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

Cold Spray Technology and Experience in Army Applications

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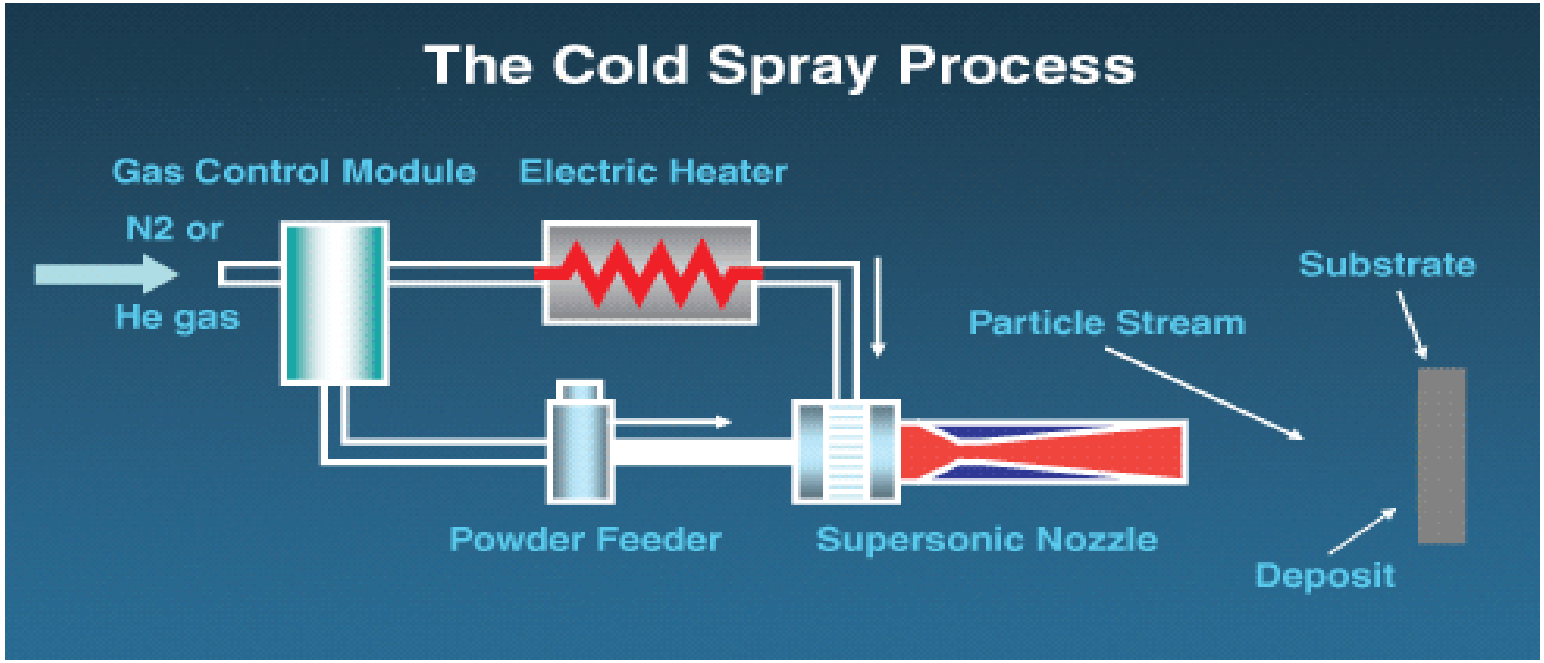
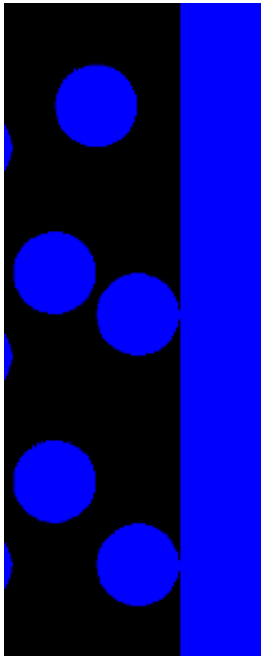
CCDC-Army Research Labs

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.

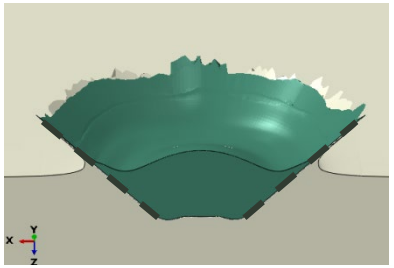


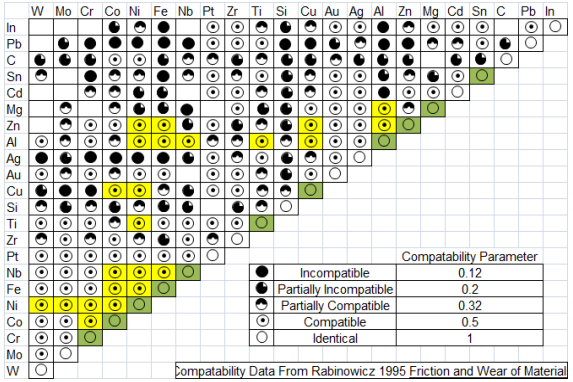


- Main Gas Stagnation Pressure 100-1,000 psi
- Main Gas Flow Rate 30-100 CFM
- Particle Velocity 300-1500 m/s
- Gas Temperature 0-1000°C
- High Powder Feed Rates >10 lbs/hr
- Particle Size 10-75 µm diameter

