SAND2022-1736C

Sandia National Laboratories

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Accelerated Corrosion Testing of Cold Spray Coatings on 304L in Chloride Environments

Speaker: Erin Karasz

SNL: Rebecca Schaller, Timothy Montoya, Jason Taylor

PNNL: Kenneth Ross

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AMPP 2022
San Antonio, TX

SAND

PNNL-SA-170363

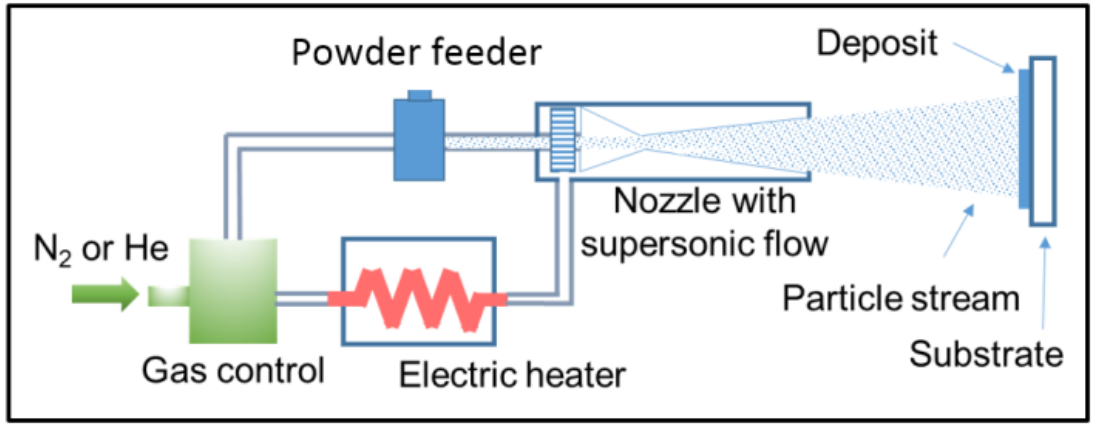
U.S. DEPARTMENT OF ENERGY

NNSA

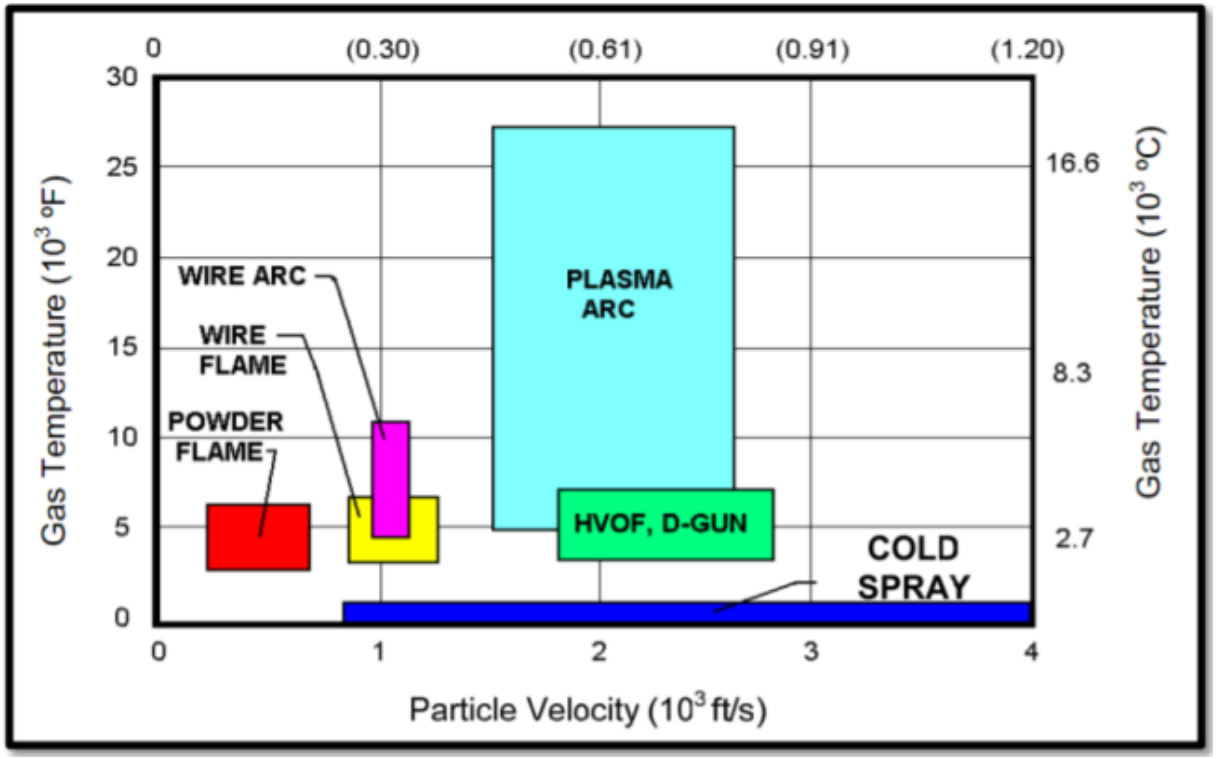
Cold Spray Technique

Cold Spray:

Metal particles accelerated by a stream of inert gas into a substrate.
Adhered by plastic deformation (not melting like thermal spray & other additive manufacturing techniques).



High-pressure cold spray process. Image from Ken Ross



M. Neshastehriz, 2014, Pennsylvania State University

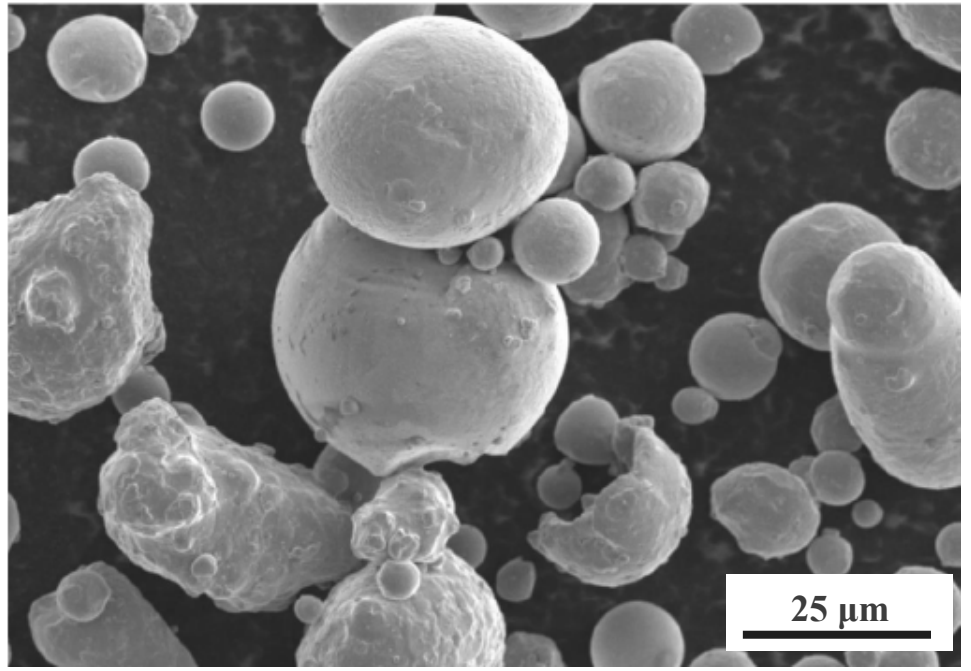
lower temperature helps prevent:

- temperature-dependent crystalline transformations
- oxidation
- vaporization

Cold Spray Applications

Functions:
- Additive manufacturing light weighting
- Structural repairs
- Temperature protection coating
- Corrosion prevention/repair coating

Applications:
- Medical devices
- Aircraft
- Automobiles
- Nuclear reactors



316L stainless steel powder

Potential Concerns:

1. Whole surface may not be accessible or able to be coated
2. Patch leaves interface between coating and substrate exposed
3. In-situ spraying presents difficulties with surface finishing

Down-selection for corrosion prevention/repair coating on 304L

Characterize cold spray (as-sprayed and polished)
Characterize pitting stability at patch edge

Coatings of Interest:
Inconel 625
Super C
Nickel
316
304
Duplex Stainless Steel

Start with these

Cold Spray Samples

304L stainless steel base material

Cold Spray:

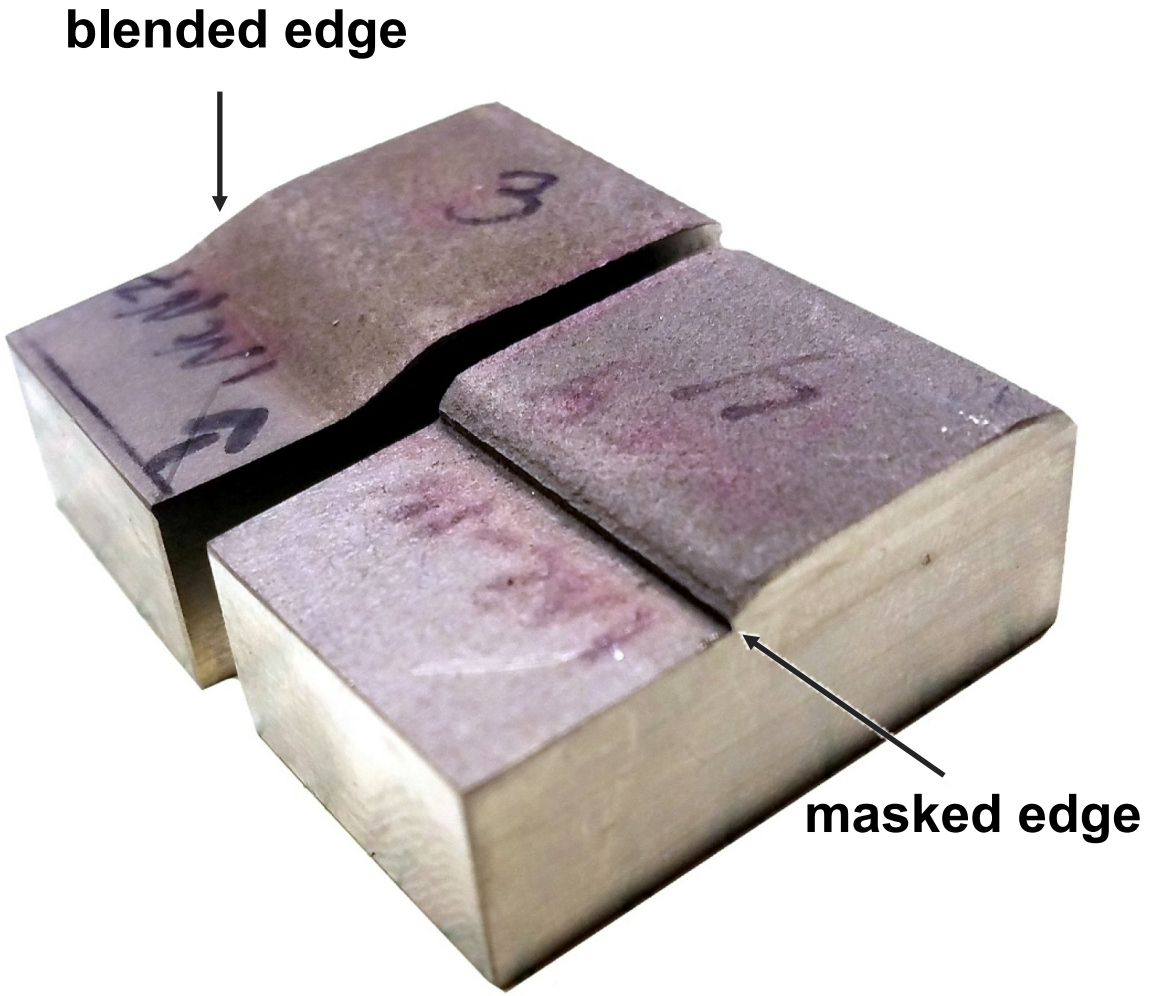
- inconel 625, nickel, super C
- nitrogen, helium

