U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMY RESEARCH LABORATORY

Cold Spray Additive Manufacturing and Structural Repair Technology

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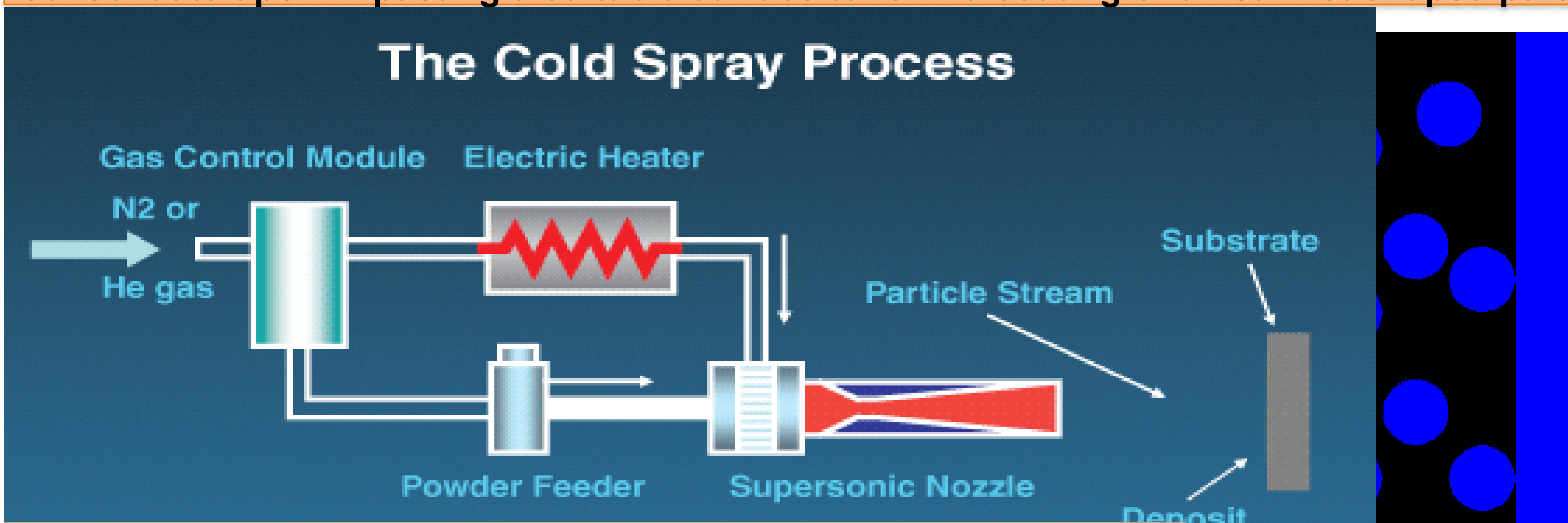
DD MMM YYYY

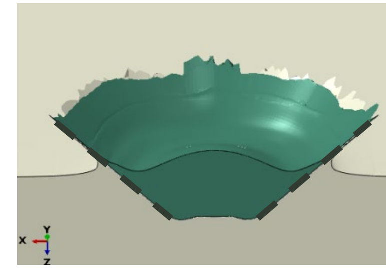
COLD SPRAY OVERVIEW

Cold spray is an AM process that incorporates a heated high-pressure gas such as He or N2 together micron sized particles of a metal, ceramic and/or polymer into a gun fitted with a De Laval rocket nozzle designed such that the particles exit at supersonic velocities and consolidate upon impacting a suitable surface to form a coating or a near-net shaped part.

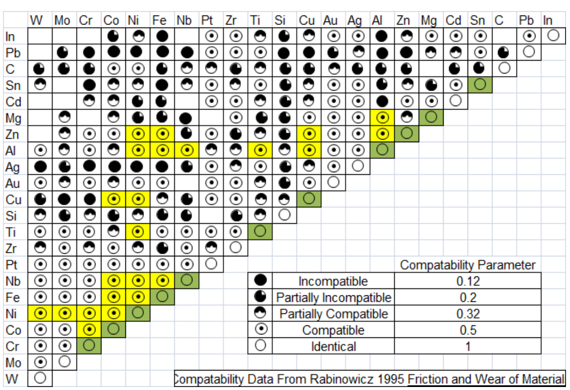


- Main Gas Stagnation Pressure 100-1,000 psi
- Gas Temperature 0-1000°C
- Main Gas Flow Rate 30-100 CFM
- High Powder Feed Rates >10 lbs/hr
- Particle Velocity 300-1500 m/sec.
- Particle Size 10-75 µm diameter and nanostructured

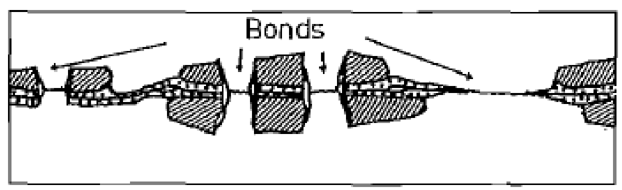
METALLIC BONDING IN COLD SPRAY



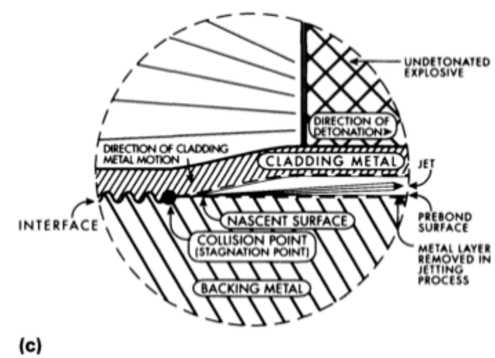
- **Materials compatibility enables increased bond strength (bond layers, encapsulated powders, etc.)**
- **Surface contamination requires higher surface expansion (strain) to achieve bonding (oxides, hydroxides, chemisorbed layers, etc.)**
- **High plastic strain of both surfaces improves bonding**
- **Material jetting from interface can eliminate or further breakdown surface contamination**