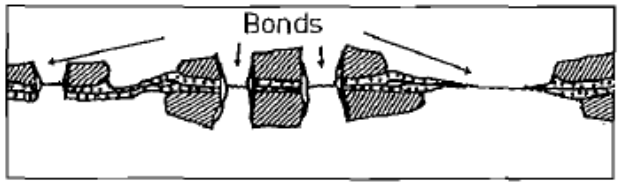
METALLIC BONDING IN COLD SPRAY

- 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

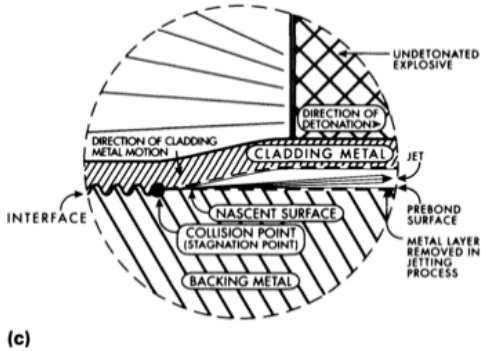




Material Compatibility



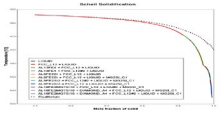
High Plastic Strain



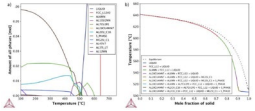
High Strain Rate Jetting

ARL Holistic Approach to CS Development

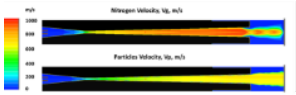
Solidification



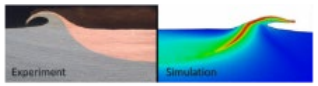
Thermodynamic



Particle Acceleration

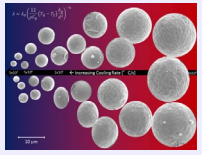


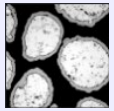
Particle Impact



Modeling & Simulation

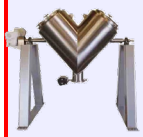
- *Chemistry*
- *Manufacturing process*
- *Particle Size and*





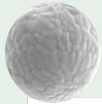
Powder / Material Selection

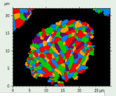
- *Degassing*
- *Heat Treating*
- *Blending*
- *Milling*

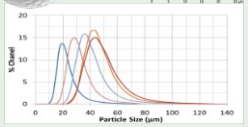


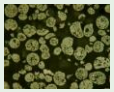
Powder Processing

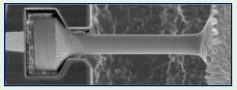
- *Microstructure*
- *Particle Size*
- *Morphology*
- *Mechanical Properties*





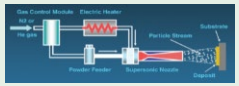






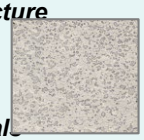
Powder / Material Characterization

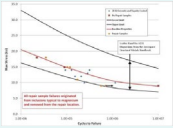
- *Pressure*
- *Temperature*
- *Nozzle Geometry*
- *Substrate Preparatio*
- *Motion Control*

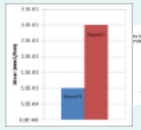


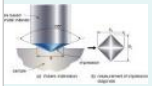
Cold Spray Process

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









Post-Processing Characterization

POWDER PROCESSING

Key Considerations

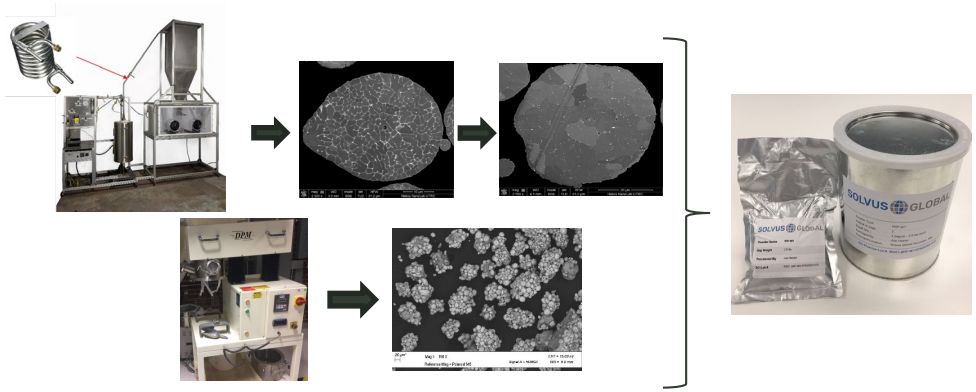
- Mechanical properties (hardness, flow stress, etc.)
- Grain structure
- Phase distribution
- Surface cleanliness (oxide/hydroxide)
- Powder size distribution
- Morphology (clad, layered, etc.)

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

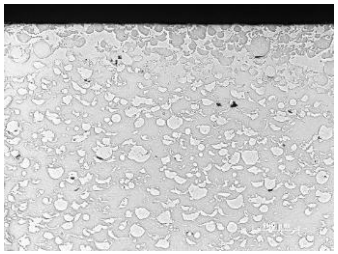
Soft Phases

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

Methods of Combination

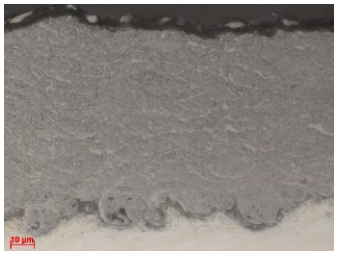
- Blending
- High Energy Milling
- Powder Plating
- Small-Large Powder Granulation
- Spray Drying / Agglomeration

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



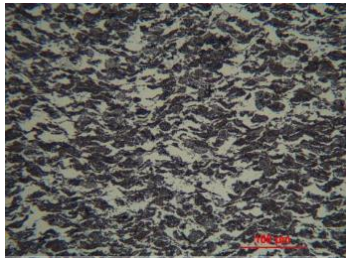
Mechanical Blend

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



Spray Dried and Sintered

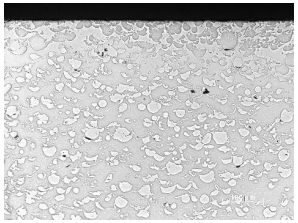
- Design optimized clad agglomerate powders show the best overall properties including higher DE, good toughness, and excellent wear performance



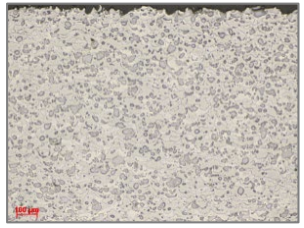
Combined Processing
Spray Dried + Coated

