Cold Spray Technology for Repair of Magnesium Rotorcraft Components

ESTCP Proposal 06-E-PP3-031

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ARL

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Report Documentation Page

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Cold Spray Technology for Repair of Magnesium Rotorcraft Components

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Program Objectives:

- To reclaim ZE 41A magnesium alloy components on Army and Navy helicopters that have been removed from service due to severe corrosion and/or wear.

- ARL will provide a repair/rebuild cold spray procedure for scrapped parts and assist in the transition and implementation of this technology, initially, at NADEP, Cherry Point, NC.

Cold Spray Technology for Repair of Magnesium Rotorcraft Components

Meeting Objective: to lay the foundation for a JTP that can be executed by the ESTCP team such that at the completion of the program NADEP, Cherry Point has a fully functional cold spray system that is reclaiming magnesium rotorcraft components.

- **Overview of Cold Spray Technology**
  - Leveraged Programs **(unprecedented head start)**
  - Discuss ARL Capabilities and Advantages of Cold Spray
- **Present Test Results to Date**
  - Coating Integrity and Microstructural Analysis
  - Adhesion, Hardness and Corrosion Tests
  - Coating Material Selection and Powder Development
  - Cold Spray Process Development and Hardware Modifications
  - Cold Spray Demonstration on ZE 41A Mg Housings

Cold Spray Center at the
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ARL Cold Spray Research Team

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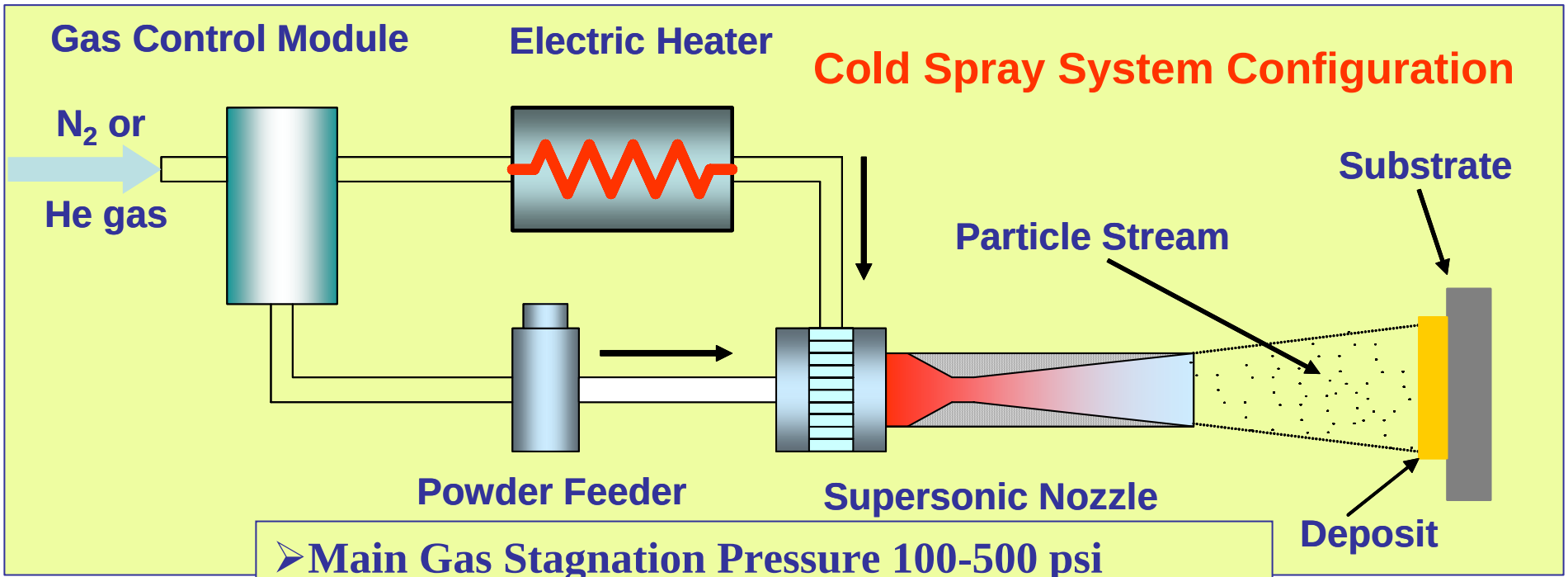
ARL Leveraged Formal Programs

•to develop aluminum cold spray coatings for aluminum, magnesium and/or steel substrates have been established with the following:

1. Defense Science & Technology Organization (DSTO)
2. Joint Strike Fighter (JSF)
3. National Center for Manufacturing Sciences (NCMS)
4. Lockheed Martin
5. Penn State Applied Research Laboratory
6. Lawrence Livermore National Labs (LLNL)
7. South Dakota School of Mines (SDSM)

Overview of Cold Spray Technology

Cold Spray: a process by which particulates are deposited by means of ballistic impingement upon a suitable substrate at super sonic velocities to form a coating or a free-standing structure.



- Main Gas Stagnation Pressure 100-500 psi
- Gas Temperature 0-1300ºF
- Main Gas Flow Rate 30-100 CFM
- Powder Feed Rate 10 to 30 pounds/hour
- Particle Velocity 300-1500 m/sec.
- Particle Size 1-100um diameter

Cold Spray Advantages

Super Plastic Particle Agglomerate Mixing (SPAM) bond

- plastic deformation may disrupt thin oxide surface films to permit bonding
- similar to explosive welding

Compressive residual stresses

- particles “peen” surface
- plasma and wire-arc thermal spray coatings tend to be in tension

High density

- low porosity: < 0.5 %
- low oxide content <0.3%

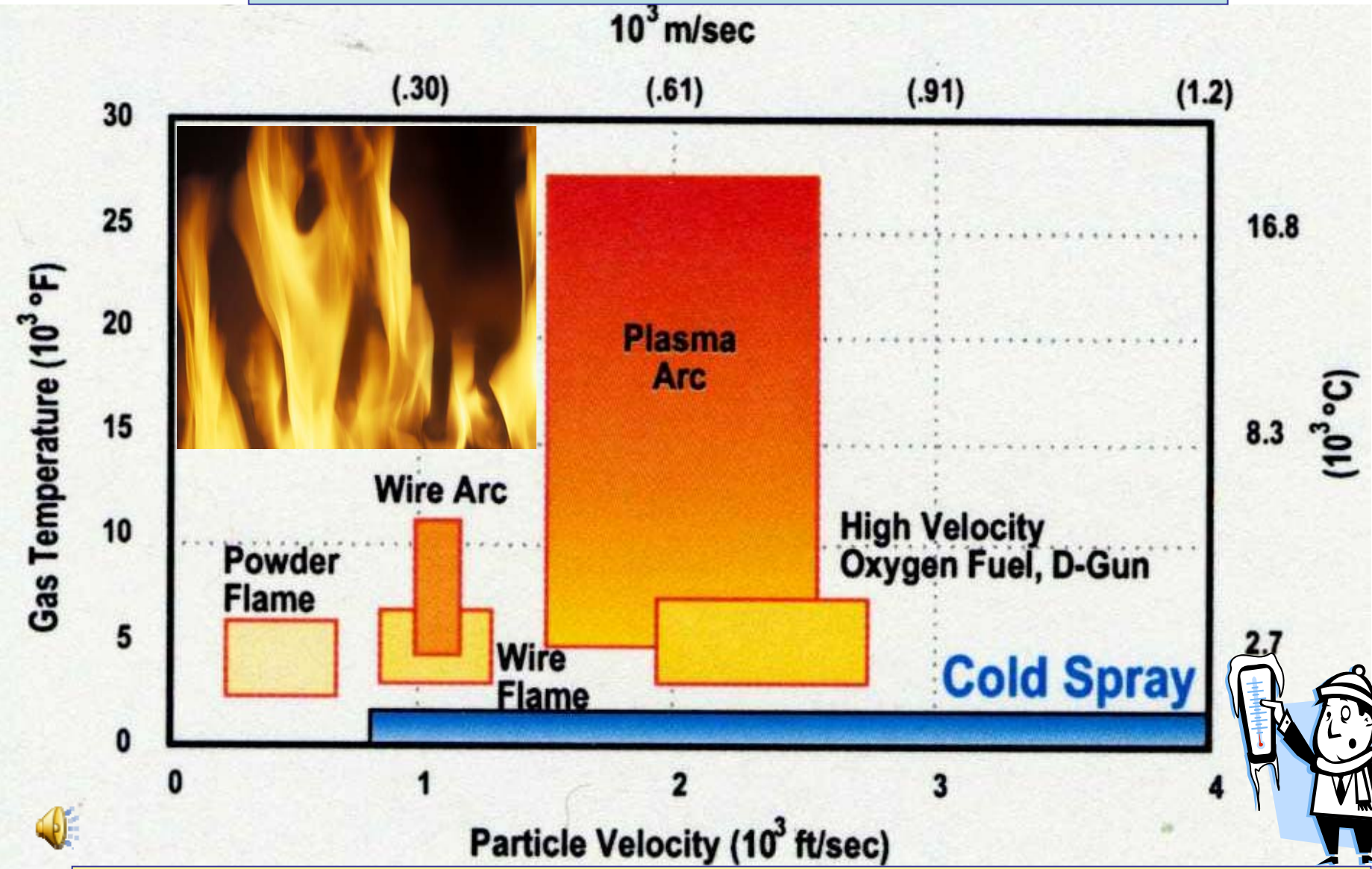
Thick coatings

- free-form fabrication

Low Temperature Application

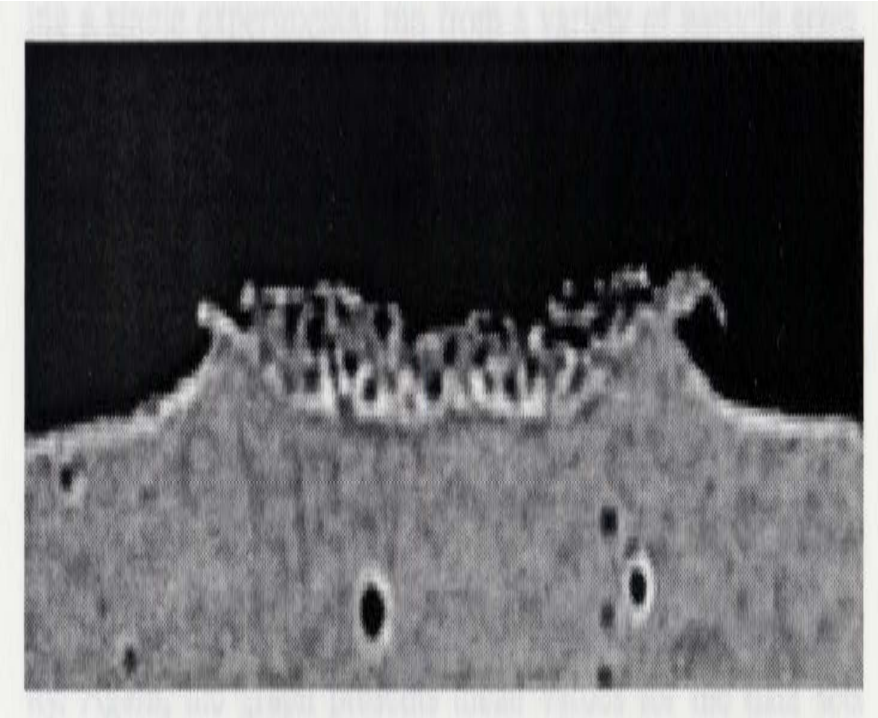
- thermally sensitive substrates
- low stresses due to CTE mismatch

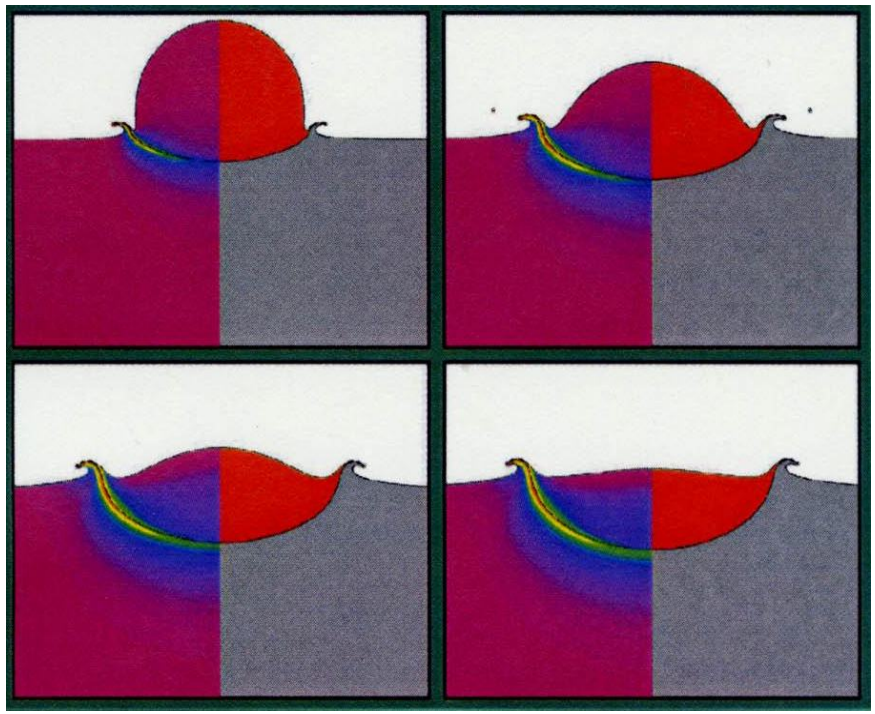
Cold Spray vs. Thermal Spray



Cold Spray is performed at lower temperatures at high particle velocities

Copper Particle Impact Site



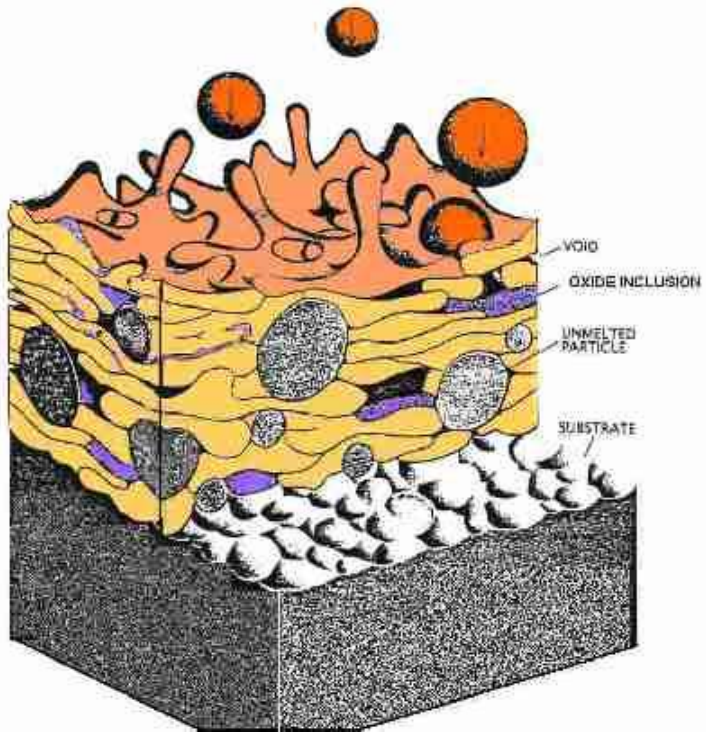


Cross section of the impact site between a copper particle and a stainless steel substrate.

