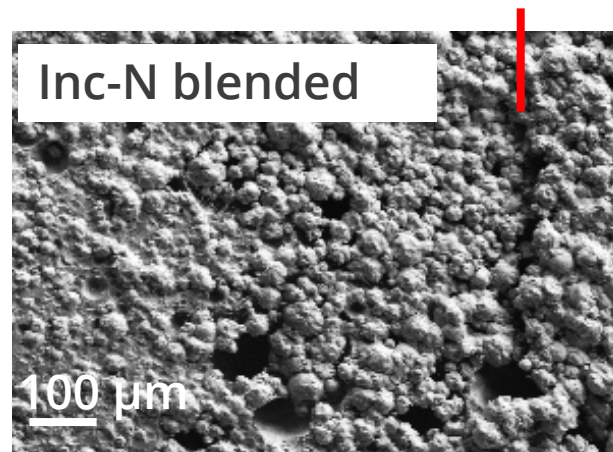
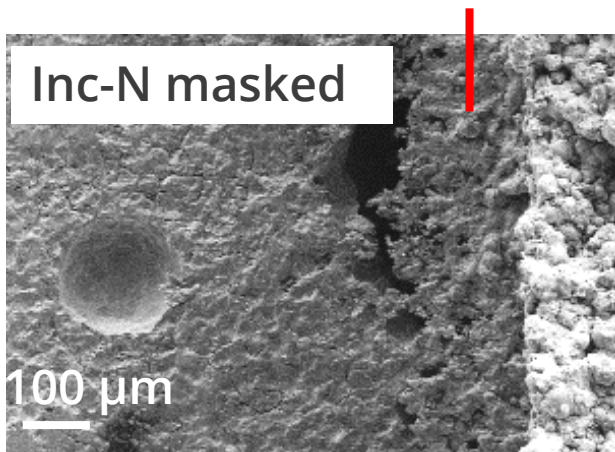


Corrosion seems to travel more rapidly through deformed layer but spreads beyond it



Interface Damage

- Damage morphology differs with interface type
- Surface roughness obscures extent of attack
- Top-down damage $\neq$ corrosion under the cold spray
- Porosity influences location of corrosion damage
- Deformation layer thinner than damage



Atmospheric Corrosion

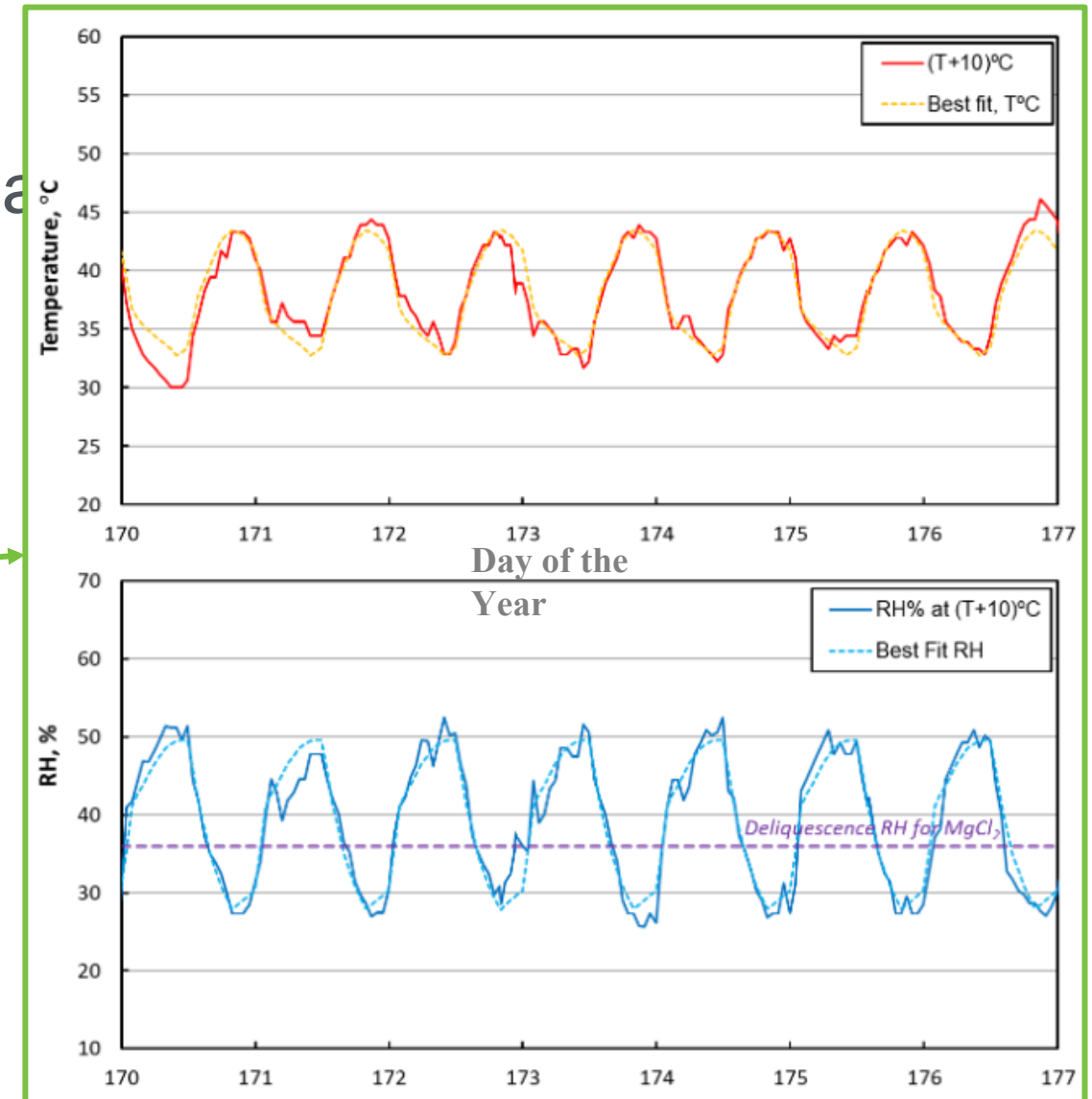
Printed 300 $\mu\text{g}/\text{cm}^2$ of Artificial Sea

