Corrosion Evaluation of Cold Spray Materials on SS304L Material

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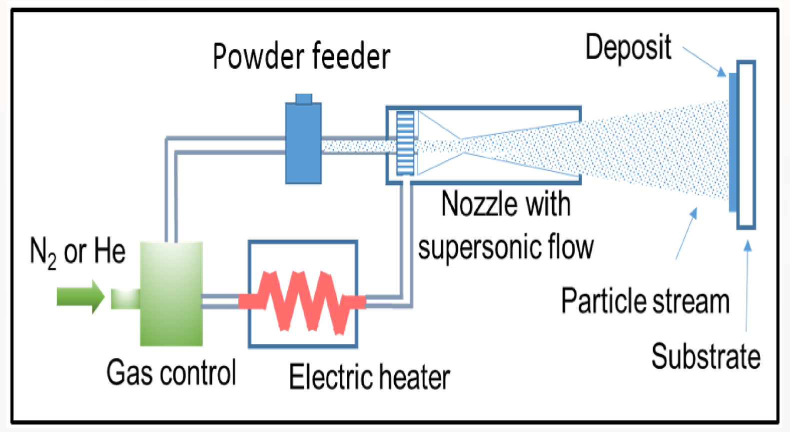
1. Objectives

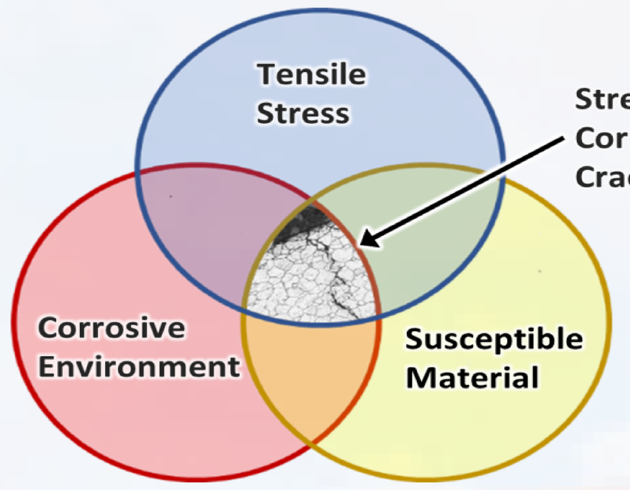
- In order to understand application of cold spray (CS) as a potential mitigation and repair technique for stress corrosion cracking:
  - Explore corrosion susceptibility of CS materials through accelerated testing: ASTM G-5 anodic polarization and ASTM G-48 accelerated pitting.
  - Compare the corrosion resistance for variations in: CS edge morphology, CS composition, and material-carrier gas combination.

2. Why study cold spray materials?

- High-pressure cold spray (HPCS) uses small solid particles in the range of 5 to 100 µm.
- Particle velocity ranges from 300 to 1200 m/s. No melting occurs.[6]
- Upon impact, the particles undergo adiabatic heating and plastic deformation at very high shear rates causing them to flatten and bond to the underlying surface.[6]
- Cold spray layer can be infinitely thick.[6]



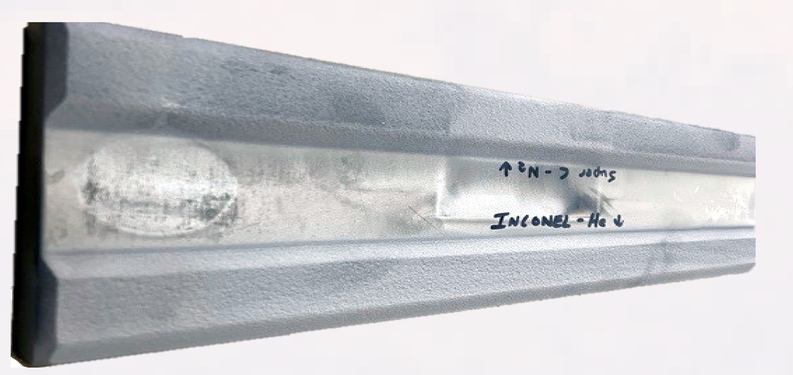
High-pressure cold spray process diagram.[1]