Current State of Development with WIP Coatings

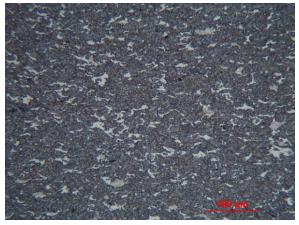
- WIP-C1 and WIP-C2
  - These deposits are being rolled out into several applications and have by far the most robust set of data and spray conditions of all WIP materials
  - Vendors have been set up to produce this material commercially for easier procurement
  - Deposits have been demonstrated with 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



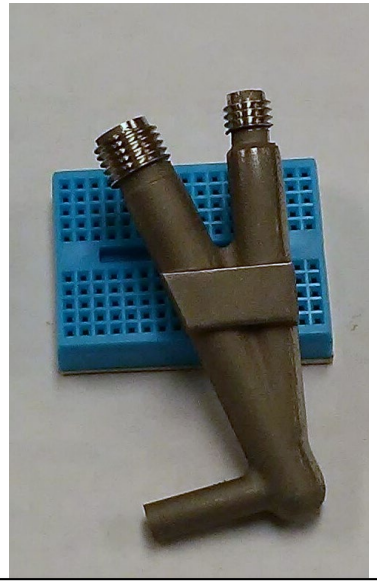
- WIP-W1
  - This material has the greatest potential for direct chrome replacement in most applications
  - The data generated has shown excellent wear and
  - Deposits must be ground, but can be ground with SiC or diamond
  - All powders have been produced using production robust processes



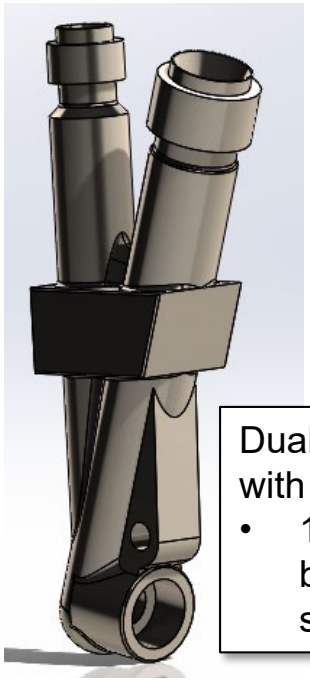
All coatings can be applied in line of site applications as well as in features as small as 1.8 - 2 inches

ID NOZZLE DEVELOPMENT

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

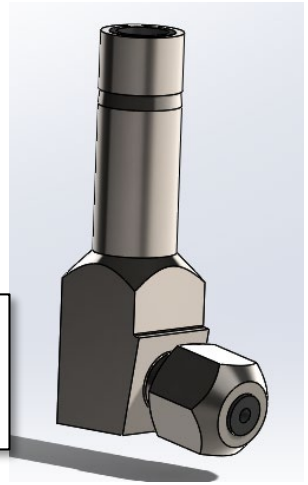


Dual injection design with integral Co-Cr nozzle
- 1.5 in minimum bore, 0.5” standoff



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

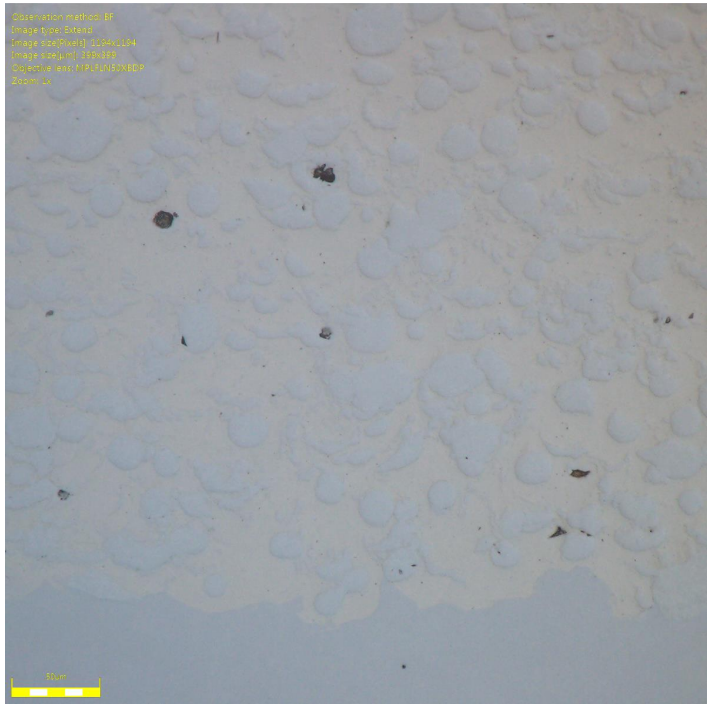
Single injection large bore design
- 4 in minimum bore, 0.5” standoff



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

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%

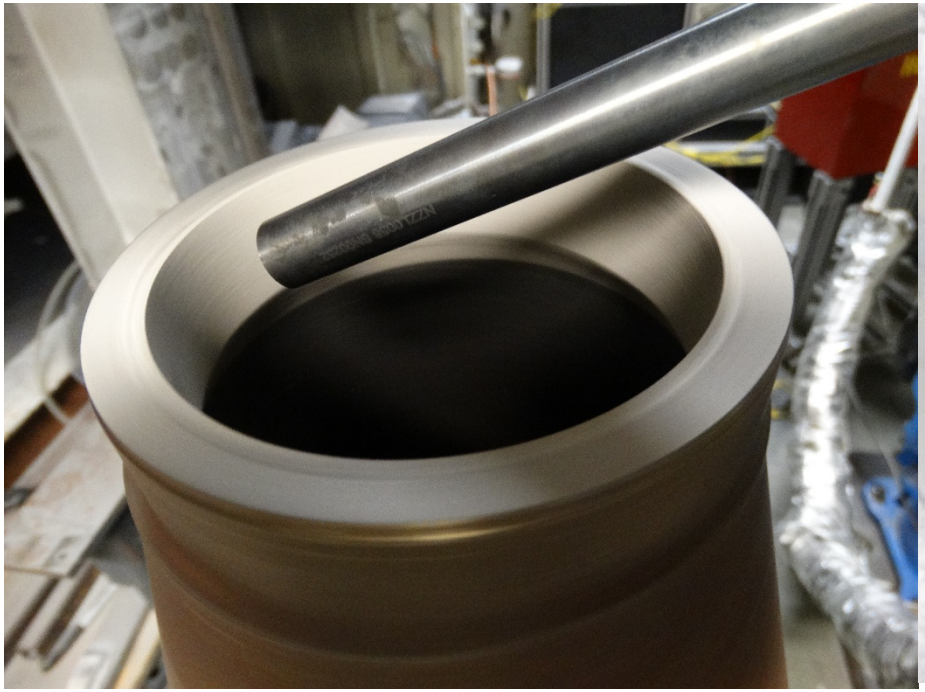
Substrate	Lug Shear Strength (ksi)
17-4PH	~20
High Hardness Steel	~20-25
4340	40.6 (He), 28 (N2)
4330V	38.3