Material Compatibility



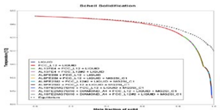
High Plastic Strain



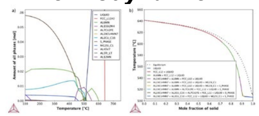
High Strain Rate Jetting

ARL Holistic Approach to CS Development

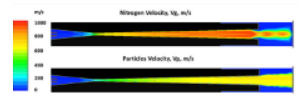
Solidification



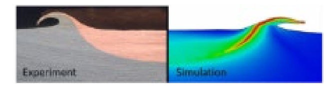
Thermodynamic



Particle Acceleration



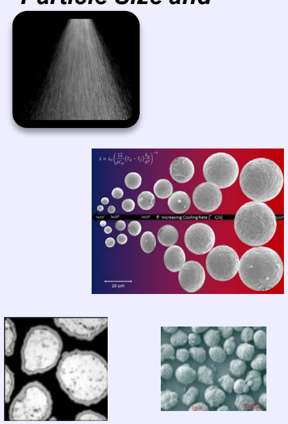
Particle Impact



Modeling & Simulation

Powder / Material Selection

- *Chemistry*
- *Manufacturing process*
- *Particle Size and*

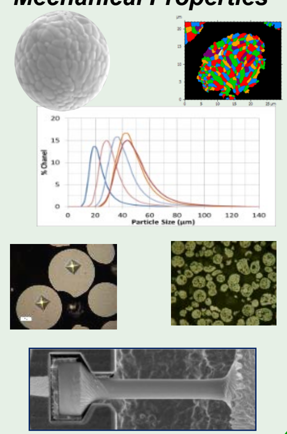


Powder Processing

- *Degassing*
- *Heat Treating*
- *Blending*
- *Milling*

Powder / Material Characterization

- *Microstructure*
- *Particle Size*
- *Morphology*
- *Mechanical Properties*

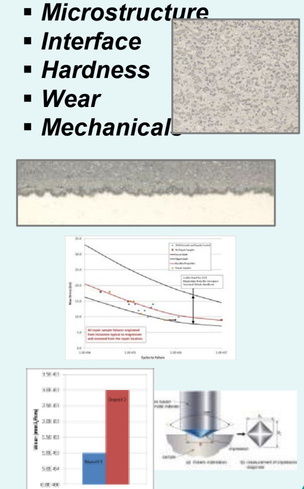


Cold Spray Process

- *Pressure*
- *Temperature*
- *Nozzle Geometry*
- *Substrate Preparatio*
- *Motion Control*

Post-Processing Characterization

- *Porosity*
- *Microstructure*
- *Interface*
- *Hardness*
- *Wear*
- *Mechanical*



POWDER PROCESSING

Key Considerations

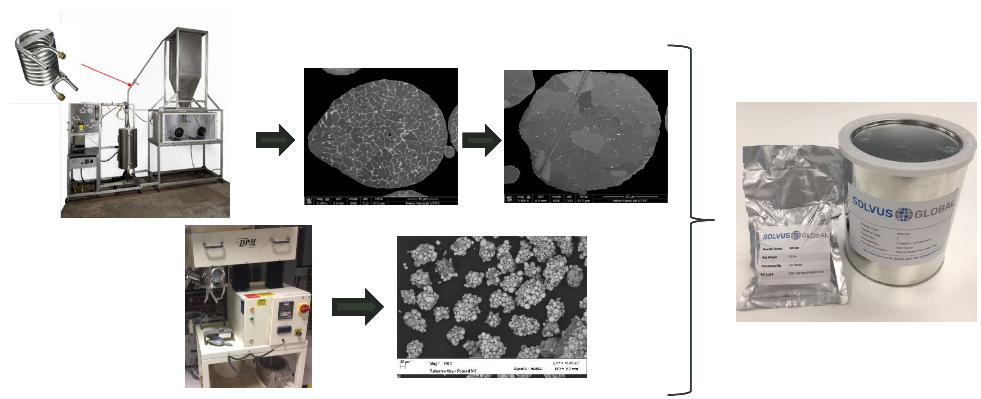
- Mechanical properties (hardness, flow stress, etc.)
- Grain structure
- Phase distribution
- Surface cleanliness (oxide/hydroxide)
- Powder size distribution
- Morphology (clad, layered, etc.)

Supporting Modeling and Testing

- Thermodynamic phase modeling
- FEA Modeling
- Single particle impact testing
- Surface characterization
- Conductivity testing
- Microtrac and other PSD evaluation and separation
- Thermal processing

ARL Team Developments

- Development of thermal treatments to degas, homogenize, solution treat, over-age, or anneal powders
- Processes to cost effectively clad powders to develop Cold Sprayable cermets, control chemistry, and improve DE of certain material blends
- Development of fluidized bed processes and equipment on the laboratory and small production scale to perform
  - Thermal processing
  - Degassing
  - Particle sizing
- Worked with Supplier to commercialize powder processing techniques developed



Cold Spray Powder Development – WIP Coatings

What makes a high quality Cold Spray coating

- The Cold Spray process achieves particle bonding through a process of high velocity impact and plastic deformation
- Powders used in Cold Spray must contain a "soft" plastic phase in order to properly consolidate when the powder undergoes plastic deformation
- To create hard coatings, a significant quantity of hard phase is required in the coating
- For high toughness coatings less hard phase is required while inter-particle bonding is critical

Materials Selection

Hard Phases

- Tungsten Carbide
- Chrome Carbide
- Iron Based Hard powders

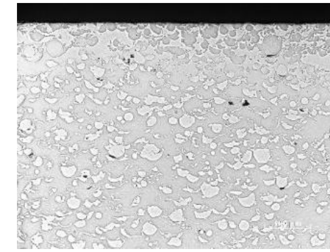
Soft Phases

- Nickel
- Stainless Steel
- Cobalt
- Chrome
- Tantalum
- Niobium
- Bronze
- Copper-Nickel

Methods of Combination

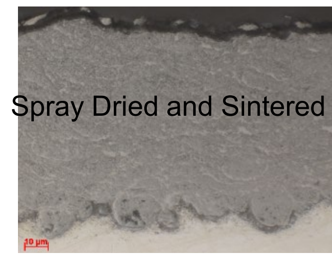
- Blending
- High Energy Milling
- Powder Plating
- Small-Large Powder Granulation
- Spray Drying / Agglomeration

- Powder Blends have achieved approximately 375-450 HV hardness deposits
  - Moderate to high wear resistance with the best impact properties



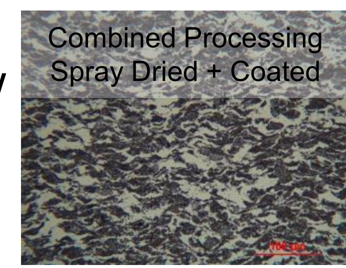
Mechanical Blend

- Spray Dried or agglomerated and sintered powders have achieved the highest hardness ranging from 800 – 1300 HV depending on composition