Relative Humidity:

- 40% RH; 35 °C
- 75% RH; 35 °C
- cyclic

Above MgCl_2 deliquescence

Above NaCl deliquescence in Seawater



1 month: Ni-N masked



40% RH

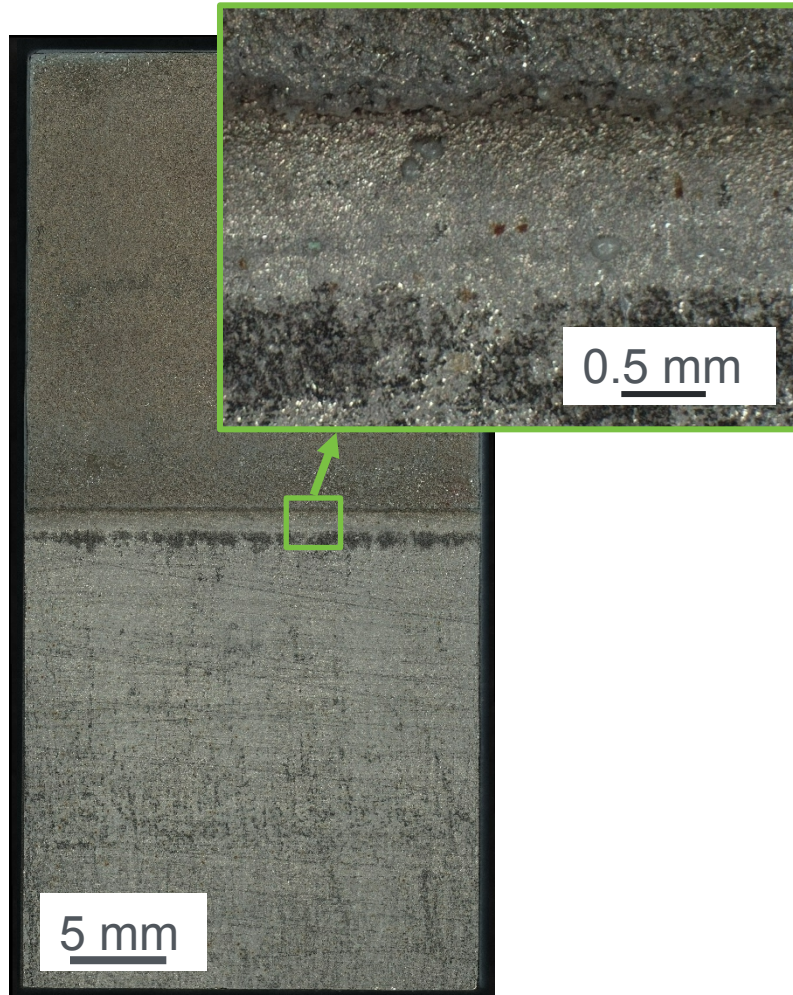


75% RH

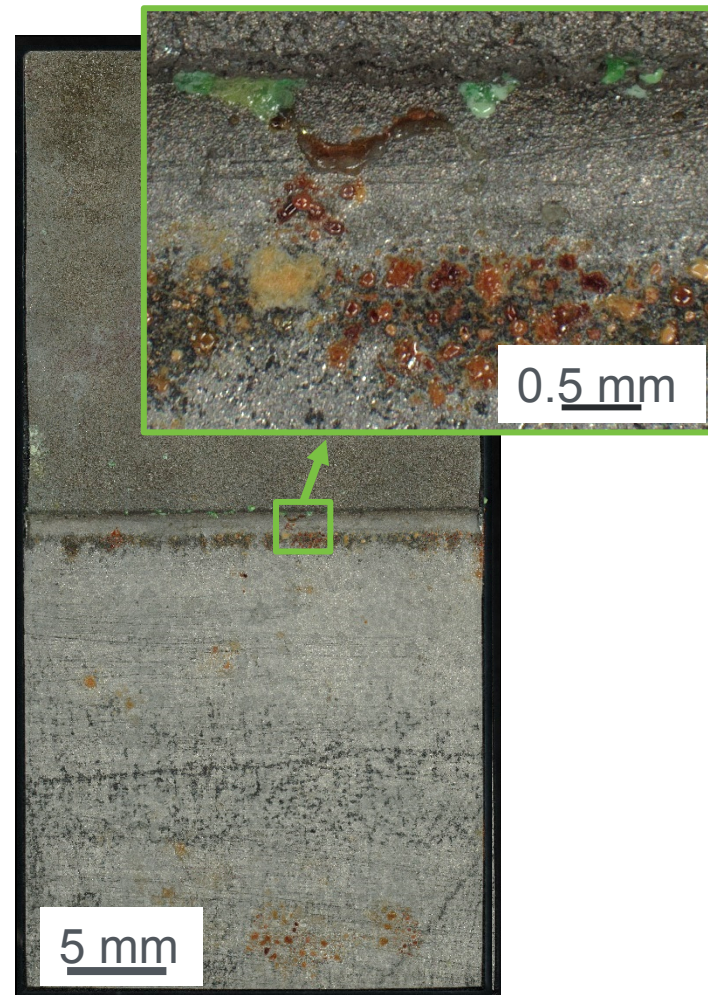


cyclic

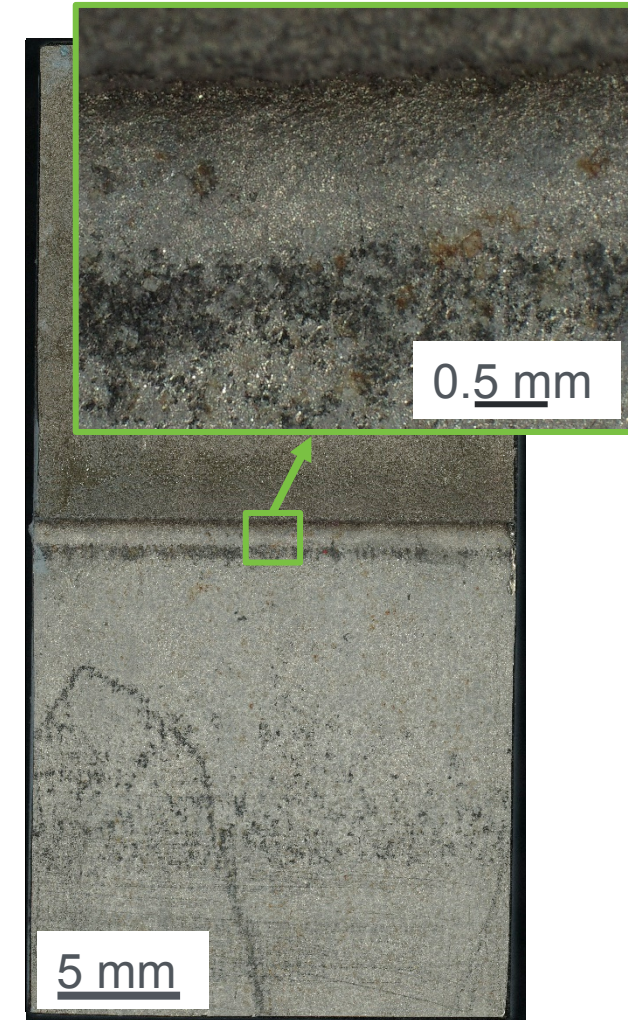
1 month: Ni-N masked



40% RH



75% RH



cyclic

Knowledge Gaps

Materials Selection:

- galvanic influences

Deformation:

- microstructural transformation
- residual stresses

Optimize Processing:

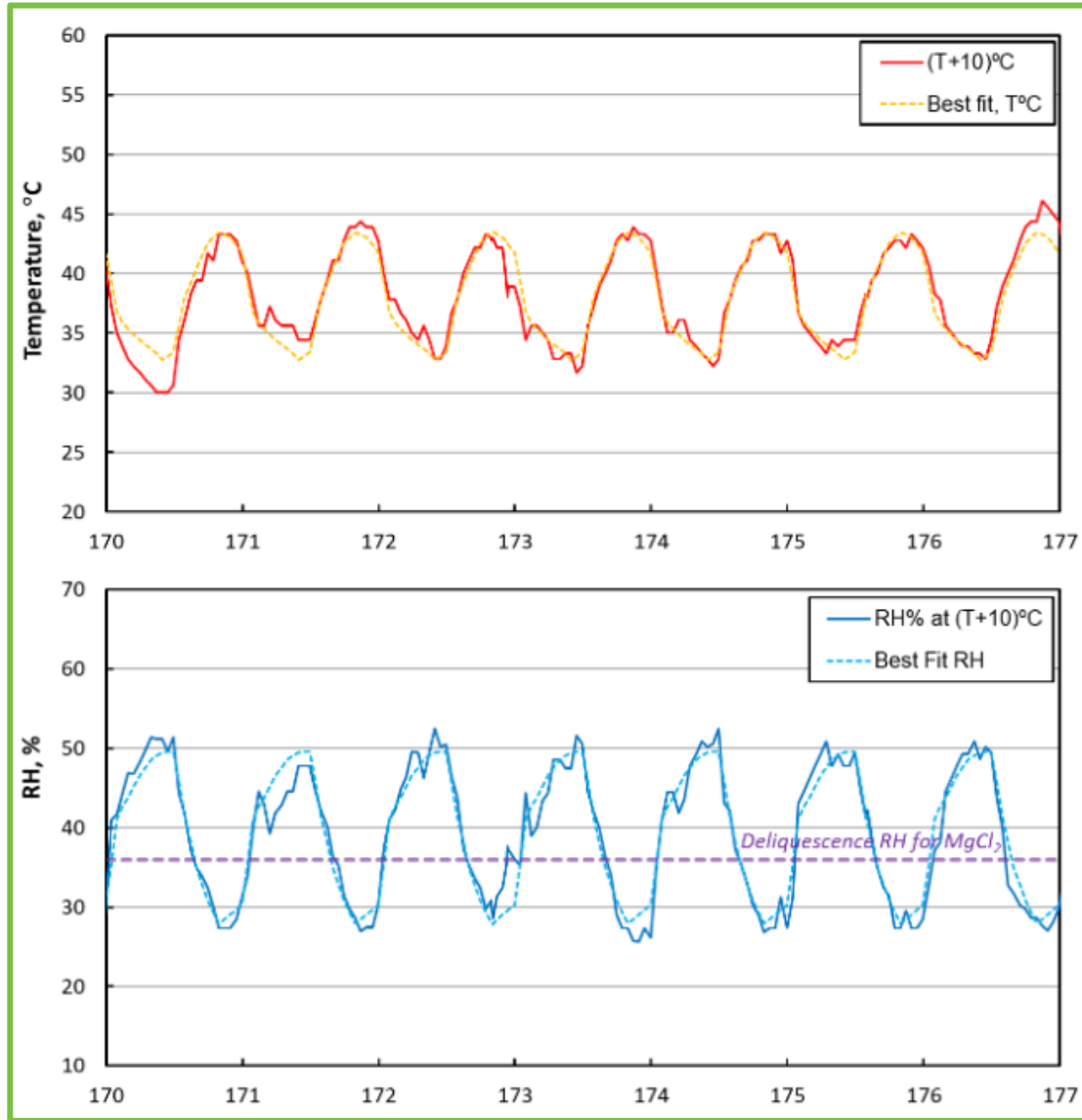
- gas selection
- powder mixing
- interface selection

