



**The ASM Thermal Spray Society
Workshop on Cold Spray Technology
(Cold Spray 2007) October 8-9**

**COLD SPRAY:
AN EMERGING TECHNOLOGY**

**Presented by:
Victor Champagne
Army Research Laboratory**

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OBJECTIVE:

- Facilitate Implementation of Cold Spray Technology



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Why hasn't Cold Spray been more embraced in North America?



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“If we could first know *where* we are, and *whither* we are tending, we could then better judge *what* to do, and *how* to do it.”



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Approach:



- **Establishment of a Cold Spray Center at ARL**
 - Provide Leadership and Direction
 - Accessible to Anyone, Exchange Information, Free Applications Development
- **Development and Implementation of Standards and Specifications**
 - Engineering drawings, technical data packages, repair procedures
 - Original Equipment Manufacturers (OEM)
 - Depots and Repair Facilities
 - Automotive and Aerospace Industry
 - Military and ASTM
- **Formation of Important Alliances**
 - Equipment Companies, Industry, Academia, Government & Private Labs
 - Powder Producers ('Cold Spray' Powders)
 - Develop Programs (Industry, DARPA, SERDP, MANTECH, NSF, SBIR, DOE)

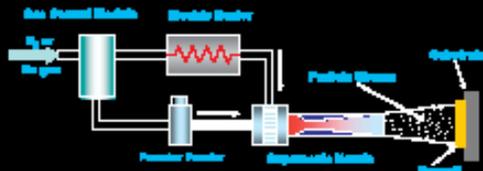




ARL Center for Cold Spray



ENHANCING THE PERFORMANCE OF MATERIALS AND COMPONENTS

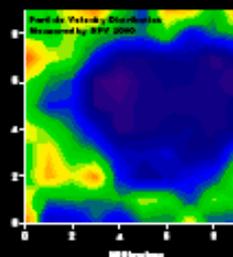


Cold Spray System Configuration



- Max Gas Pressure: 100-300 psia
- Gas Temperature: 0-1000 °F
- Max Gas Flow Rate: 30-400 CFM
- Powder Feed Rate: 10 to 200 gph
- Particle Velocity: 600-1200 m/s

Stationary Cold Spray System



- 20 Micron Copper Particles
- 25 m/s Streamline
- 400 psia, 400 °F N₂ Gas

- 100 m/s
- 200 m/s
- 300 m/s
- 400 m/s
- 500 m/s

Modeling of Cold Spray Process Parameters

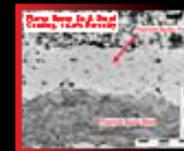
ADVANTAGES

- Low Temperature Process
 - Below Melting Point of Metals
 - No Combustion Fuels, Gases
 - Results in Highly Conductive Deposits
- Solid State Bonding
 - Mechanical Mixing of Particles and Substrate
 - Similar to Explosive Bonding
 - Plastic Deformation of Particles Disrupt Oxide Films
 - Compressive Residual Stresses
- High Density Deposits
 - Form Thick Coatings at High Deposition Rates
 - Low Oxide and Porosity Content (<1%)
 - Form Free-Standing Structures



- HMMWV Shelter Shows EMI Shielding to Protect Electronics from Electromagnetic Interference
- The Joints in Assembly Composite Walls Meet as Solder with a Low-Porosity, Conductive Seal
- The Composite Structure Shows Low-Temperature Application of Seal

EMI Shielding for HMMWV Shelter by Cold Spray



Comparison of Cold Spray and Thermal Spray

APPLICATIONS

- Corrosion Resistant Coatings (Zn, Al)
- Dimensional Restoration and Repair (Ni, Stainless Steel, Titanium, Aluminum)
- Wear Resistant Coatings (CrC-NiCr, WC-Co, WCu)
- EMI Shielding
- Portable Units for Field Repair



• SEE A SECTION OF COLD SPRAY COATING

• Cores and Tie Rods are Coated with the Porous Cold Spray Seal

• Aerosol/Seal Applied to Interior Walls

Applied EMI Shielding on the HMMWV Shelter



Appropriate Applications for Cold Spray

- The 'Only Game In Town' Applications: Target those applications that are either not possible and/or not feasible by other methods.
 - EMI Shielding (HMMWV Electronic Shelter)
 - Dimensional Restoration (Apache Mast Support-AI, Black Hawk & Seahawk-AI)
 - Wear Resistant Coatings (M1A1 Tank Ammunition Box-Ni)
 - Casting Repair (magnesium, aluminum)
 - Electronics (metalizing ceramics)
 - Fabrication of Parts (graded structures, unique materials)
 - Novel Weapon Systems (land vehicles, munitions, aerospace, electronics)



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EMI Shielding for HMMWV Shelter by Cold Spray

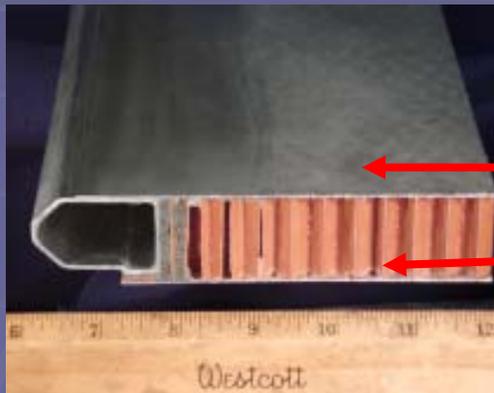


ARL Produces First Prototype Using Cold Spray Technology for the Terminal High Altitude Area Defense (THAAD) Project Office.



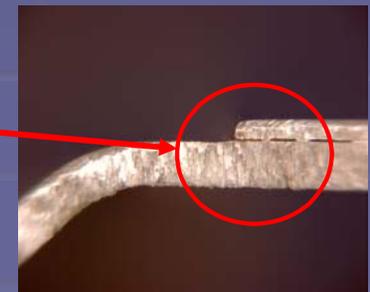
- HMMWV shelters require EMI shielding to prevent entrance/escape of electronic signals.
- The joints in al-composite walls must be sealed with a non-porous, conducting metal.
- The composite structure requires low-temperature application of sealer.

Conductive material needed to fill seams



Aluminum

Composite



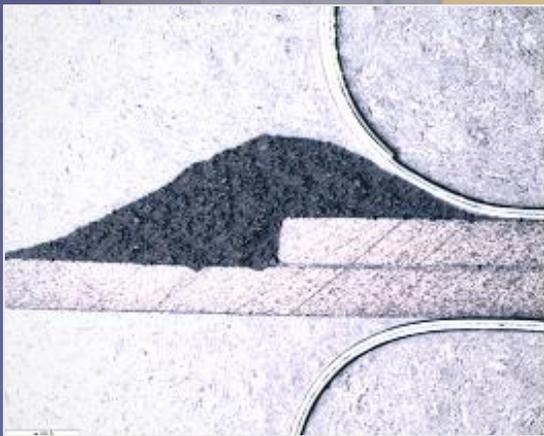
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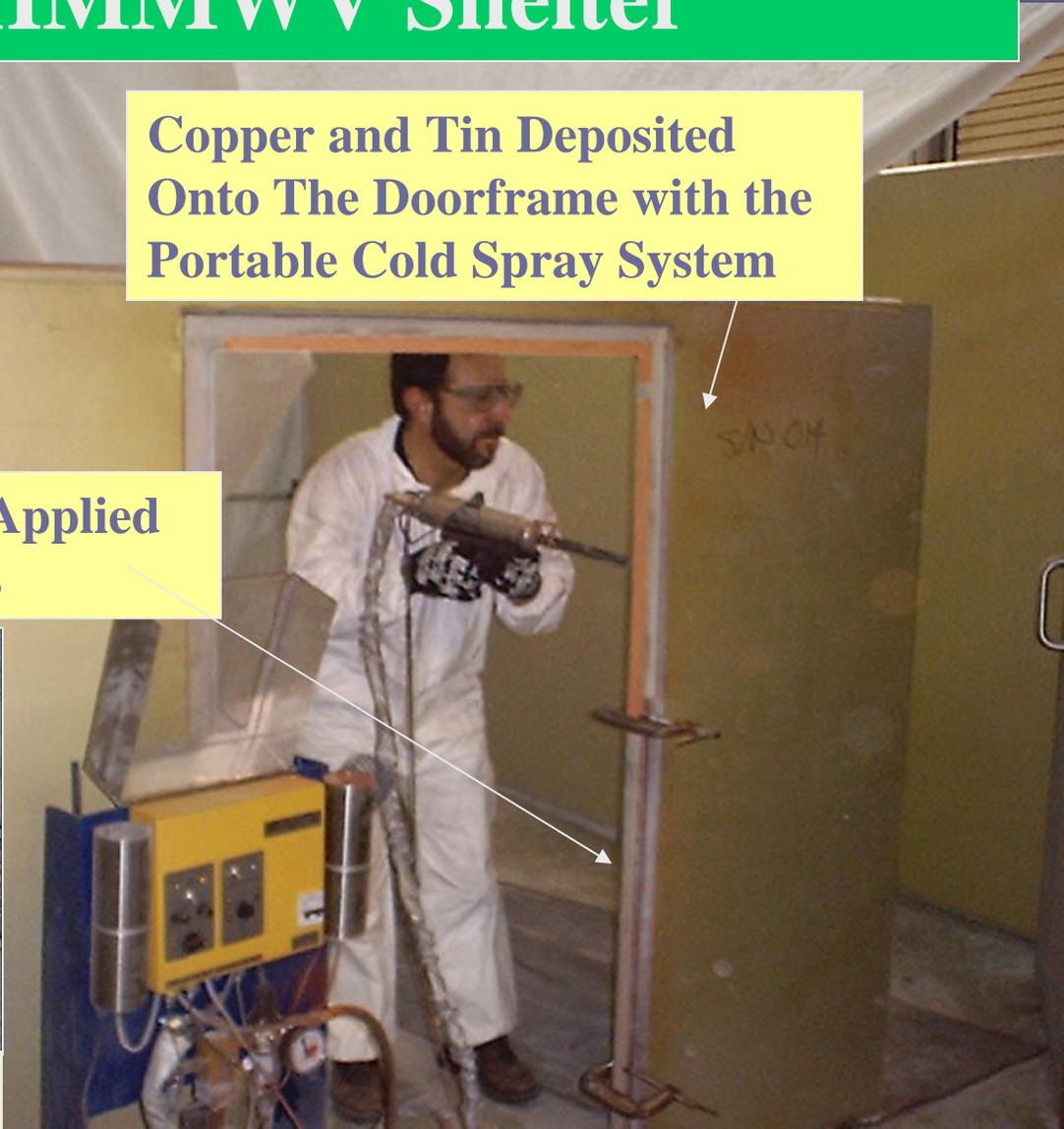
Applying EMI Shielding on the HMMWV Shelter