From Dykhuizen et al, J. Thermal Spray Tech, Dec 1999.

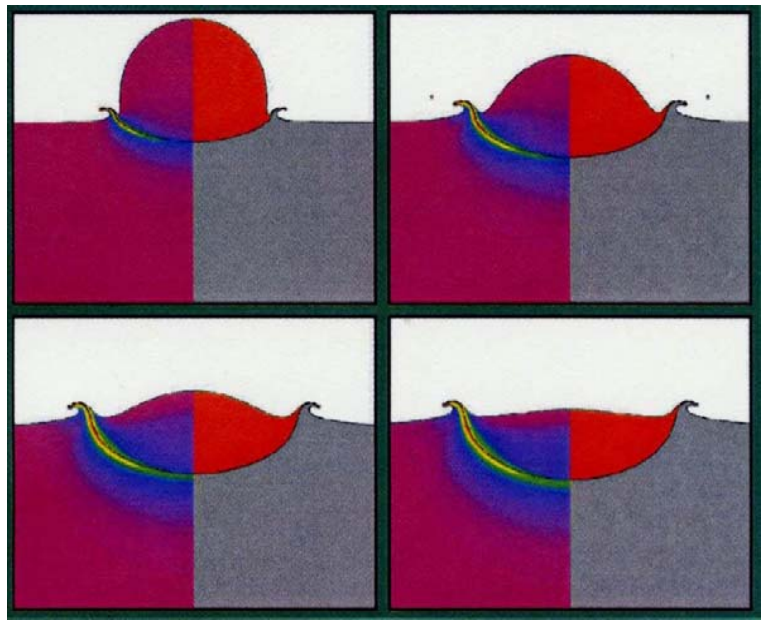
Advantages of Low Temperature Process

Thermal Spray



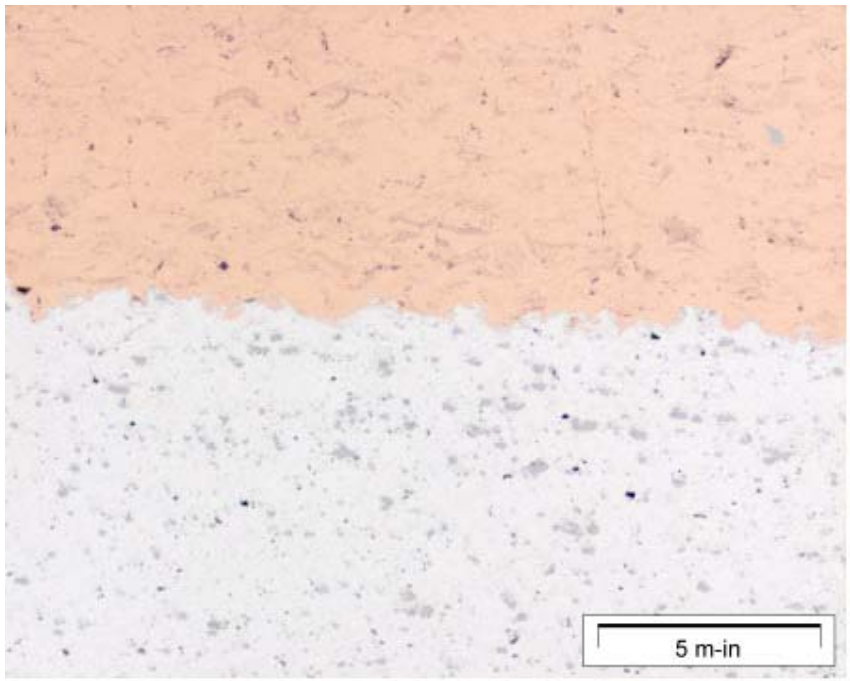
www.gordonengland.co.uk

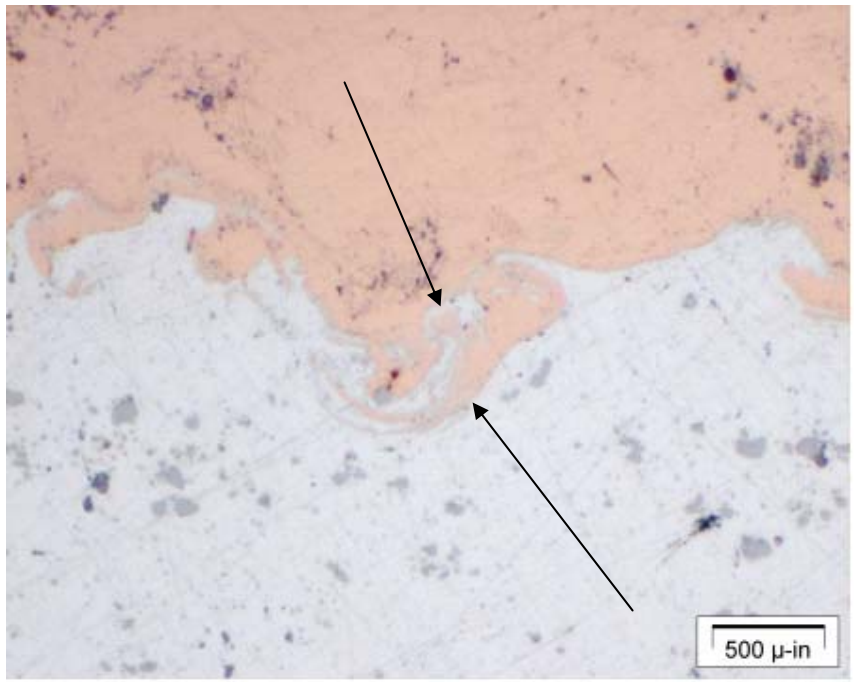
Cold Spray

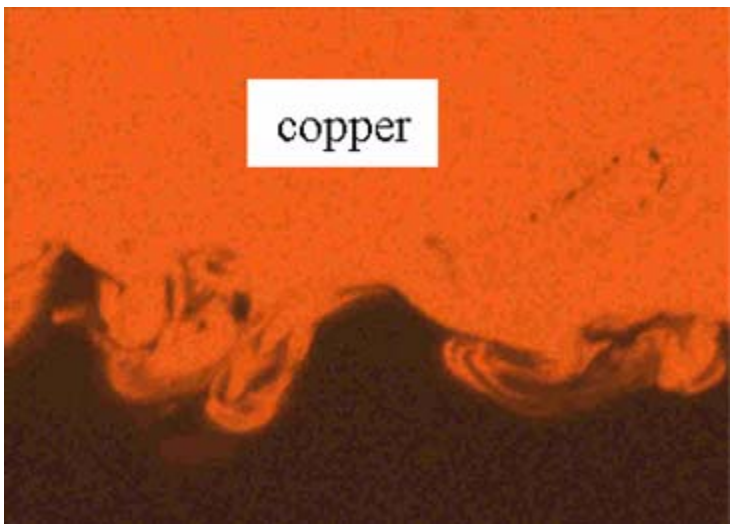


The melting of particles that occurs during most thermal spray processes can result in oxidation of both the coating and substrate materials. The resulting oxides decrease the adhesive and cohesive strengths of the coating. The cold spray process avoids such reactions.

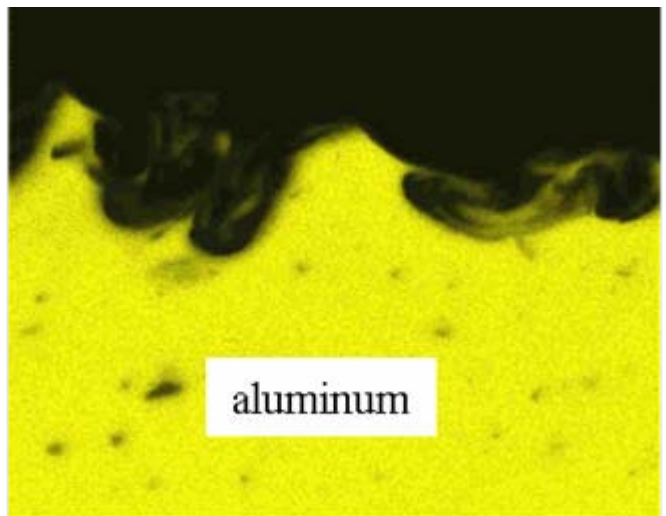
Mechanical Mixing at Interface



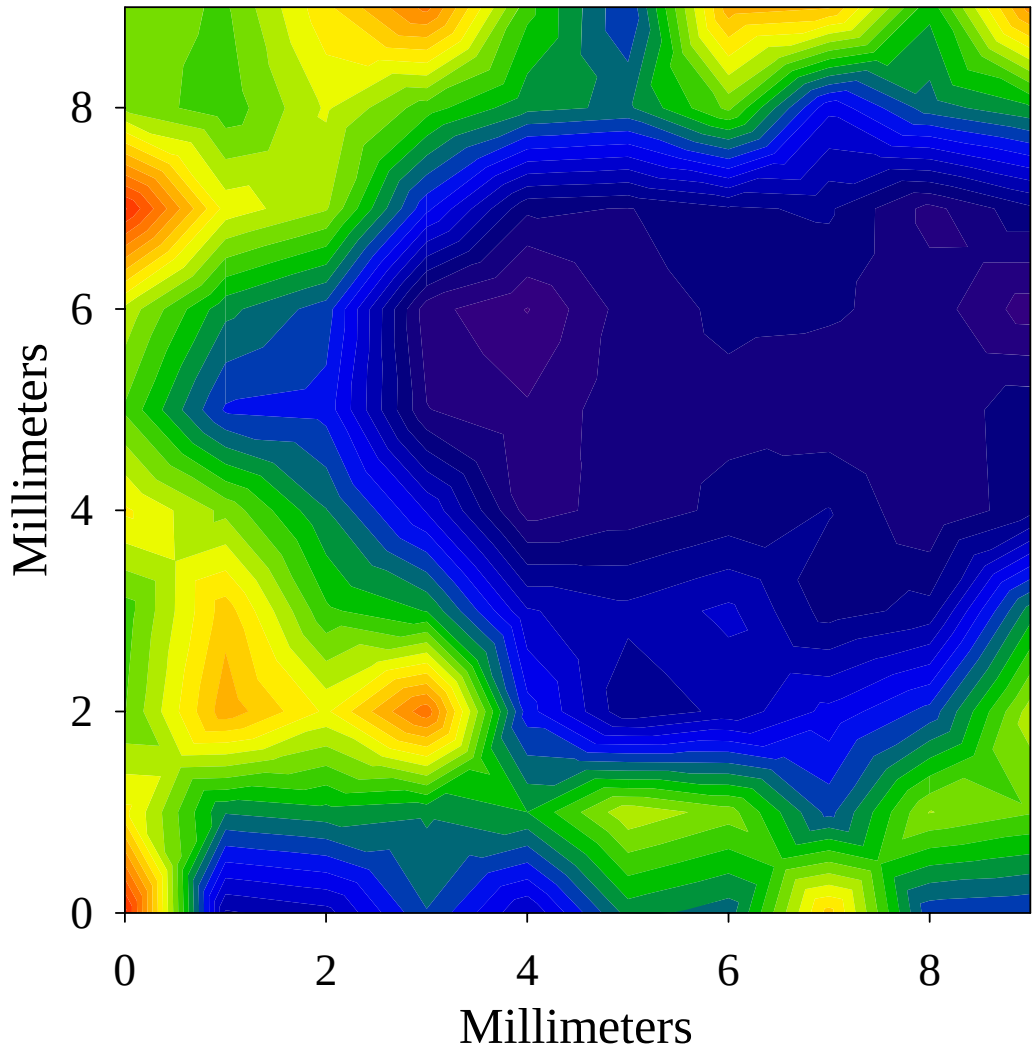




EDS X-ray Mapping showing mechanical mixing between coating material and substrate



Particle Velocity Distribution Measured by DPV 2000



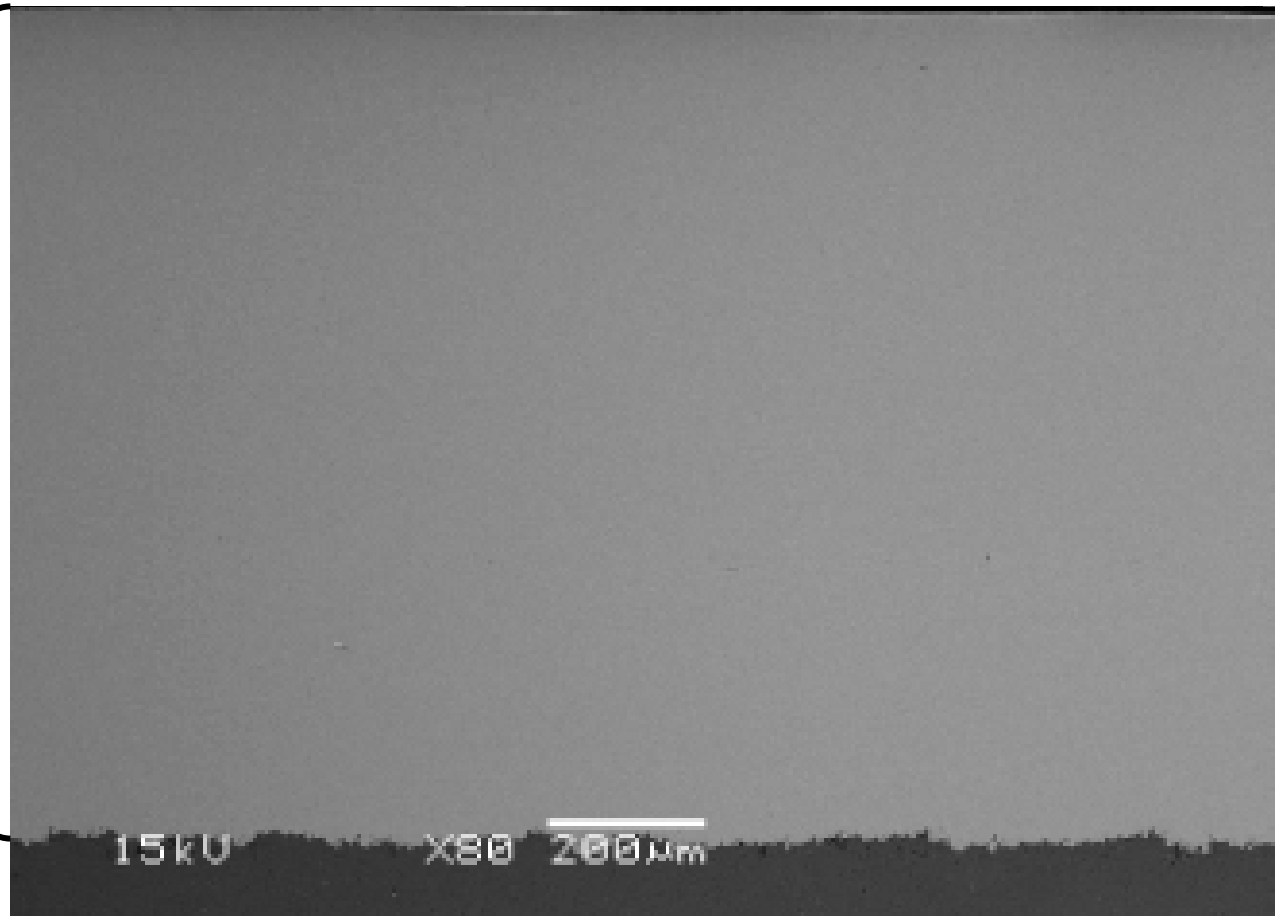
20 micron copper particles
25 mm downstream
400 psi, 400 C N_2 gas