Behavior in Realistic Environments

- long term
- different brine chemistries
- different stress-states

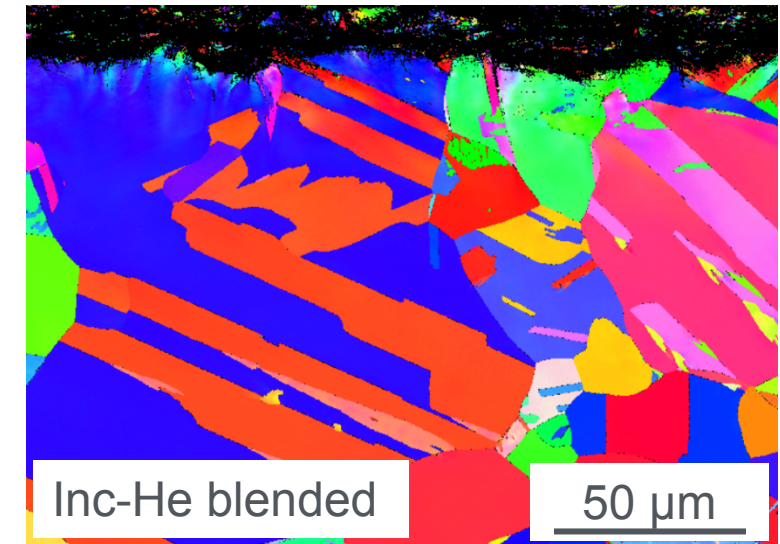
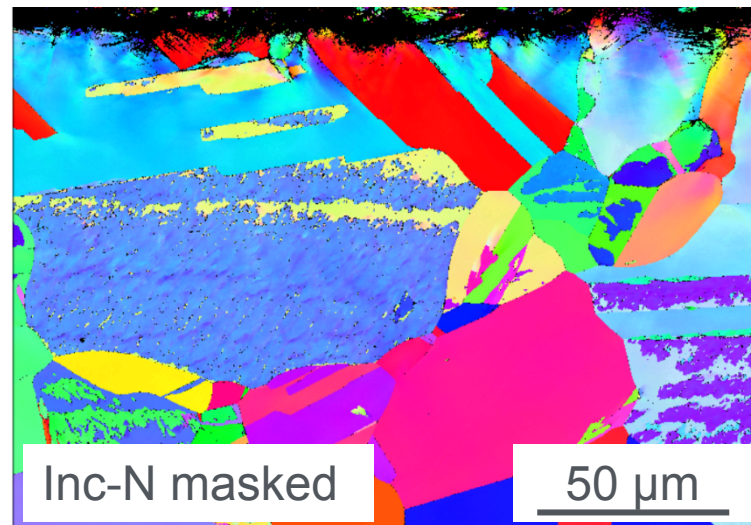