Spray Dried and Sintered

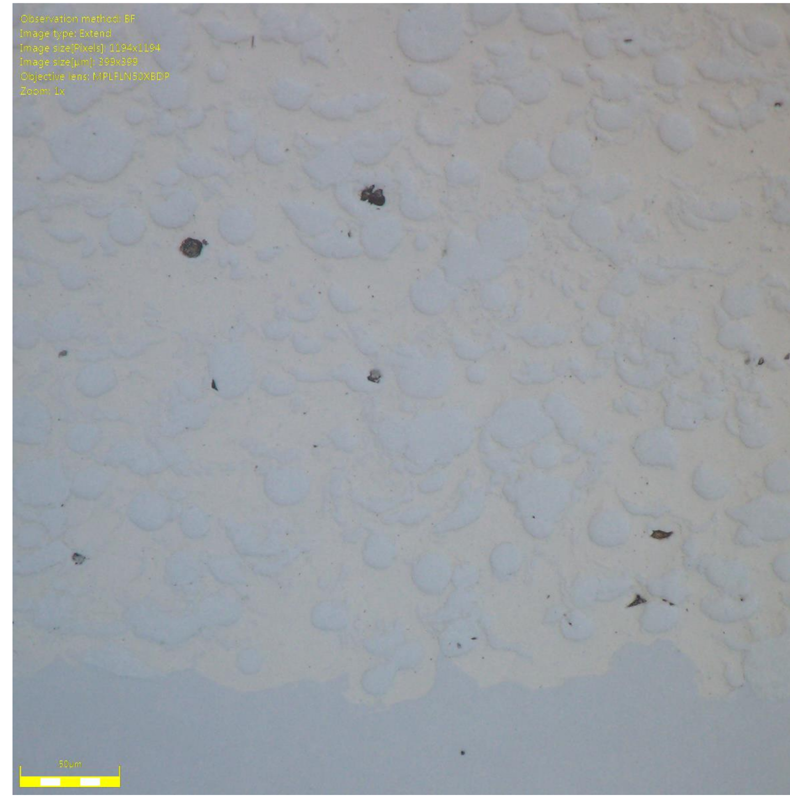
- Design optimized clad agglomerate powders show the best overall properties including higher DE, good toughness, and excellent wear performance



Combined Processing
Spray Dried + Coated

WIP-C1 TECHNICAL DATA

- Sprayable with N_2 or He
  - 1.5%-3% porosity with N_2
  - <1% porosity with He
- Suitable for many substrates
  - HRC 30-55 steels
  - Stainless
  - Monel
  - Copper-Nickel
- Similar or better wear performance than Cr plating
- Suitable for high impact conditions



Measured Porosity: <0.5%

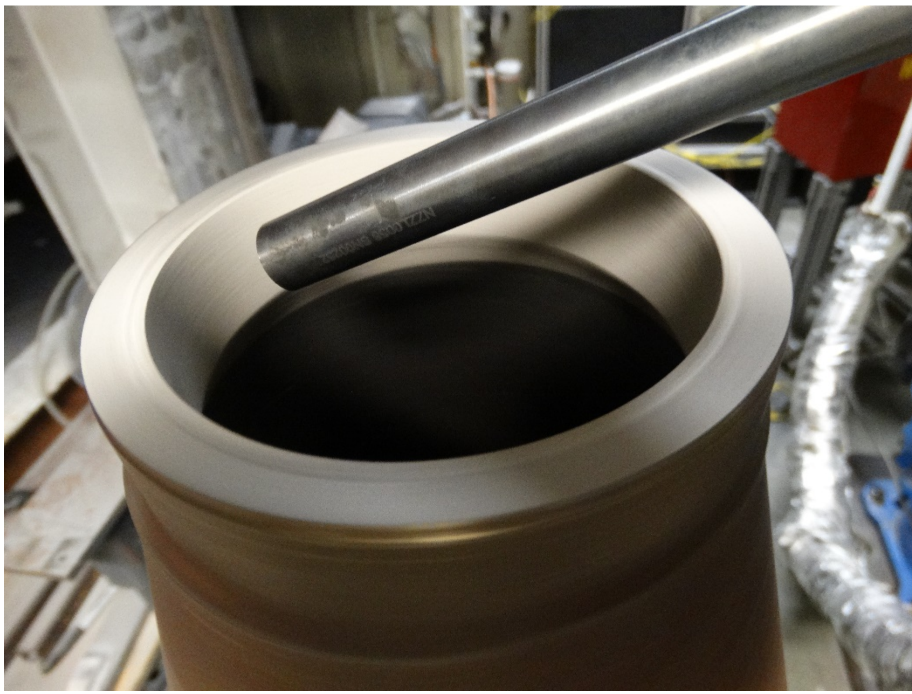
Substrate	Lug Shear Strength (ksi)
17-4PH	~20
High Hardness Steel	~20-25
4340	40.6 (He), 28 (N2)
4330V	38.3

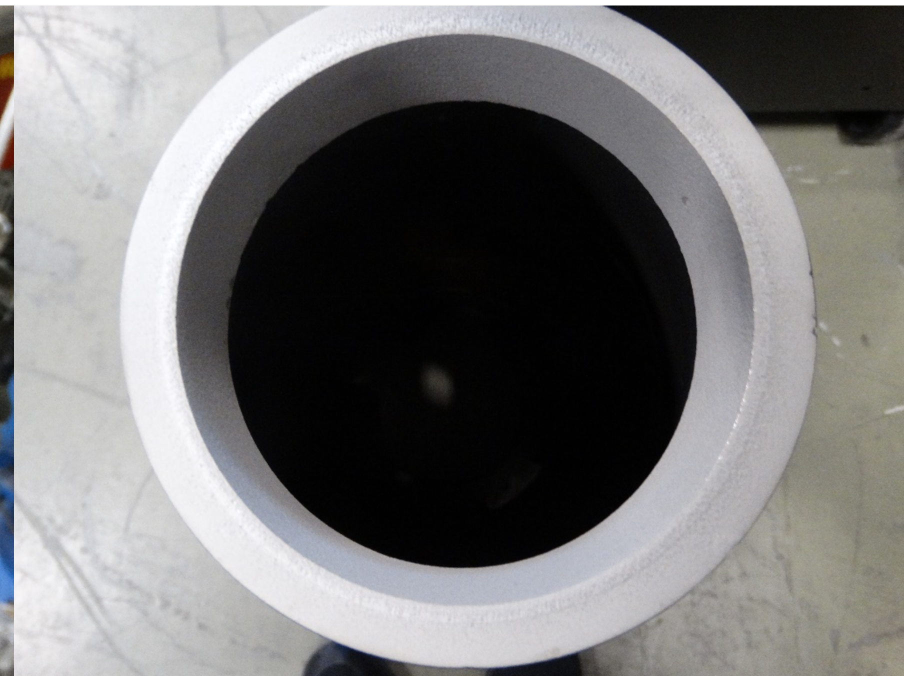
BRADLEY TURRET MOUNT

- **Turret mount wears over time**
- **Becomes out-of-round**
- **Repair technology provides:**
  - Cost savings
  - Improved Warfighter readiness