500 m/sec
600 m/sec
700 m/sec
800 m/sec
900 m/sec

Cold Spray Coating of Nickel On 6061-T6 Al

Nickel Coating

100% Dense

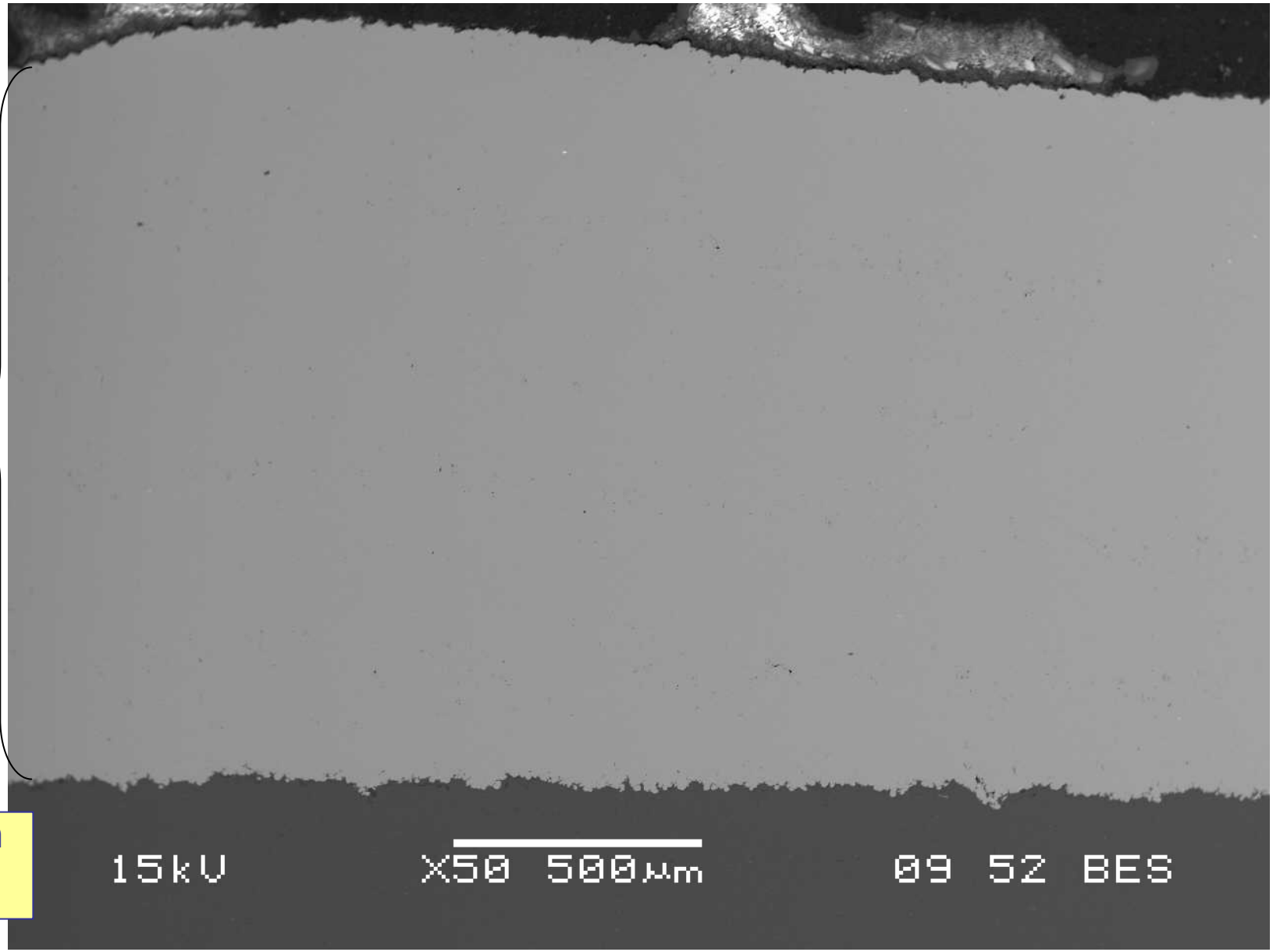


Cold Spray Ni has a hardness of HRC 41 and a resistivity of 6.84uohm/cm

316L SS Deposited by the Stationary System Using He

316L SS Cold Spray Coating

Aluminum Substrate

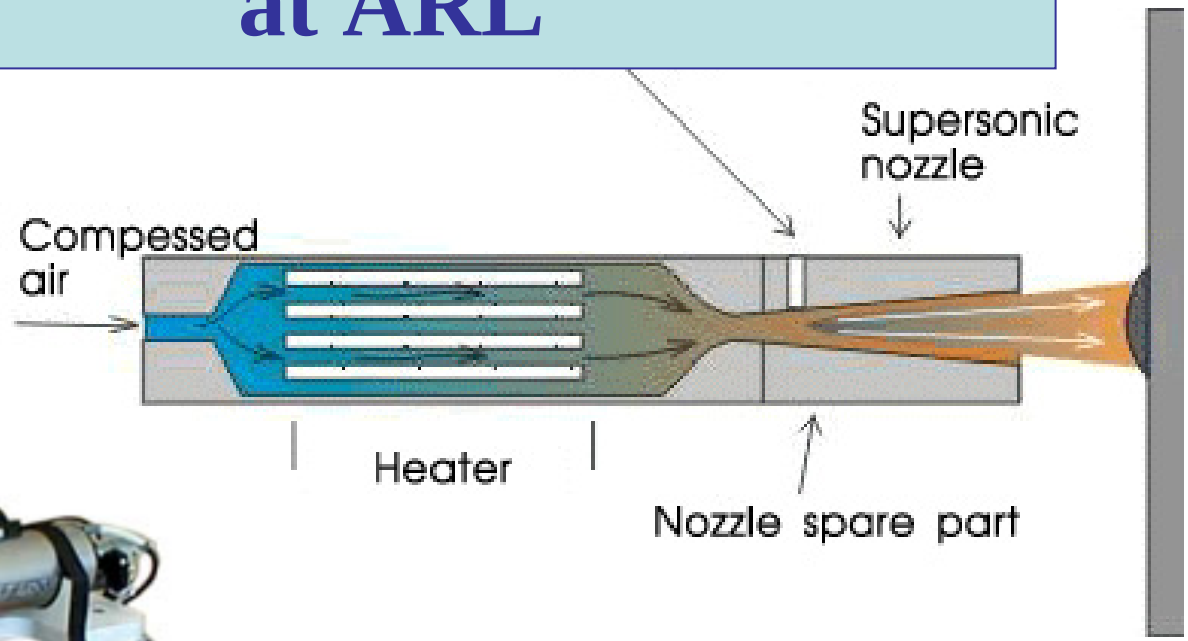


Stationary Cold Spray System at ARL

Main Gas Stagnation Pressure 100-500 psi Gas Temperature 0-1300ºF Main Gas Flow Rate 30-100 CFM

Powder Feed Rate 10 to 30 pounds/hour Particle Velocity 300-1500 m/sec.

Portable Cold Spray Systems at ARL



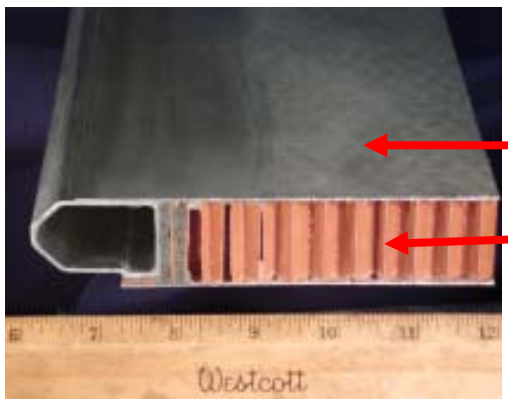
- Hand-Held Heater-Nozzle
- Shop Compressed Air
- Particle Velocity 300-500 m/s

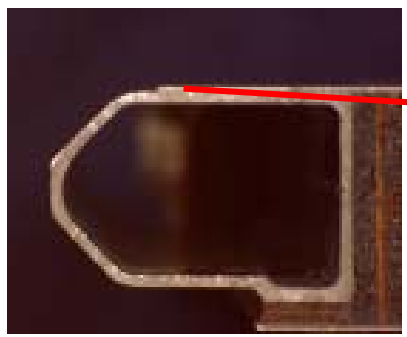
EMI Shielding for HMMWV Shelter by Cold Spray

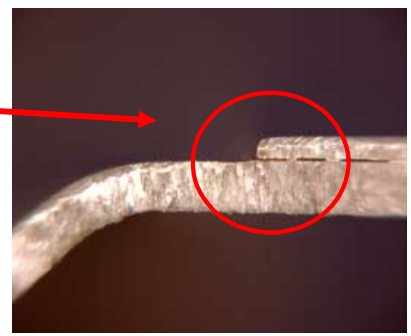
ARL Produces First Prototype Using Cold Spray Technology for the Terminal High Altitude Area Defense (THAAD) Project Office.

- **HMMWV shelters require EMI shielding to prevent entrance/escape of electronic signals.**
- **The joints in al-composite walls must be sealed with a non-porous, conducting metal.**
- **The composite structure requires low-temperature application of sealer.**

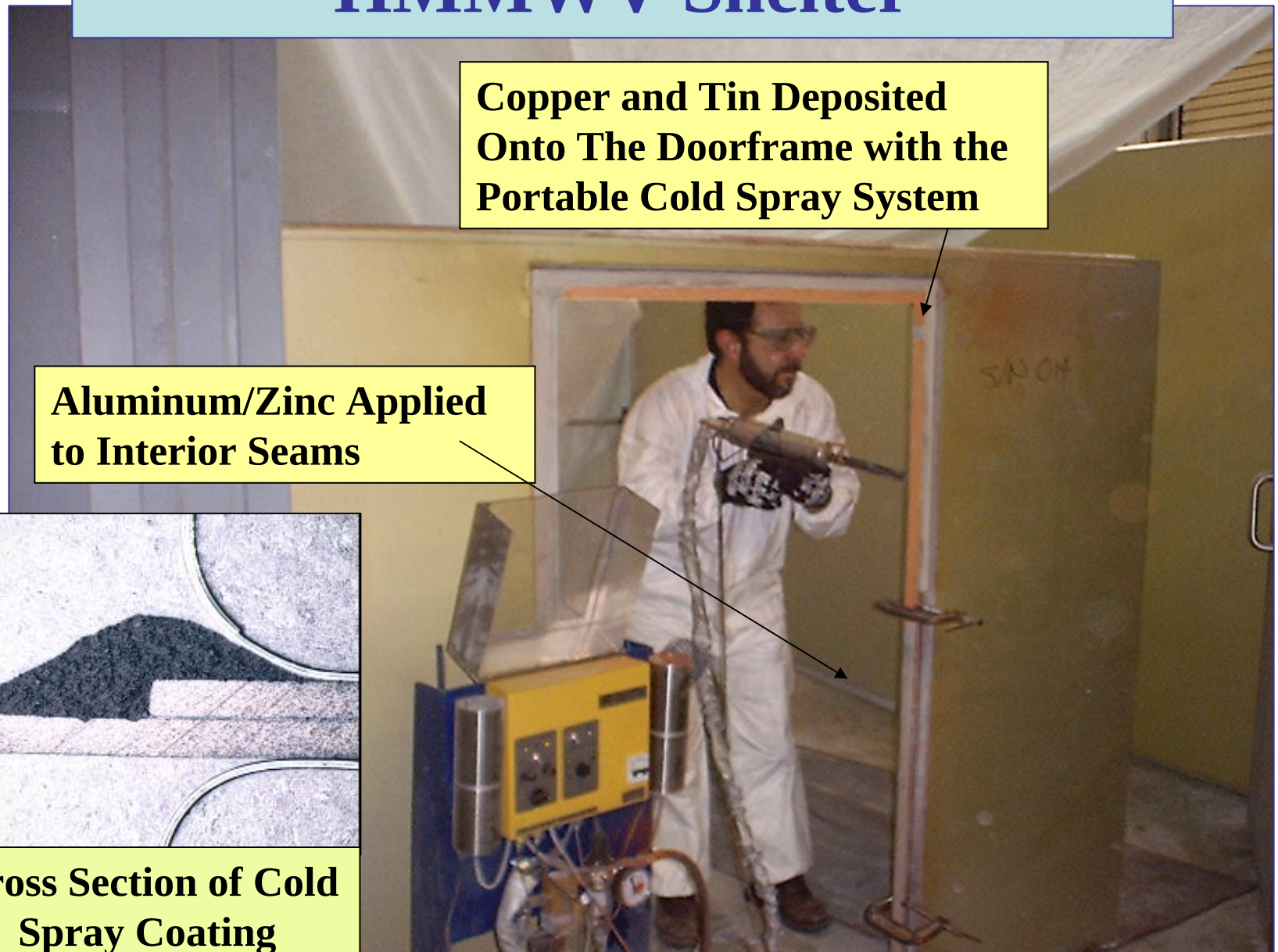
Conductive material needed to fill seams







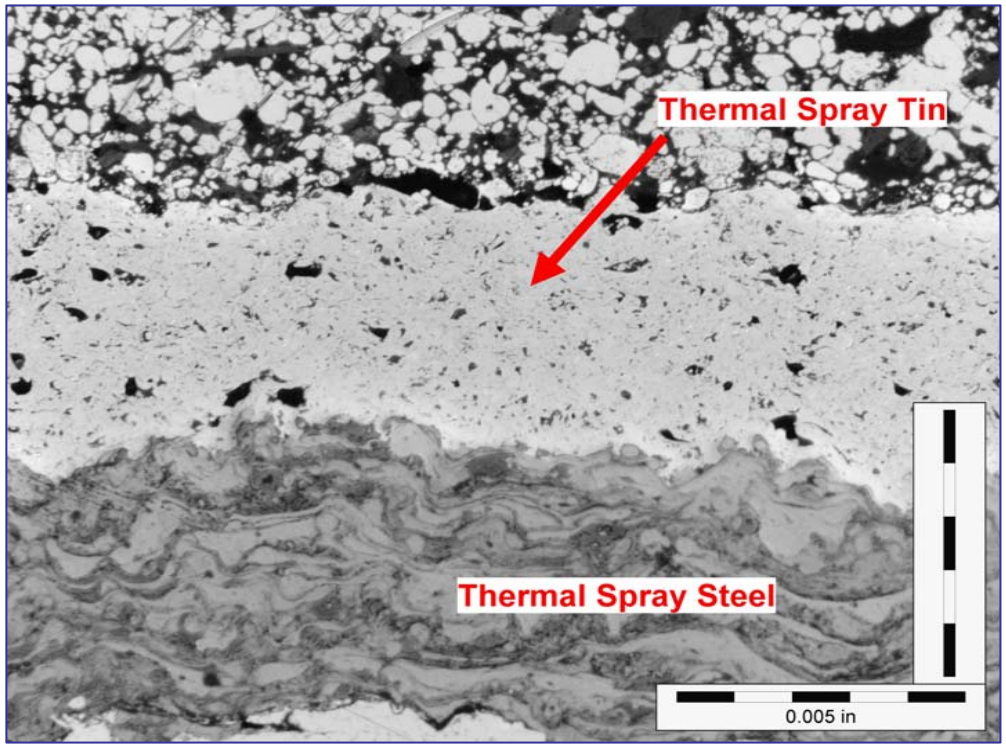
Applying EMI Shielding on the HMMWV Shelter