Interface:

- blended, masked

Aqueous, Accelerated Testing:

- electrochemical, ferric chloride



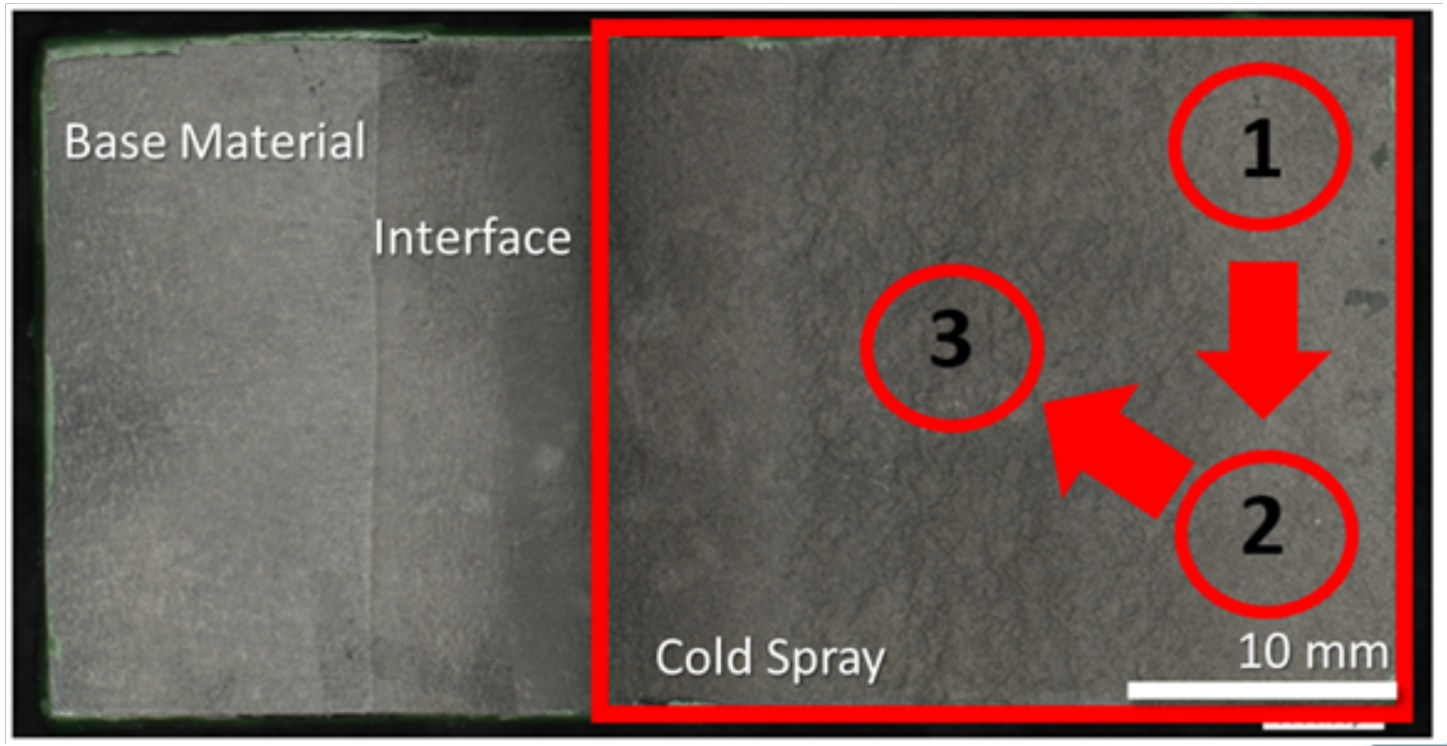
Electrochemical Testing

Assess electrochemical & corrosion properties of the cold spray

Tested 3 spots per sample (compare to substrate)
0.6 M NaCl, platinum counter electrode, Ag/AgCl reference electrode

Finishes:
- As-Sprayed
- Polished (600, 1200 grit)

1 hour open circuit potential (OCP)
Potentiodynamic scan, 0.167 mV/s
- Metastable pitting
- Breakdown potential
- Passive Current Density