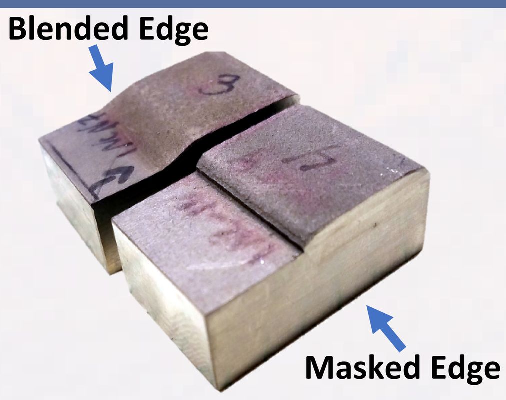
Conditions for CISCC.[1]

- Cold spray is being explored for repair and mitigation of chloride induced stress corrosion cracking (CISCC).[1]
- Three criteria for CISCC to occur:
  - Tensile Stress
  - Corrosive Environment
  - Susceptible Material
- Cold Spray can potentially remove each of these factors by protecting the material from the corrosive environment and creating compressive residual stress.[1]

3. Cold Spray Materials and Processes



Single allow cold sprayed plates and samples.[1]



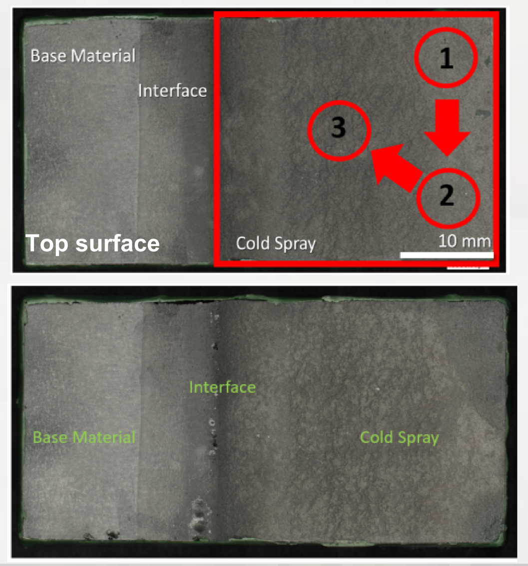
Test coupons cut from plates with blended and masked edges.[1]

- Commercially pure (CP) Ni, Inconel 625, and Super C powders were deposited onto stainless steel (SS) 304/304L to create test samples.
- Cold spray coatings were deposited on SS plates using nitrogen and helium carrier gases.
- Two edge morphologies were produced; masked edges (cliff-like interface) and blended edges (tapered interface).