Copper and Tin Deposited
Onto The Doorframe with the
Portable Cold Spray System

Aluminum/Zinc Applied
to Interior Seams



Cross Section of Cold
Spray Coating



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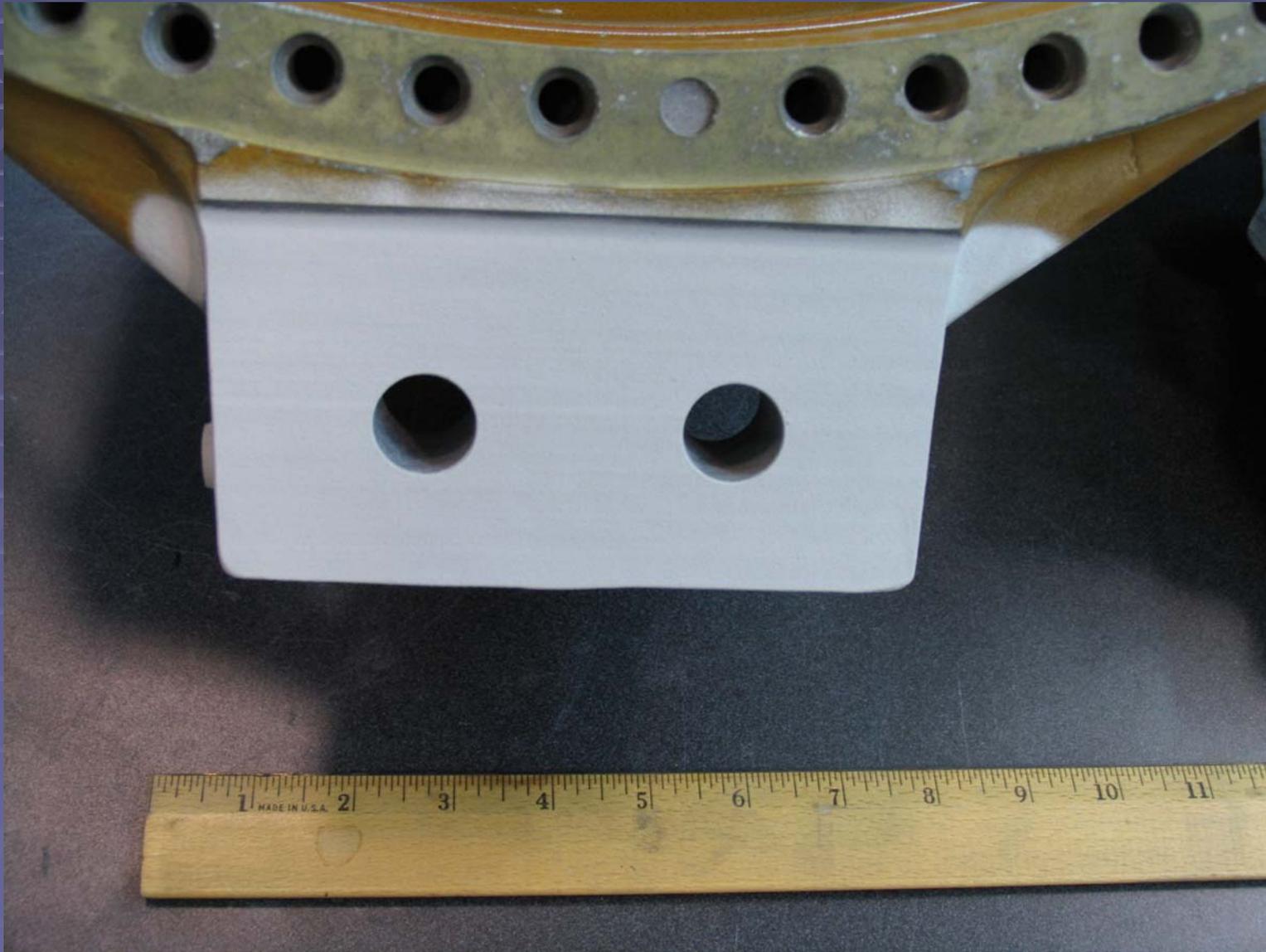
Cold Spray Is Applied on Complex Geometries UH-60 Transmission Housing



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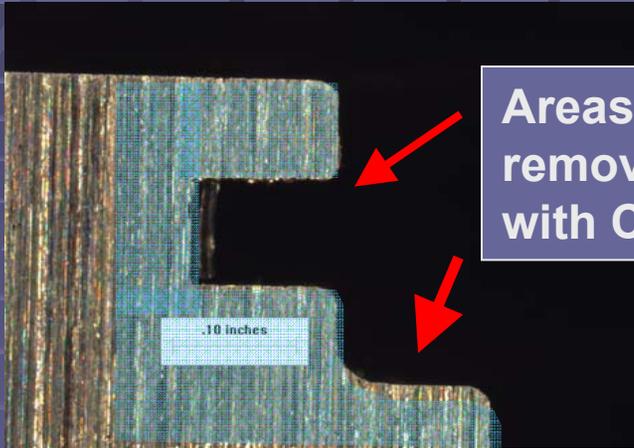
Completed Cold Spray Repair of ZE-41A Mg



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Apache Helicopter-Ring Groove Repair



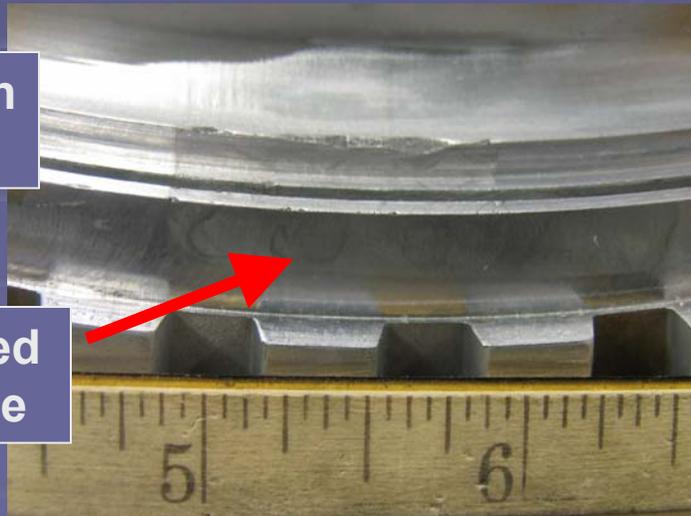
Areas to be removed and filled with Cold Spray