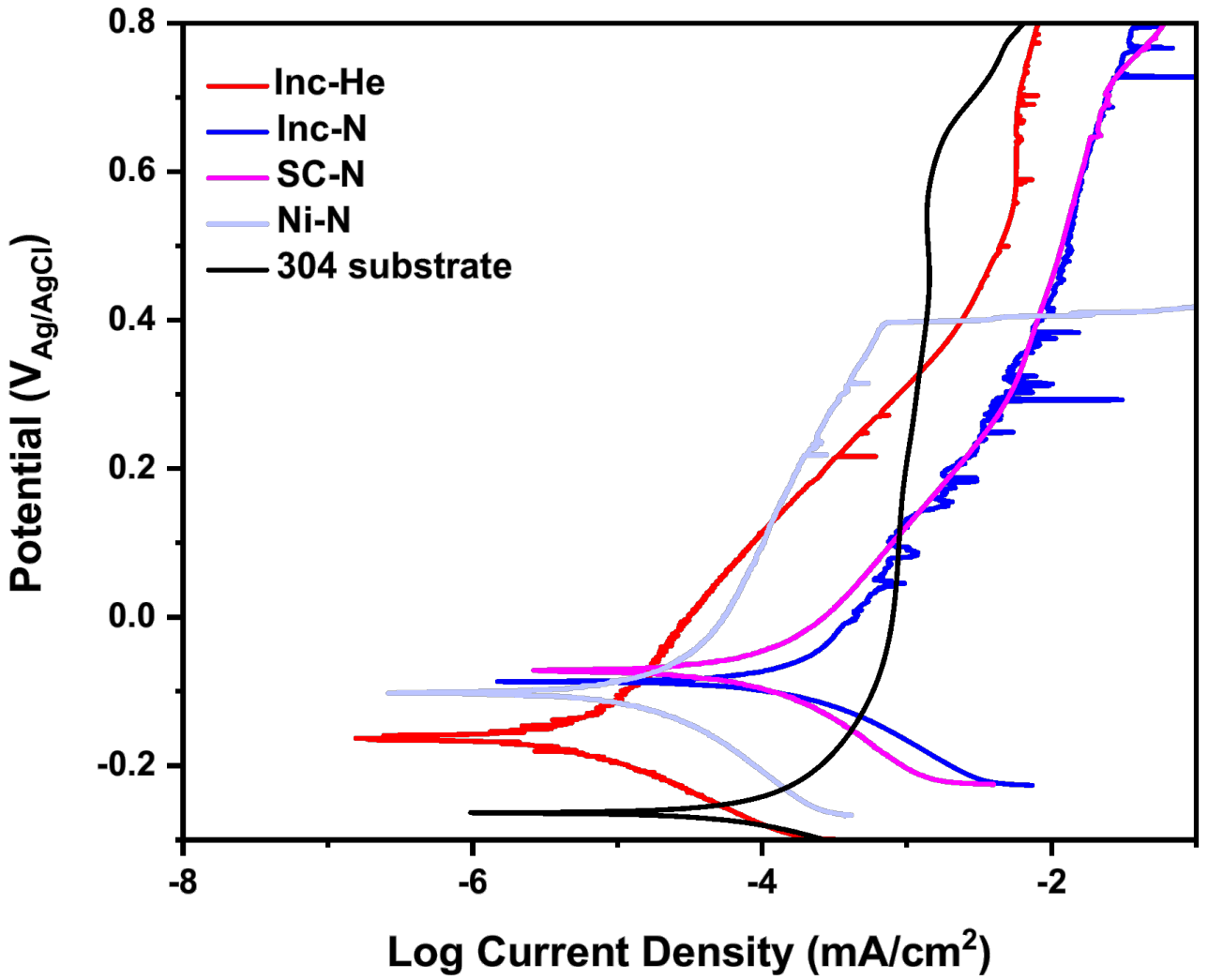


Potentiodynamic Scans: As Sprayed

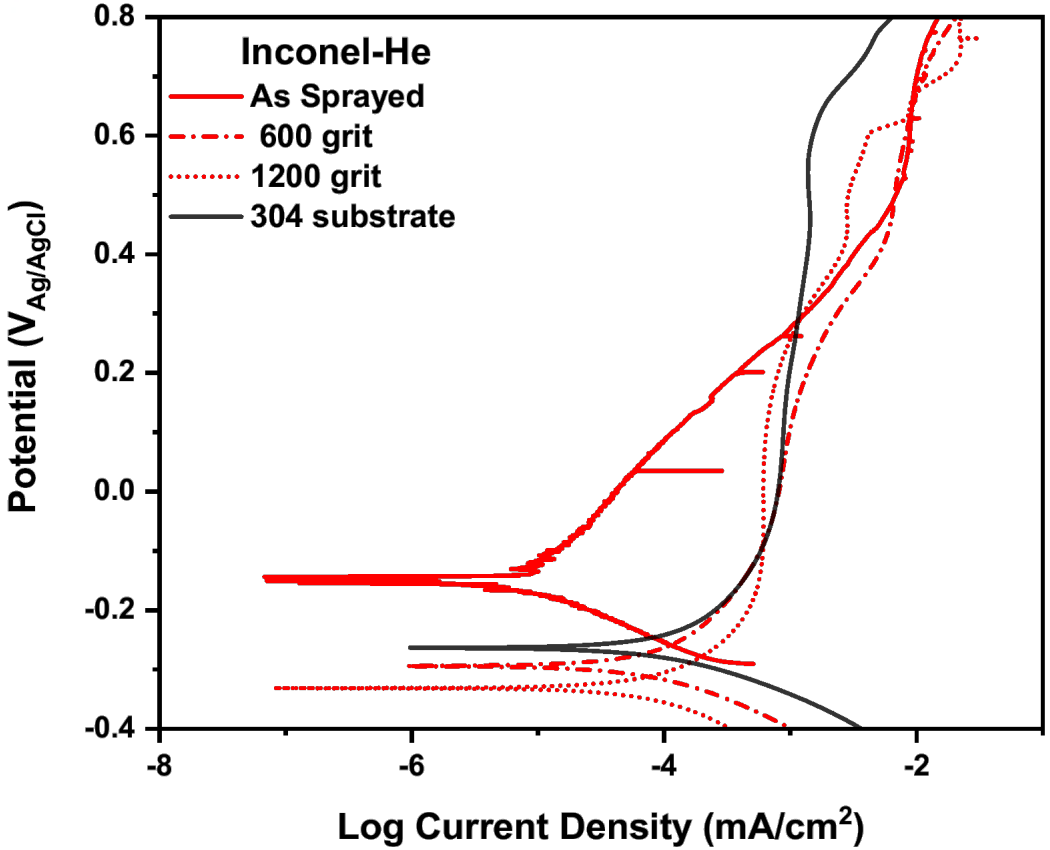
- Ni breakdown very early in scan
- Metastable pitting

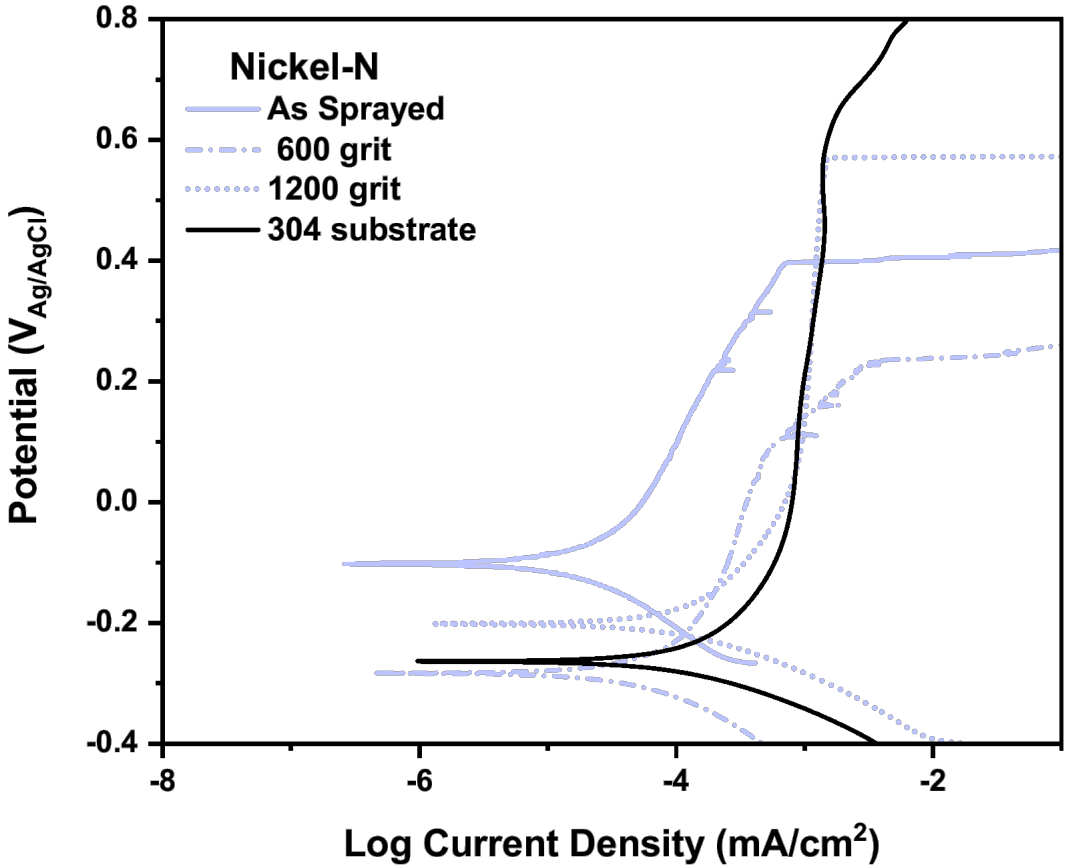
Passive Current Density
- Lower- Ni & Inc-He
- Higher- SC & Inc-N

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



Effects of Polishing



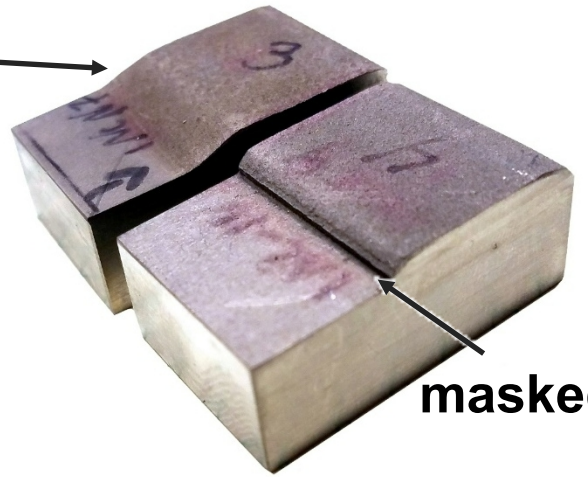


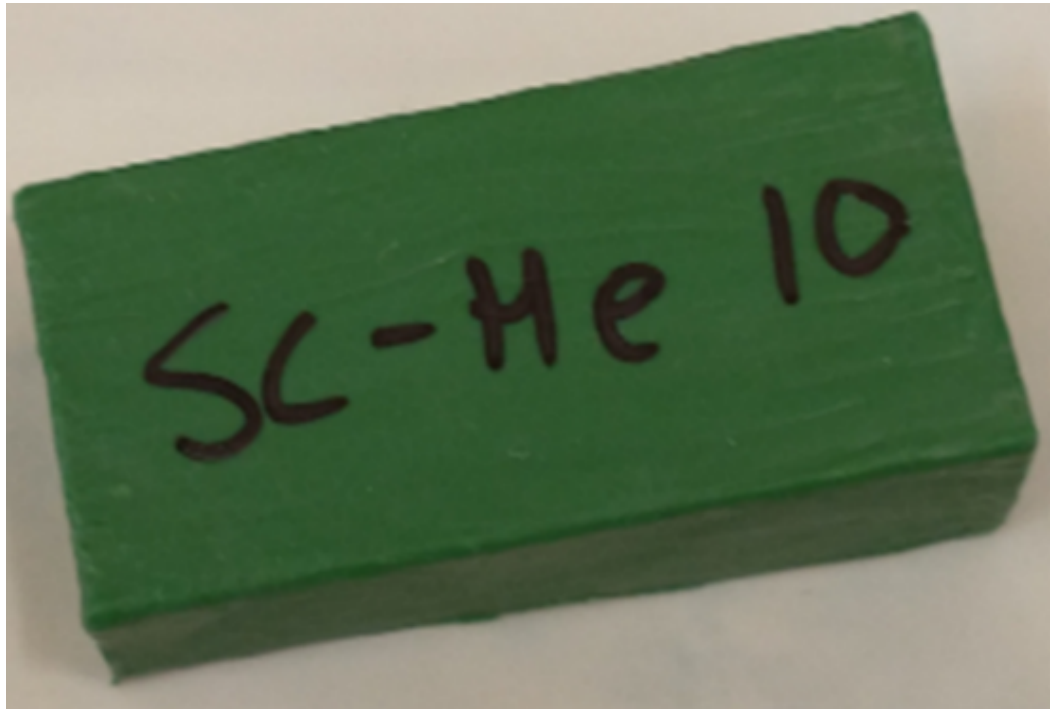
- OCP changes due to polishing (expected)
- Nickel breakdown very early in scan
- Polishing reduces metastable pitting
- Polishing removed native oxide, higher passive current density observed initially

Ferric Chloride Testing

Samples were coated in Peelseal Green Maskant for full immersion

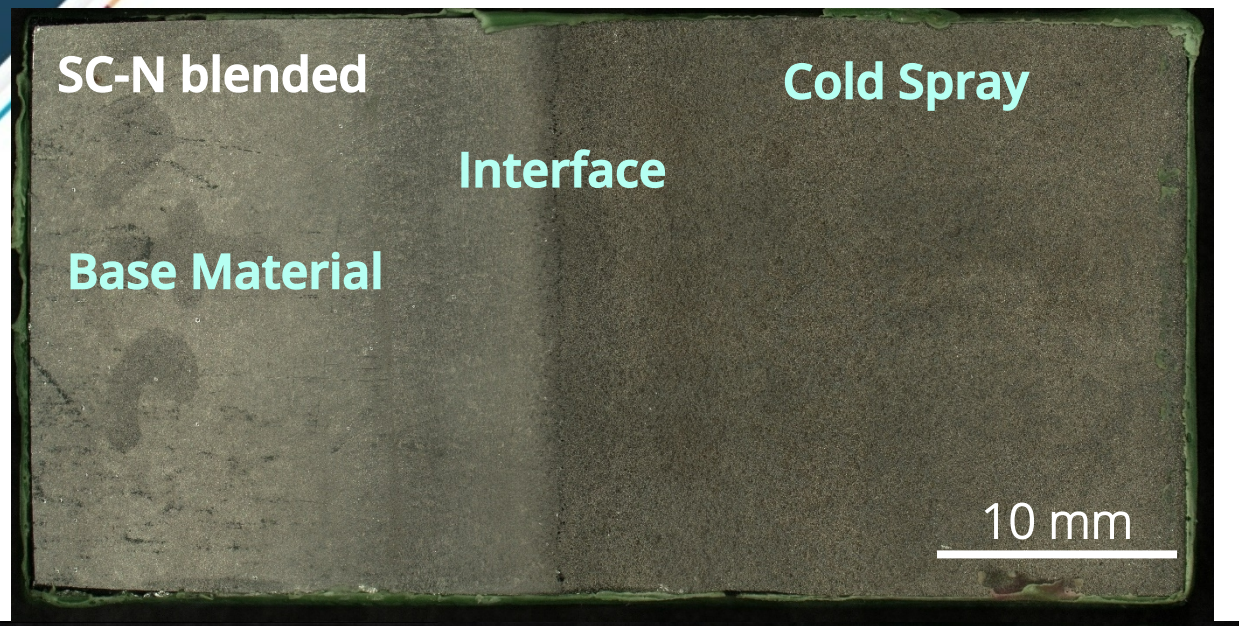
ASTM G48 Method A
6% by mass ferric chloride solution
72 hours at 22 °C