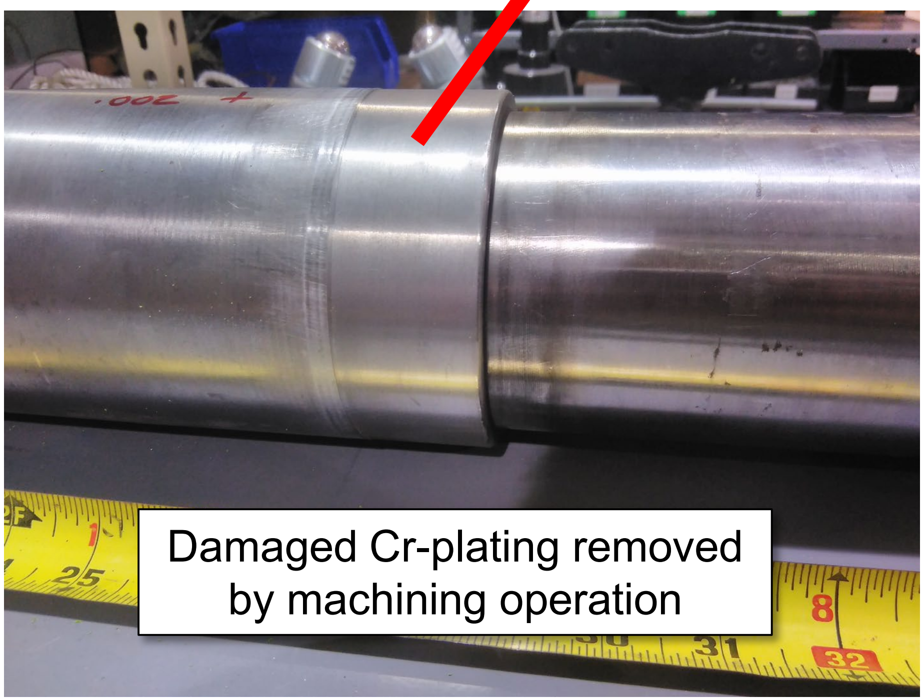
BRADLEY TURRET MOUNT

- Cold spray can be used to re-establish new drawing dimensions
- Improved wear performance reduce lifecycle sustainment costs



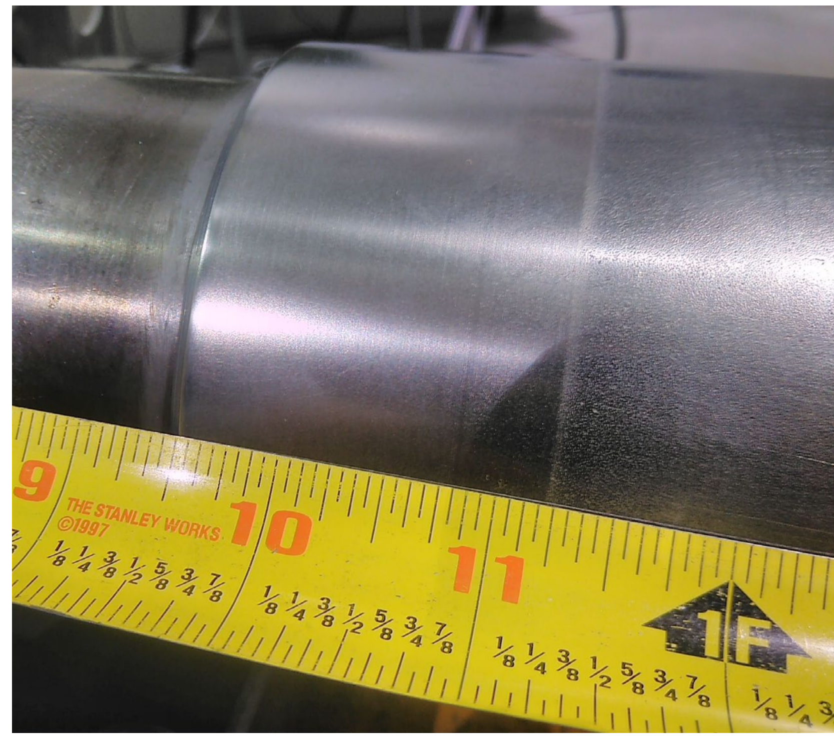


LETTERKENNY BALL SCREW ACTUATOR



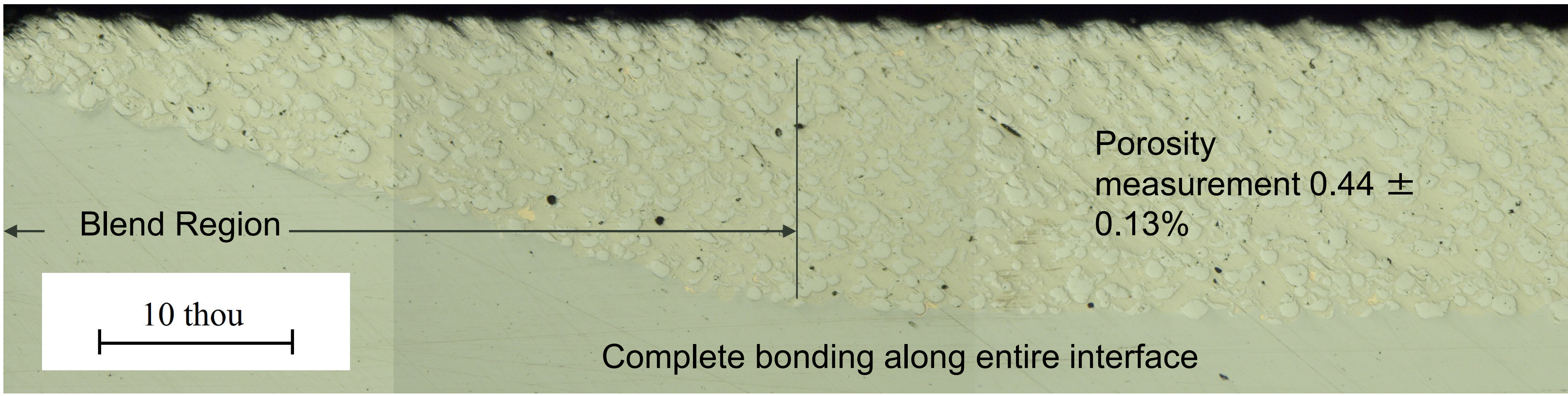
Damaged Cr-plating removed by machining operation

With dry Cold Spray process minimal masking or complicated tooling required!!