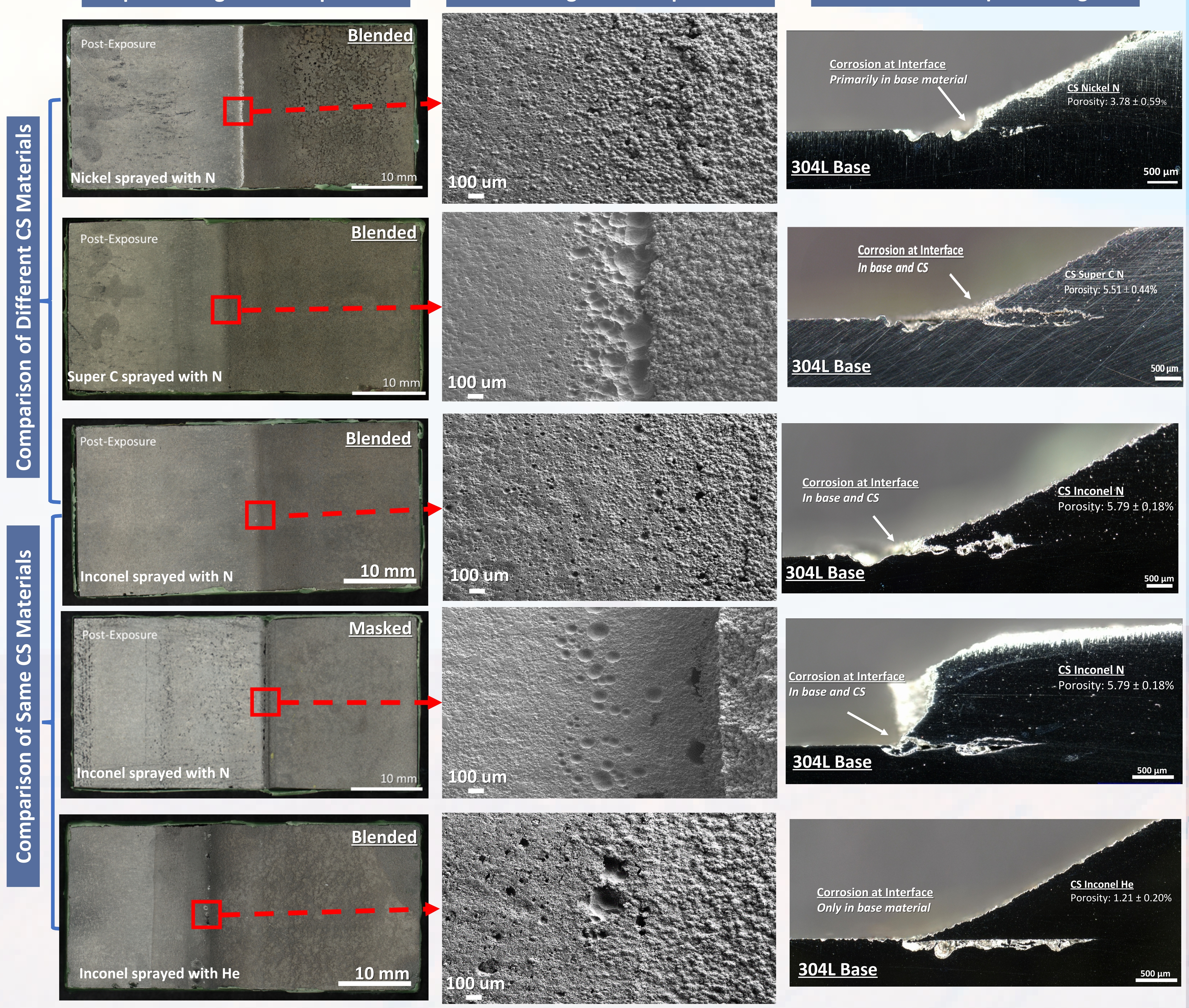
4. Experimental Matrix

CS Material	CS/Base metal Interface	Process Gas	Electrochemical Testing (ASTM G5-14-e1)			Pitting Corrosion Test (ASTM G48)
			As Sprayed	*600 grit*	*1200 grit*	
Inconel 625	Blended	He	X	X	X	X
Inconel 625	Blended	N	-	-	-	X
Inconel 625	Masked	N	X	X	X	X
Nickel	Blended	N	-	-	-	X
Nickel	Masked	N	X	X	X	X
Super C	Blended	N	X	X	X	X

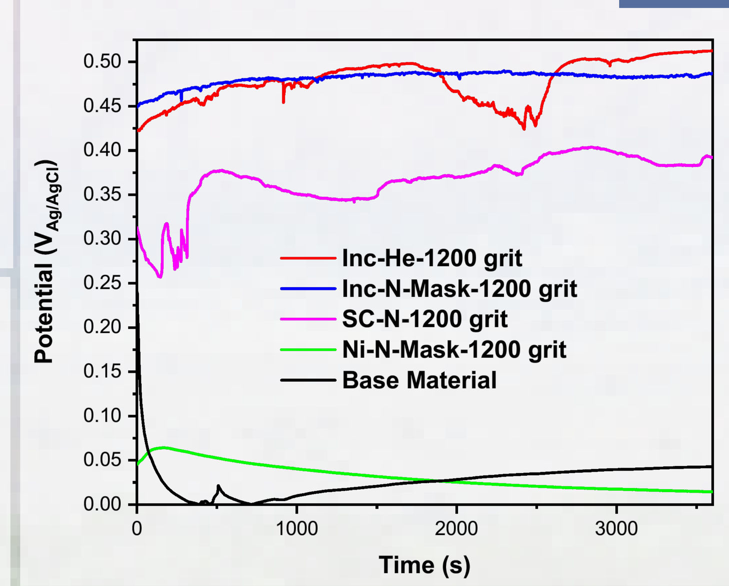
- All CS samples were analyzed using electrochemical polarization testing in 0.6 M NaCl (ASTM G5-14-e1) and full immersion $FeCl_3$ exposures (ASTM G48).
- All electrochemical tested samples were imaged through optical microscopy.
- Pre and post exposure, samples were imaged through optical microscopy, scanning electron microscopy (SEM), and energy dispersive x-ray spectroscopy (EDS).
- Porosity was measured by ImageJ (ASTM E2109-01).