Metal removed from Ring Groove



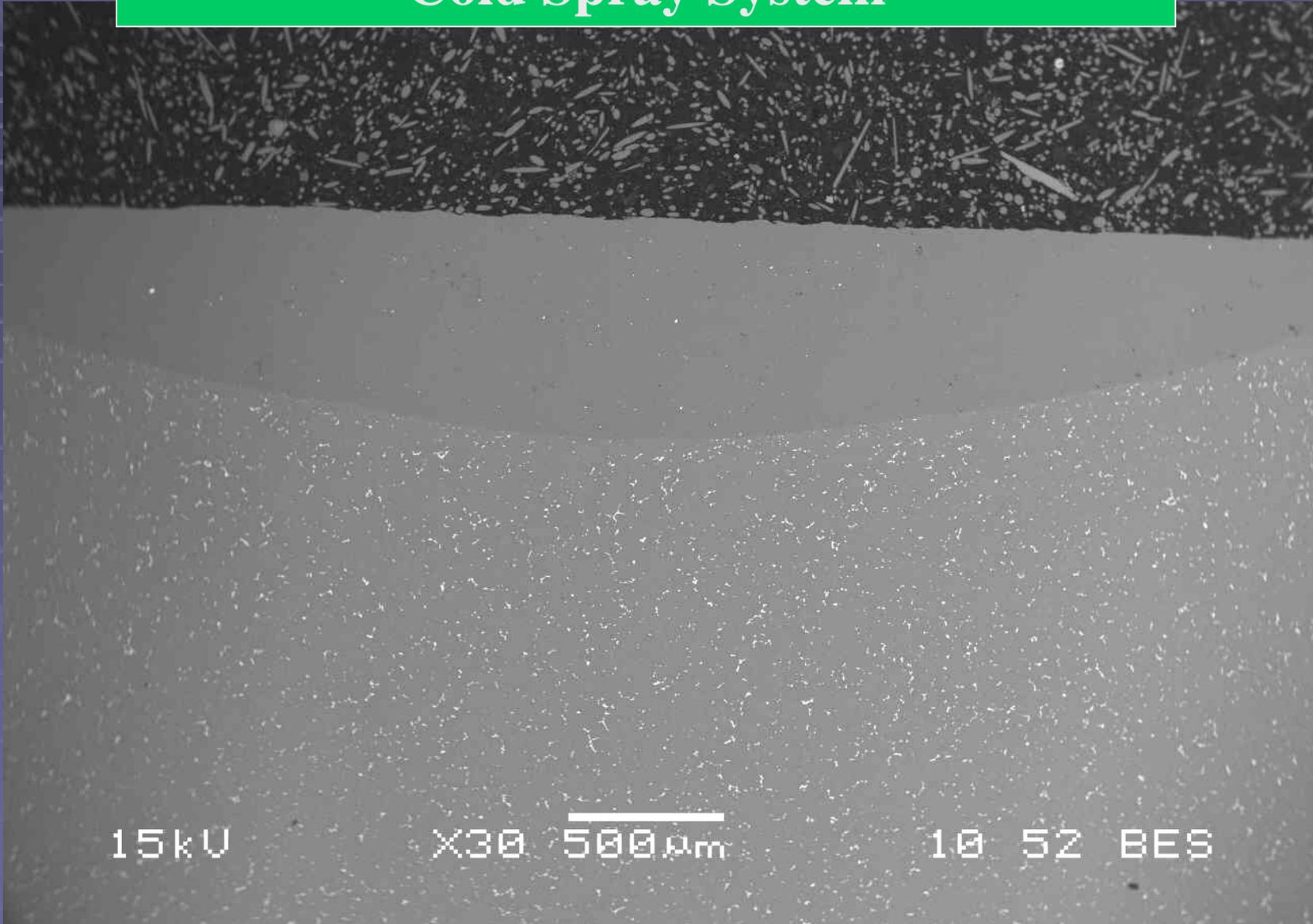
Area filled with Cold Spray



Re-machined Ring Groove



CP-Al Deposited by the ARL Portable Cold Spray System



15kV

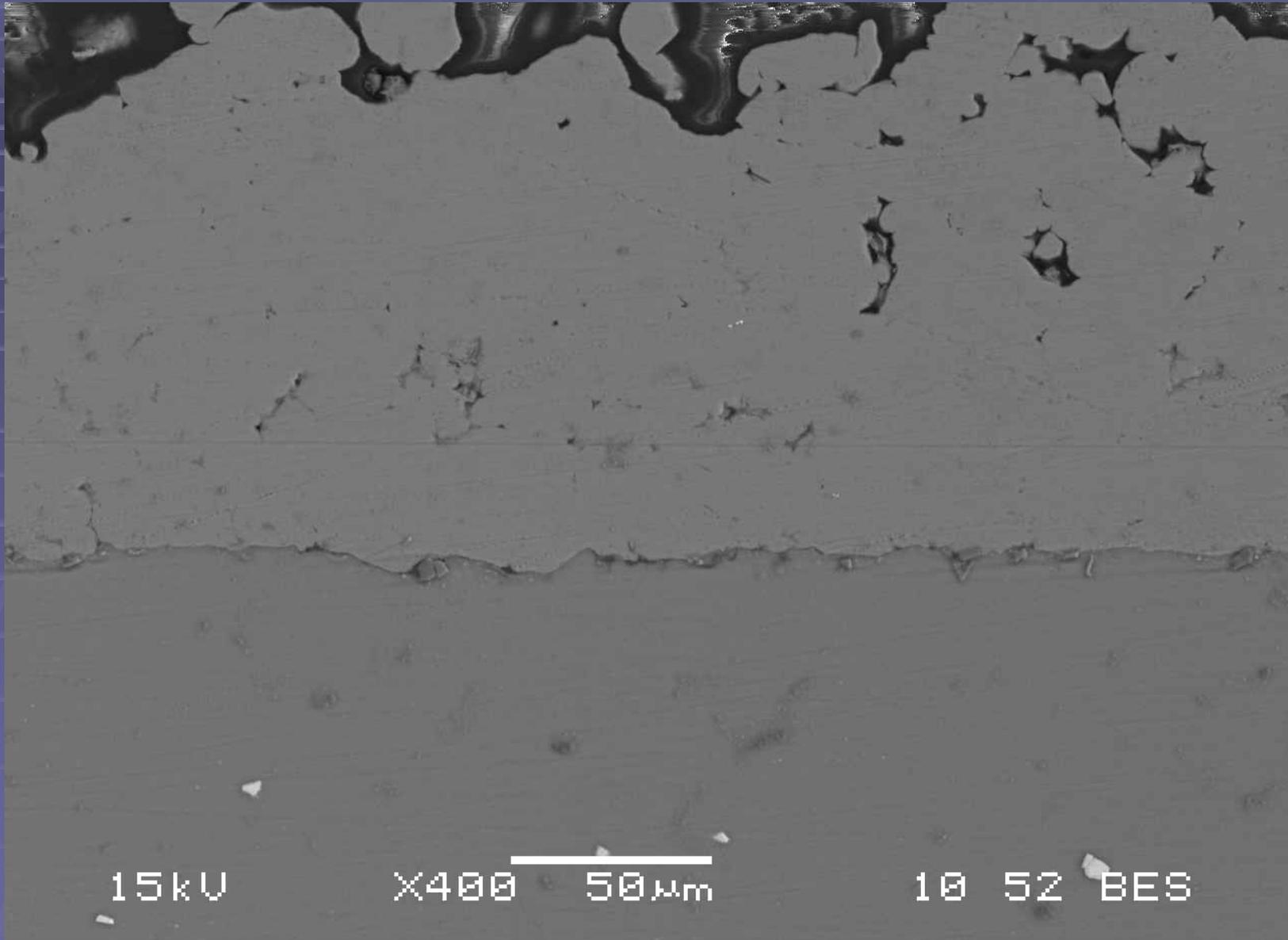
X30 500µm

10 52 BES

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CP-Al Deposition Prior To Optimization



15kV

X400 50µm

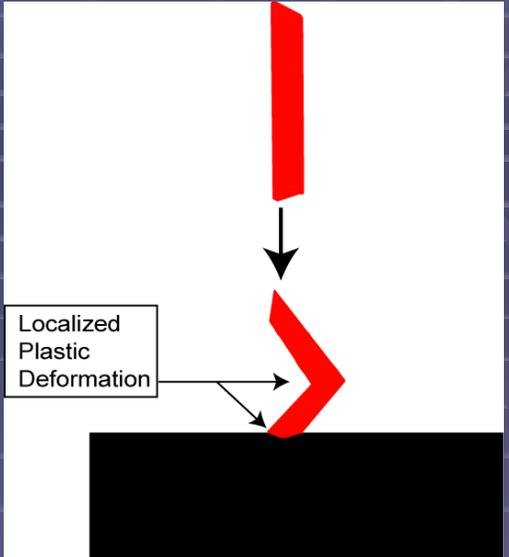
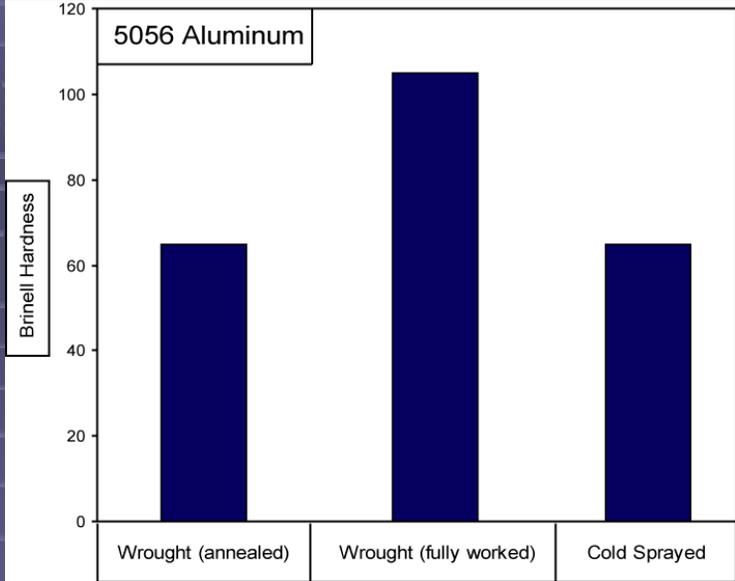
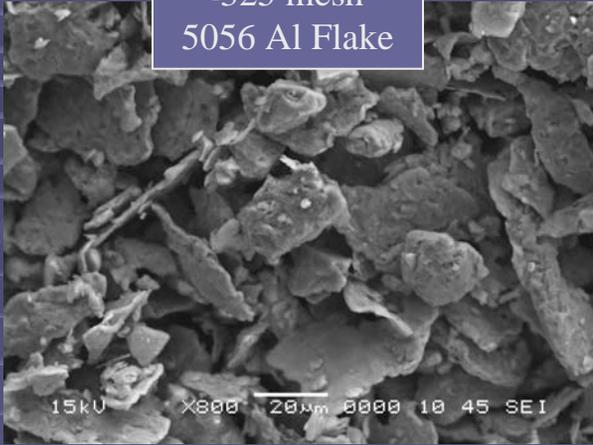
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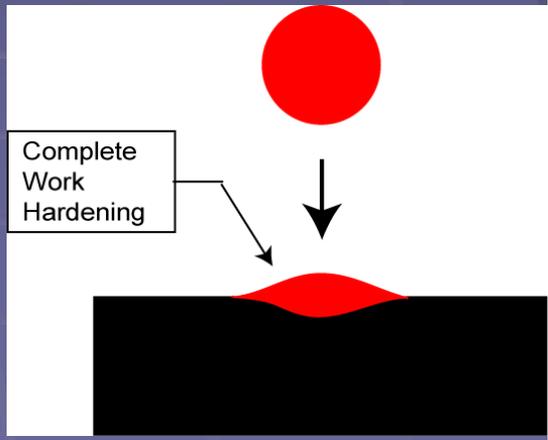
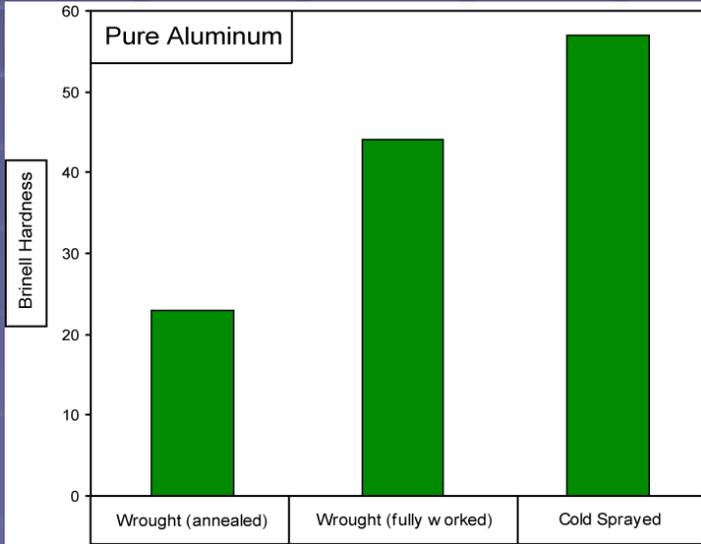
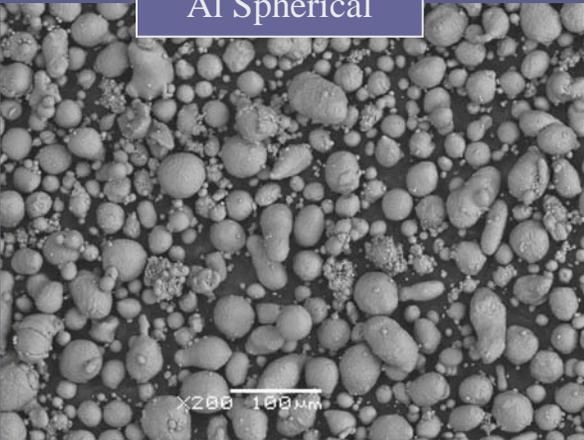