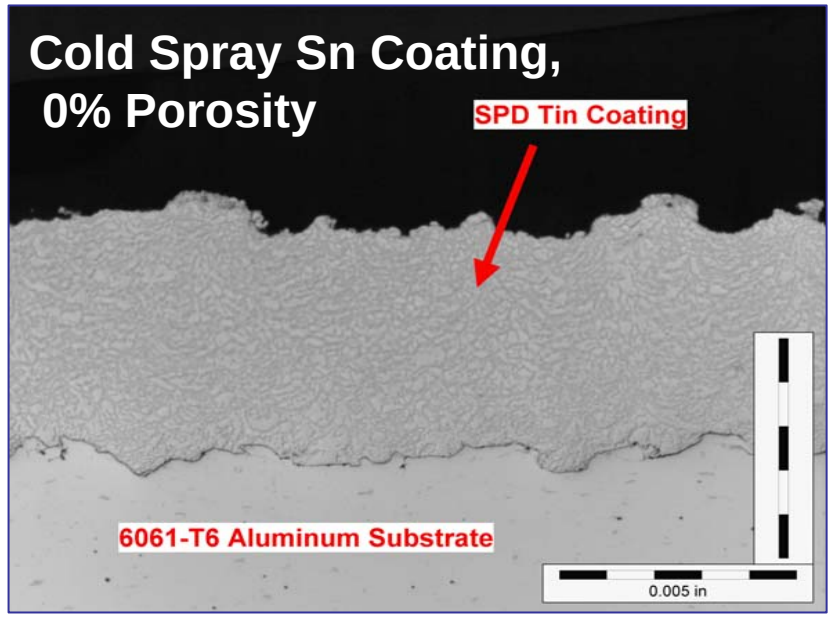


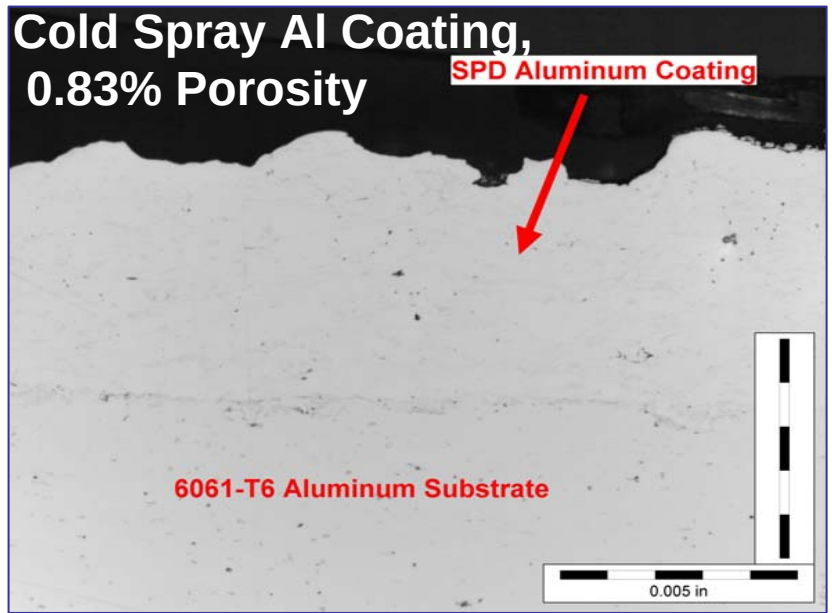
Cross Section of Cold Spray Coating

Cold Spray vs. Thermal Spray

Flame Spray Sn & Steel Coating, 12.2% Porosity







CTMA*-NCMS** Collaborative Project

1. **Corrosion protection of ferrous materials**
   - Painted structures – viz. ALV – access cover (USMC)
   - Hardened steel landing structures (Boeing)
   - Iron brake components (Delphi)

2. **Corrosion protection and restoration of magnesium**
   -Repair ZE41& AZ91-D Magnesium (U.S. Army Research Lab, NADEP–Cherry Point, Ford)

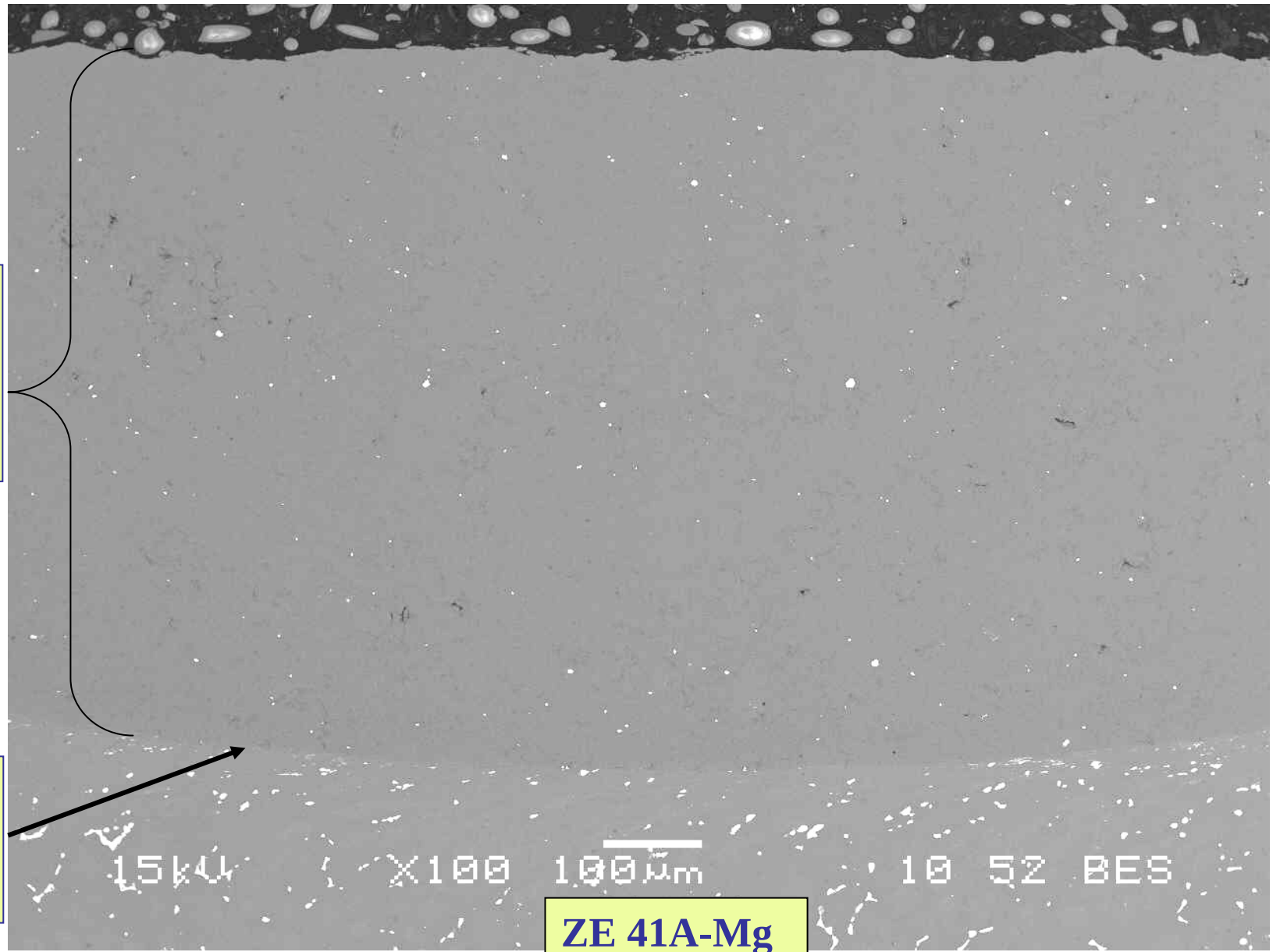
3. **Corrosion protection and restoration of aluminum**
   - repair of Alclad (Boeing commercial, Air logistics, Cherry Point)

4. **Aluminum brazements** (Delphi)

5. **Cold-spray consolidation by Ultrasonics** (Solidica)

* Commercial Technologies for Maintenance Activities
** National Center for Manufacturing Sciences

Cold Spray Coating of CP-Al On ZE 41A-Mg



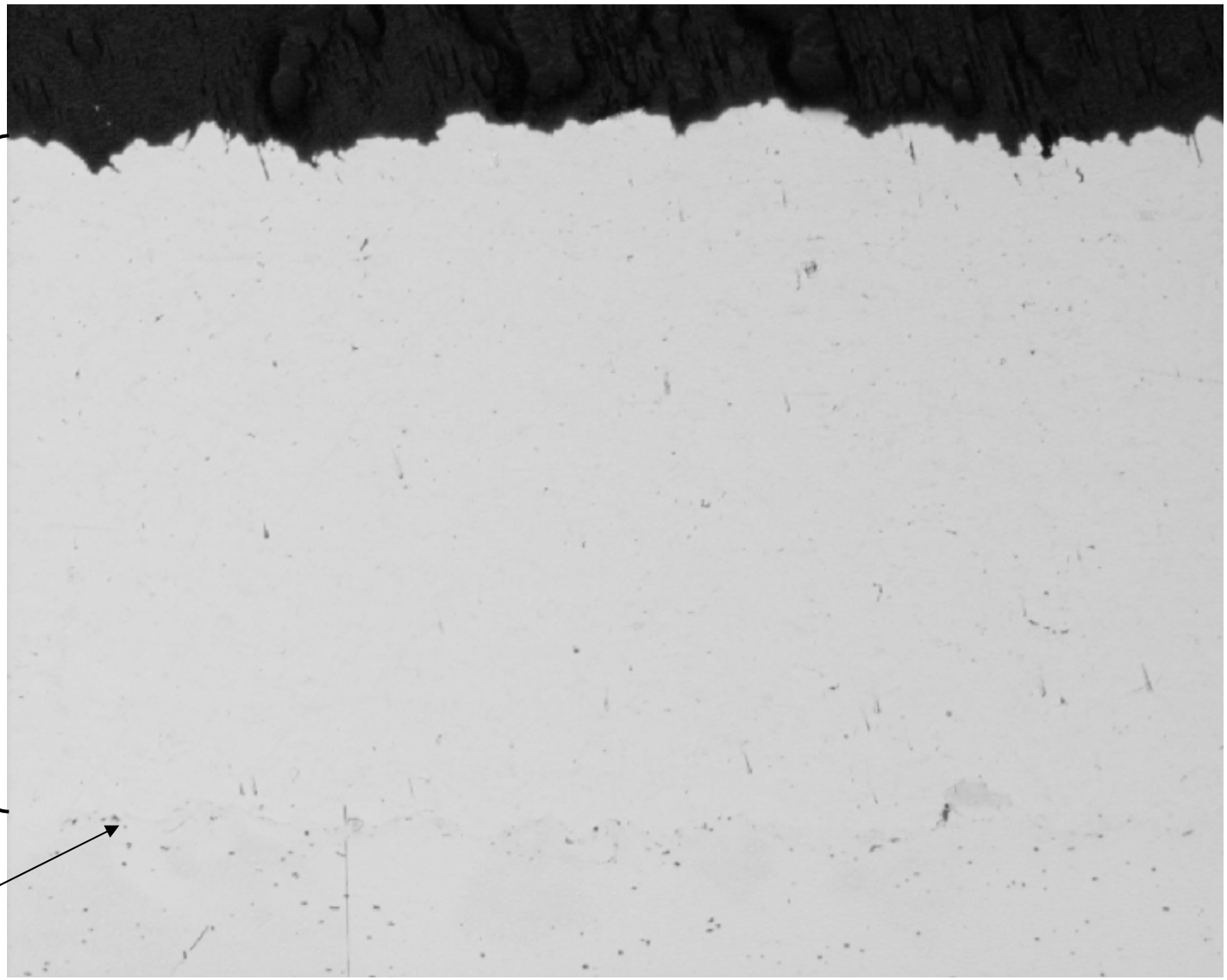
Cold Spray CP- Al Coating

~100% Dense

Coating / Substrate Interface

ZE 41A-Mg

CP- Al Cold Spray Coating Applied to ZE 41AMg



Cold Spray Al Coating 0.015 inch

8,500 psi adhesion

Interface is free of voids and oxides

CP- Aluminum Cold Spray Coating Adhesion to Magnesium

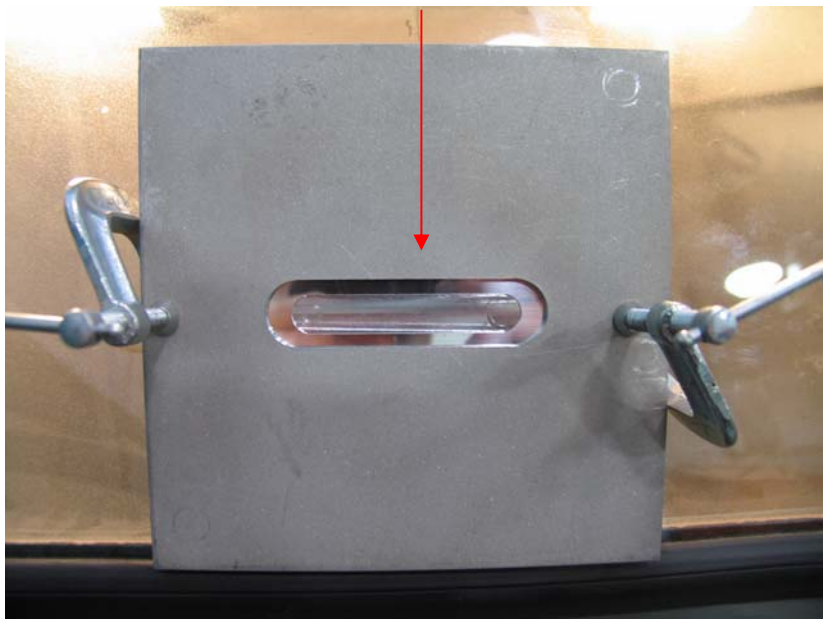
Program	Conditions	Adhesion (psi)
ARL-DSTO	N_2, 380 psi, 250°C	2743
ARL-DSTO	He, 380 psi, 20°C	>6527
ARL-NCMS	He, 380 psi, 20°C	>8505