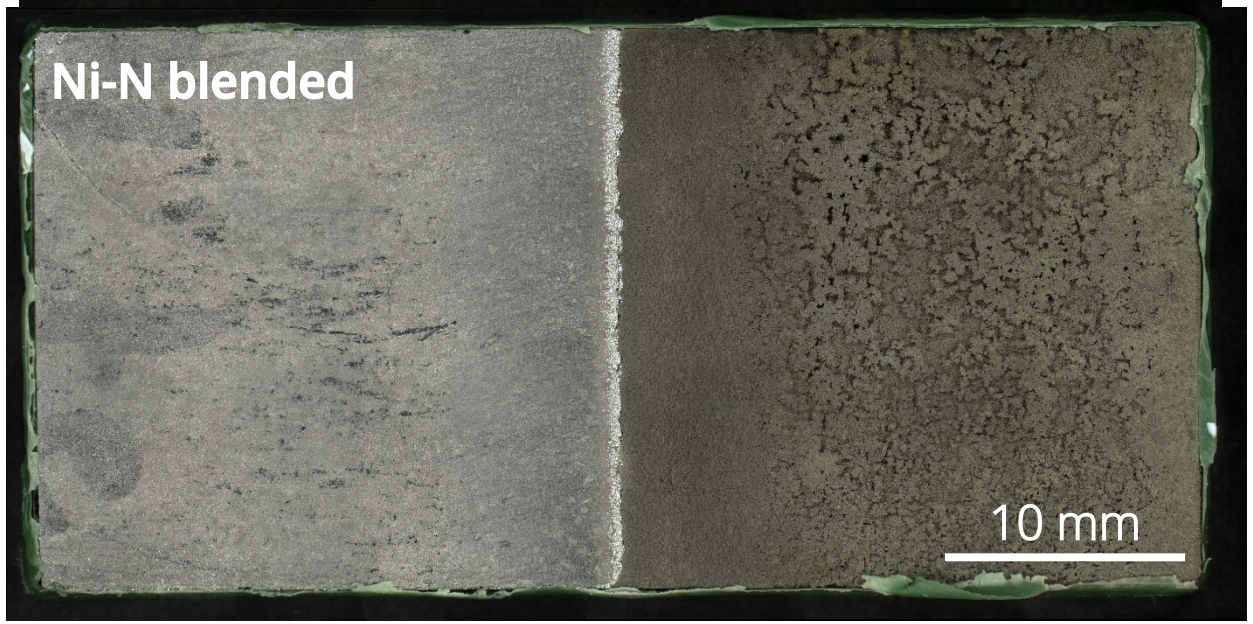




- Accelerated pitting test
- Evaluate potential galvanic couple influences
- Evaluate interface-type impact

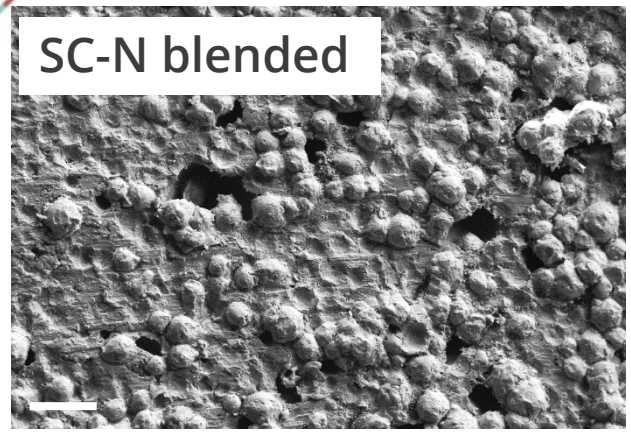
Material Selection

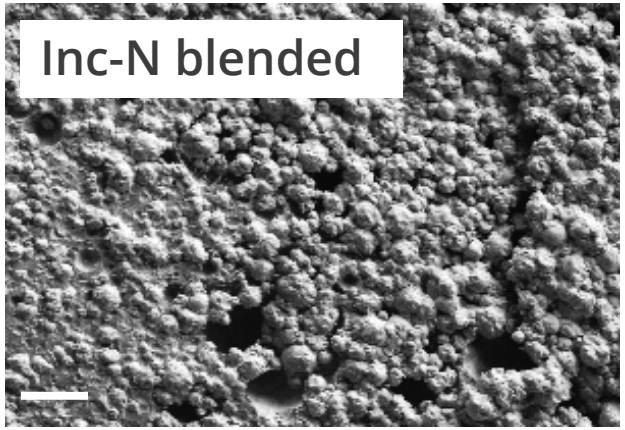


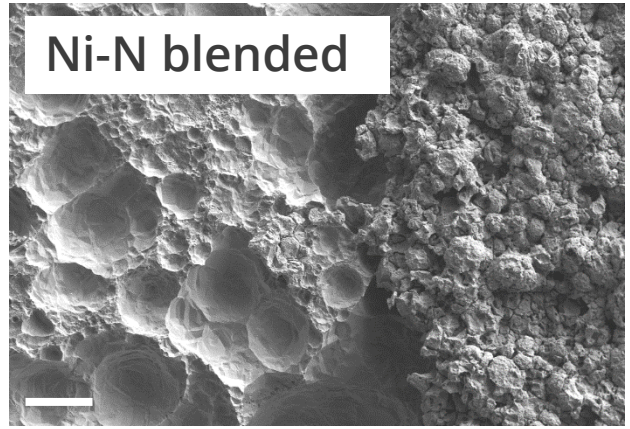


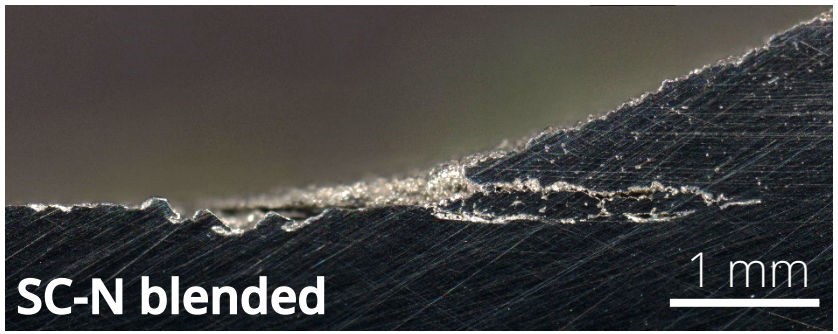
- Ni shows lots of damage in the cold spray & at the interface
- Inc-He damage looks different than Inc-N
- Inc-N & SC-N damage is harder to see