Aluminum Powder Morphology

-325 mesh
5056 Al Flake



-325 mesh Pure
Al Spherical

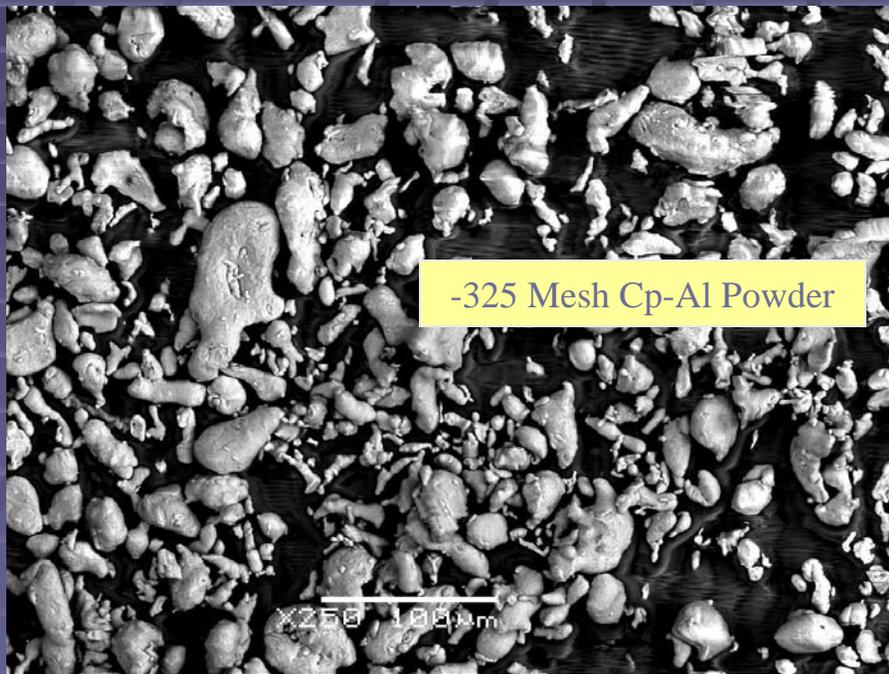


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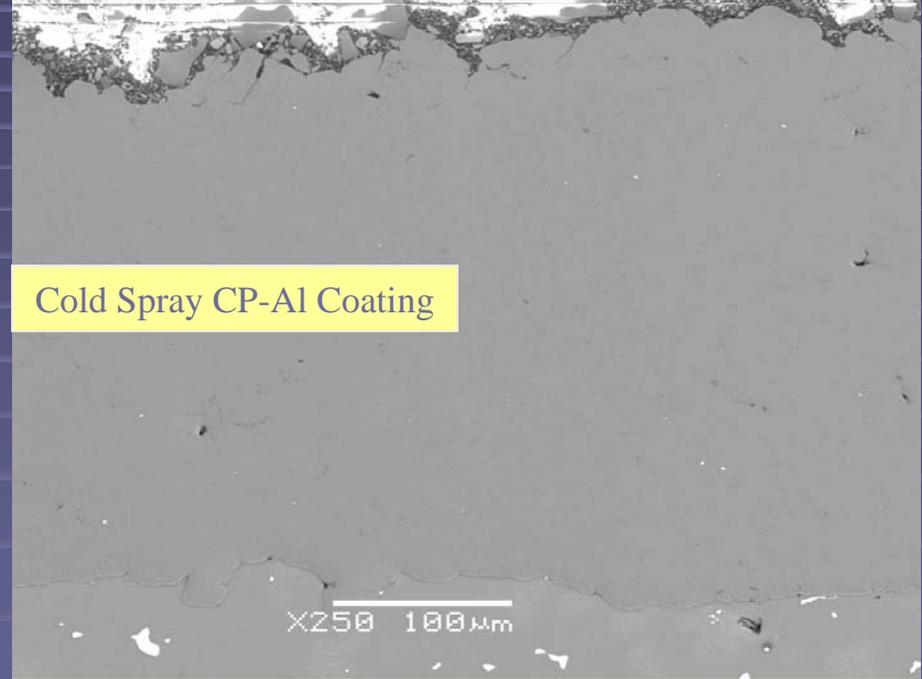


Purity of Cold Sprayed Aluminum

Oxygen content measured by Inert Gas Fusion
ASTM E 1019-03



-325 Mesh Cp-Al Powder



Cold Spray CP-Al Coating

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.

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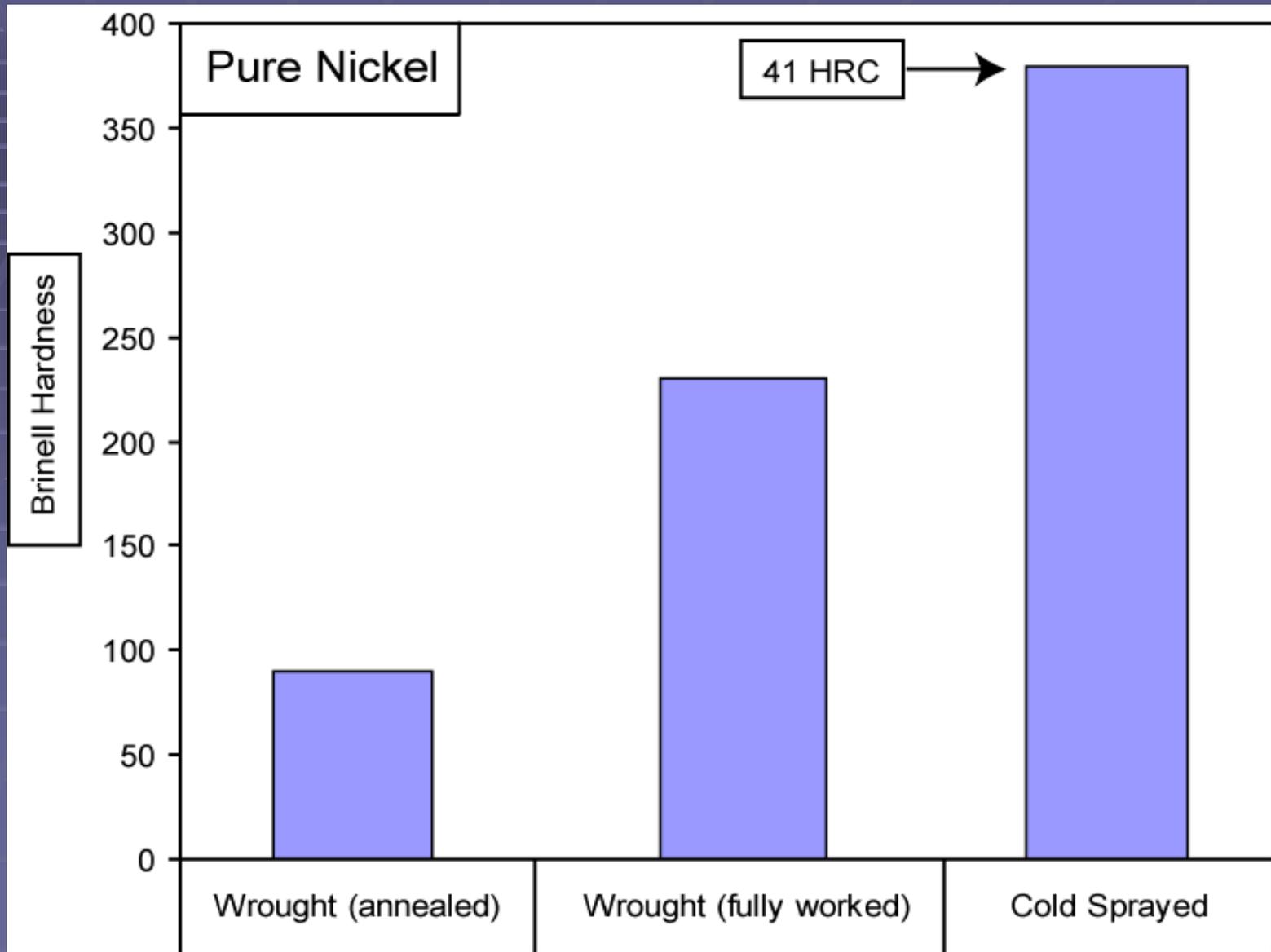


Cold Sprayed vs. Wrought Materials Hardness Comparison

- The hardness of a cold-sprayed material can be 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.



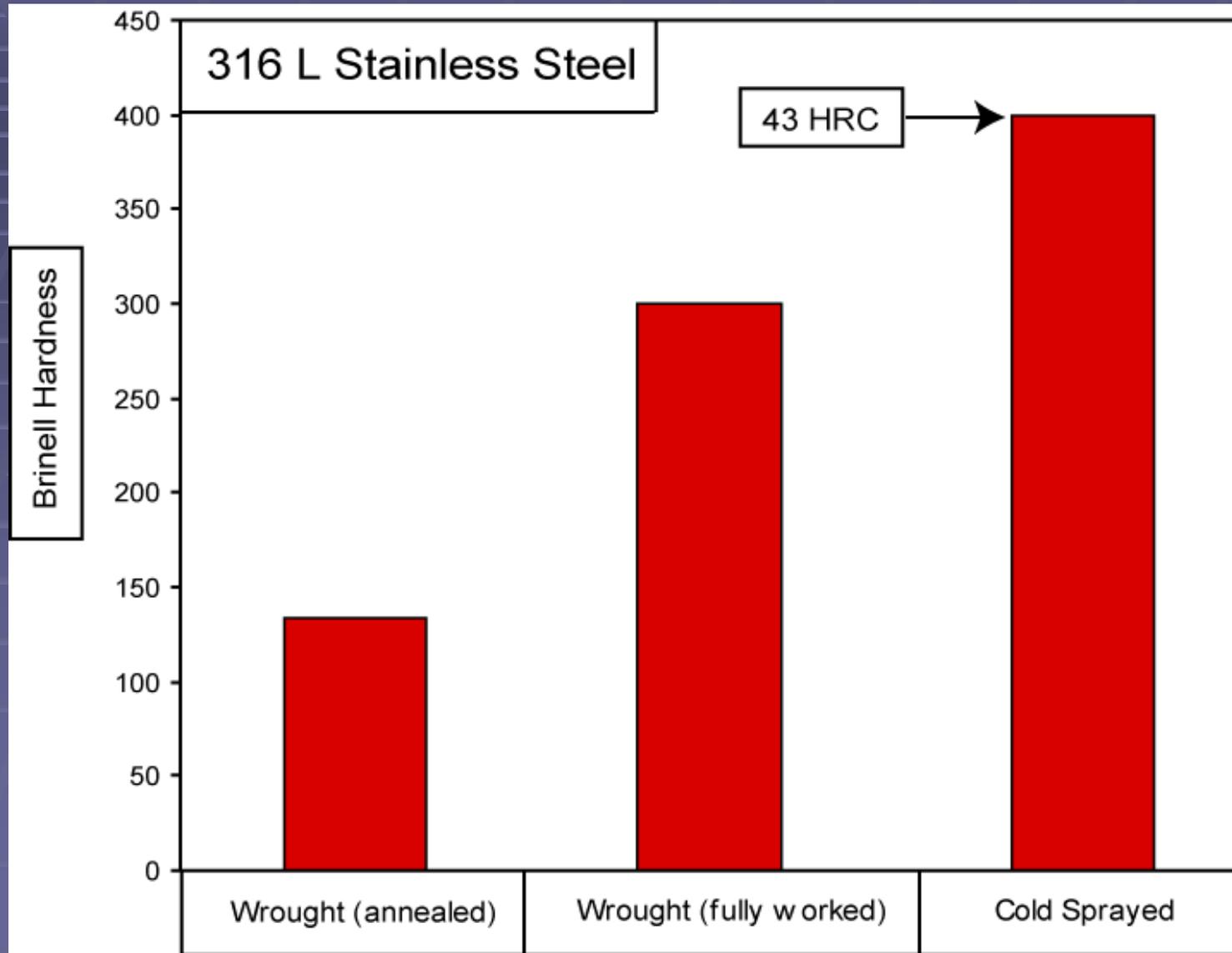
Cold Sprayed vs. Wrought Materials: Hardness