New Data Generated FY07 for ESTCP

ARL-ESTCP	N2, 380 psi, 400°C	>10,350

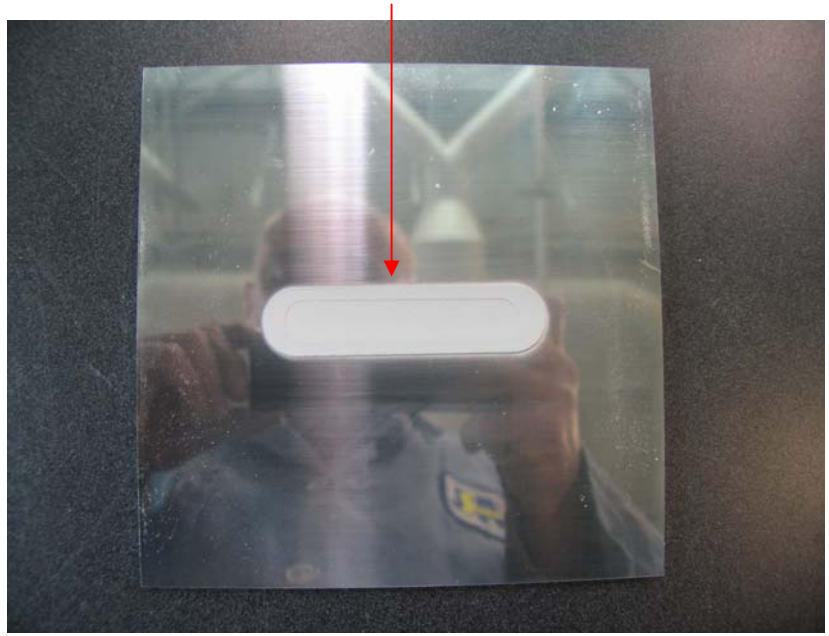
Repair of Alclad Aircraft Skin by Cold Spray using CP Aluminum

Machined slot



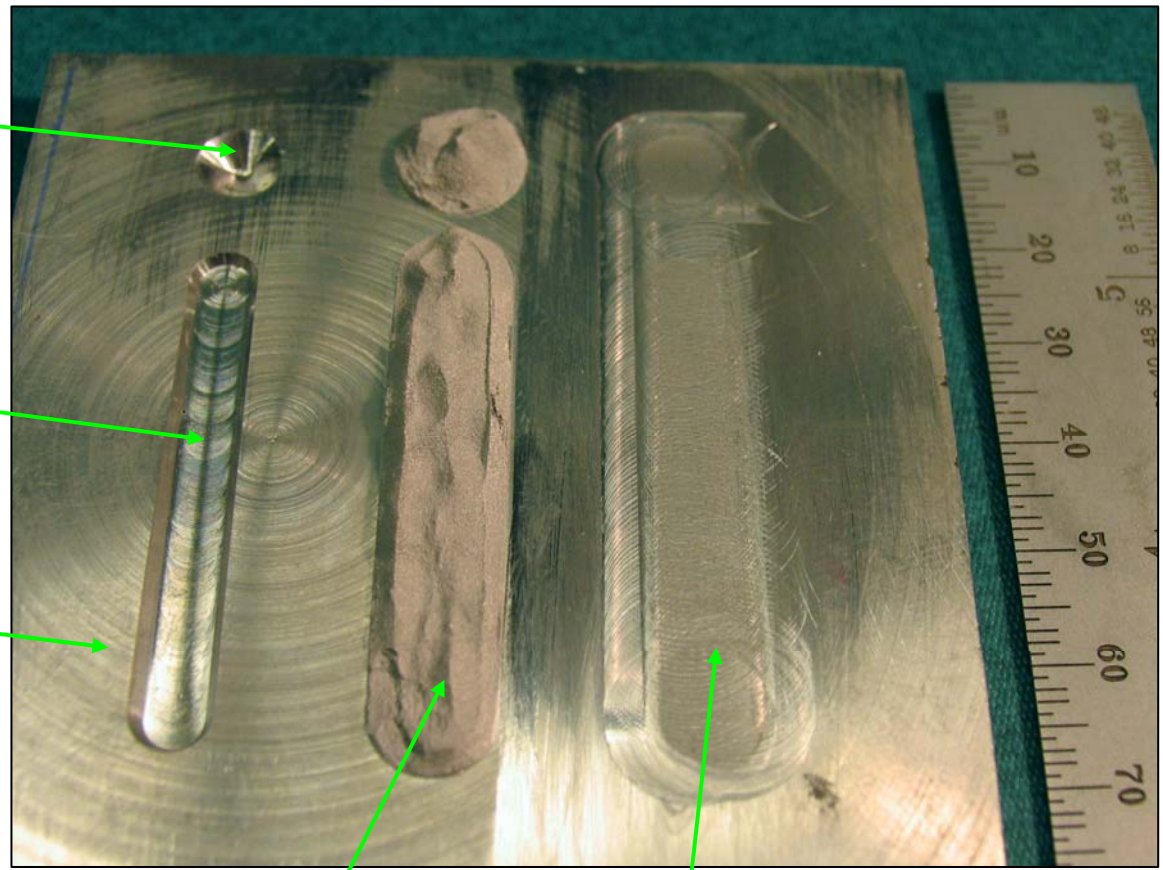
Template shielded before spray

Cold Spray CP Al



0.035 inch thick cold spray repair

Example of Damage Repair

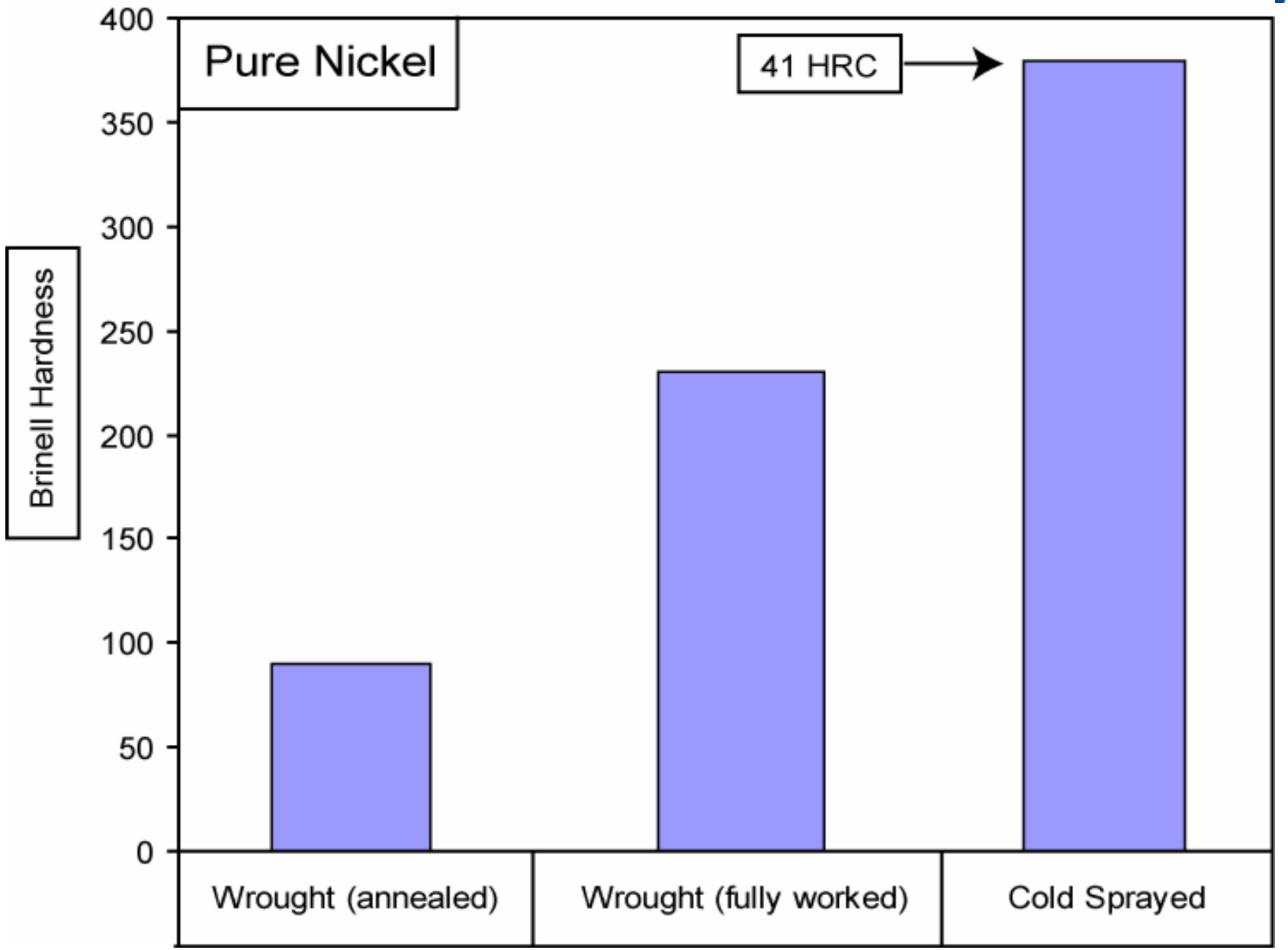


Cold Sprayed vs. Wrought Materials Hardness Comparison

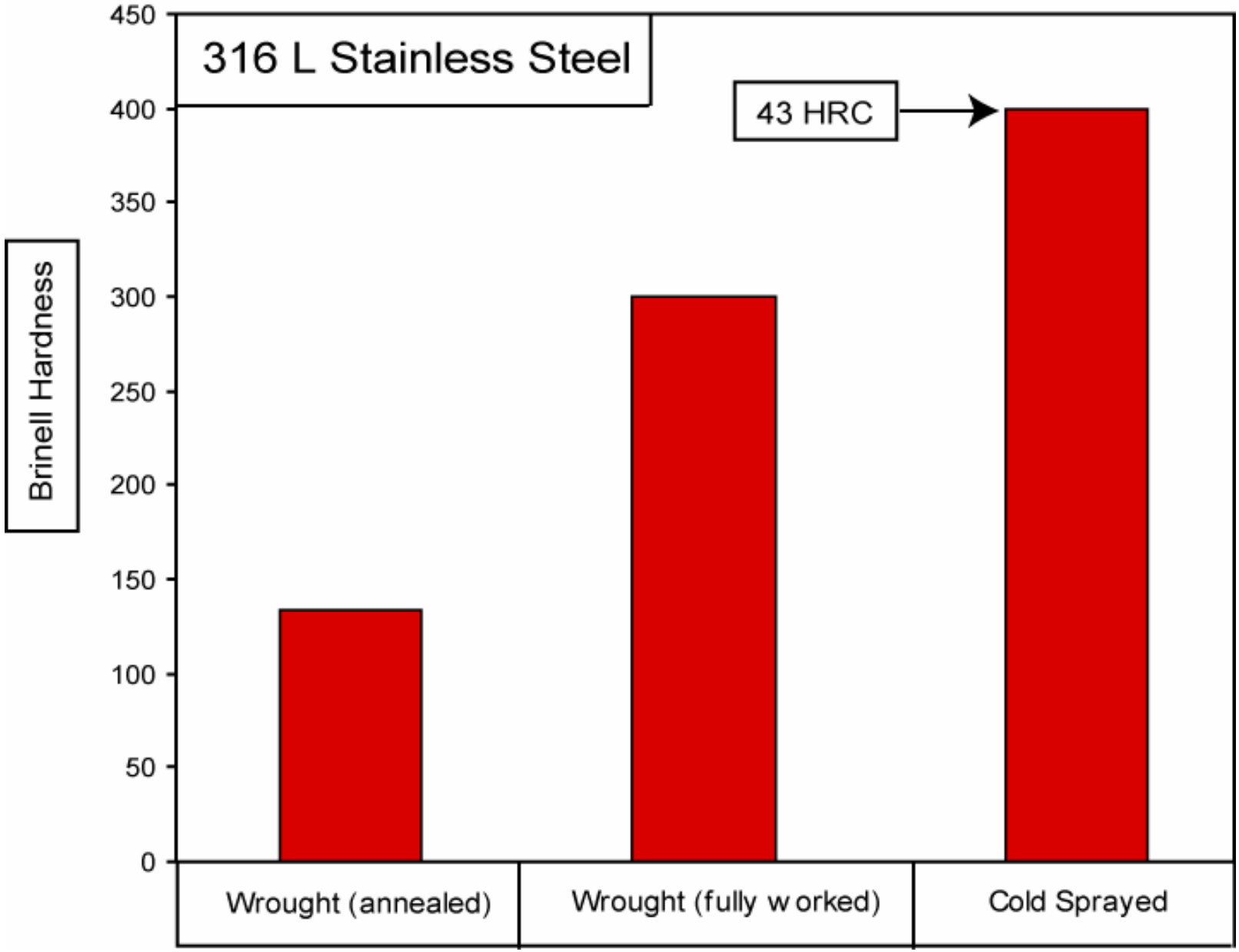
- The hardness of a cold-sprayed material is significantly higher than that of a conventional wrought material.

- The hardening is a result of the plastic deformation that occurs during particle impact and the refined microstructure of the material.