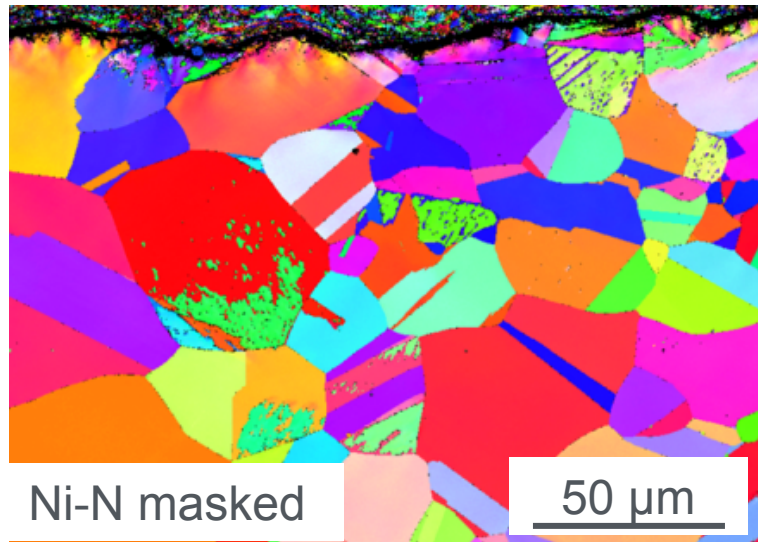
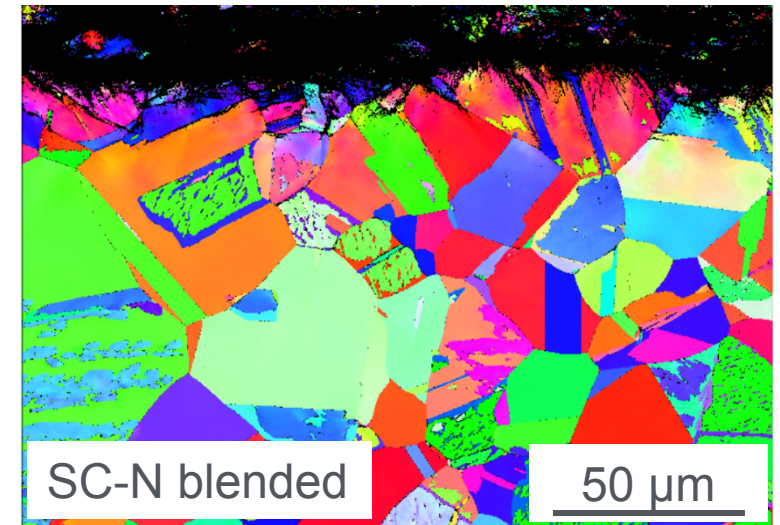
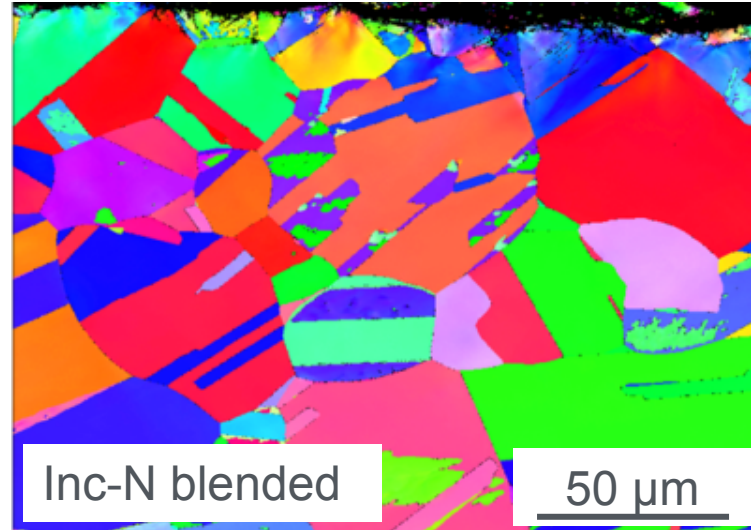
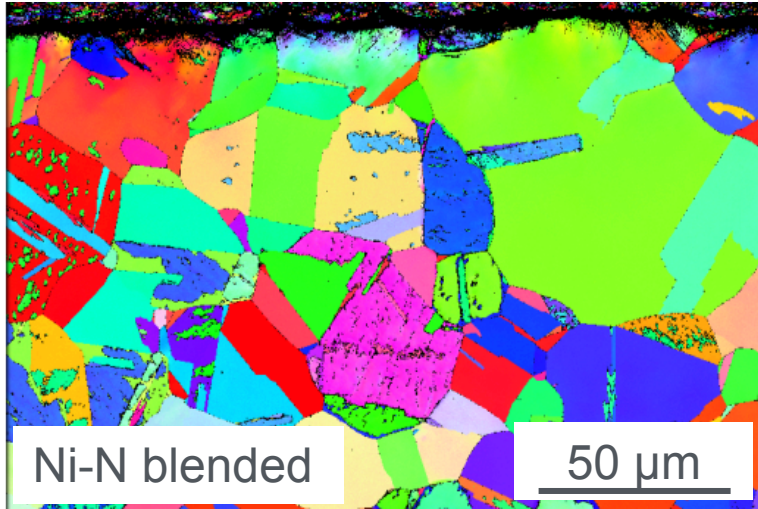
Questions?