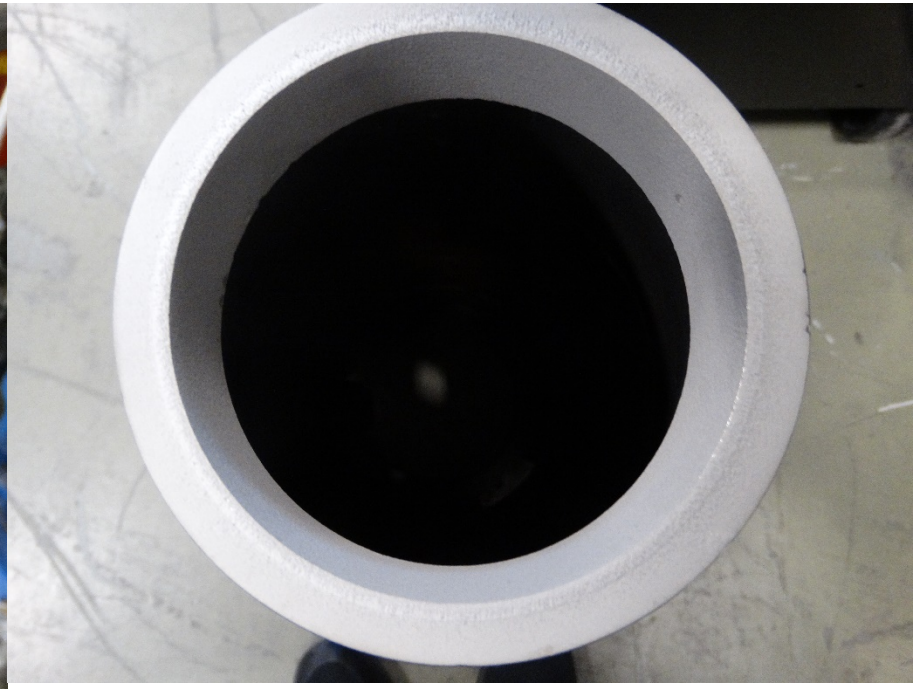
BRADLEY TURRET MOUNT

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

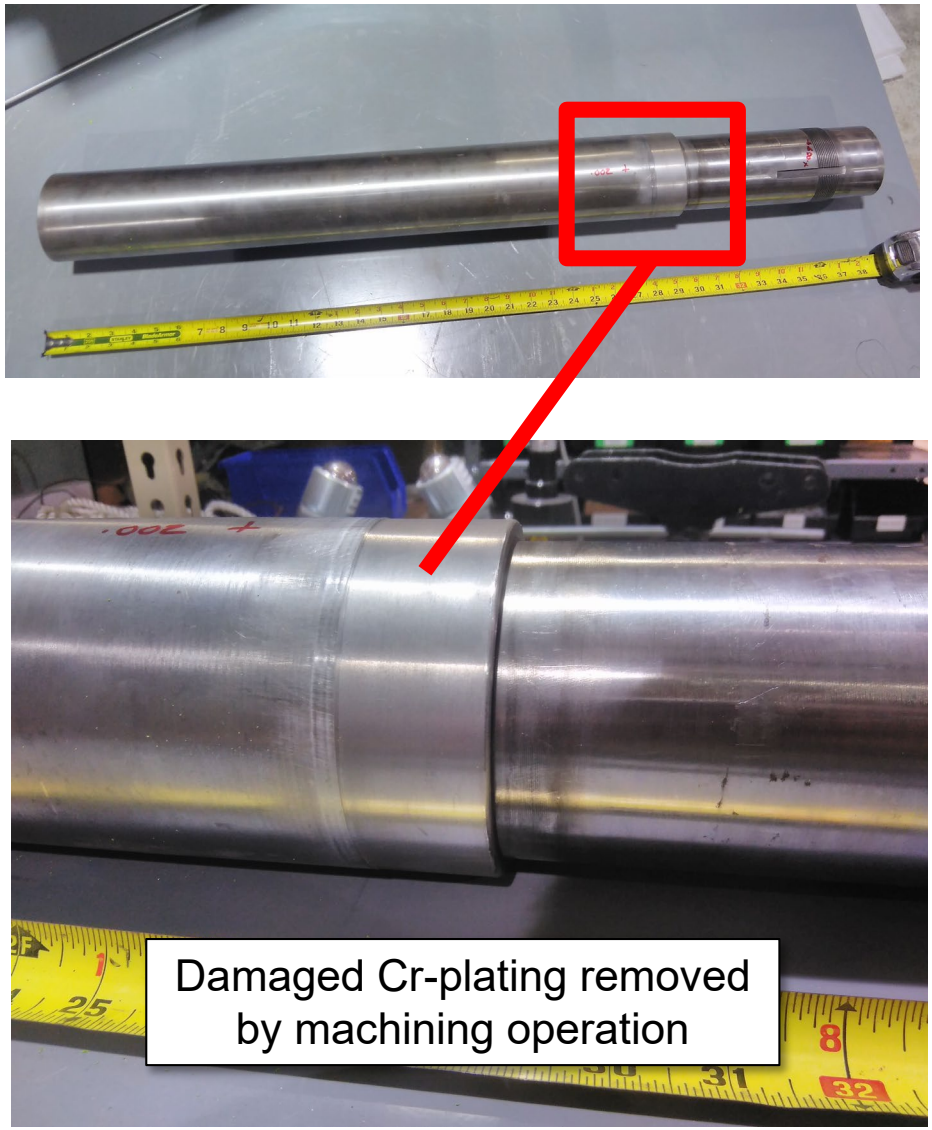
BRADLEY TURRET MOUNT

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

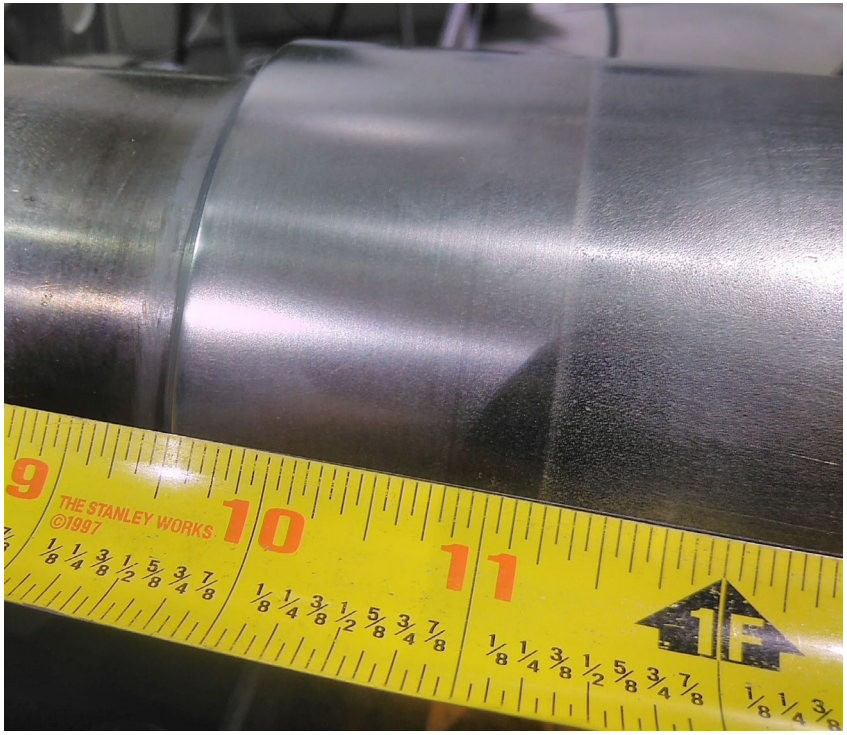




LETTERKENNY BALL SCREW ACTUATOR

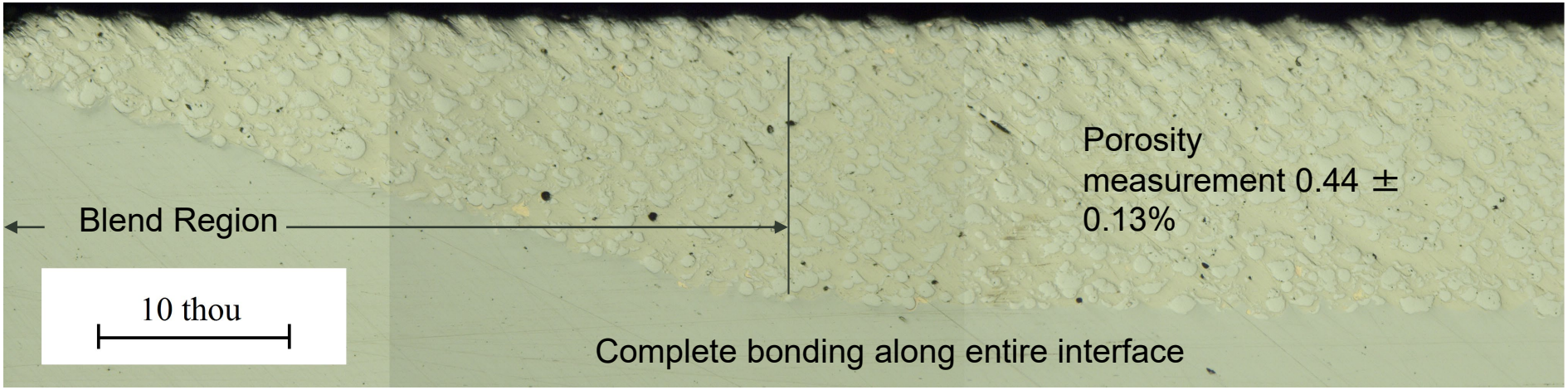