5. Results: Accelerated Pitting Corrosion Tests (ASTM G48)



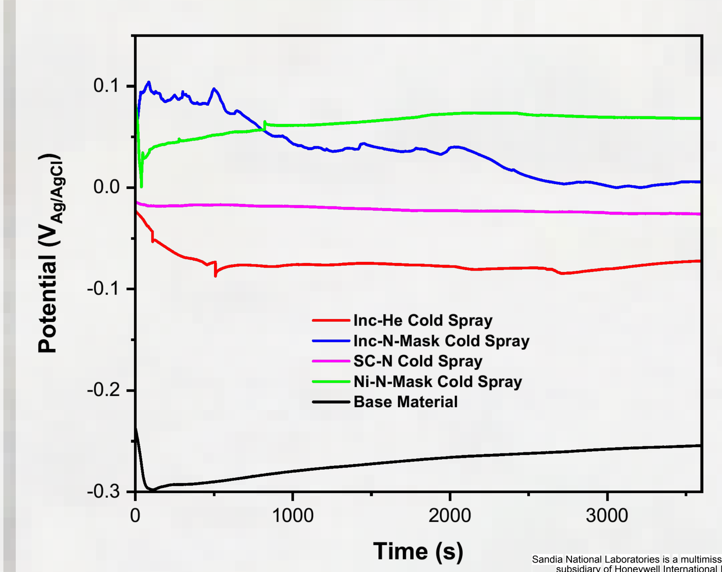
Summary Comparison of OCPs in 6 wt% $FeCl_3$ Solution on All CS Samples

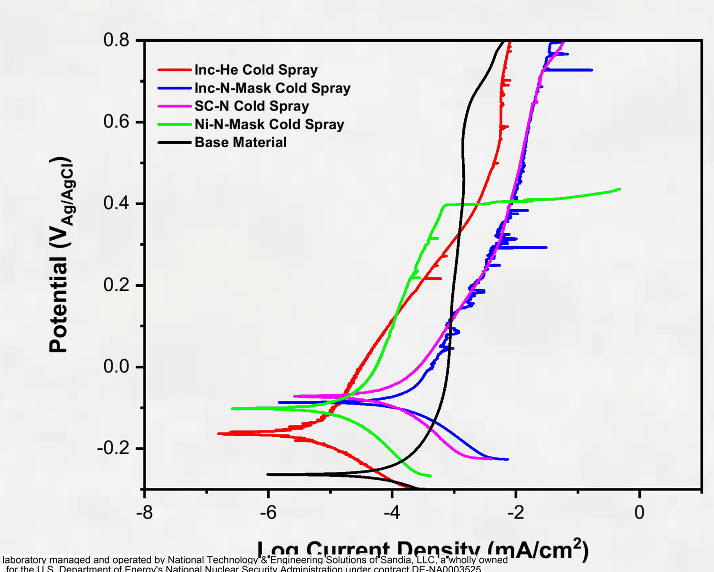


- All samples were ground to 1200 grit finish prior to testing in $FeCl_3$ solution.
- Inconel sprayed with Helium and Super Carbon sprayed with Nitrogen displayed unstable OCP behavior.
- Inconel sprayed with Nitrogen and Nickel sprayed with Nitrogen displayed stable OCP behavior.
- All samples, except Ni, displayed a roughly 450 mV higher OCP than the base material.
- Galvanic effects observed in full immersion testing at the interface can be related to the observed OCPs (Ni exhibits slightly lower attack).