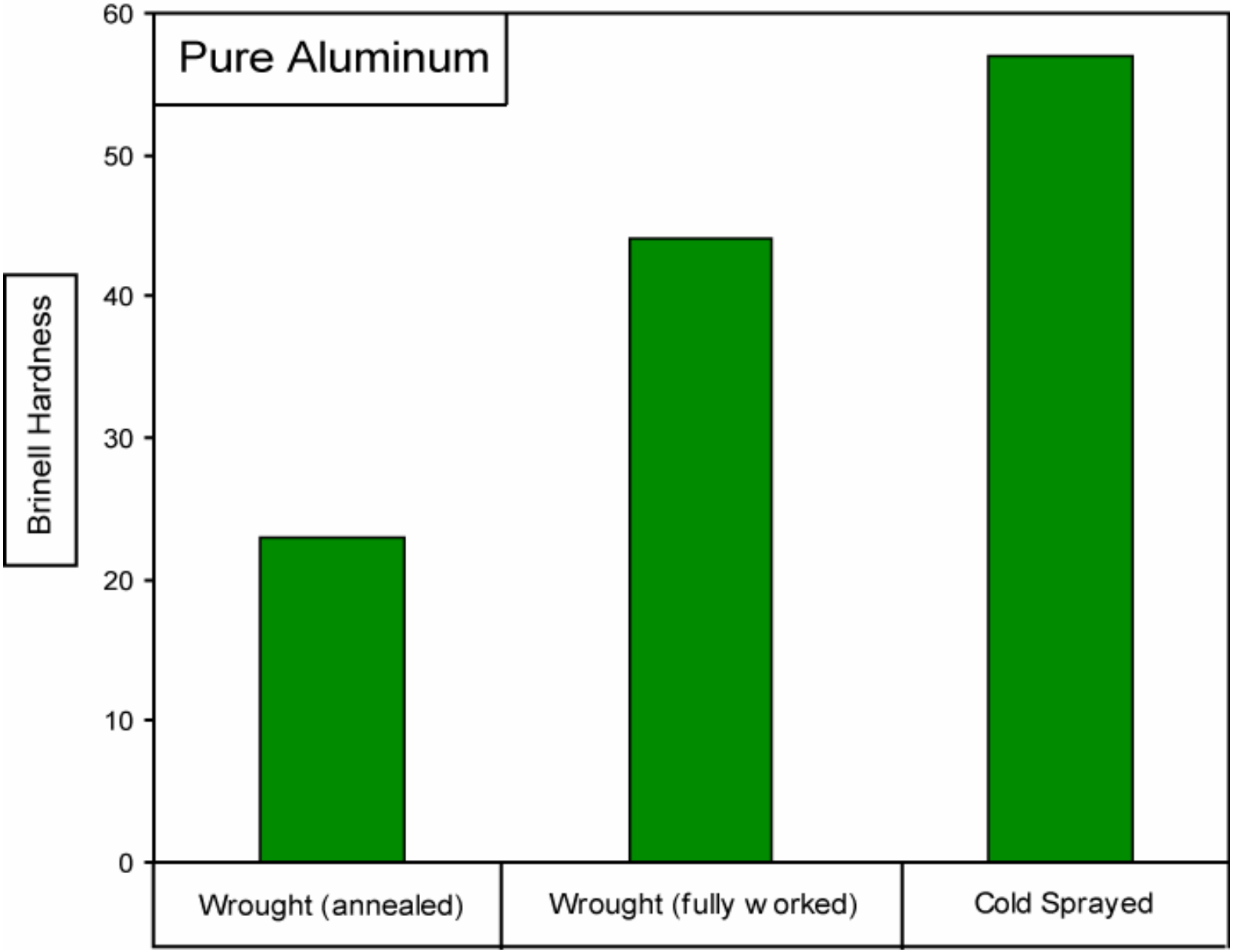
Cold Sprayed vs. Wrought Materials: Hardness



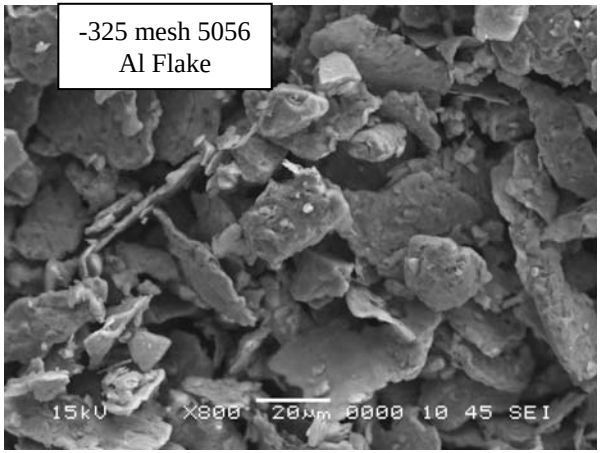
Cold Sprayed vs. Wrought Materials: Hardness

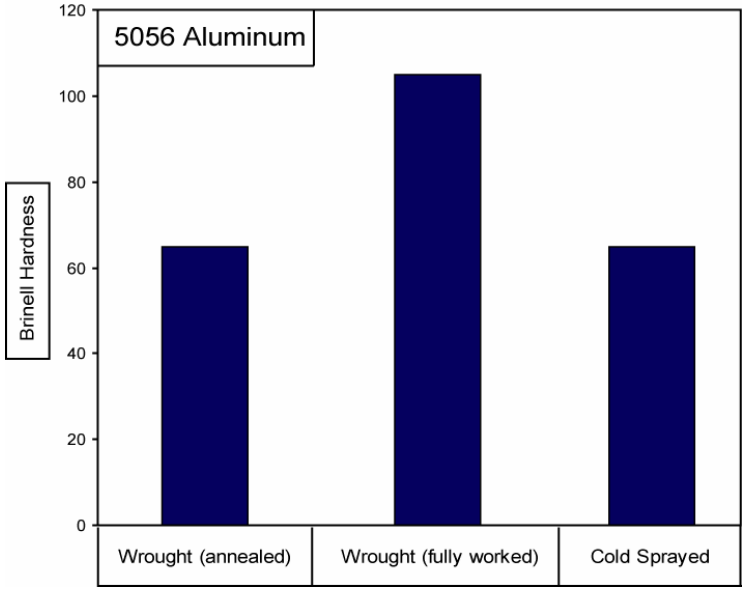


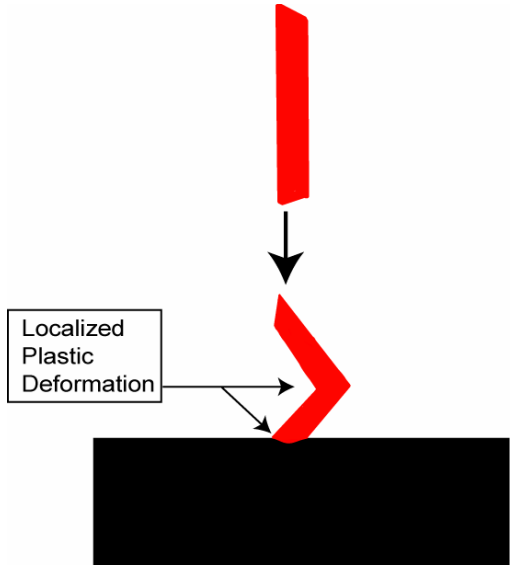
Cold Sprayed vs. Wrought Materials: Hardness