With Cold Spray process minimal masking or complicated tooling required!!

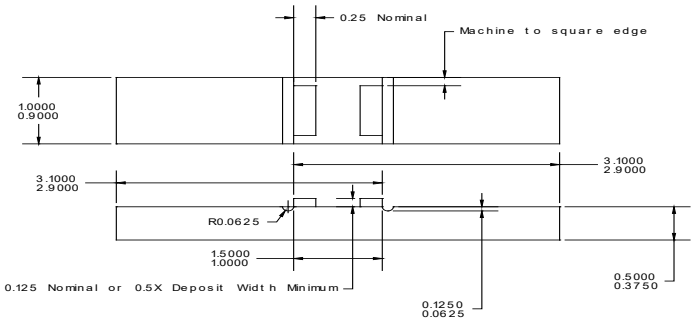


Ball Screw Actuator Cover, Mock Part Evaluation

Letterkenny Army Depot

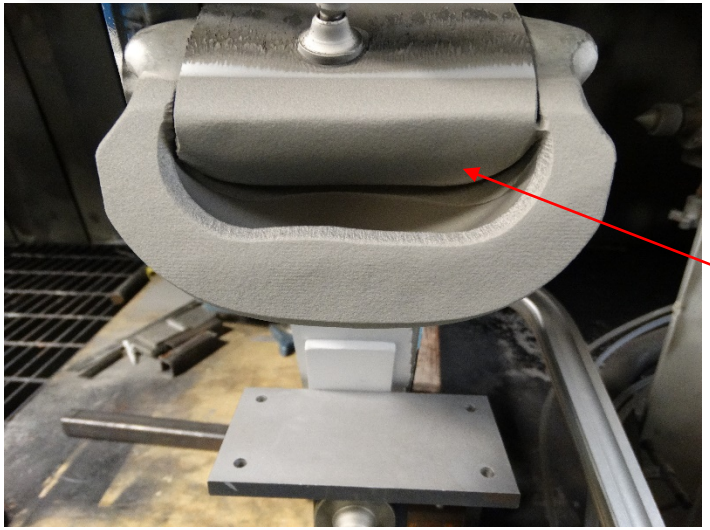


- Deposition process was performed with WIP-BC1 followed by WIP-C1
- Lug Shear testing was performed on 4340 (40-44HRC) which closely represents part material
- Results → 28 ksi bond strength

