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

Cold Spray Action Team Meeting

Chrome Replacement and Recent Advancements

Presenter: Aaron Nardi, aaron.t.nardi.civ@mail.mil, 301-787-3859

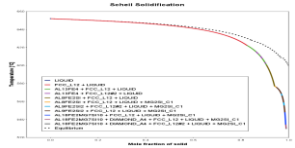
Team Members: Victor Champagne, Gehn Ferguson, Isaac Nault, William Story, Dan Nikolov

ARL Weapons and Materials Directorate

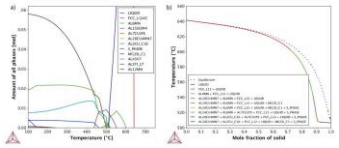
Manufacturing Science and Technology Branch

ARL Holistic Approach to CS AM Development

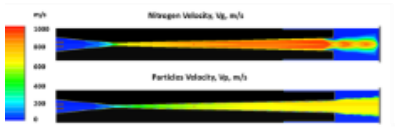
Solidification



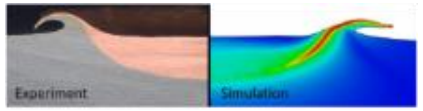
Thermodynamic



Particle Acceleration

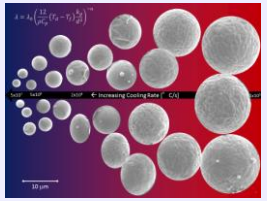


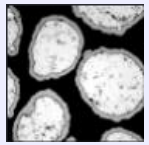
Particle Impact



Modeling & Simulation

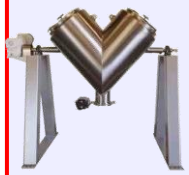
- ***Chemistry***
- ***Manufacturing process***
- ***Particle Size and***





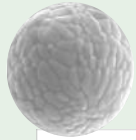
Powder / Material Selection

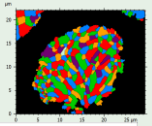
- ***Degassing***
- ***Heat Treating***
- ***Blending***
- ***Milling***

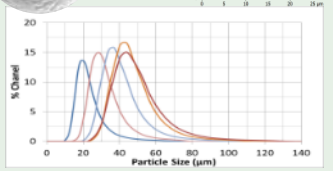


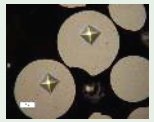
Powder Processing

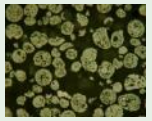
- ***Microstructure***
- ***Particle Size***
- ***Morphology***
- ***Mechanical Properties***

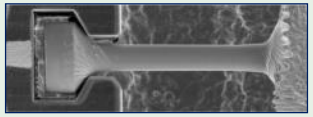






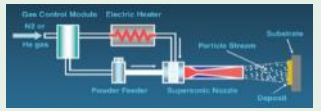






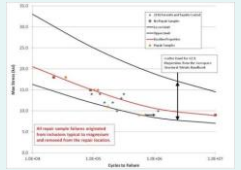
Powder / Material Characterization

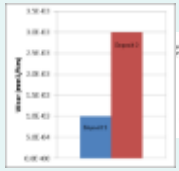
- ***Pressure***
- ***Temperature***
- ***Nozzle Geometry***
- ***Substrate Preparatio***
- ***Motion Control***

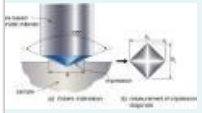


Cold Spray Process

- ***Porosity***
- ***Microstructure***
- ***Interface***
- ***Hardness***
- ***Wear***
- ***Mechanicals***