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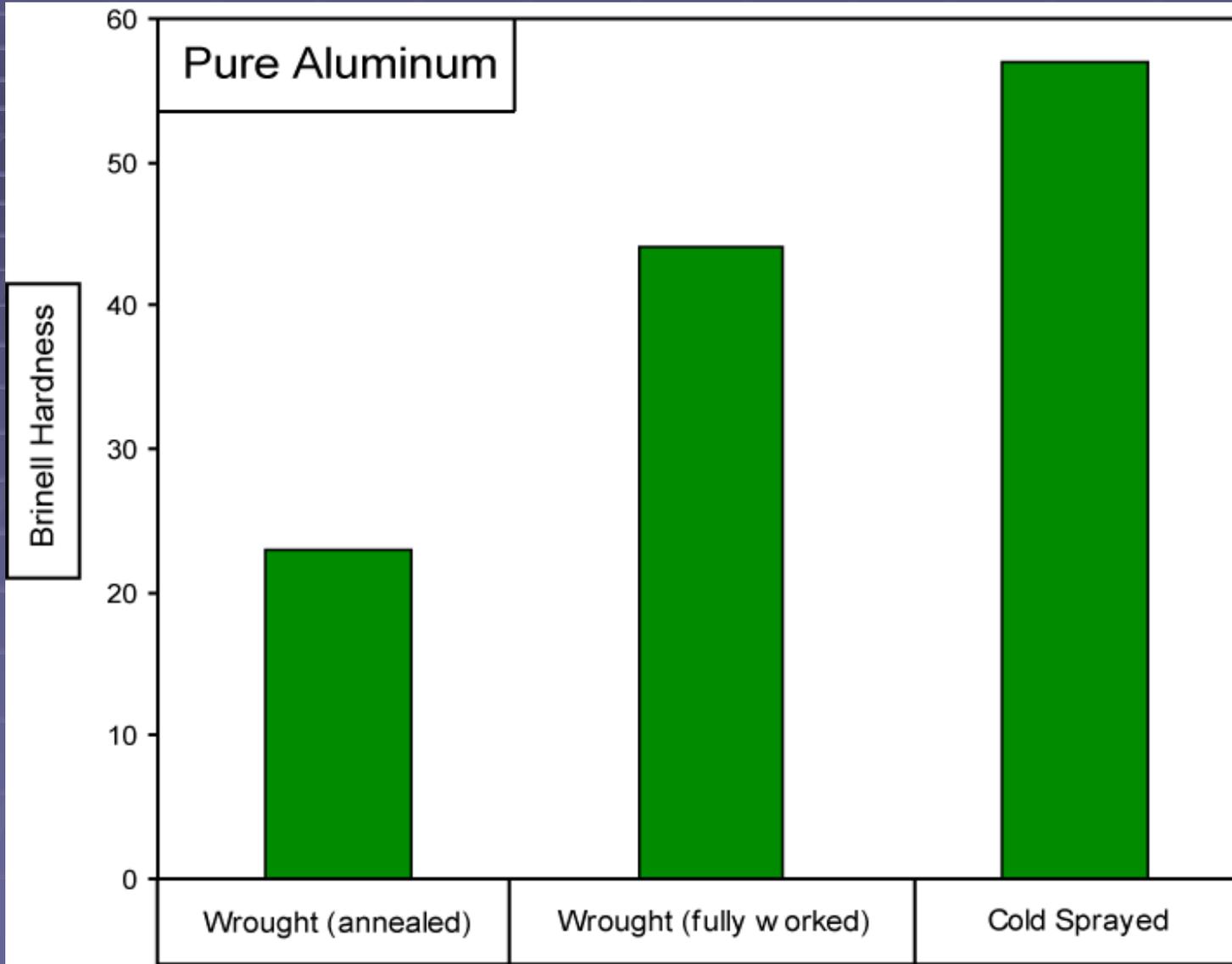
Cold Sprayed vs. Wrought Materials: Hardness



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Cold Sprayed vs. Wrought Materials: Hardness



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MIL-STD-XXXX

DEPARTMENT OF DEFENSE MANUFACTURING PROCESS STANDARD

COATING, COLD SPRAY DEPOSITION

COATING METHOD UTILIZING HIGH-VELOCITY PARTICLES



AMSC N/A

AREA MFFP
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Military Coordination Letter



REPLY TO ATTENTION OF

AMSRD-ARL-WM-MC

6 August 2007

From: Leader, Specifications & Standards Office, US Army Research Laboratory,
Aberdeen Proving Ground, MD 21005-5069

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Proposed Manufacturing Process Standard, MIL-STD-XXXX, (Project Number MFFP-2007-006), entitled, "Coating, Cold Spray Deposition", dated 2 August 2007.

1. US Army Research Laboratory (ARL) is submitting the attached proposed Manufacturing Process Standard for your review and concurrence or comment in accordance with Standardization Manual DOD 4120.24-M.
4. Please forward your replies by e-mail to rsquilla@arl.army.mil, or by facsimile to 410-306-0829, or mail to Director, US Army Research Laboratory, Weapons and Materials Research Directorate, Materials Application Branch, Specifications & Standards Office, ATTN: AMSRD-ARL-WM-MC (Richard Squillacioti), Aberdeen Proving Ground, MD 21005-5069.

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MIL-STD-XXXX

COATING, COLD SPRAY DEPOSITION COATING METHOD UTILIZING HIGH-VELOCITY PARTICLES

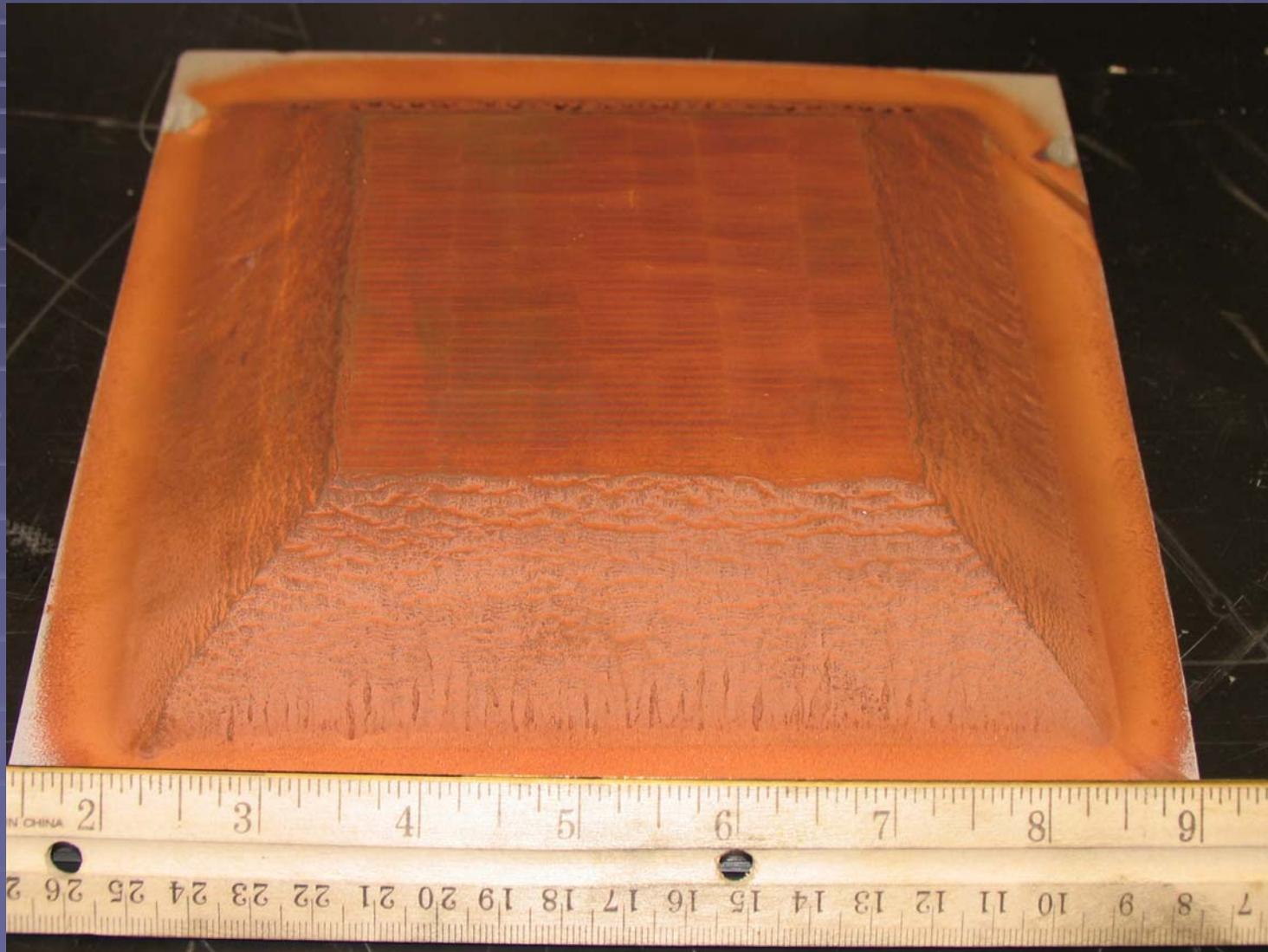
1. SCOPE

1.1 Purpose. The procedures covered by this standard are intended to ensure that cold spray coating operations, either manual or automated, meet prescribed requirements. This process can be used on parts requiring protection from wear, corrosion, or abrasion and to restore dimensionally discrepant parts.