6. Results: Electrochemical Testing ASTM G5-14-e1

Summary Comparison of All As-Sprayed CS Samples in 0.6 M NaCl Solution

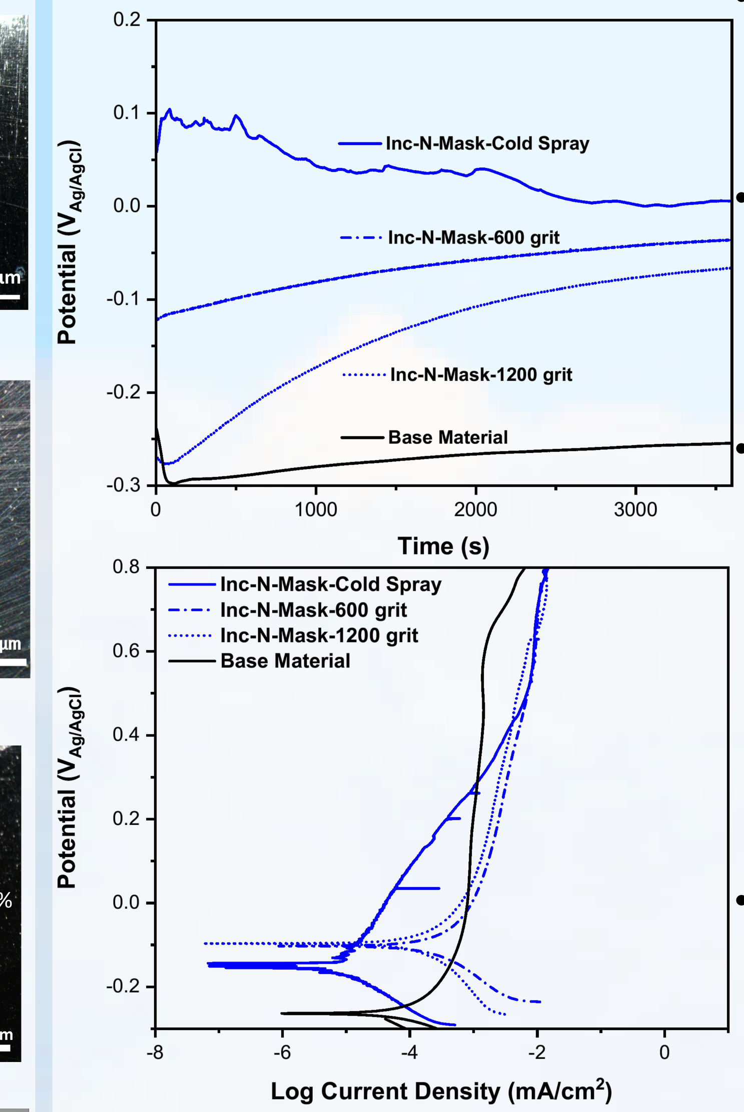




- All samples in the as-sprayed condition exhibit a roughly 200-350 mV higher OCP than the base material.
- The passive current densities displayed in the potentiodynamic polarizations are comparable to the base material; however, Ni CS displays a reduced passive region.

6. Results Continued: Electrochemical Testing

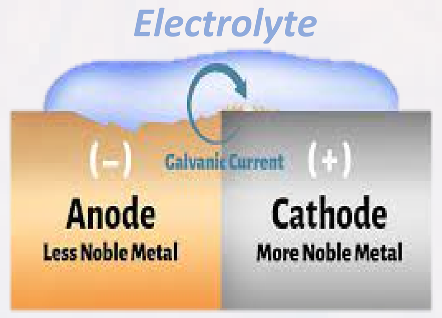
Effect of Surface Finish (Inconel, 0.6 M NaCl)



- As-sprayed condition displays unstable OCP behavior and metastable pitting in CPP scans. 600 and 1200 grit finishes display smoother evolution of OCP.
- Grinding removes oxides which can contribute to an active surface, lowering the OCP. However, CPP scans show smooth currents indicative of reduction in metastable pitting.
- Similar trends with surface finish observed for all materials.

7. Conclusions

- All samples showed detrimental pitting at the coating/base metal interfaces in $FeCl_3$ accelerated pitting testing.
- In blended samples, pitting was enhanced under regions of poorly densified (porous) cold spray coating.
- Masked samples showed crevice corrosion at the interface between the base material and cold spray, and enhanced pitting in the base metal near the interface.
- Porosity accelerates localized corrosion and crevicing attack of CS.
- Surface roughness of the cold spray material plays a role in susceptibility to metastable pitting.
- Comparison of the OCP of the CS and the base material suggest galvanic corrosion can occur.



Example of galvanic corrosion.[5]

8. Future Work

- Investigate an expanded set of CS materials and processing conditions. Evaluate under atmospheric conditions.
- Study the mechanisms behind enhanced corrosion attack at the interface and connection to underlying microstructure through SEM, EBSD, and nanoindentation.

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