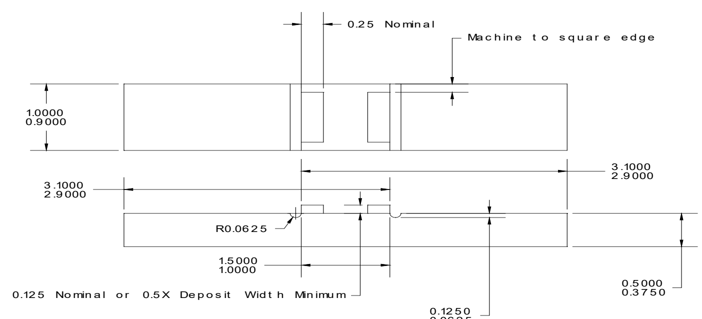


Ball Screw Actuator Cover, Mock Part Evaluation

Letterkenny Army Depot

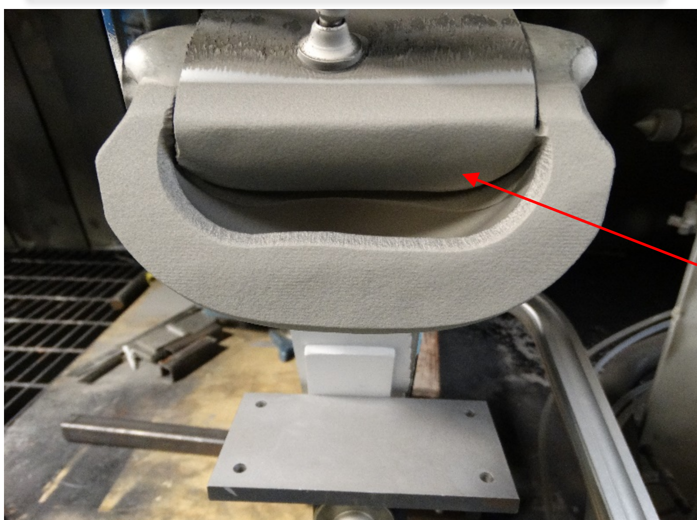


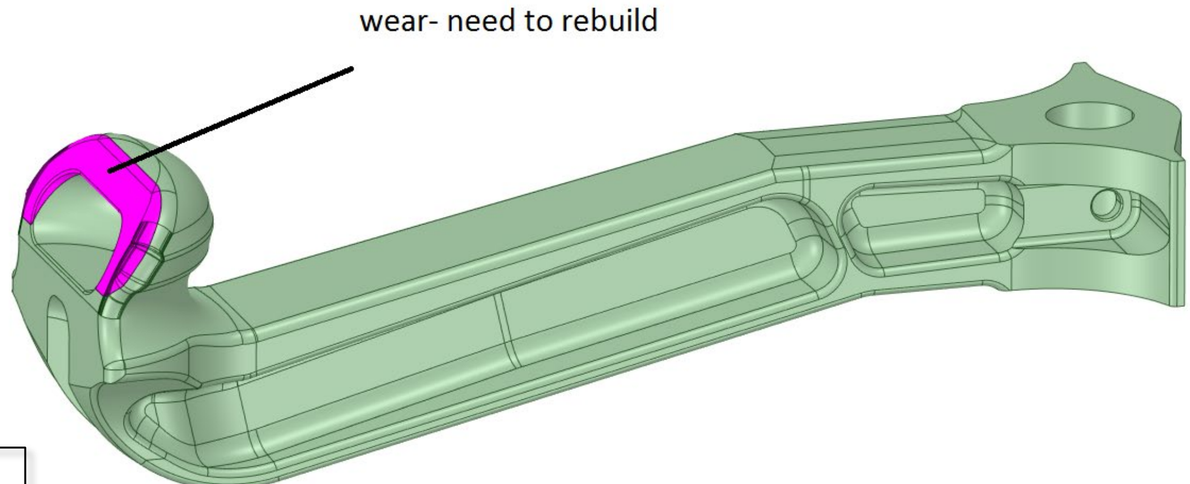
- Deposition process was performed with WIP-BC1 followed by WIP-C1
- Lug Shear testing was performed on 4340 (40-44HRC) which closely represents part material
- Results → 28 ksi bond strength