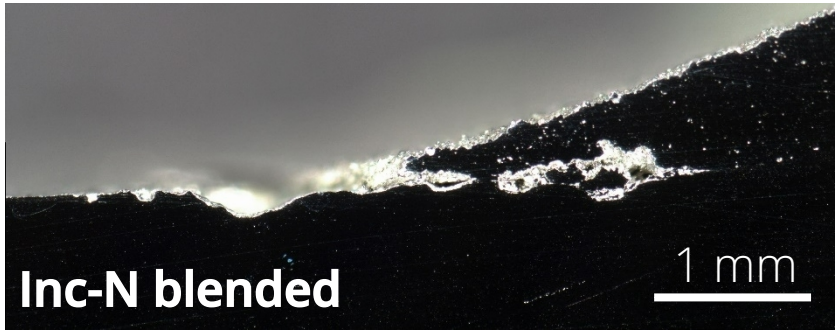
Material Selection

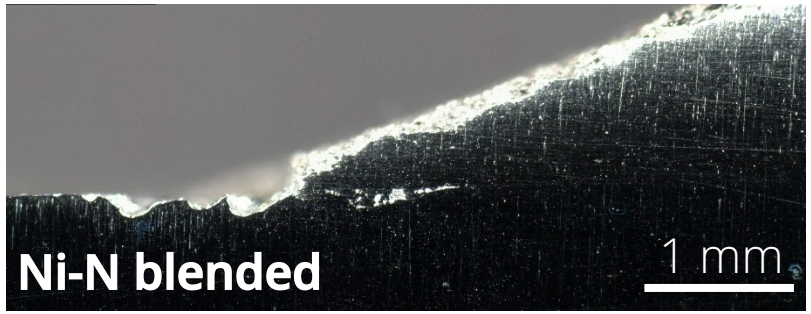












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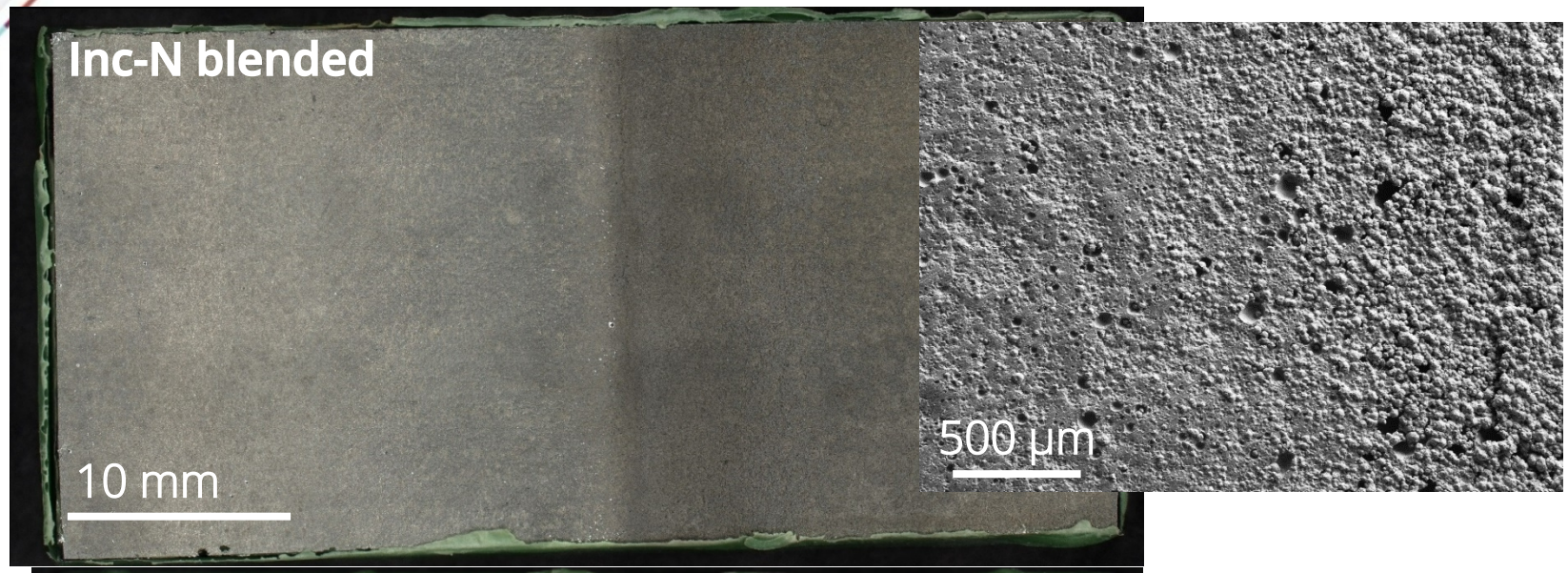
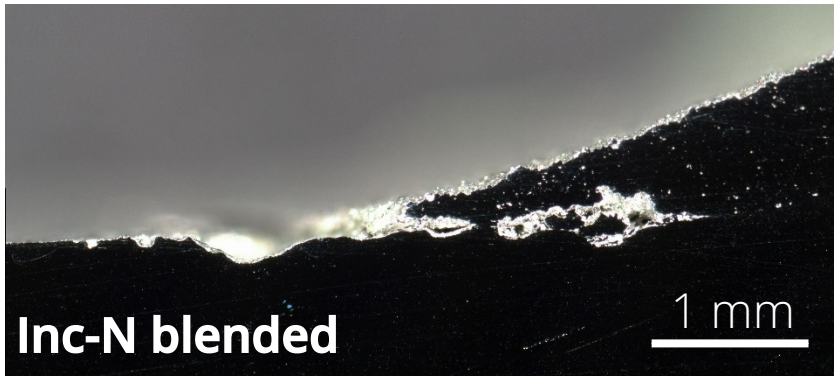
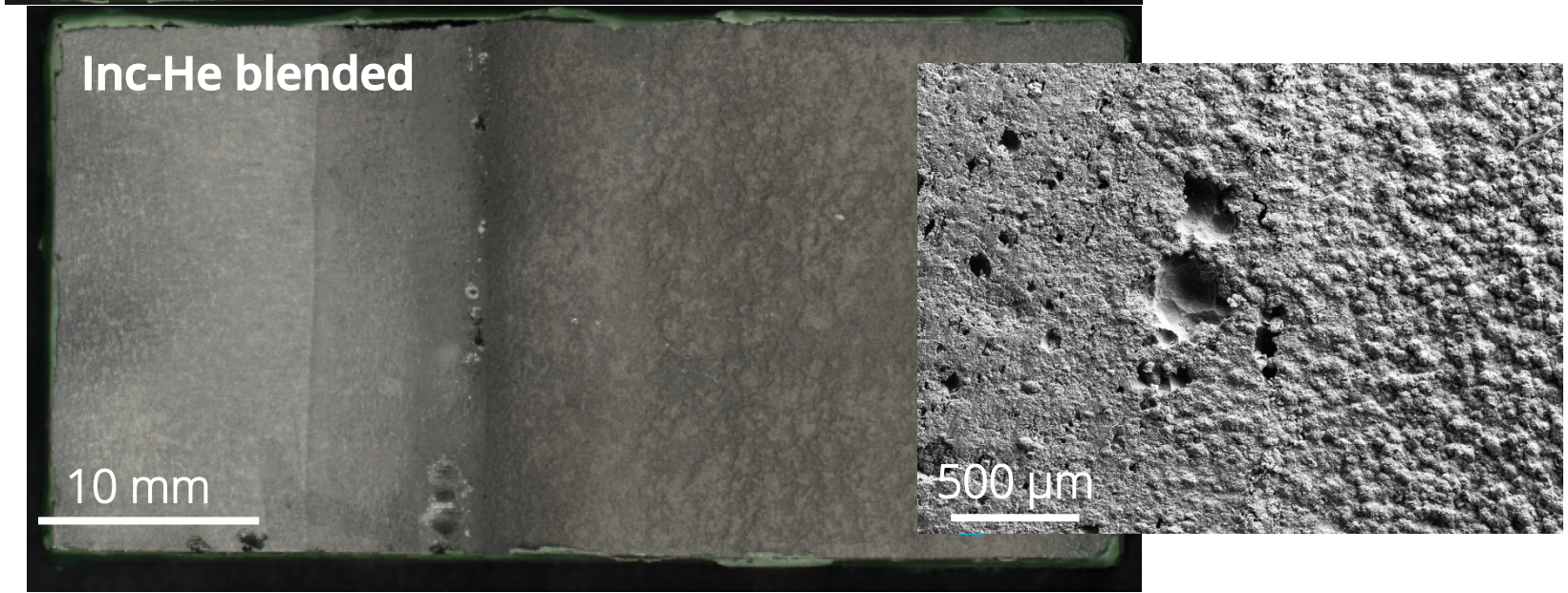
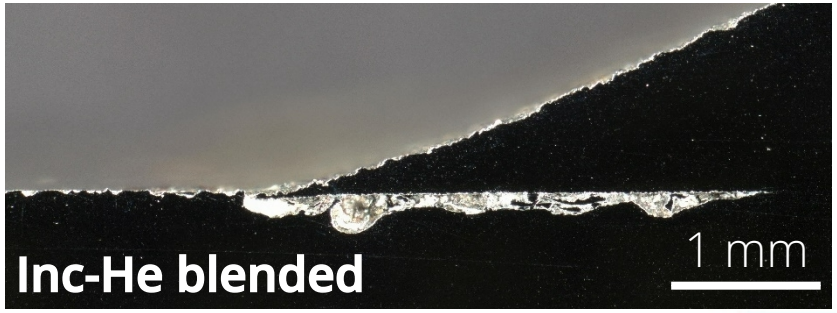
Gas Selection



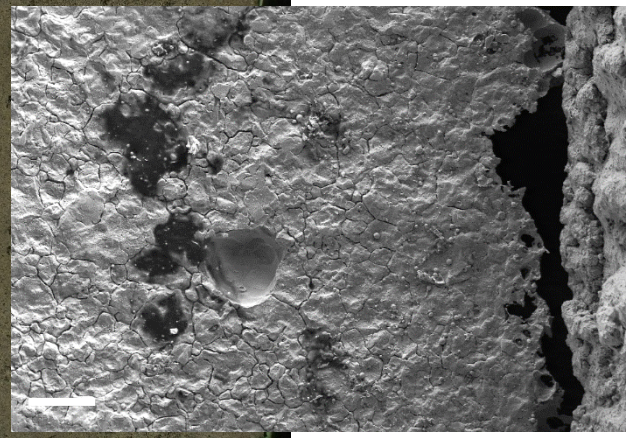


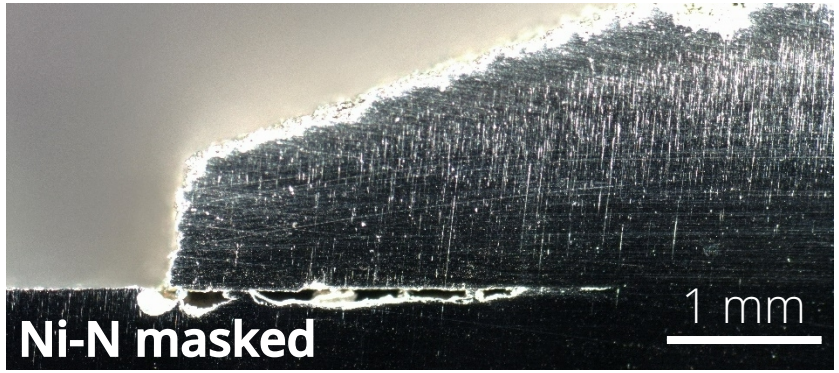
Sample	Porosity (%)
Inc-N	5.79 ± 0.18
Inc-He	1.21 ± 0.20