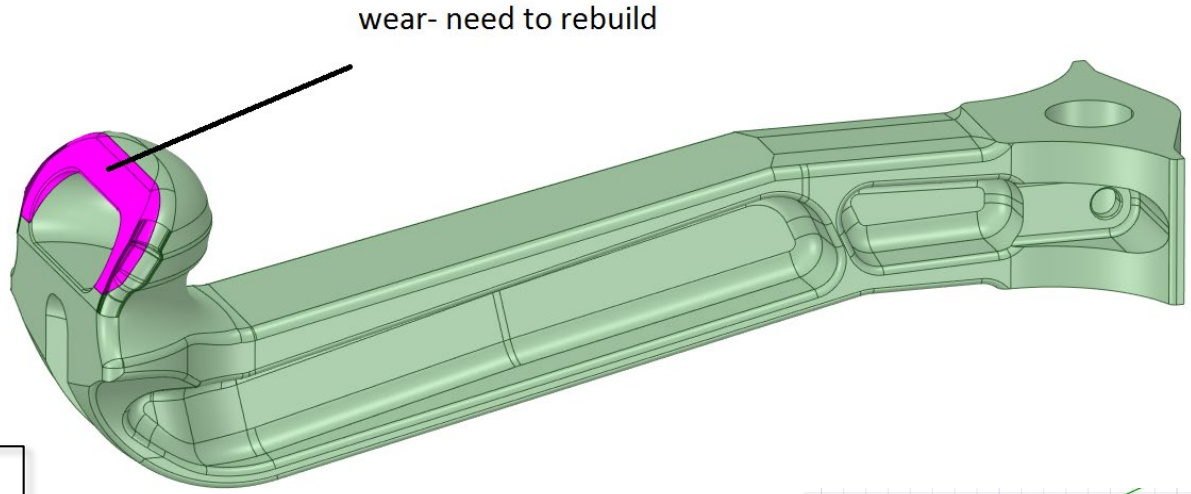


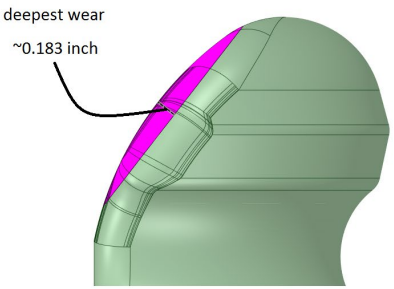
CANDIDATE REPAIR COMPONENT

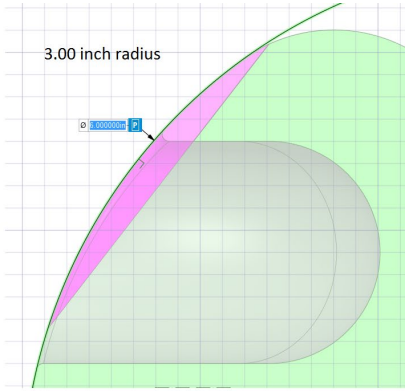
Surface wear due to adhesive/abrasive wear