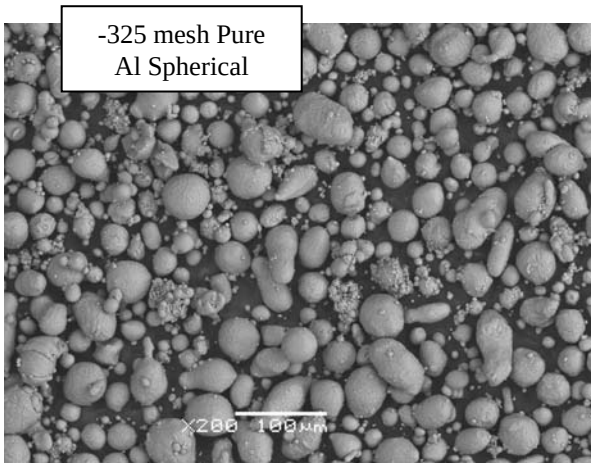


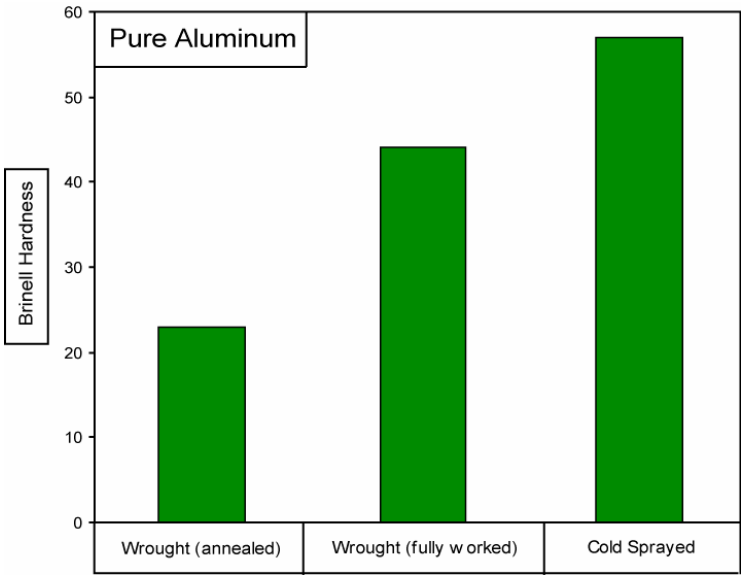
Aluminum Powder Morphology

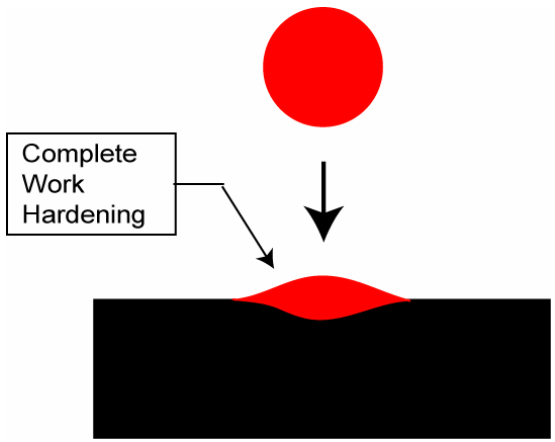






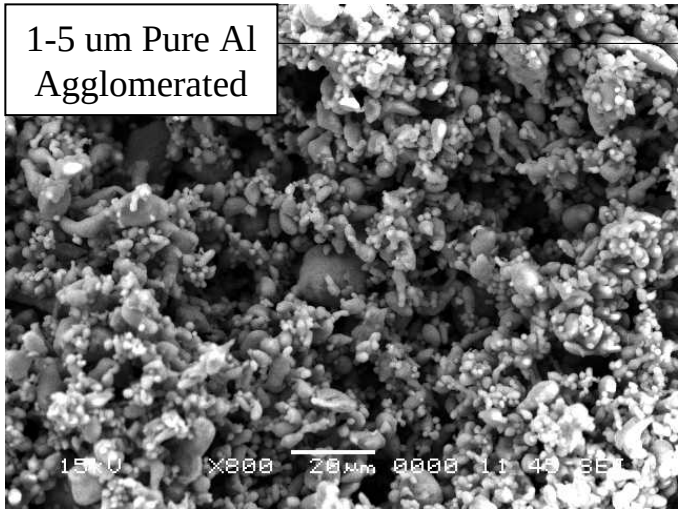




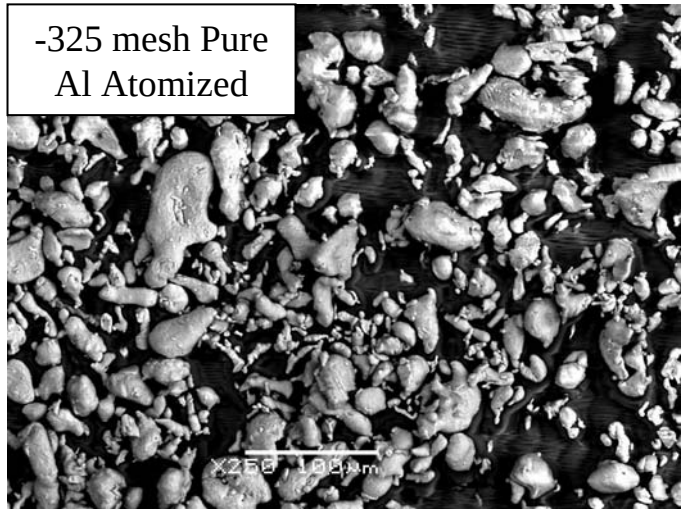


Aluminum Powder Morphology

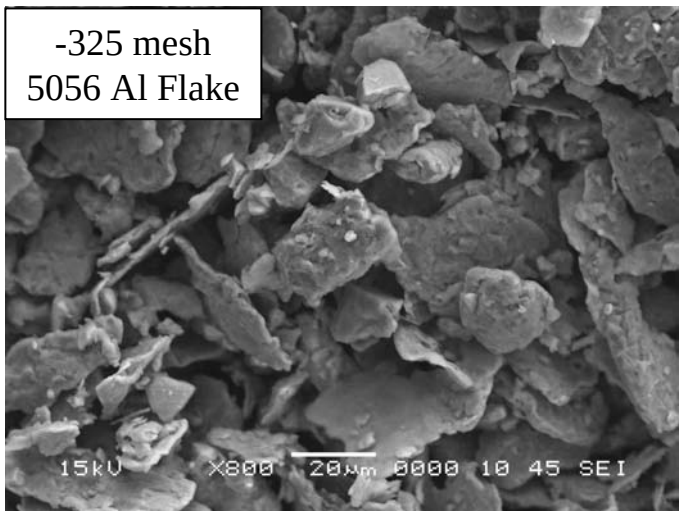
1-5 um Pure Al Agglomerated



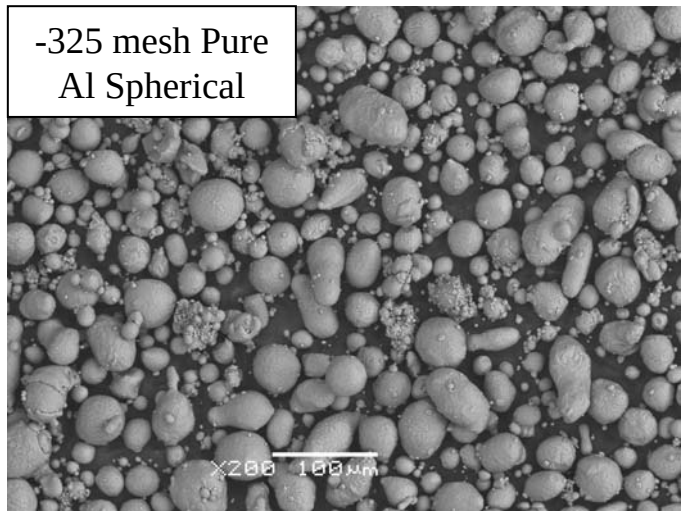
-325 mesh Pure Al Atomized



-325 mesh 5056 Al Flake



-325 mesh Pure Al Spherical

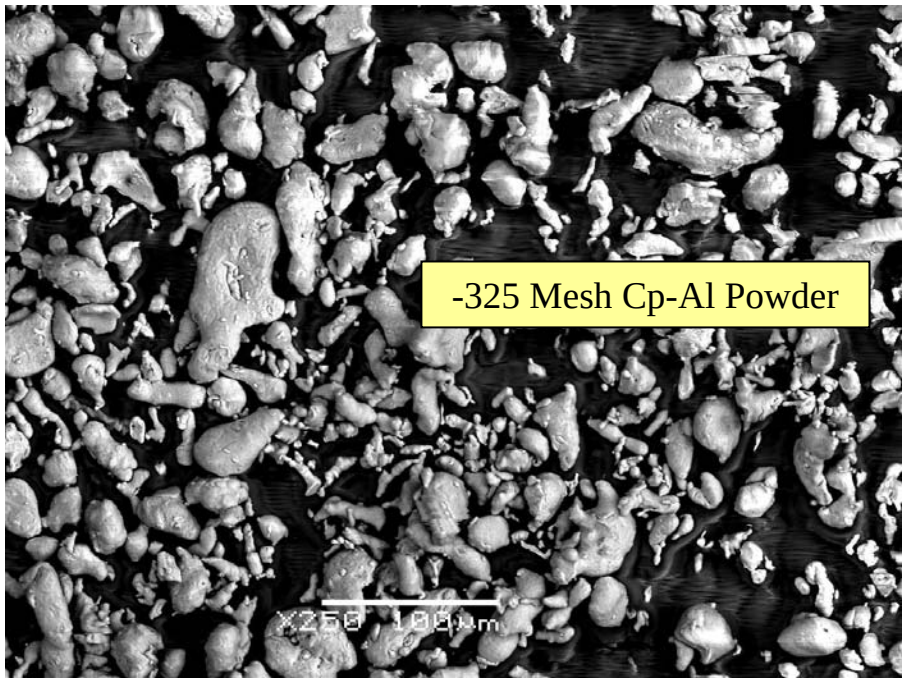


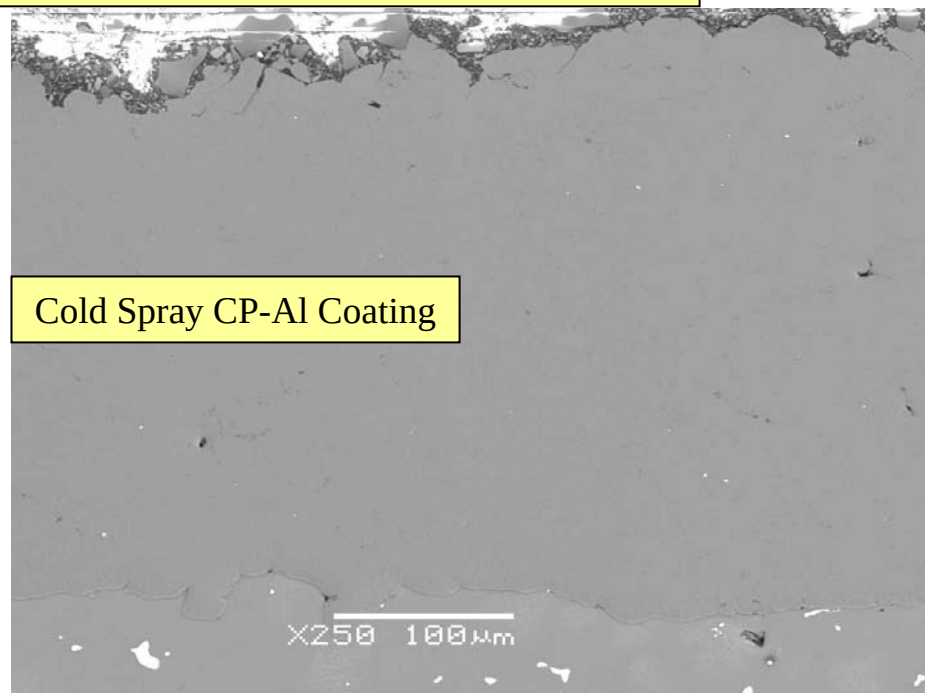
Coating quality is critically dependent on the feed powder composition, morphology, oxygen content, and mechanical properties.

Purity of Cold Sprayed Aluminum

Oxygen content measured by Inert Gas Fusion

ASTM E 1019-03



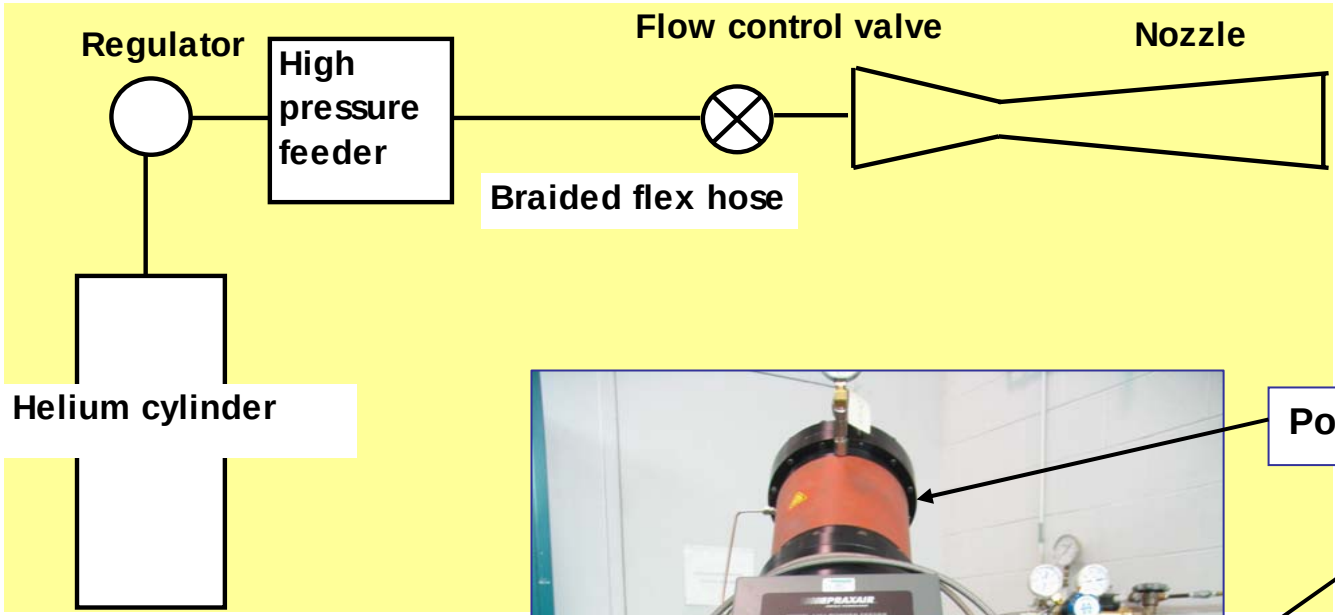


0.34 %Oxygen

0.25 %Oxygen

*The oxygen content of the cold spray coating is largely determined by the oxygen content of the original powder, not the process.

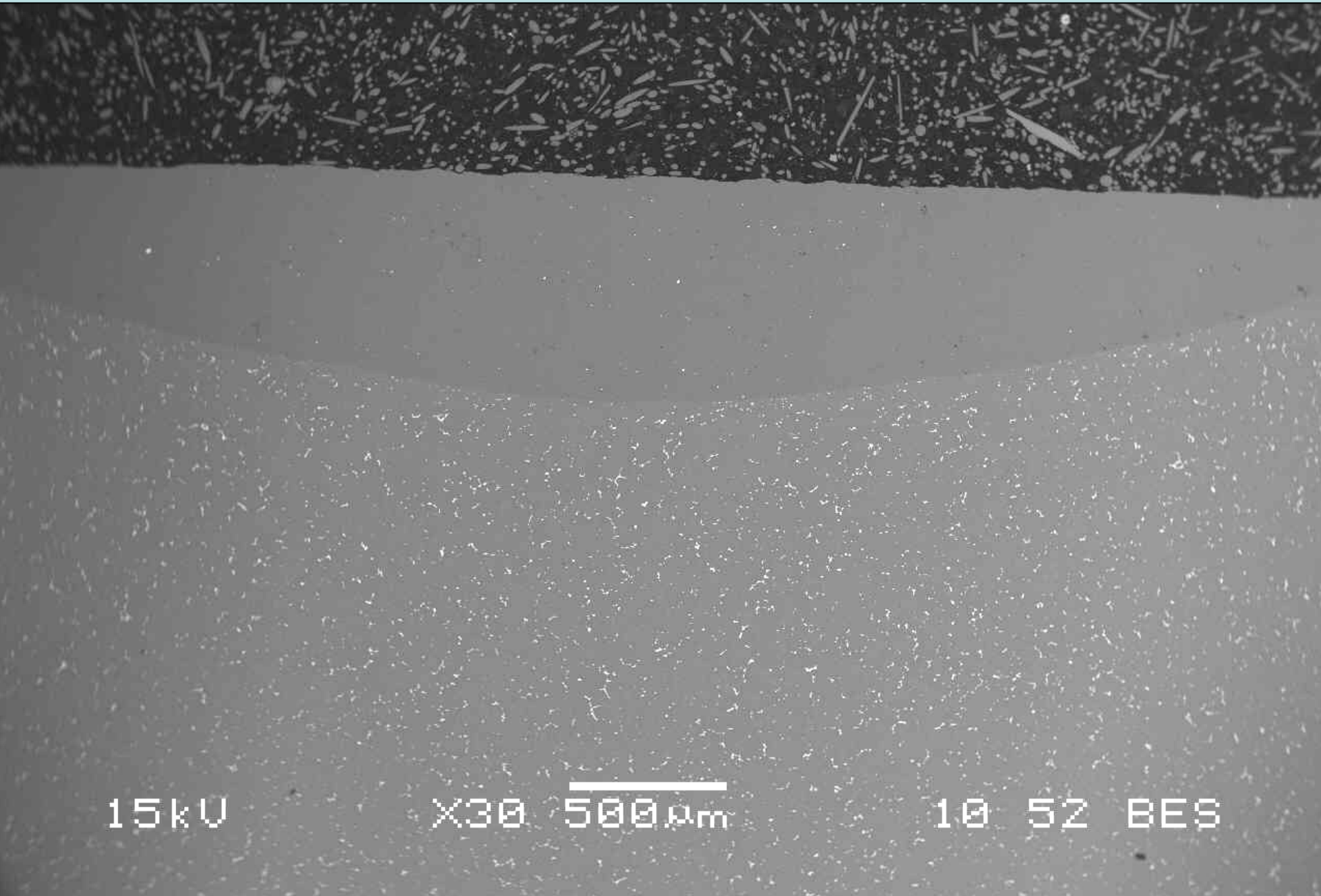
Portable ARL Cold Spray System



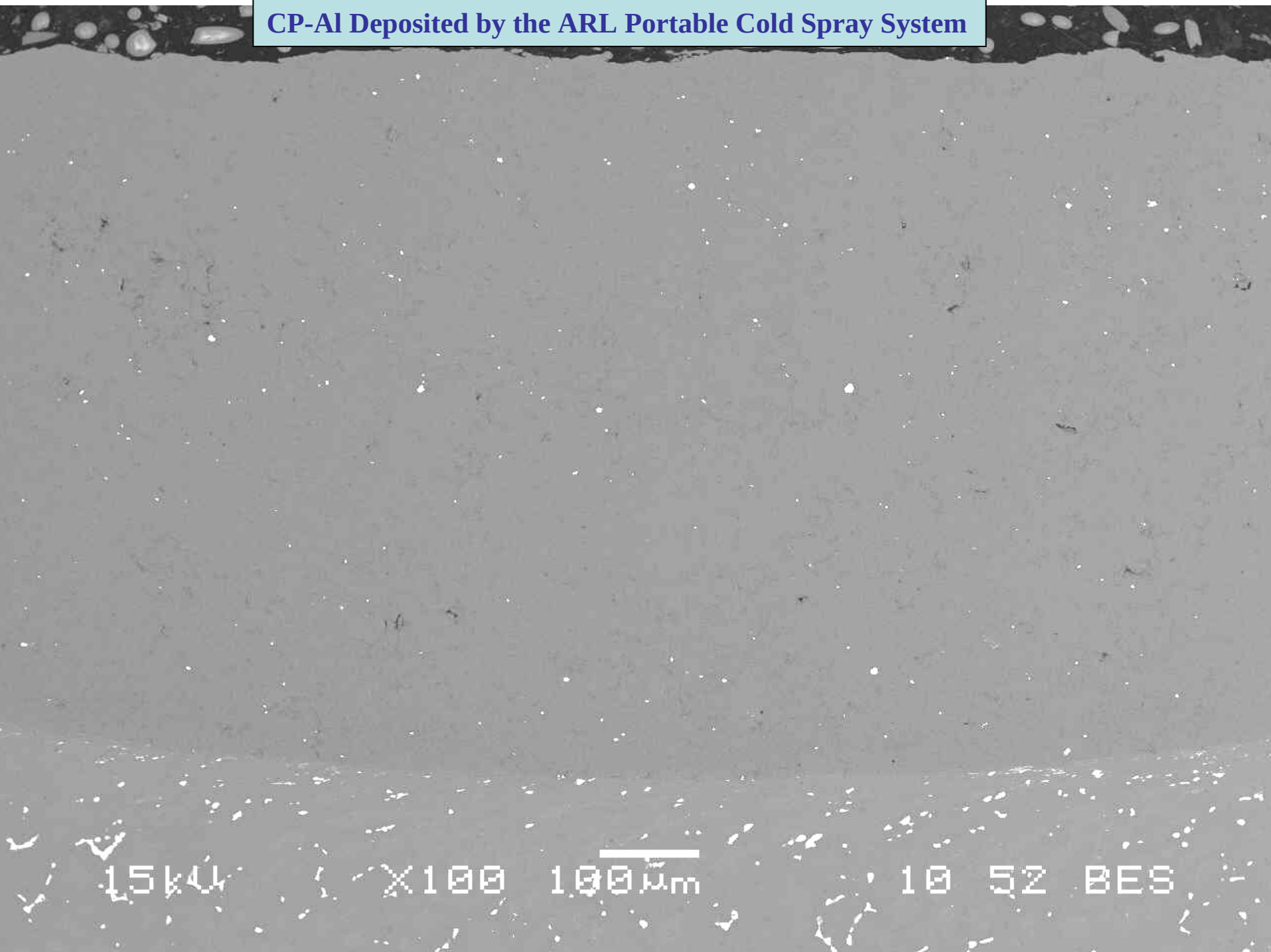
ARL Portable System Parameters for Applying CP-Al to ZE41A - Mg

Operating Parameter	Setting
Helium Pressure	400 – 500 psi
Helium Temperature	20 Degree C
Helium Flow	20 SCFM
Powder Flow	1 – 5 gram/minute
Particle Mean Diameter	20 micron
Particle Exit Velocity	1000 meter/second
Helium Cylinder Life	9 minutes