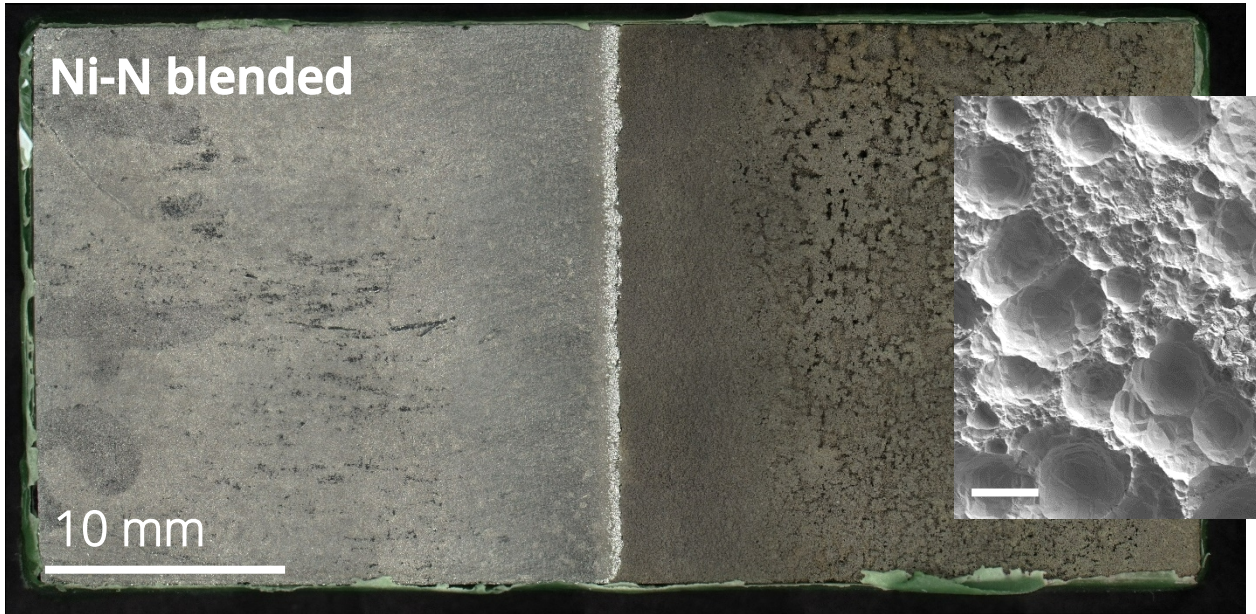


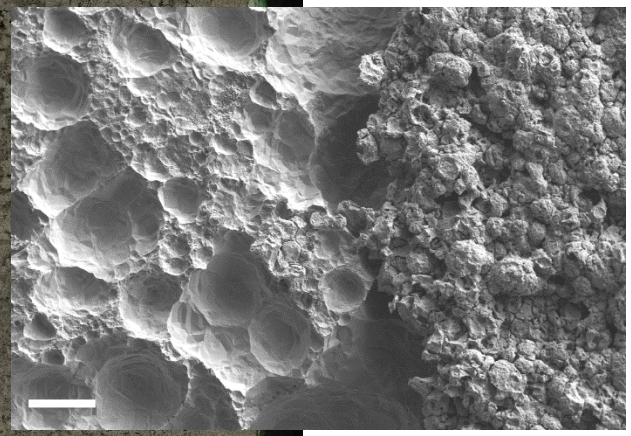


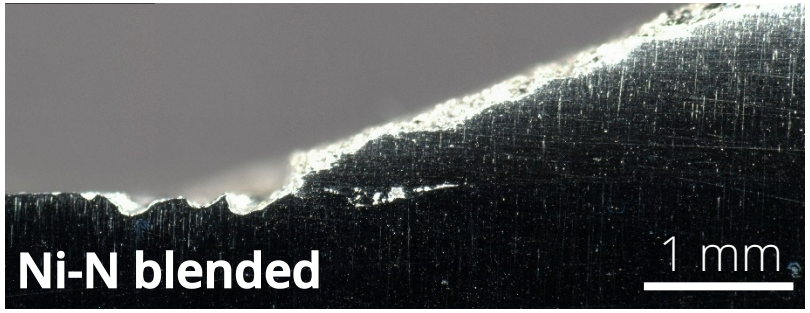
Masked vs Blended: Ni-N



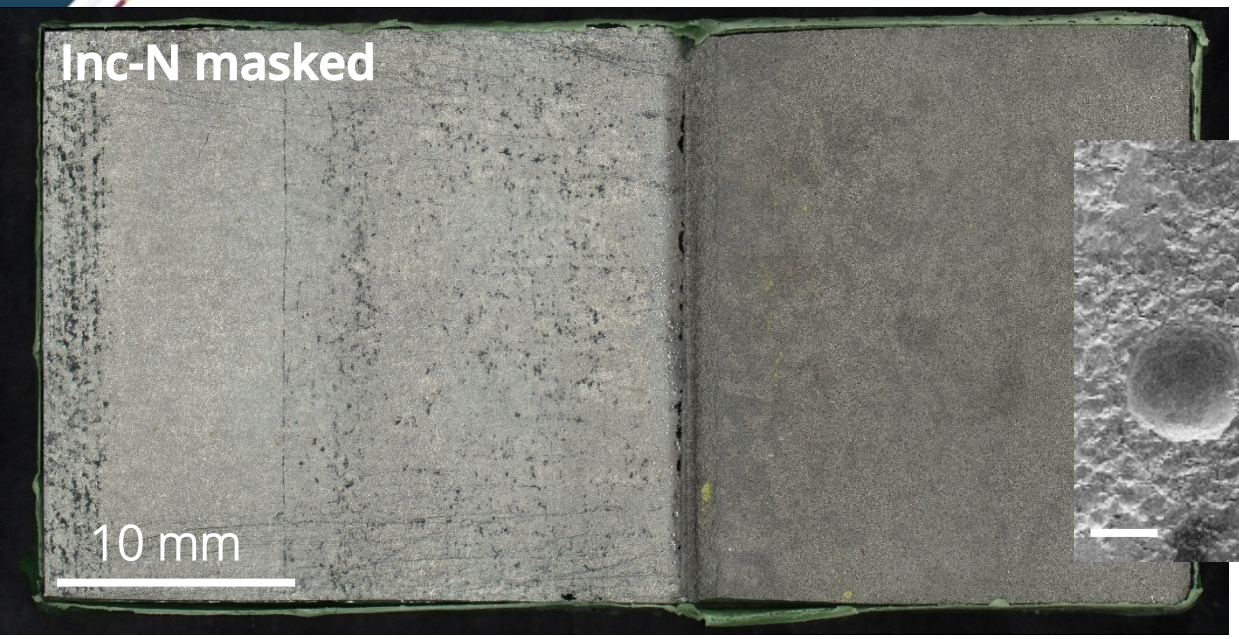


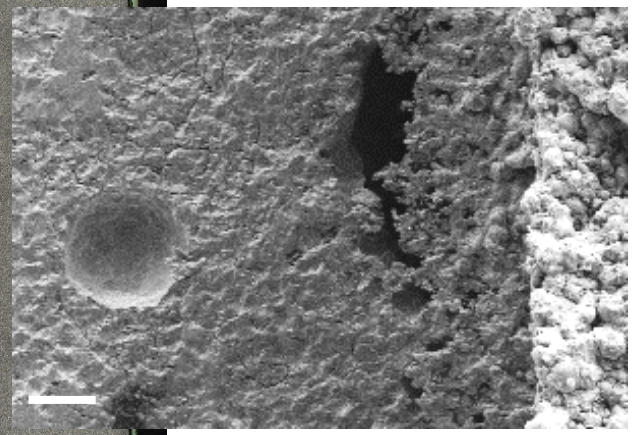


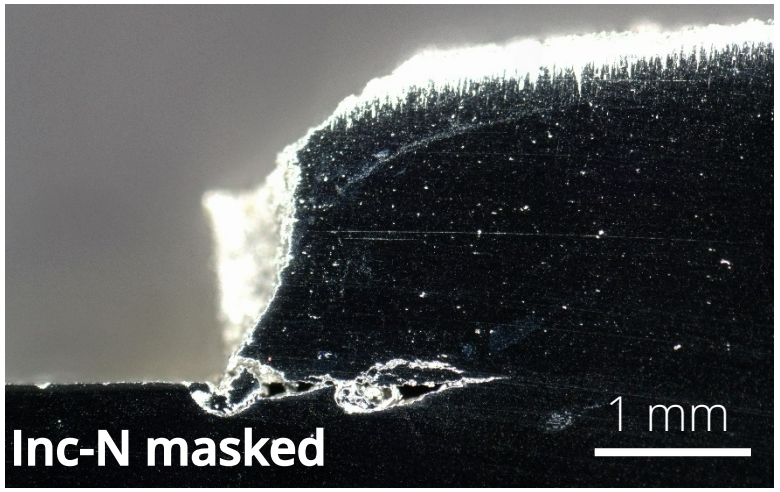


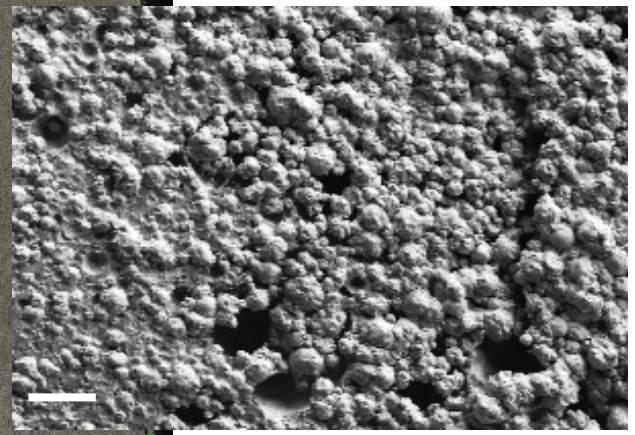


Masked vs Blended: Inc-N



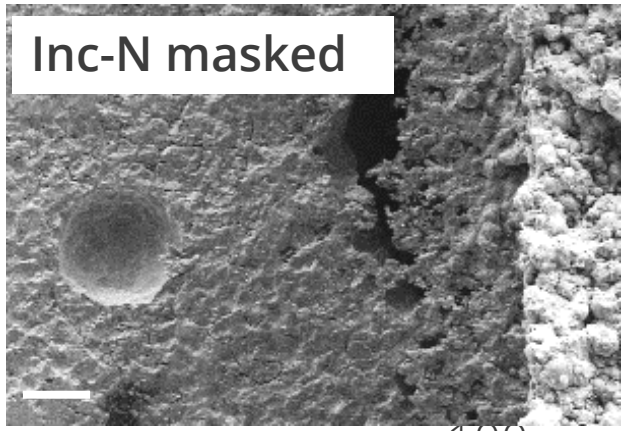


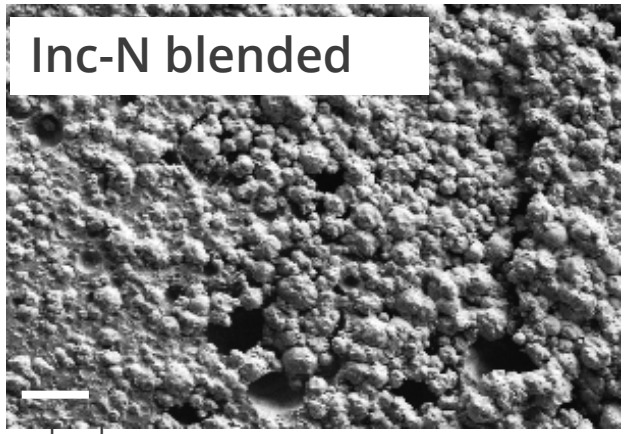




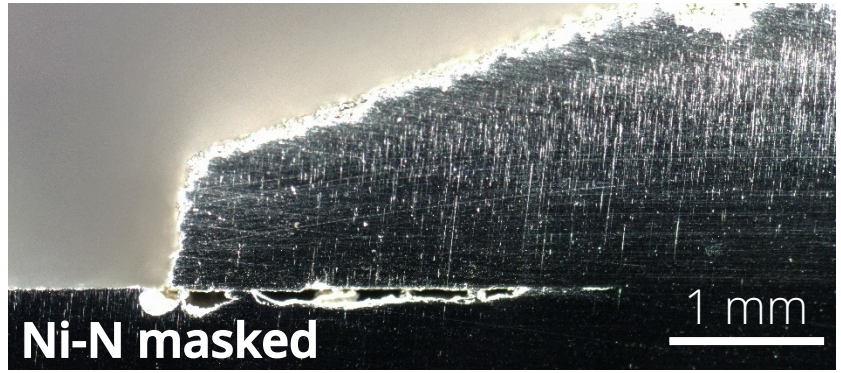
Interface Damage

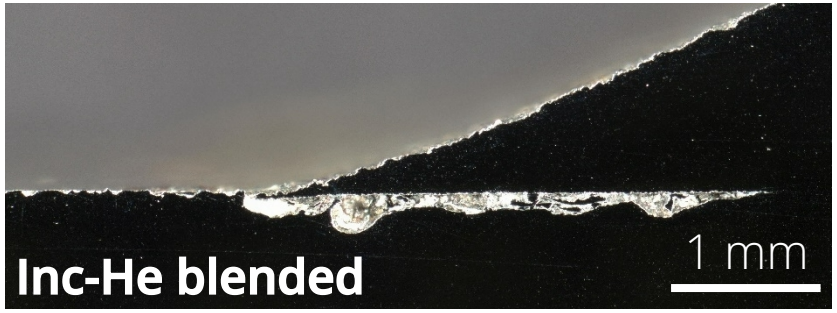
- Mask samples have deep crevicing attack at interface with some pits
  - Distance between crevicing and pits
- Blended samples tend to have less defined edge of attack
  - Surface roughness obscures extent of attack
- Top-down damage ≠ corrosion under the cold spray