Diurnal Cycle

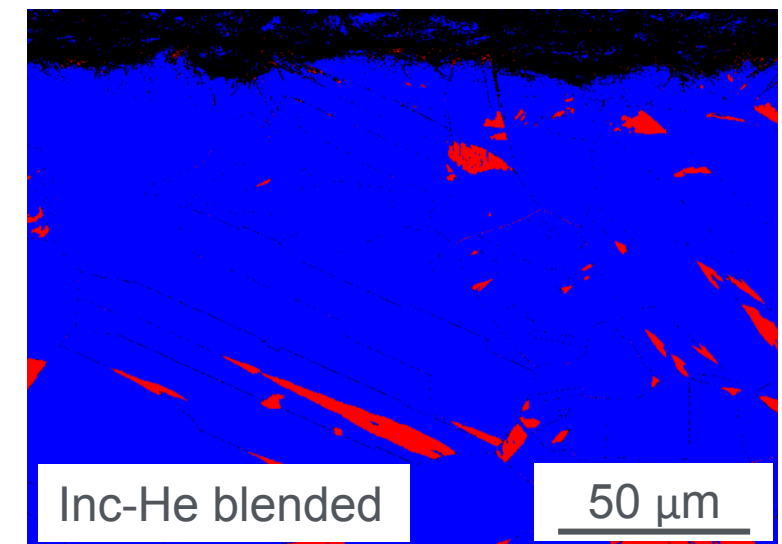
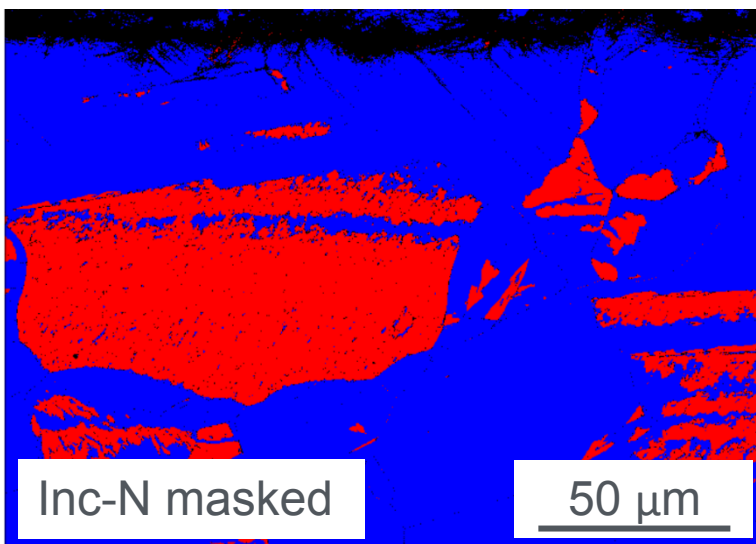
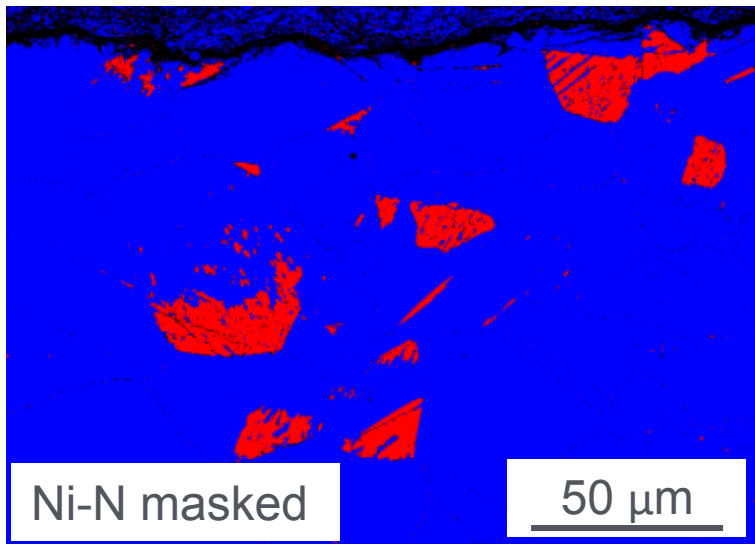