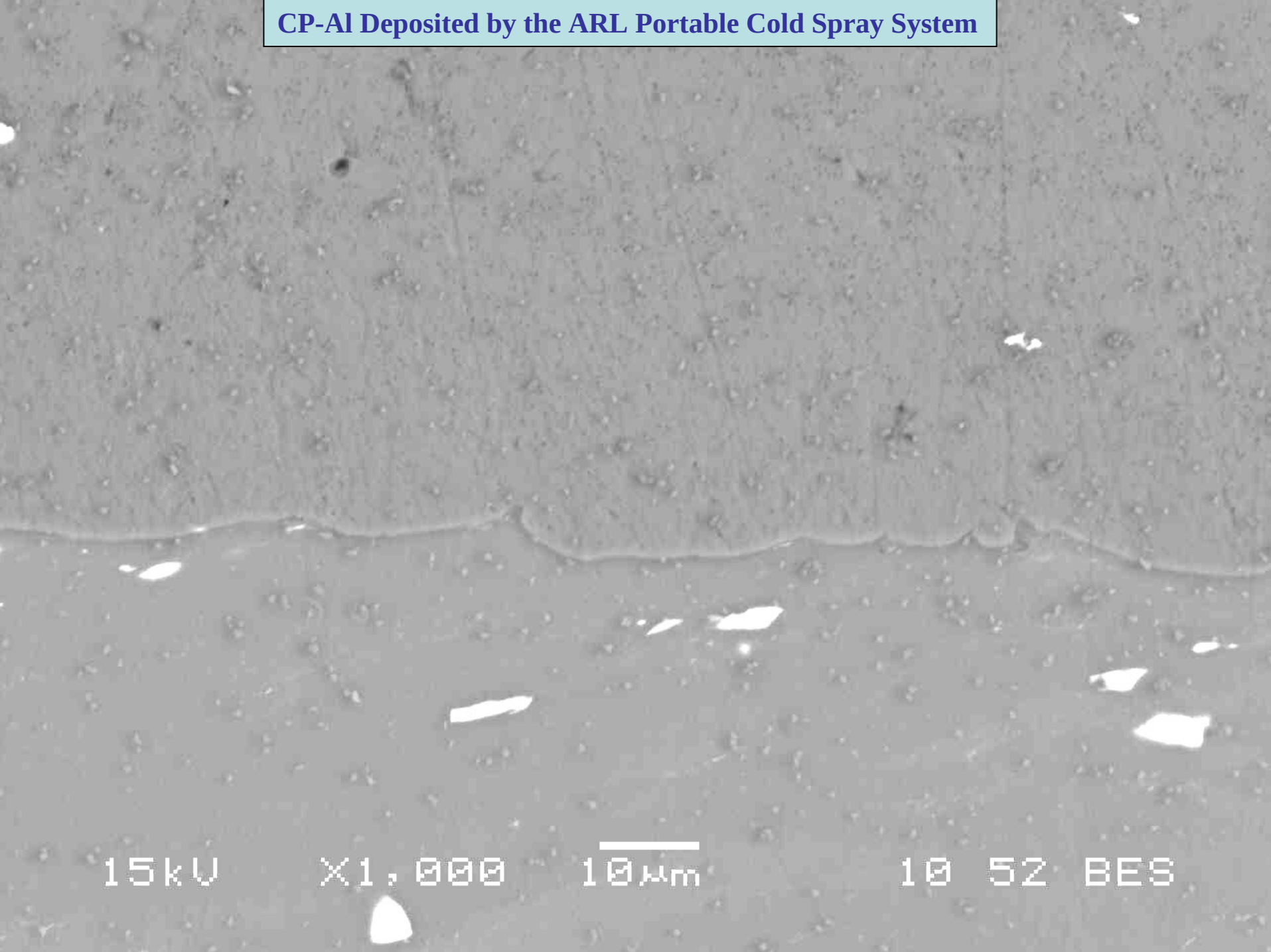
CP-Al Deposited by the ARL Portable Cold Spray System



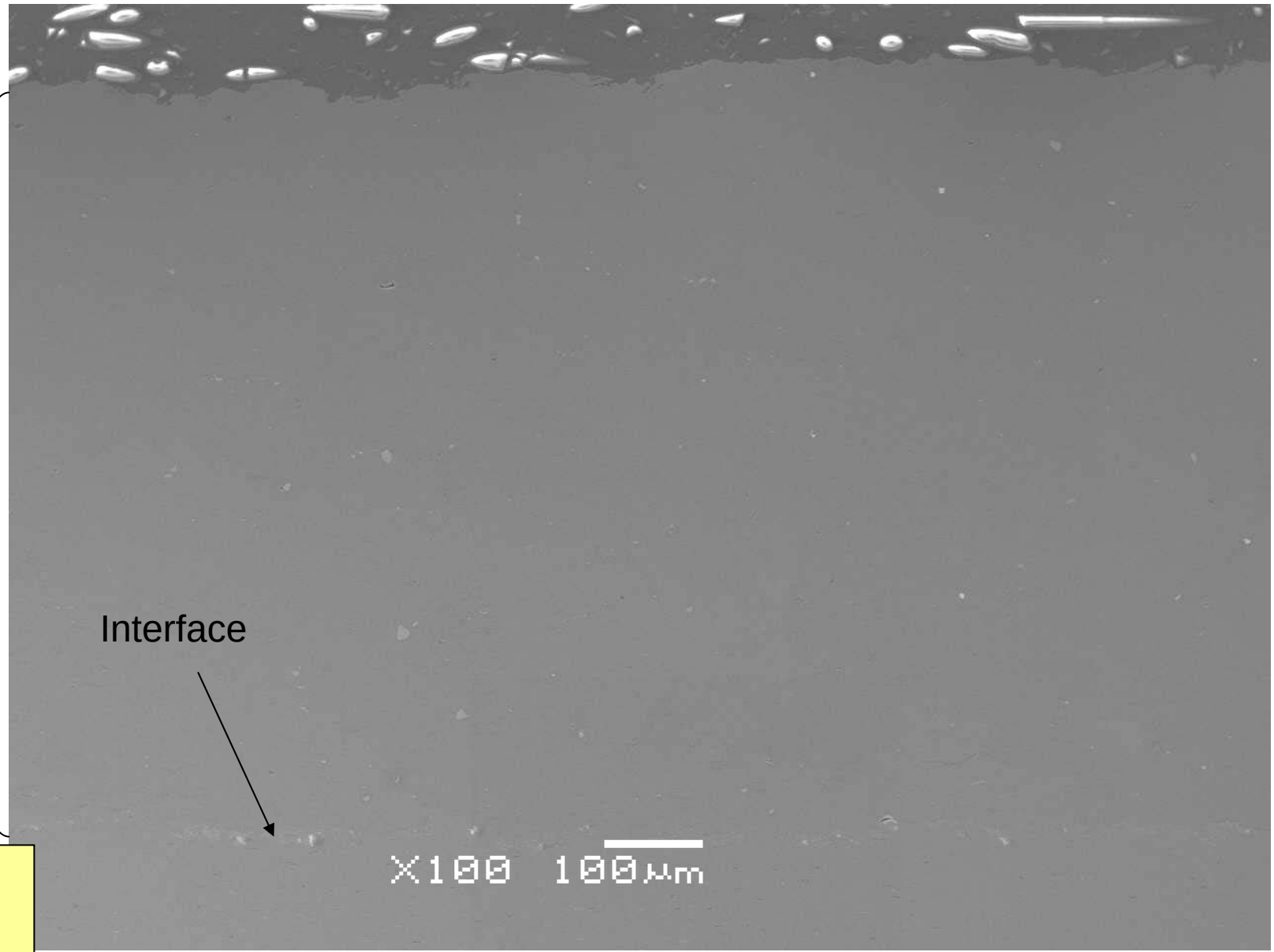
CP-Al Deposited by the ARL Portable Cold Spray System



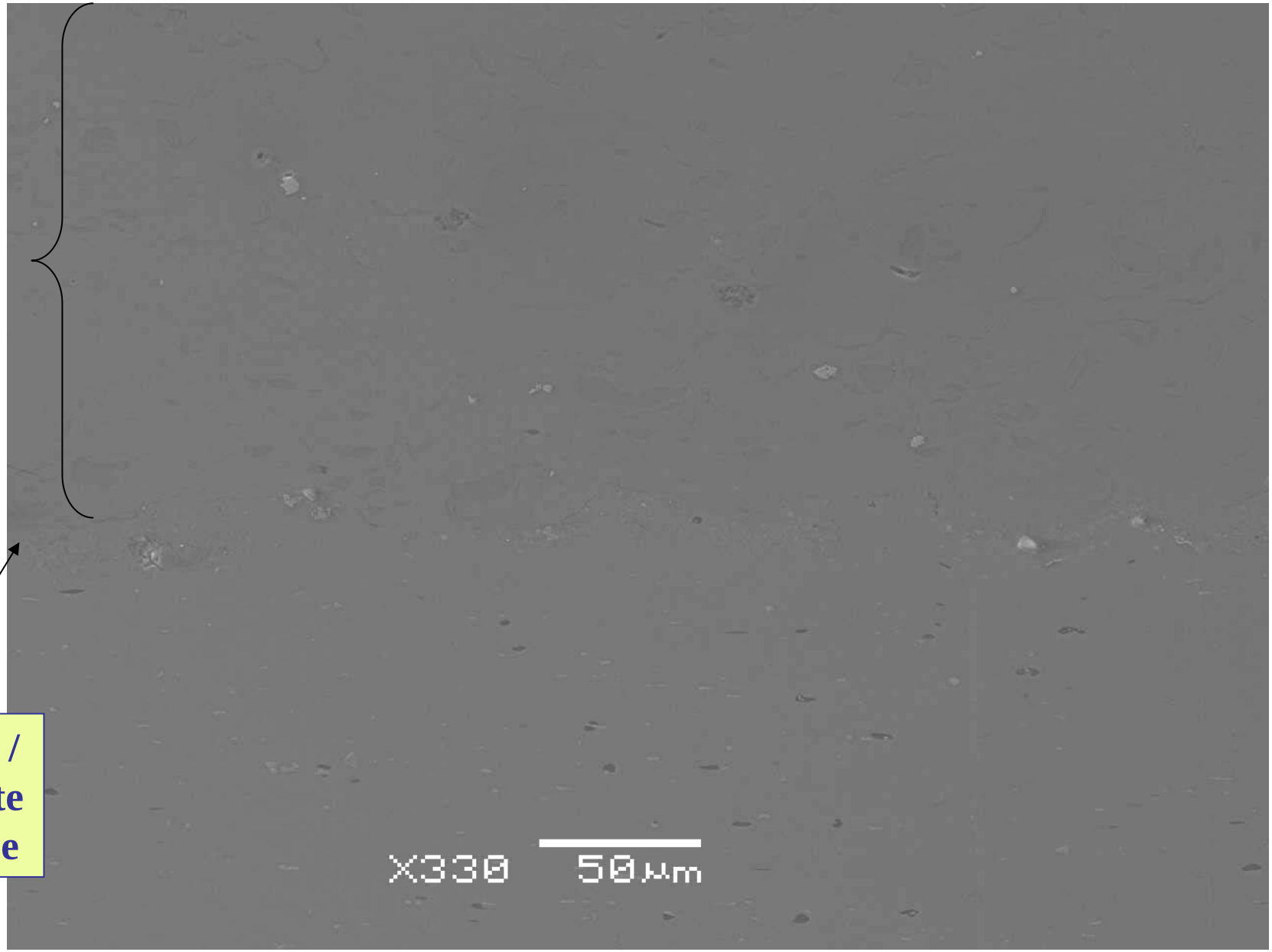
CP-Al Deposited by the ARL Portable Cold Spray System

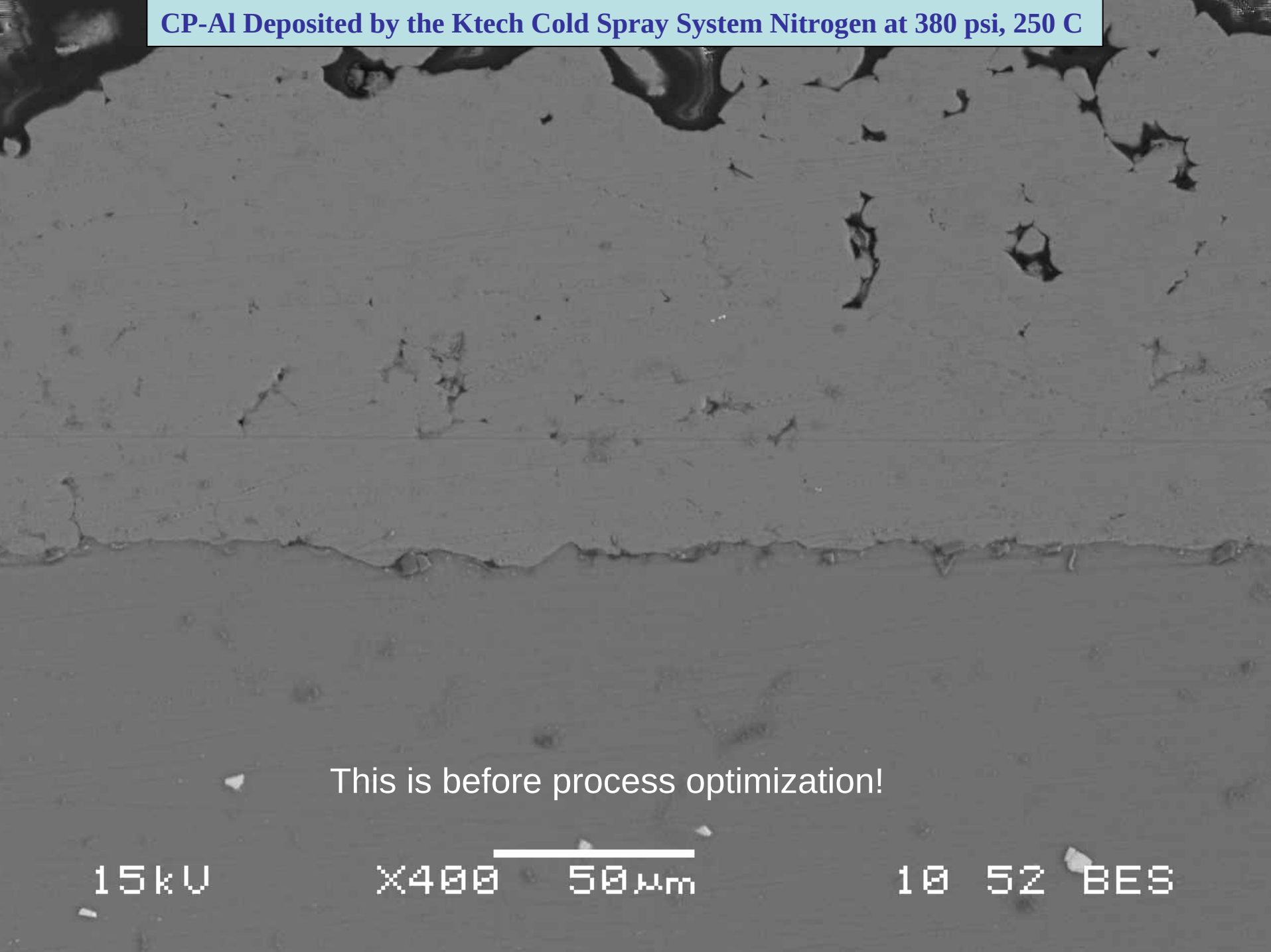


5056 Al Deposited by the Stationary System Using He



5056 Al Deposited by the Stationary System Using He




CP-Al Deposited by the Ktech Cold Spray System Nitrogen at 380 psi, 250 C
This is before process optimization!
15kV X400 50µm 10 52 BES

Applying CP-Al by Cold Spray over Magnesium

ARL Achievements (FY07 Results Highlighted in Red)

Corrosion Resistance:

>5,000, >7,000 hrs salt fog resistance-ASTM B117 (Al, 4340 steel substrates)

>619, >1,000hrs (ZE 41A magnesium substrate)

Hardness:

57 Brinell Hardness

Yield Strength:

22ksi comparable to ZE41A-T6 and AZ91E-T6 magnesium

Density:

>99% with oxide content of 0.25%

Adhesion:

> 8,500 psi, >10,350 psi

Cold Spray Process Summary:

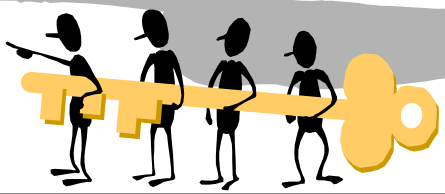
can be applied in production or in the field at room temperature

ARL Technical Hurdle

: to achieve similar results with the use of nitrogen as the carrier gas

: this hurdle has been overcome in FY07 with the use of a plastic nozzle!

Technical Approach



* nozzle design
*system modifications (heater, powder feed)
*powder morphology and condition

Future Developments

Specification Development:

Like to explore using Mantech program at ARL-PSU to create commercial specification for cold spray

Cold Spray Book:

Published through the UK