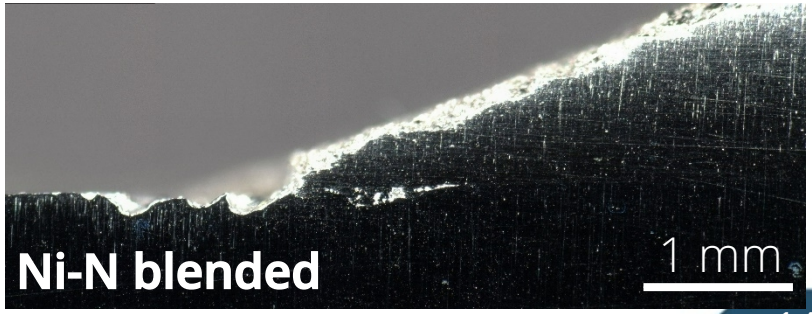




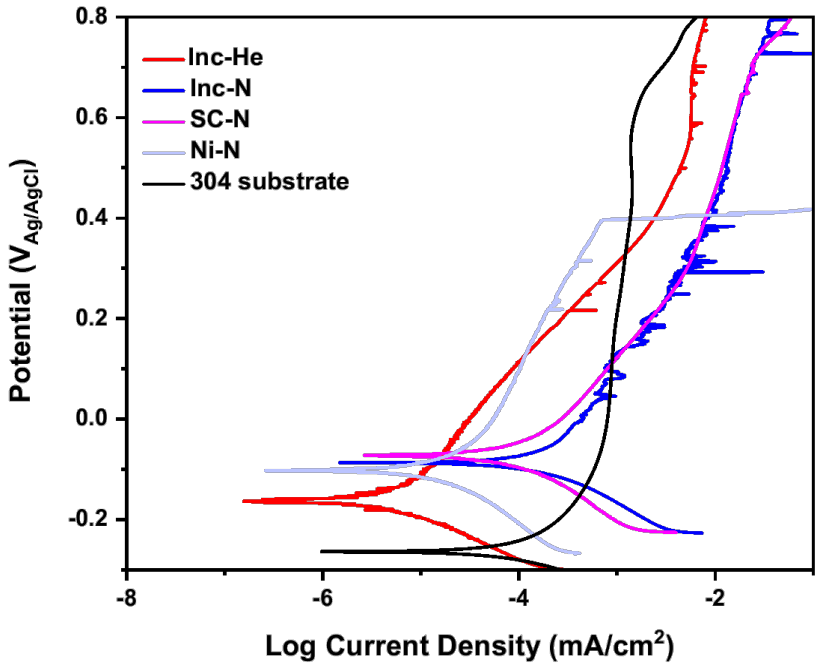
100 µm scale bars







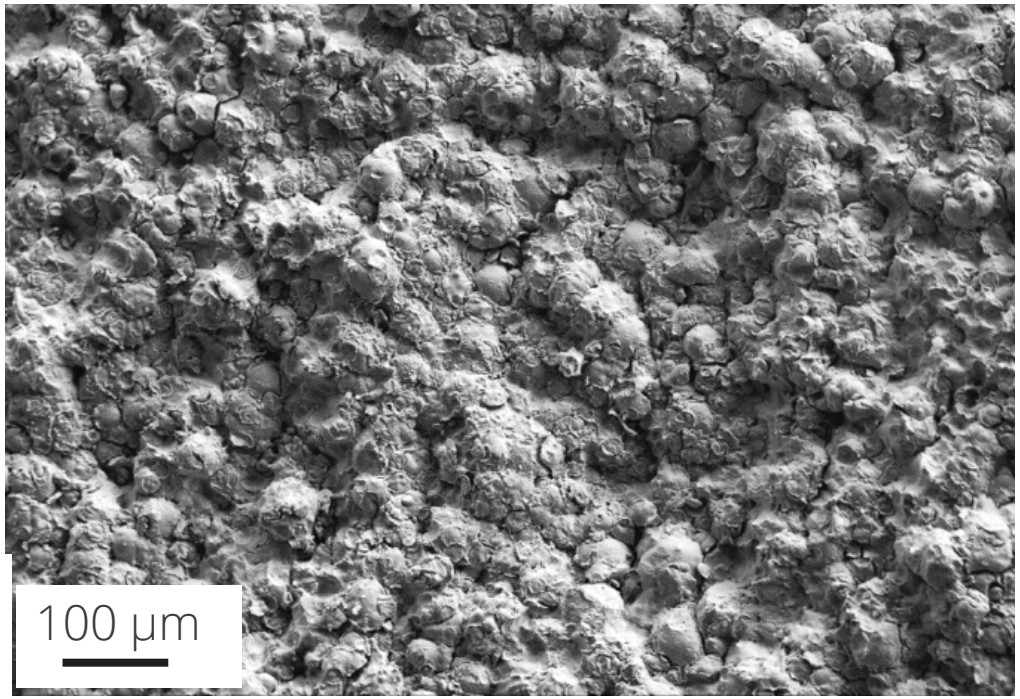
Conclusions from Accelerated Testing



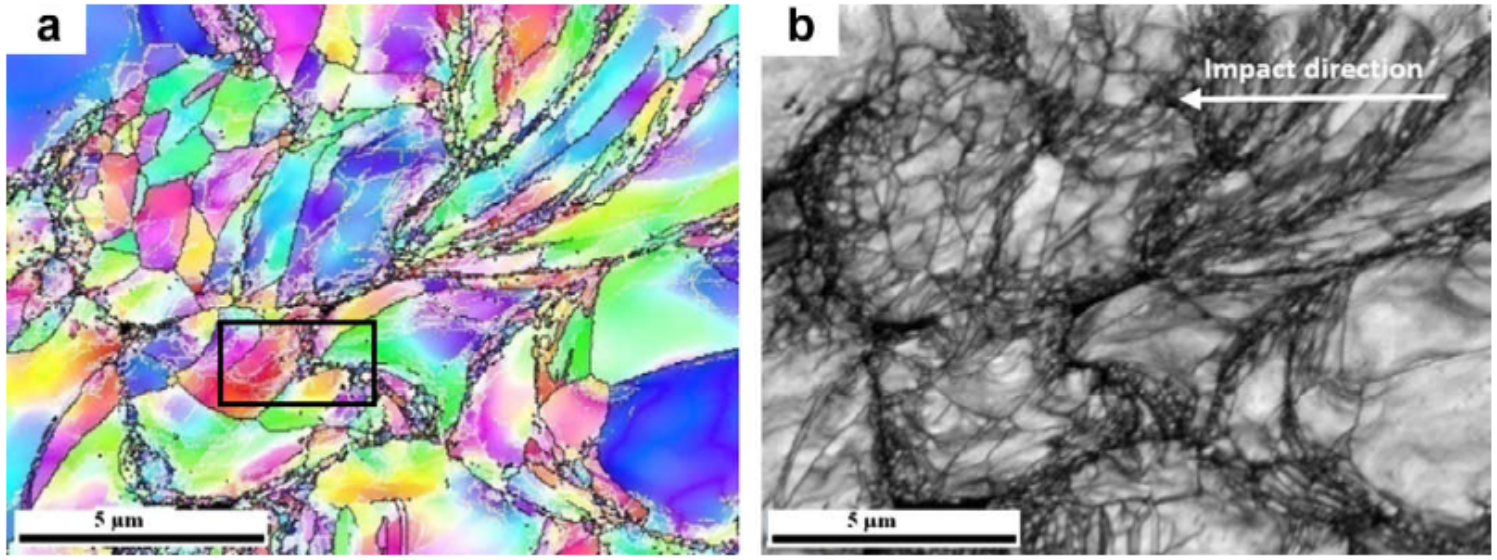
- Selection of near galvanic series materials is insufficient for corrosion protection in patch scenario in ferric chloride environment
- Material selection is important (interface & independent behavior)
- Processing parameters of the cold spray are important (porosity)
- Surface finish changes cold spray corrosion response (evaluated separate from the substrate)
- The type of interface (blended vs mask) will change where damage occurs

Future Work

- Expand types of tests (boiling $MgCl_2$, salt fog, atmospheric)
- Stainless steel cold spray (304, 316, Duplex)
- Electron backscatter diffraction in cross-section
- Examine residual stress in substrate



Inc-He Cold spray surface
as-sprayed post ferric chloride testing



Zou et al., 2009, Scripta Materialia

Other Talks

Localized Corrosion

"Atmospheric Corrosion of Laser Powder Bed Fusion 316L Stainless Steel" Michael Melia PhD, Monday 9 am

"Environmental Influences on Maximum Pit Sizes for Austenitic Stainless Steels Utilized In Spent Nuclear Fuel Storage" Ryan Katona PhD, Monday 11 am

Environmentally Assisted Cracking

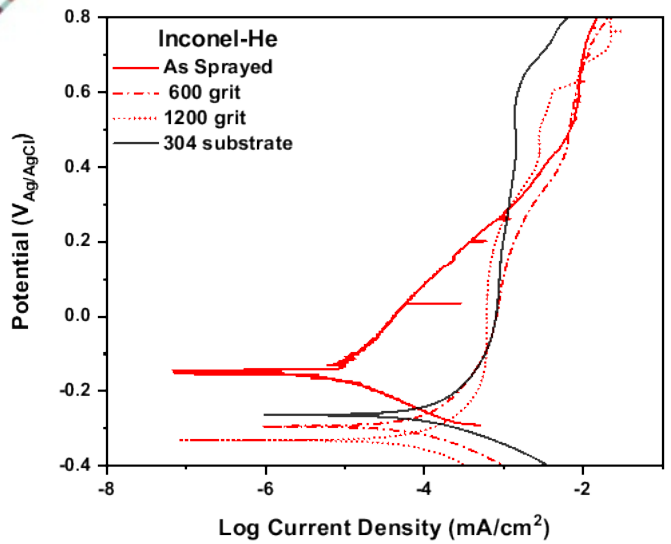
"Stress Corrosion Cracking of Austenitic Stainless Steel in Concentrated Chloride Environments" Ryan Katona PhD, Tuesday 11:25 am