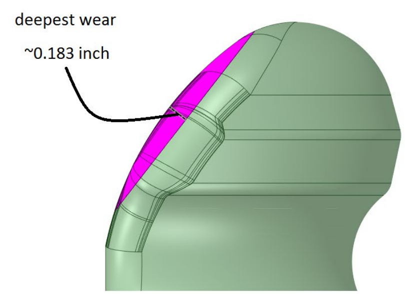


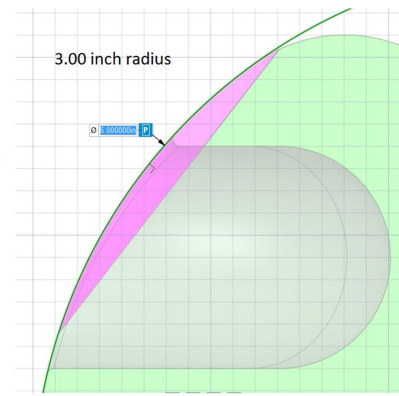
CANDIDATE REPAIR COMPONENT

Surface wear due to adhesive/abrasive wear





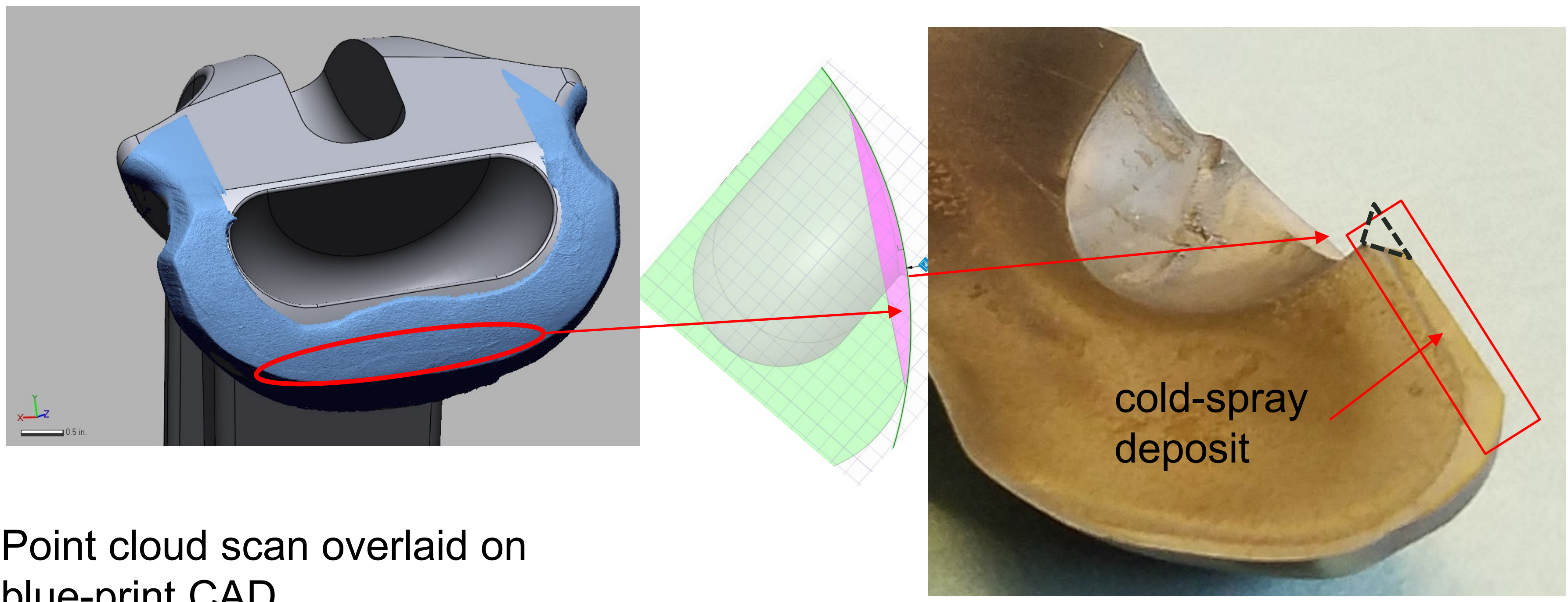




Sheet metal masking created to protect pocket

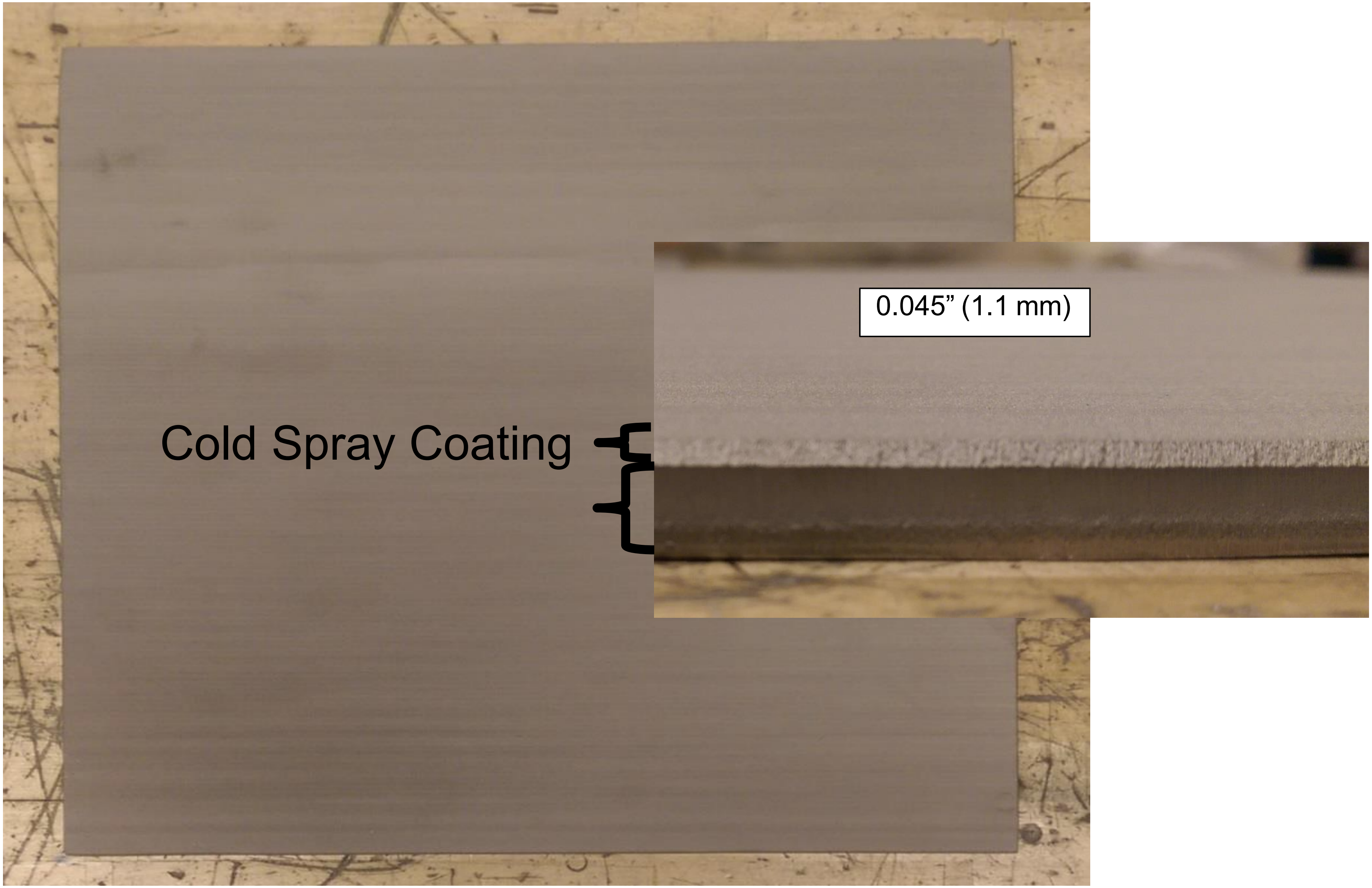
ARL Cold Spray Process Development

Repair material applied (blue texture) beyond blue-print dimensions
Edge of hole receded due to wear.