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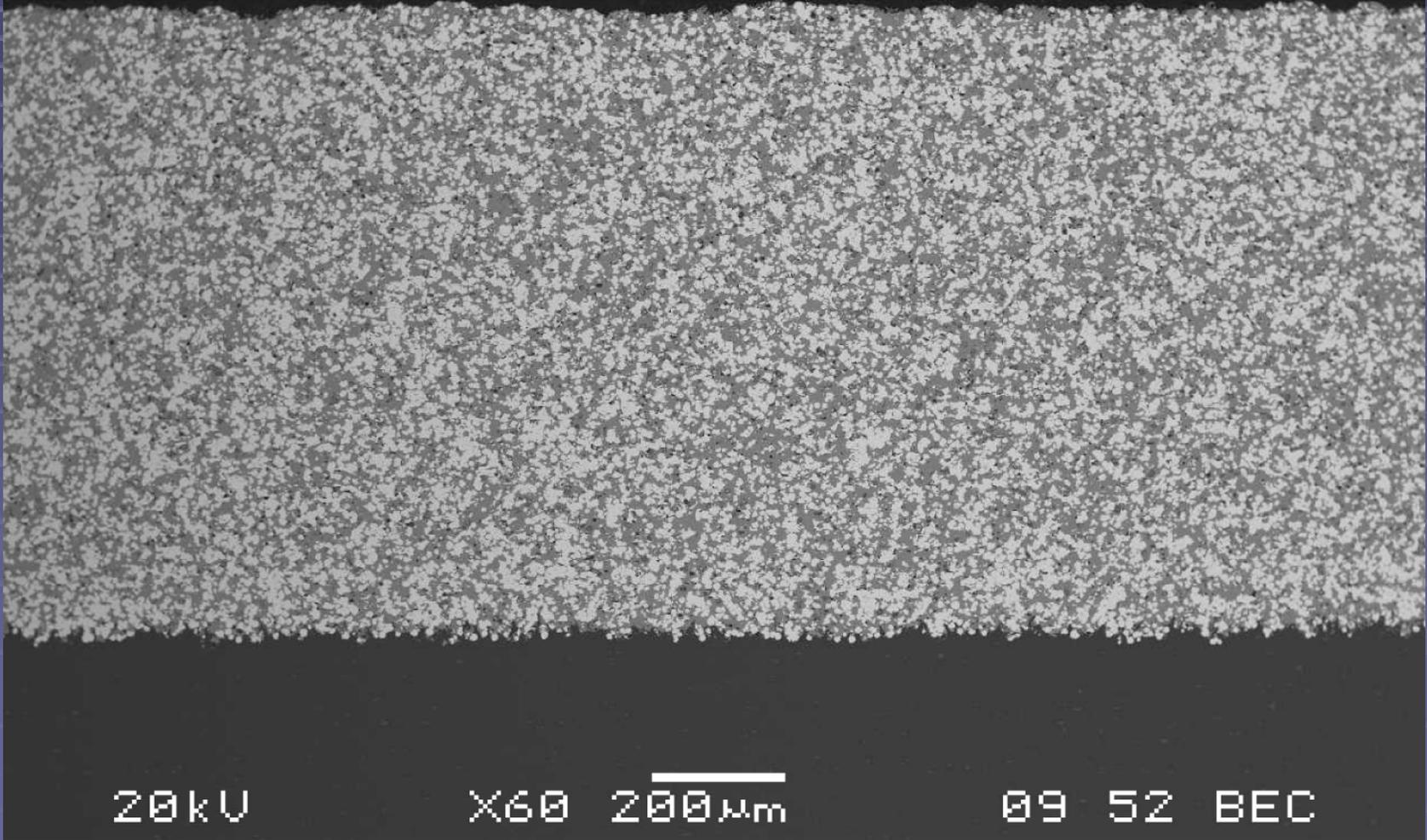
80W-20Cu wt% Block Produced by Cold Spray



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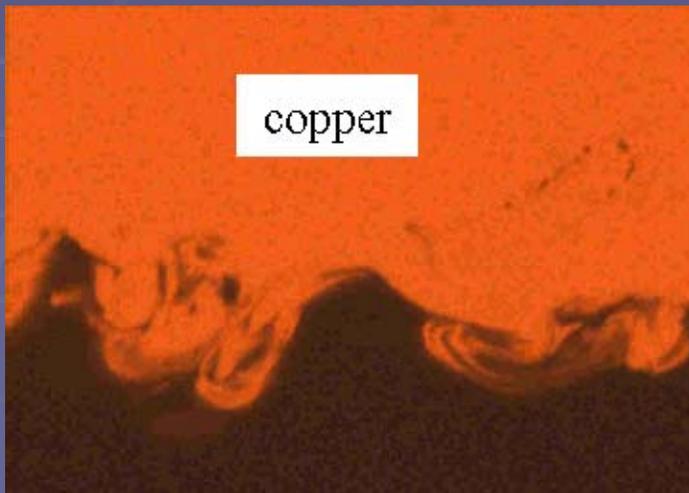
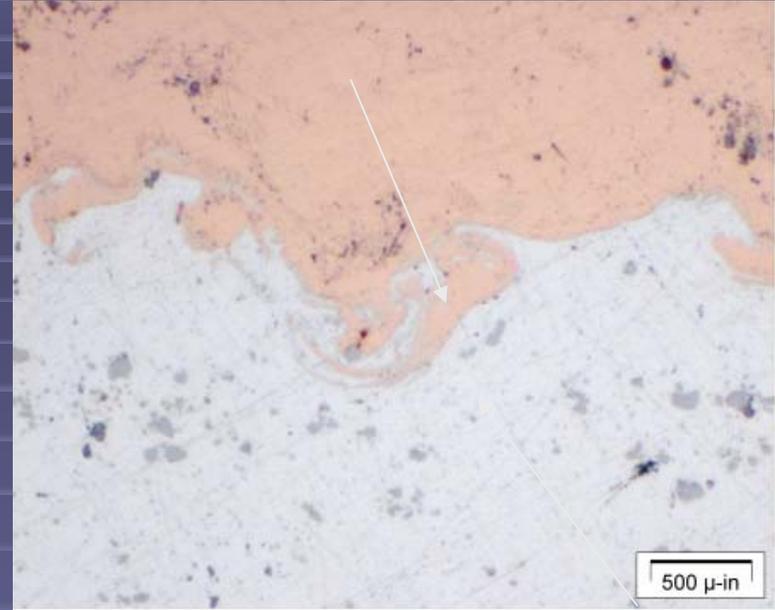
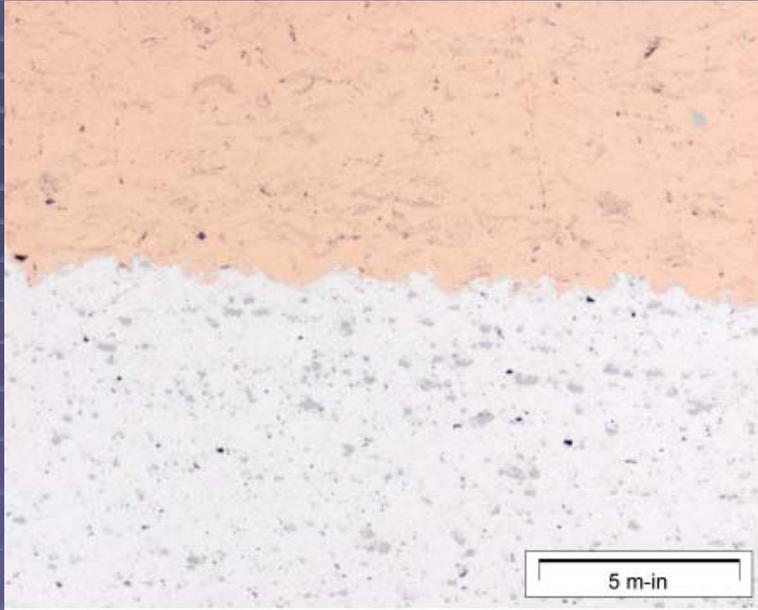


80W-20Cu wt% Cold Spray Coating

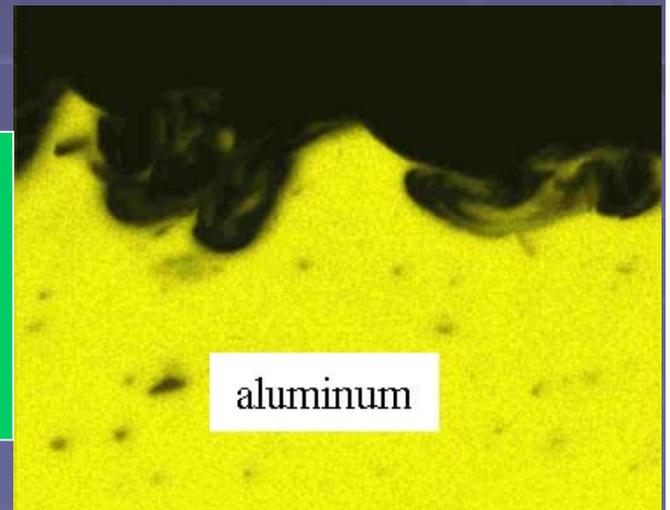


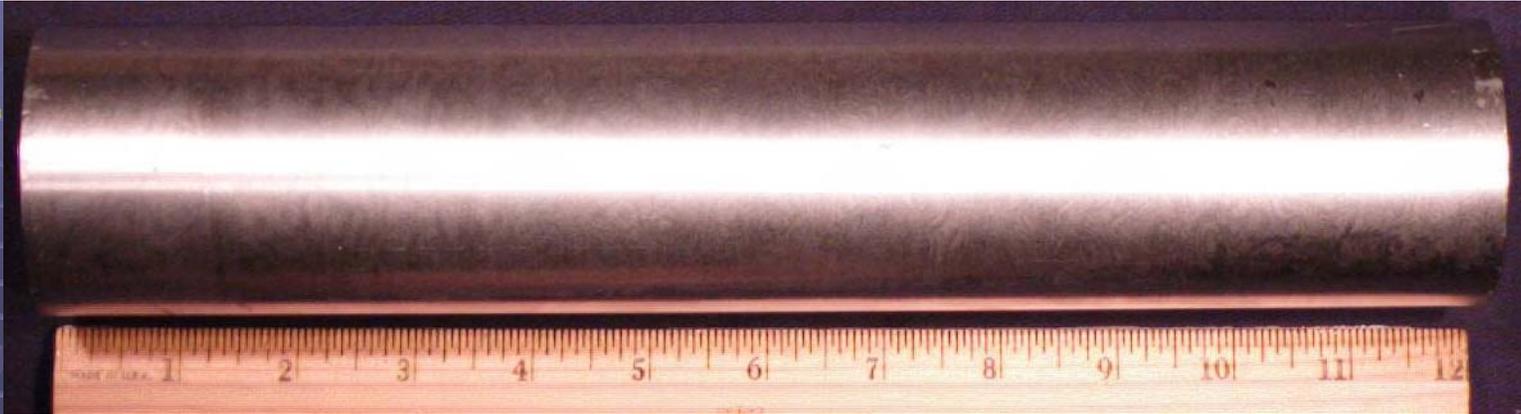


Mechanical Mixing at Interface



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





Complex Geometries Capable by Cold Spray



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Near-Net Shape Forming Capability of Cold Spray



Cases produced by Cold Spray.