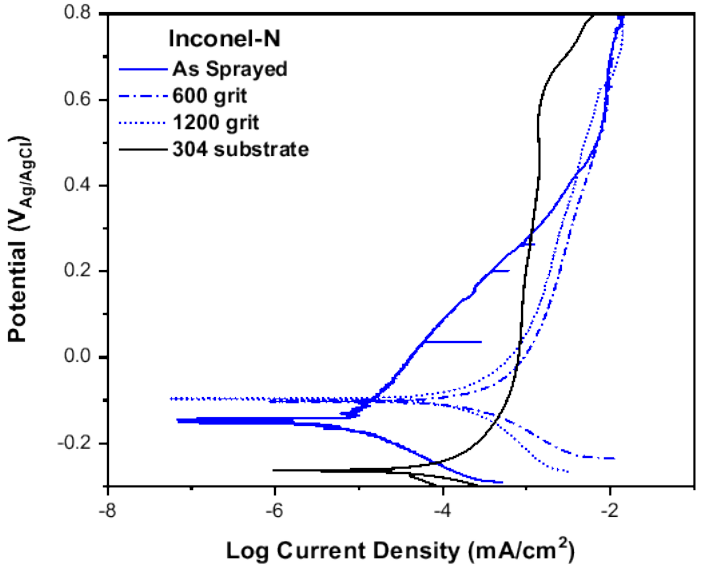
Student Poster Session

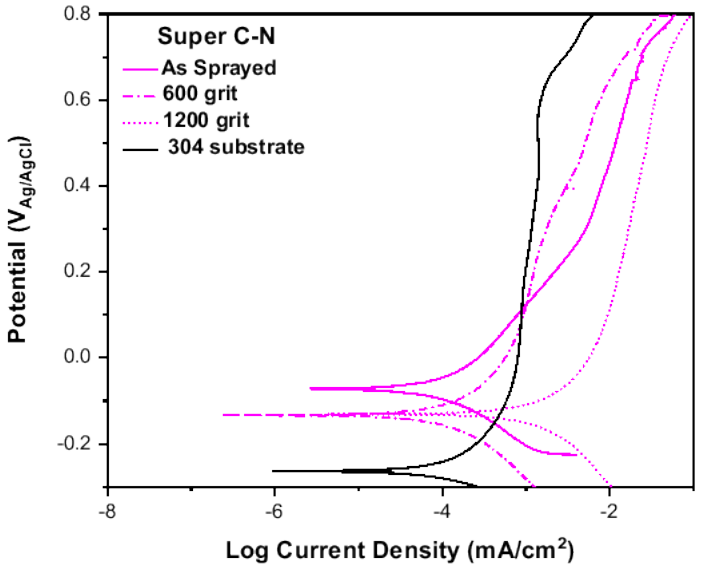
"Long Term, Simulated Marine Diurnal Exposure of Austenitic Stainless Steel at Elevated Temperatures" Timothy Montoya

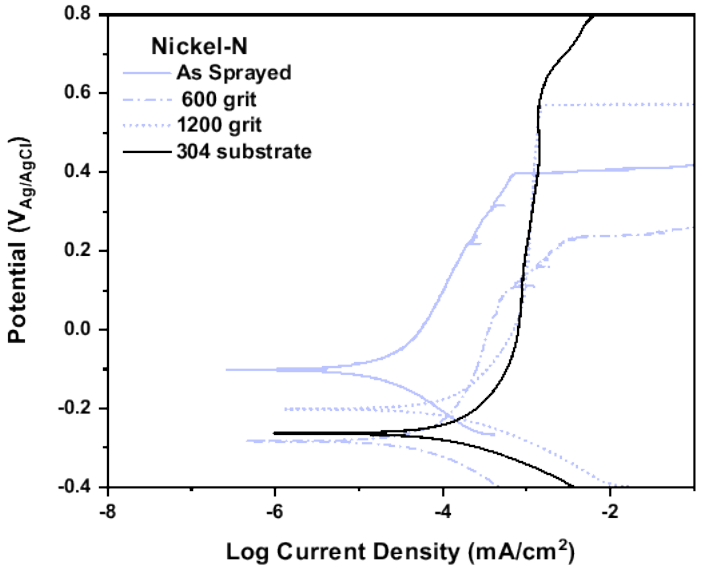
Thank you!

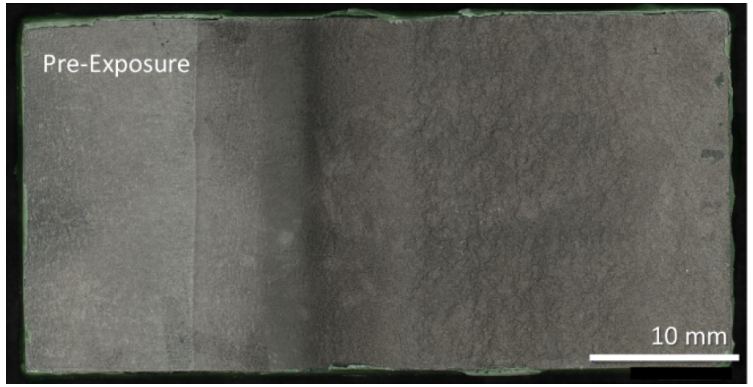
Effects of Polishing

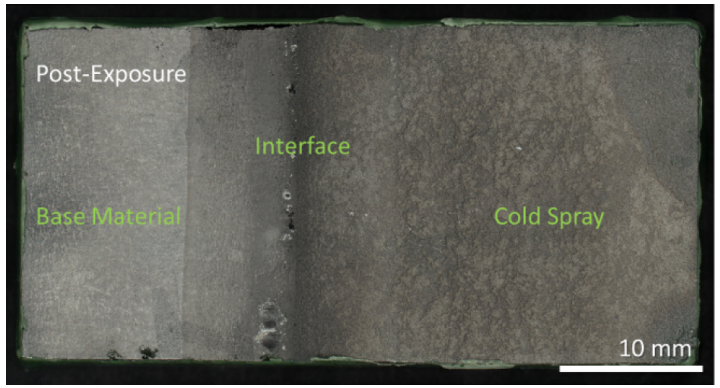




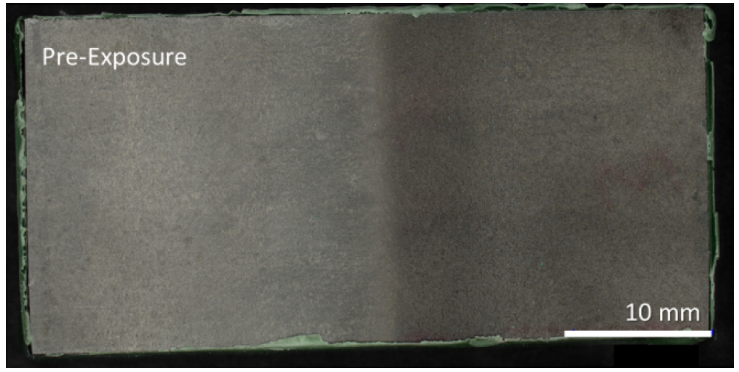






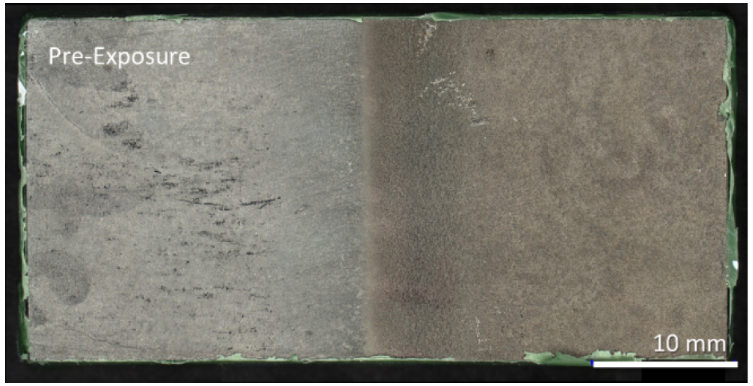


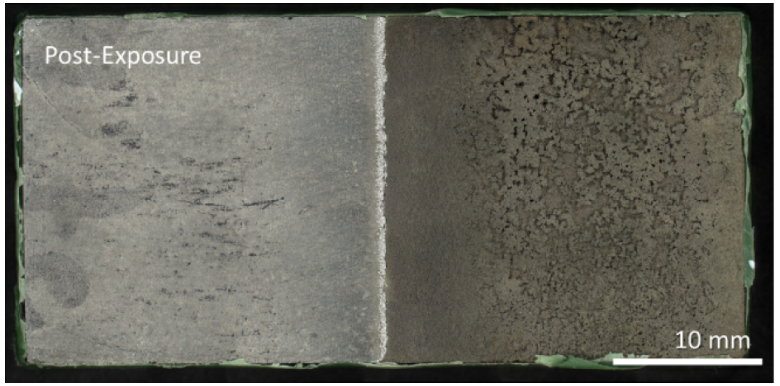
Inc-He blended



Inc-N blended

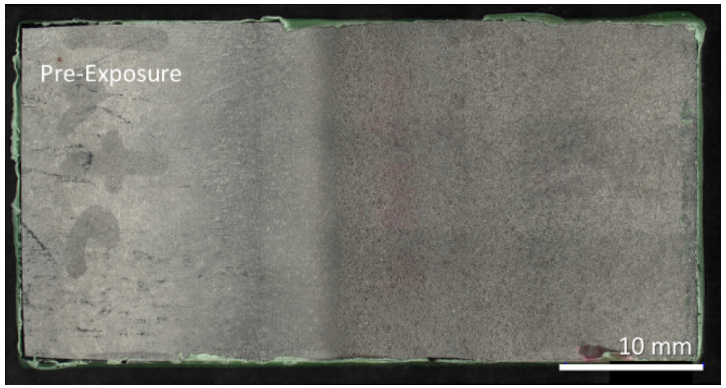
Inc-N masked





N-N blended

N-N masked



Super C-N blended