Sheet metal masking created to protect pocket

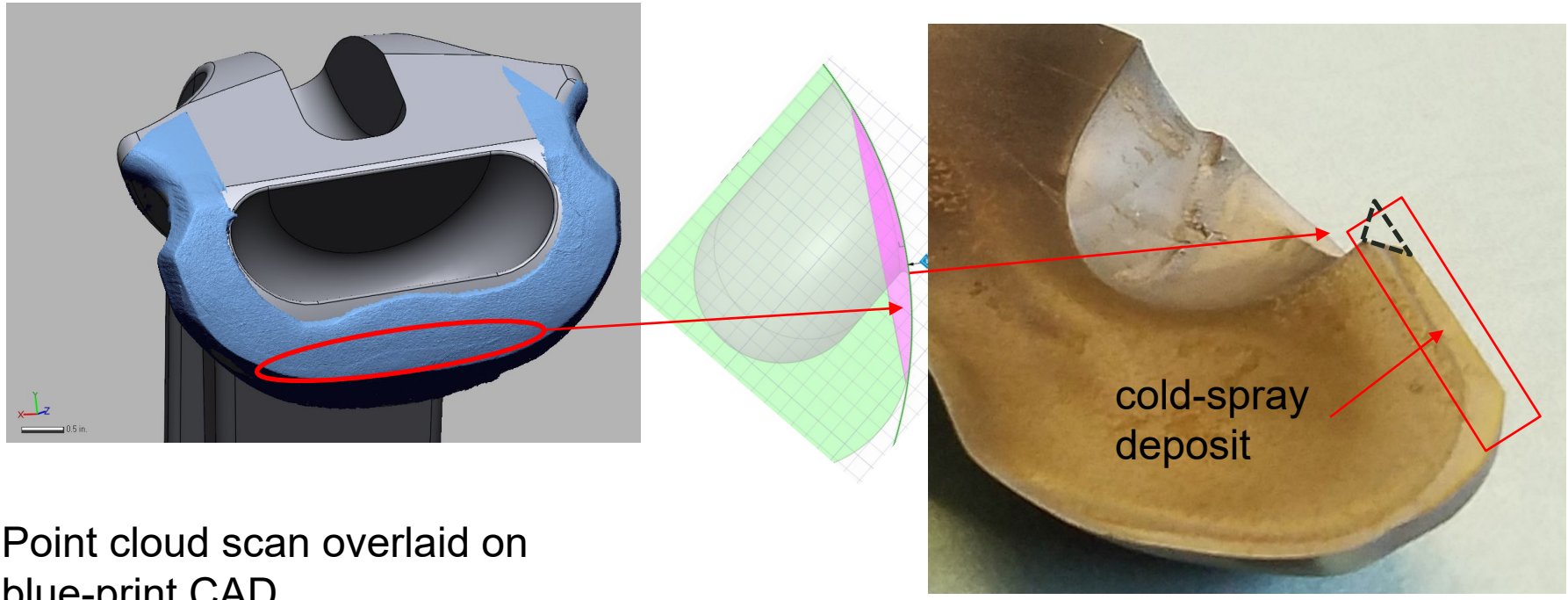






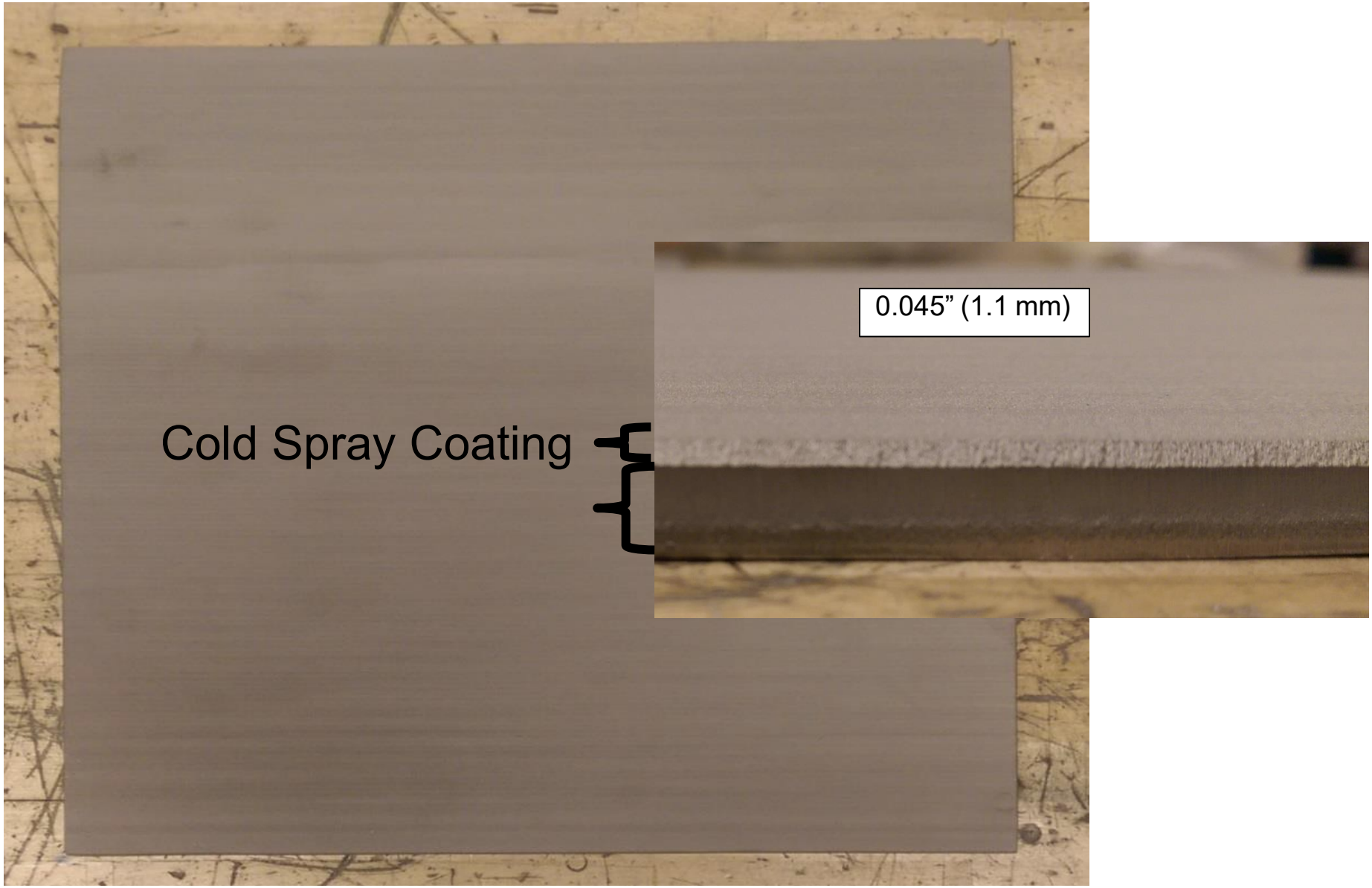
ARL Cold Spray Process Development

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



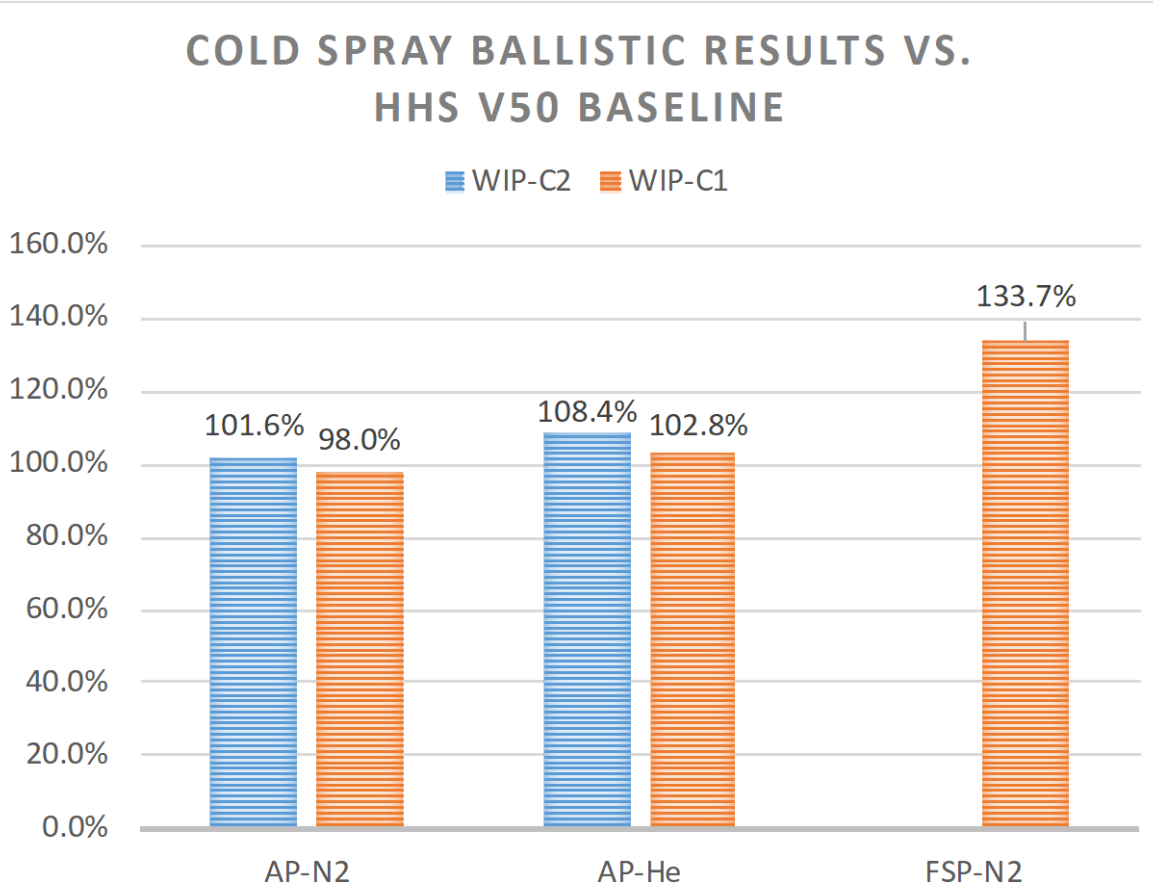
Point cloud scan overlaid on blue-print CAD