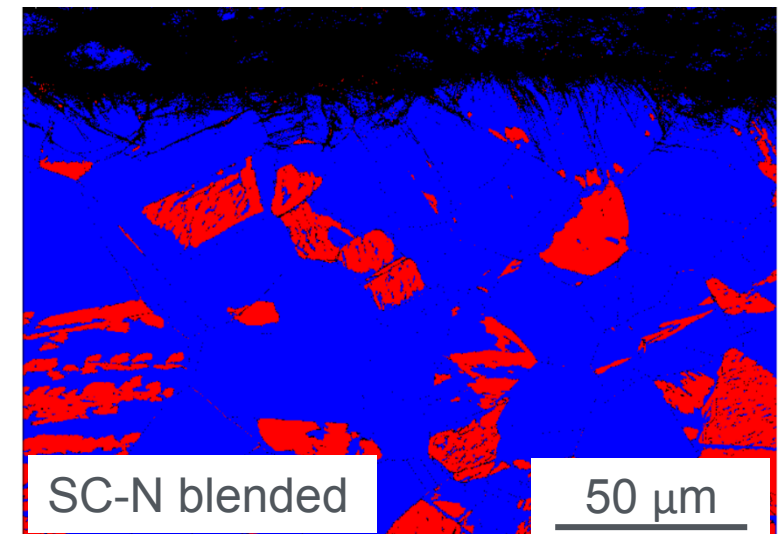
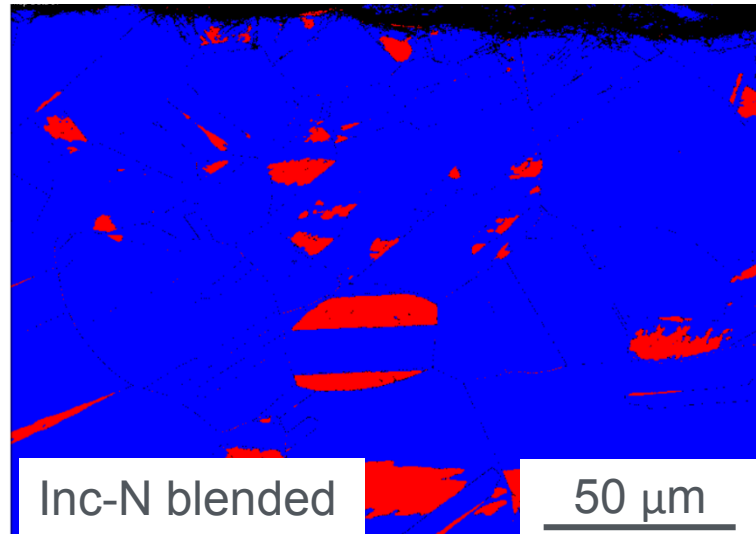
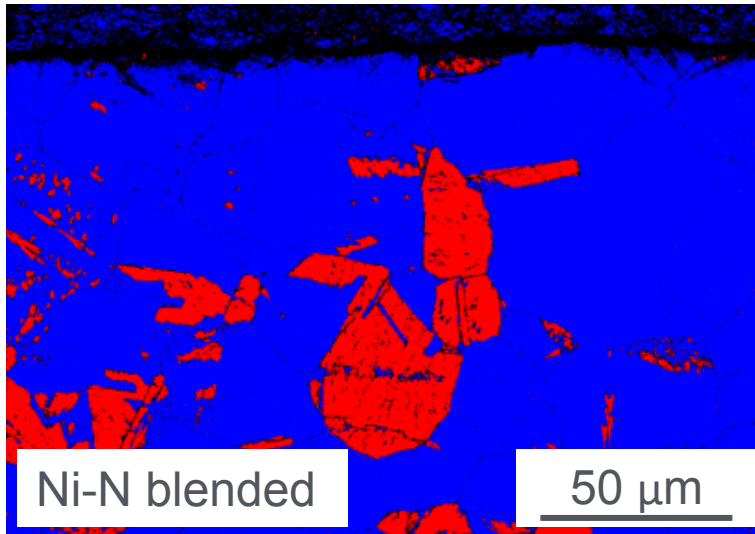