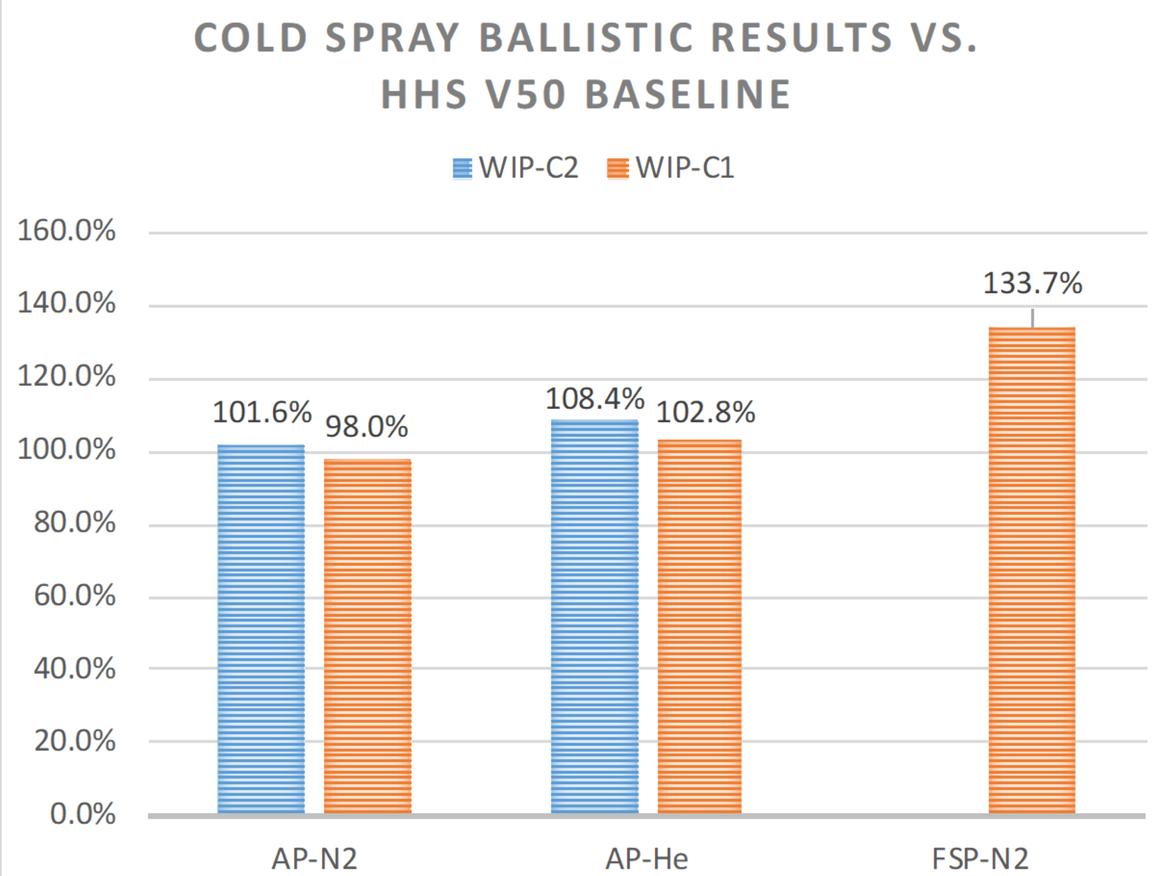
Point cloud scan overlaid on blue-print CAD

BALLISTIC ARMOR REPAIR



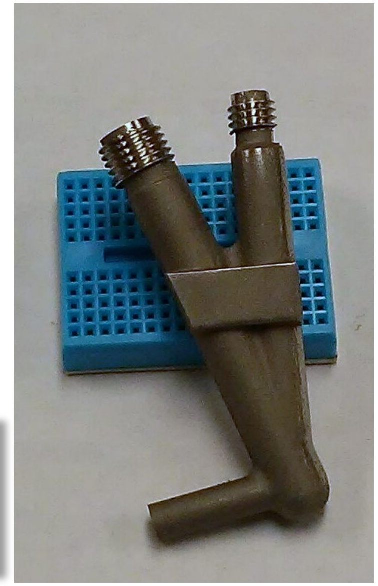
COLD SPRAY BALLISTIC PERFORMANCE

- Bar chart shows the percentage of ballistic performance restoration indexed to 100% of base metal.
- Repair depth 1mm onto thinned 6.3 mm thick HH steel for a 12” x 12” panel with full coverage.
- Using armor piercing (AP) rounds and fragment stimulating projectile (FSP) rounds.

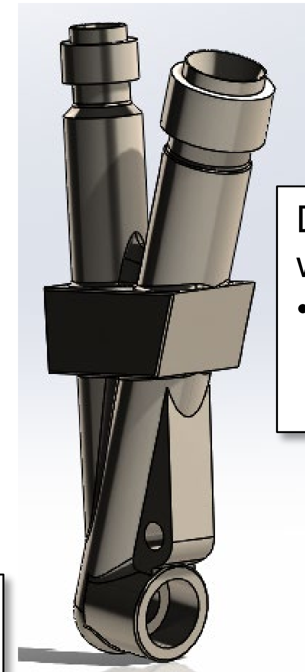


ID NOZZLE DEVELOPMENT

Single injection design for use with carbide nozzle
- 1.6 in minimum bore, 0.5” standoff

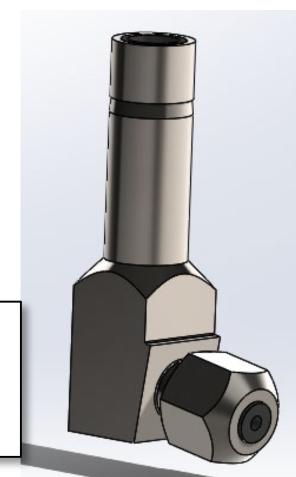


Dual injection design with integral Co-Cr nozzle
- 1.5 in minimum bore, 0.5” standoff



Dual injection design with carbide insert
- 1.5 in minimum bore, 0.5” standoff

Single injection large bore design
- 4 in minimum bore, 0.5” standoff

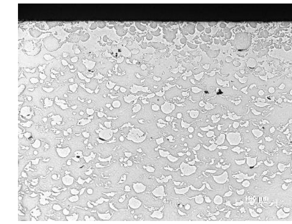


Single injection design for spraying aluminum
- 1.8 in minimum bore, 0.5” standoff