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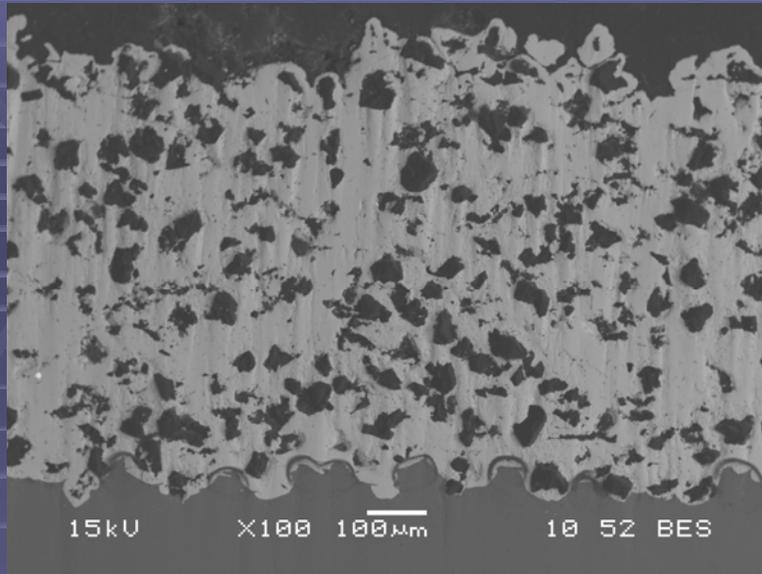
Cold Spray Cases Pressure Tested Successfully



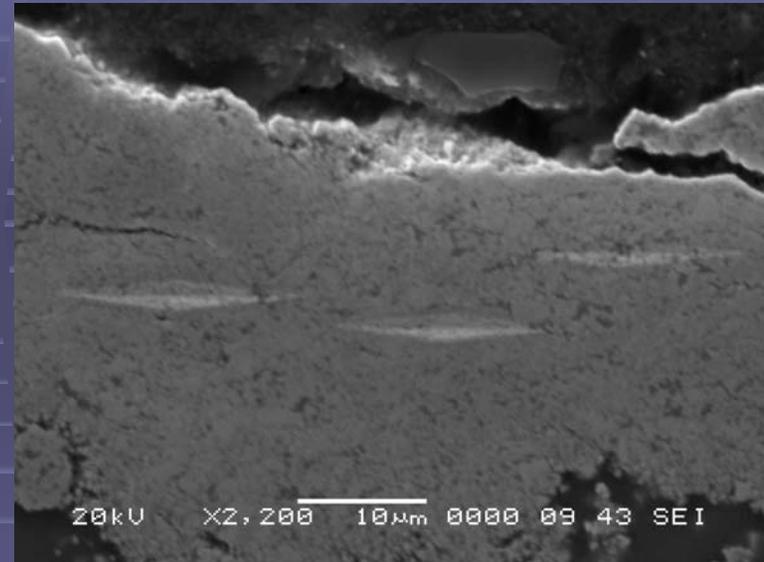
Cases produced by Cold Spray. Fine threads were machined into the material with no difficulty.

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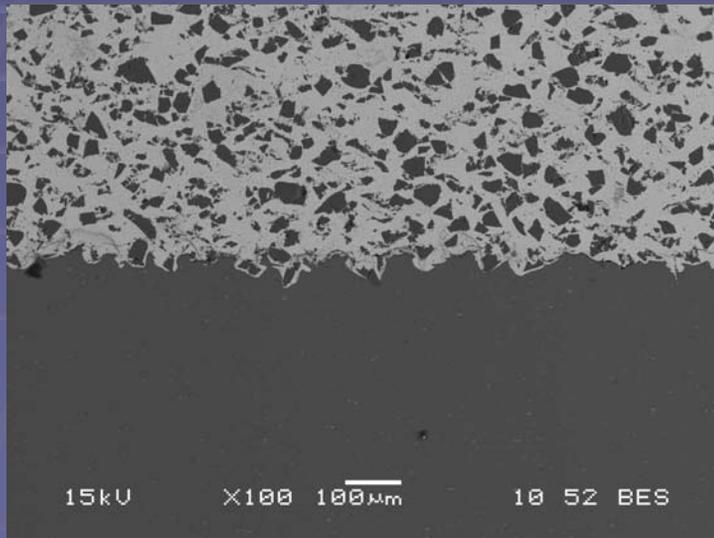
49Cu-Diamond



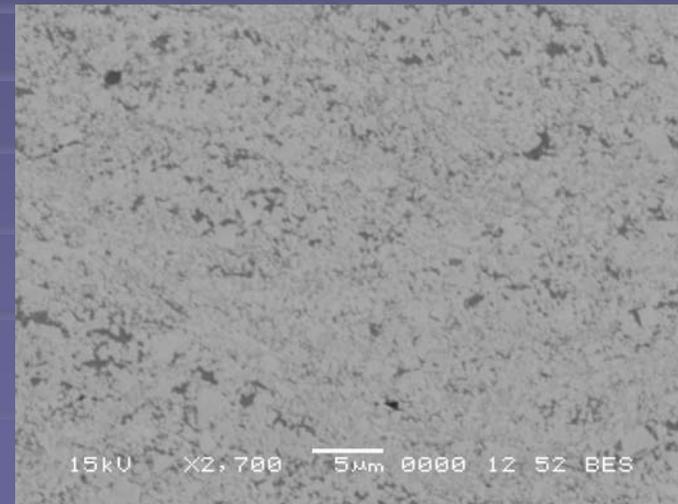
WC-12Co, Cobalt is dark-WC is light



Cu-49%SiC



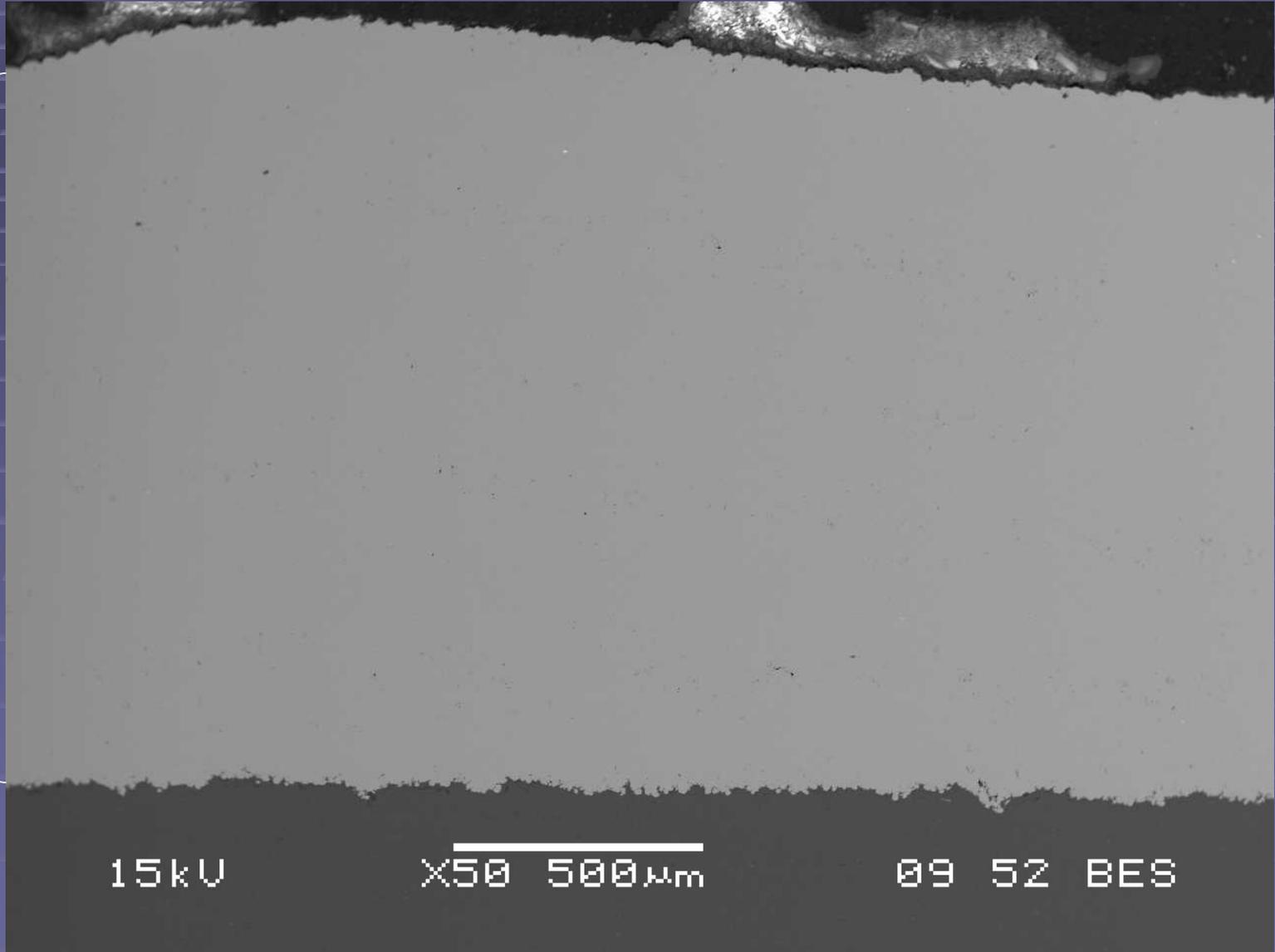
1322,1355,1389 Vickers-25g load





316L SS Deposited by Cold Spray on 6061-T6Al

316L SS
Cold
Spray
Coating



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Cold Spray Coating of Nickel On 4340 Steel

Nickel
Coating

100% Dense



Cold Spray Ni has a hardness of HRC 41 and a resistivity of $6.84 \mu\text{Ohm/cm}$

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Adhesion Results of Cold Spray Ni Coating

Bond Bar	Thickness (mils)	UTS (psi)	failure type
1	0.0011 inch	10,850	Cohesive
2	0.0070 inch	9,099	Cohesive
3	0.0013 inch	12,800	Cohesive
4	0.0080 inch	12,820	Cohesive