Hour	Temperature, °C	RH, %
2	41.68	30.33
4	36.45	41.68
6	35.27	43.92
8	34.35	46.69
10	33.69	48.68
12	32.74	49.54
14	33.44	49.57
16	38.24	40.98
18	40.55	34.62
20	42.69	30.62
22	43.51	27.82
24	42.97	29.15

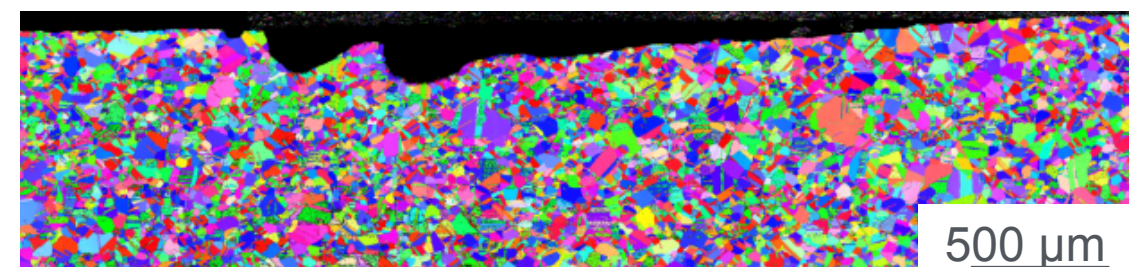
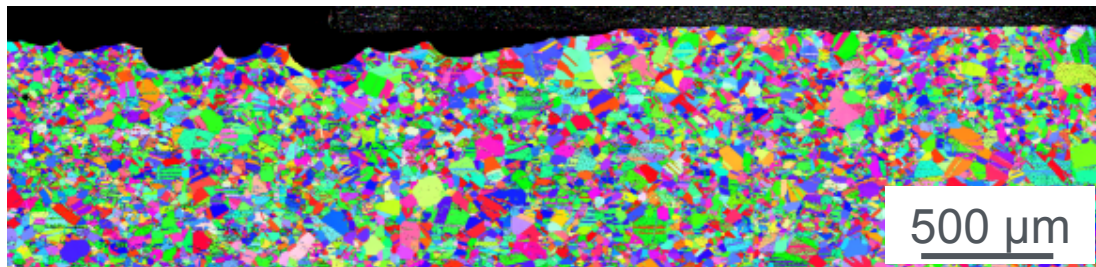
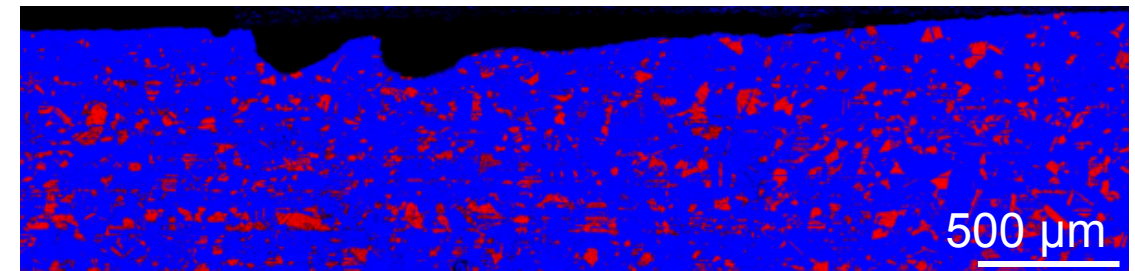
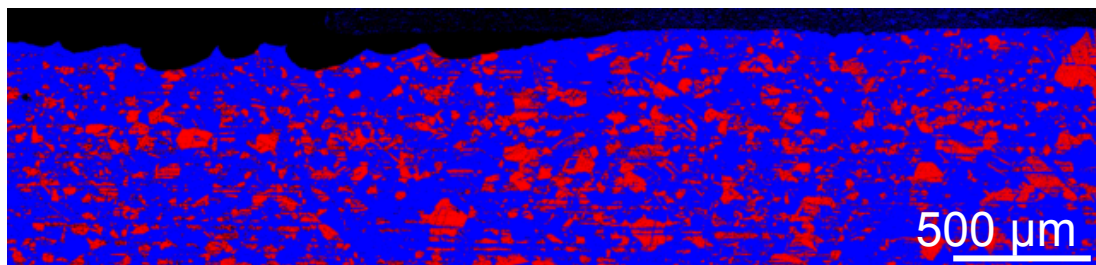
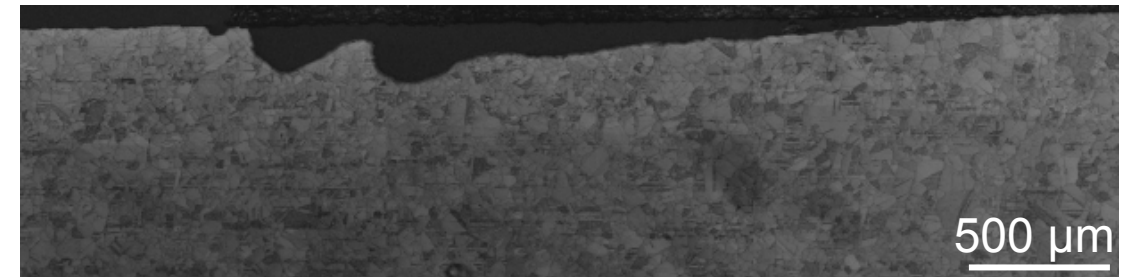
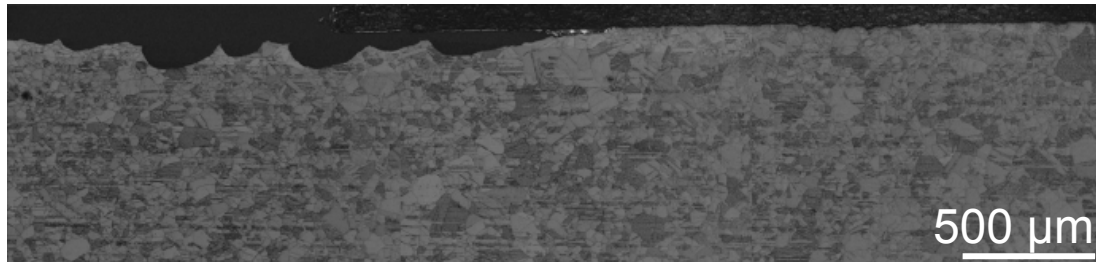
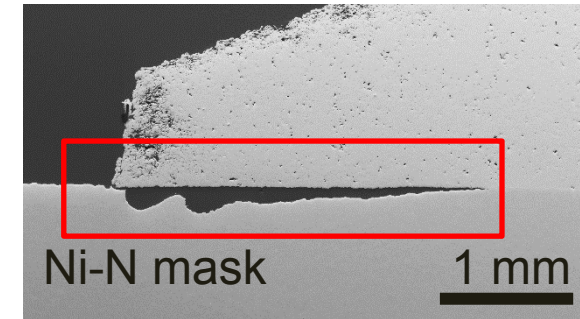
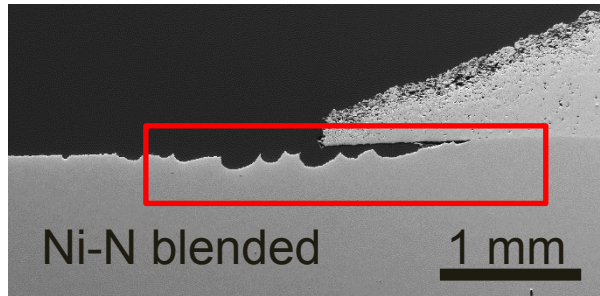
Deformation Layer- Far from Edge



Deformation Layer- Far from Edge



Masked vs Blended: Ni-N



Masked vs Blended: Inc-N