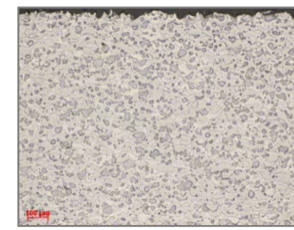
EXTRA MATERIAL

Current State of Development with WIP Coatings

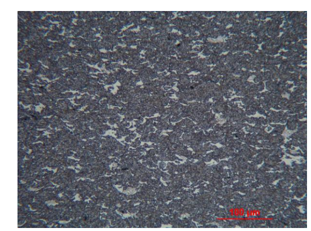
- WIP-C1 and WIP-C2
  - These deposits are being rolled out into several applications and have by far the most robust set of data and spray conditions of all WIP materials
  - Vendors have been set up to produce this material commercially for easier procurement
  - Deposits have been demonstrated with both helium and nitrogen with good quality
  - Deposits can be machined by milling, turning, or grinding



- WIP-F1
  - This material is very similar to WIP-C1 and C2 but is completely iron based for applications where EH&S concerns about nickel based deposits may be present
  - More work needs to be done to characterize the properties, especially wear performance, of this material
  - Once further data is developed scale-up of this material to production quantities will follow the process for WIP-C1 and C2

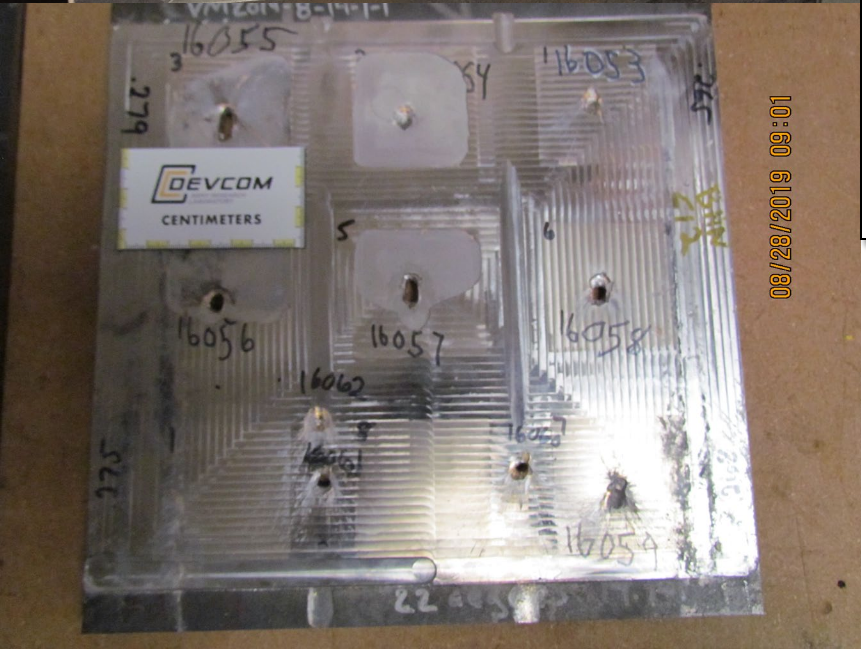


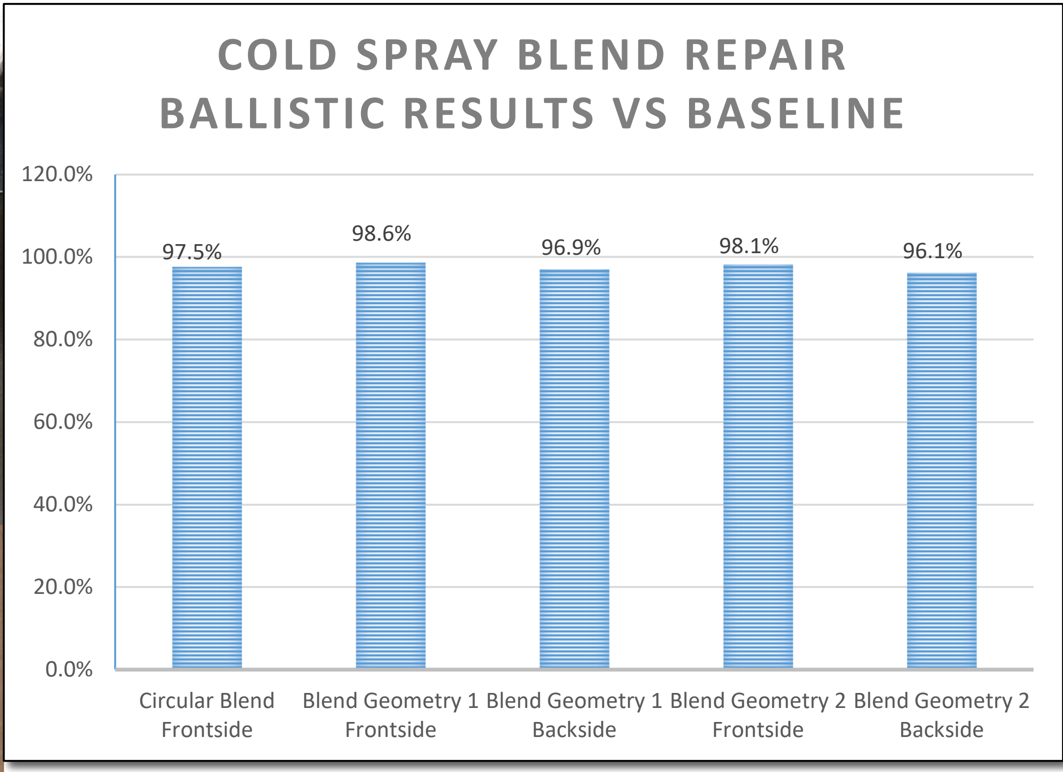
- WIP-W1
  - This material has the greatest potential for direct chrome replacement in most applications
  - The data generated has shown excellent wear and
  - Deposits must be ground, but can be ground with SiC or diamond
  - All powders have been produced using production robust processes



All coatings can be applied in line of site applications as well as in features as small as 1.8 - 2 inches

BLEND AND FILL ARMOR REPAIR





- Repairing pockets yielded similar performance
- Confined delamination area
- Improved Cost Reduction

Near repair CP and PP hit did not induce delamination.