BALLISTIC ARMOR REPAIR

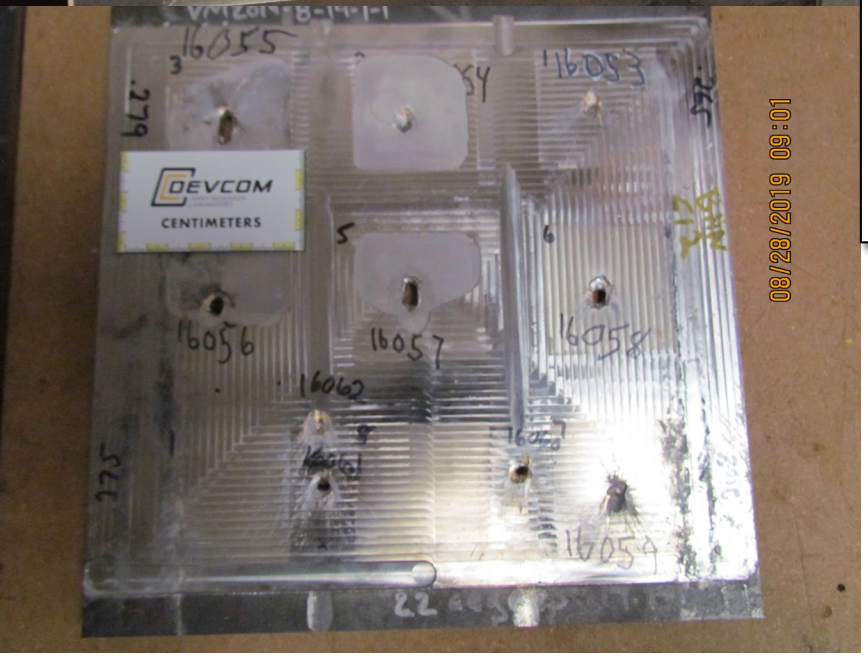


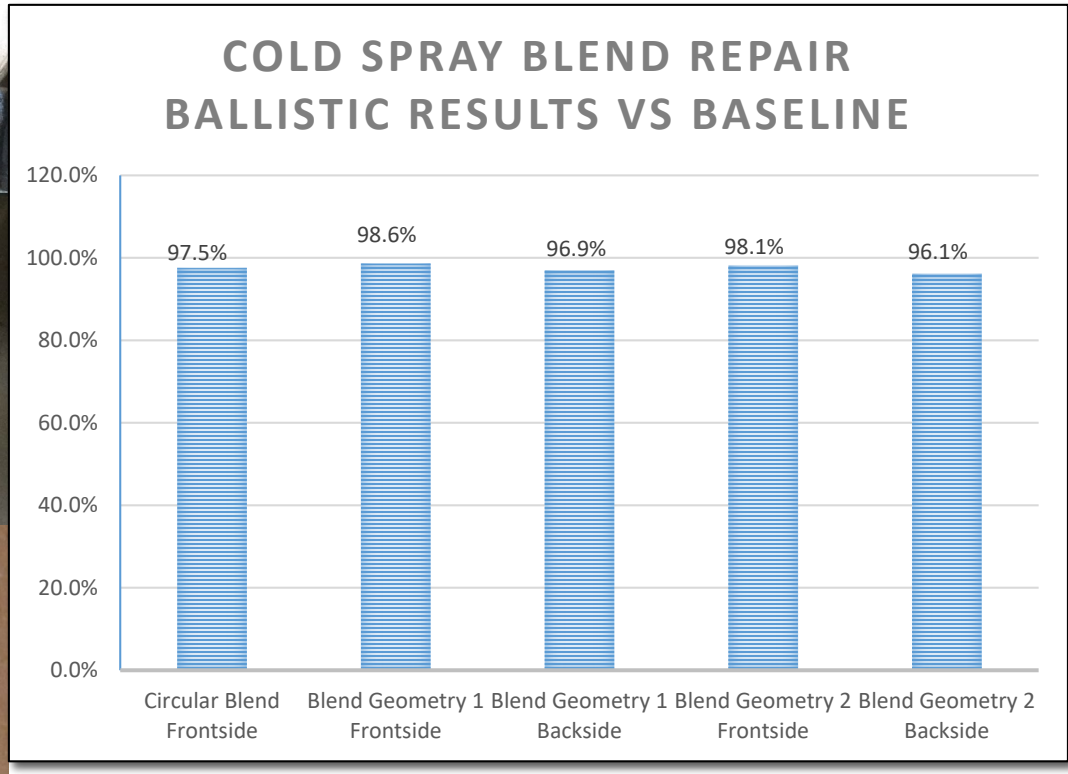
COLD SPRAY BALLISTIC PERFORMANCE

- 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.



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.

THANK YOU!