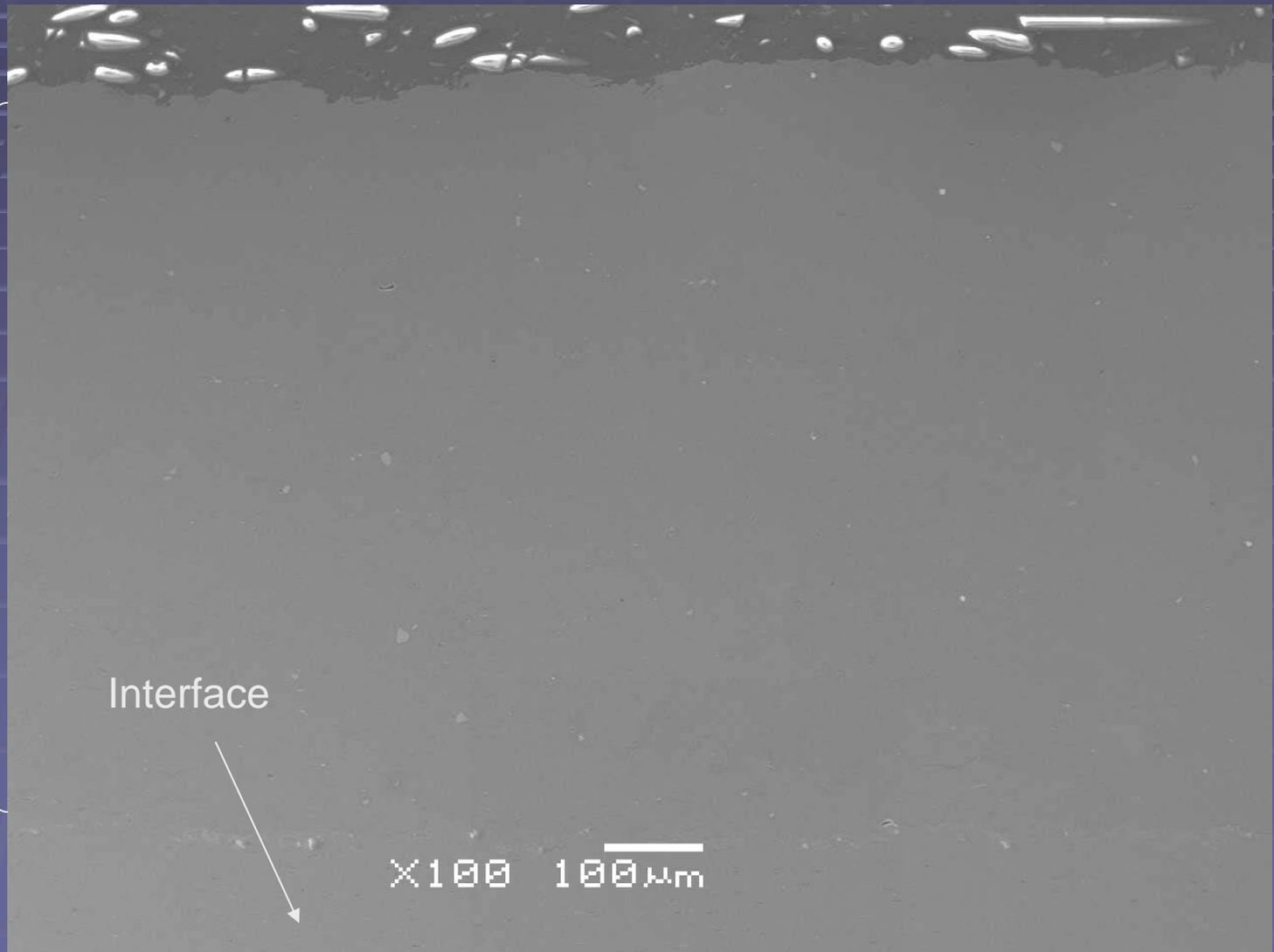
Similar values have been obtained on aluminum substrates and the failures have been adhesive or 'glue' failures



5056 Al Deposit Using Helium as the Carrier Gas

5056 Al
Cold
Spray
Coating

6061-T6
Aluminum
Substrate



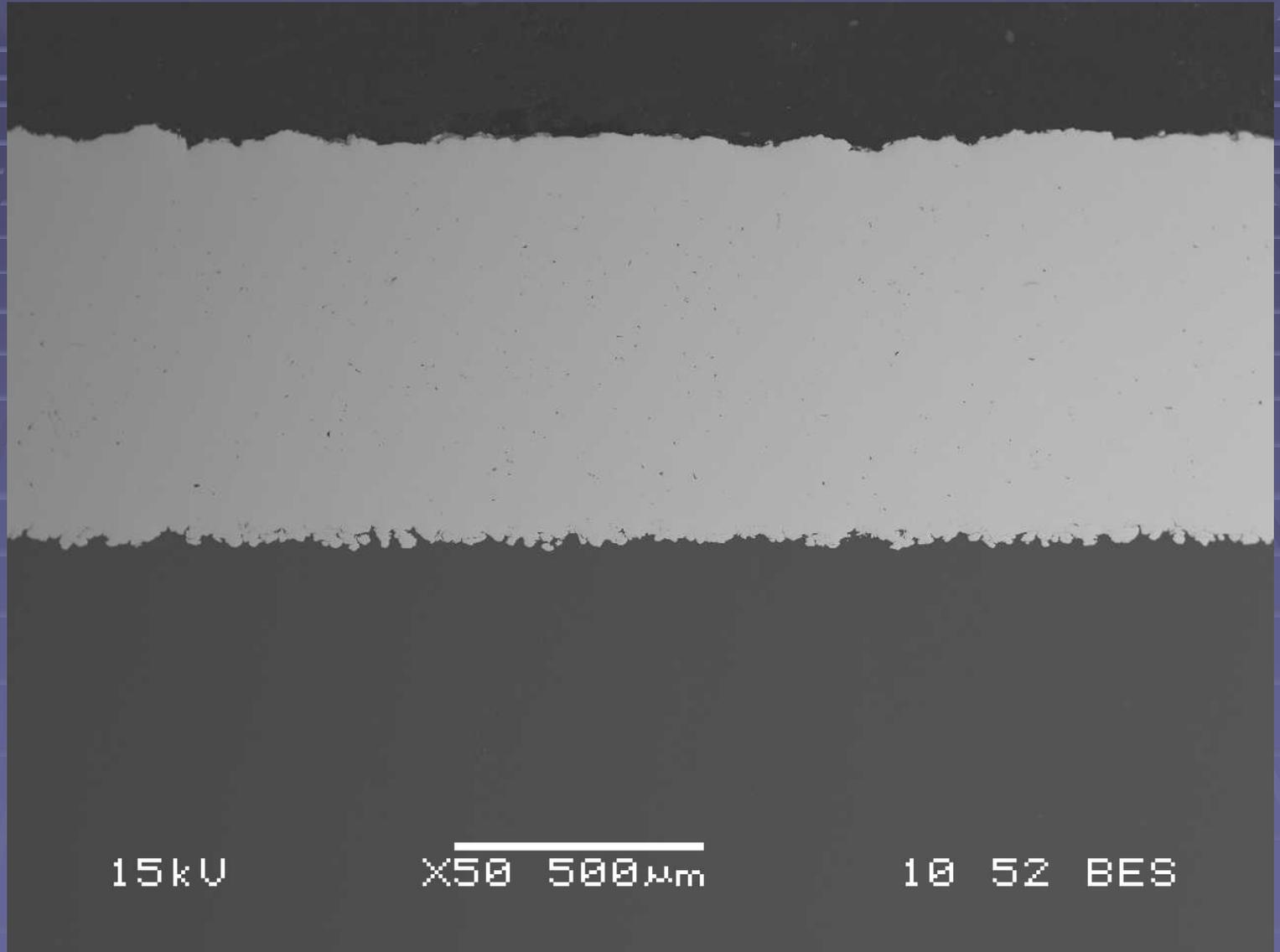
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Cold Spray Tantalum Deposited on Aluminum



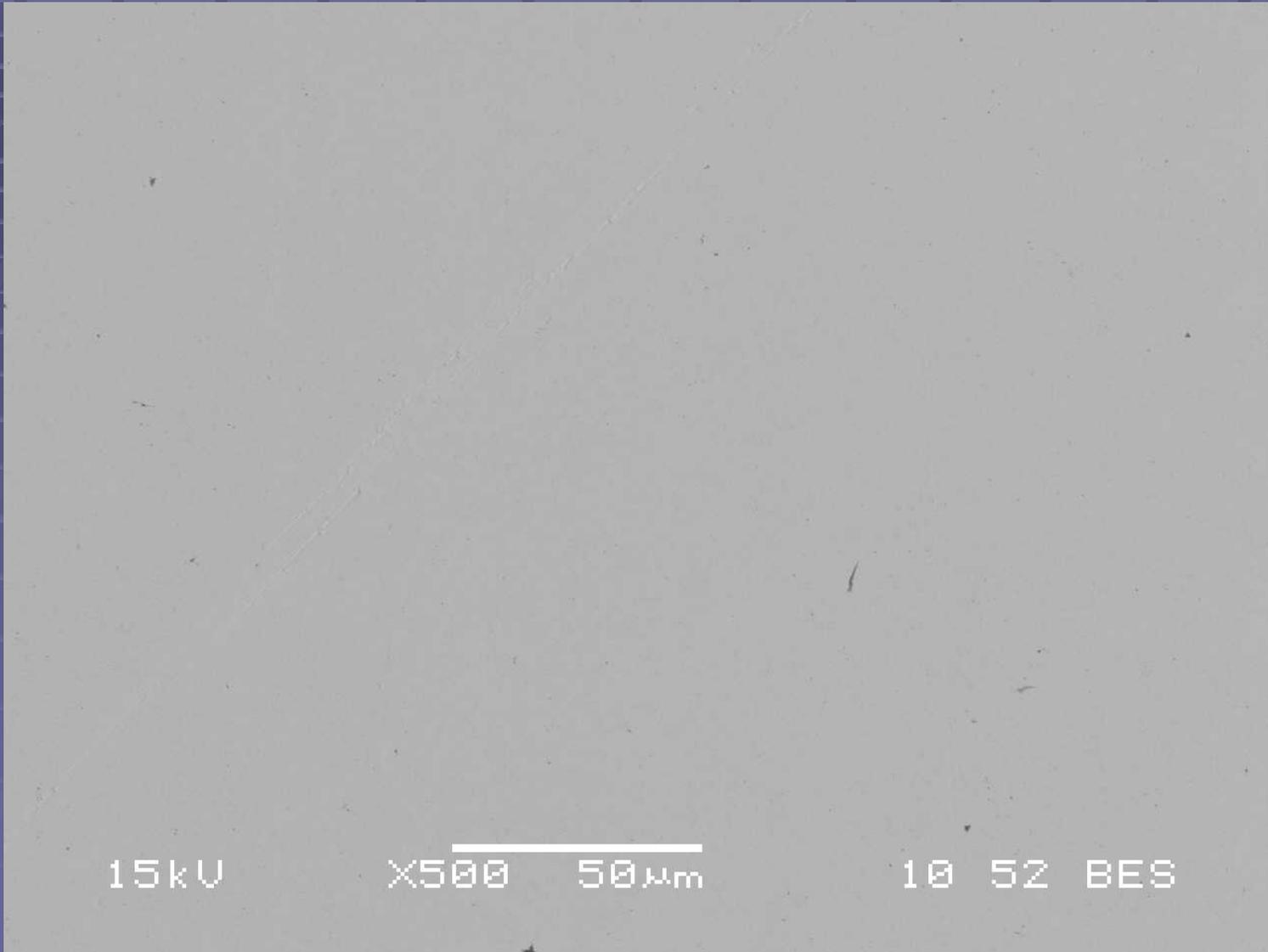
Cold Spray
Tantalum



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Cold Spray Tantalum Deposited on 6061-T6Al



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Vision for the Future

WE NEED TO:

- introduce 'cold spray' powders that are commercially available
- develop a cost effective helium recovery system
- introduce a portable cold spray system with greater capability
- participate in the development of the cold spray specification
- exchange information more freely on non-proprietary applications
- avoid 'overselling' the technology and be honest brokers
- focus on the technical issues & keep disputes where they belong

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"A House Divided Against Itself Cannot Stand"

Abraham Lincoln June 16, 1858 Springfield,
Illinois