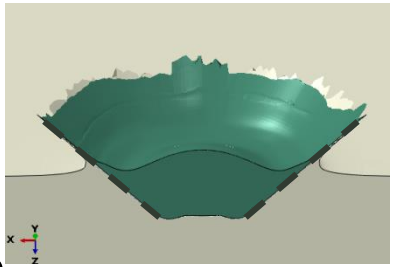




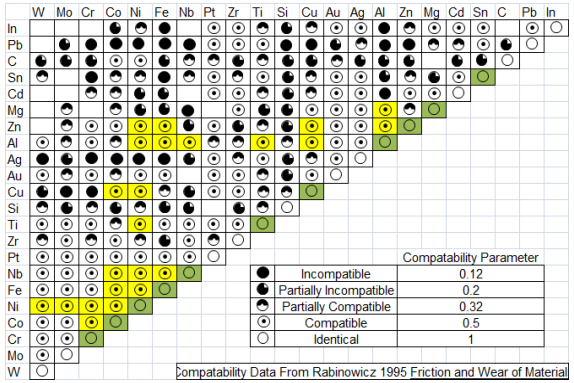


Post-Processing Characterization

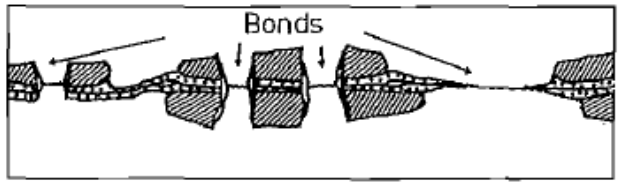
Metallic Bonding in Cold Spray



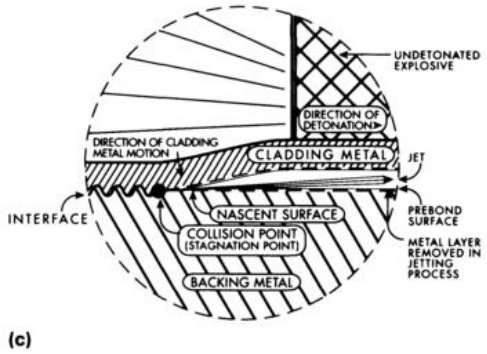
- Materials compatibility enables increased bond strength (bond layers, encapsulated powders, etc.)
- Surface contamination requires higher surface expansion (strain) to achieve bonding (oxides, hydroxides, chemisorbed layers, etc.)
- High plastic strain of both surfaces improves bonding
- Material jetting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



Material Compatibility



High Plastic Strain

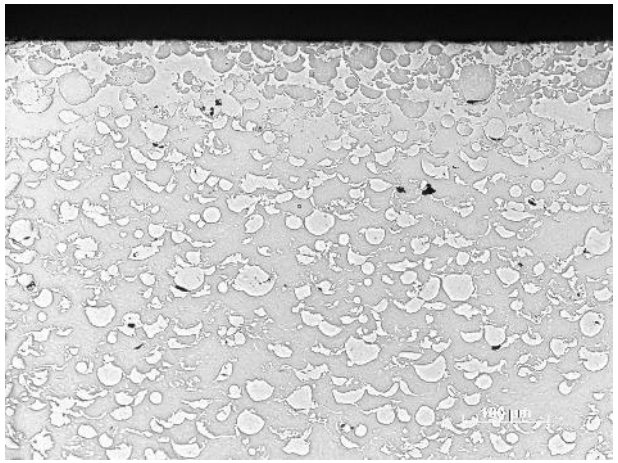


High Strain Rate Jetting

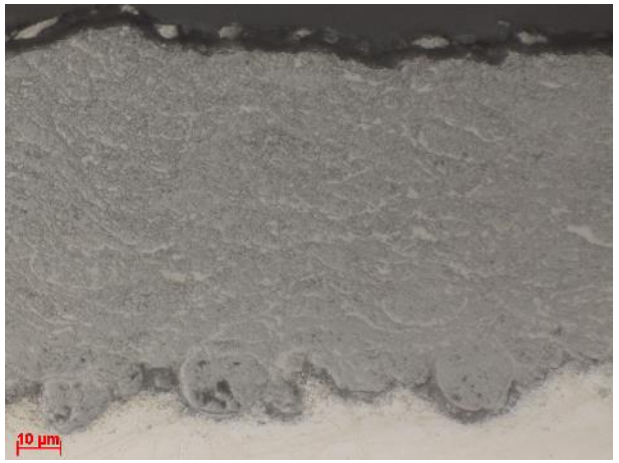
SERDP WP-2607 Cold Spray Powders

- Powder Blends have achieved approximately 375-450 HV hardness deposits
  - Moderate to high wear resistance with the best impact properties
- Spray Dried or agglomerated and sintered powders have achieved the highest hardness ranging from 800 – 1300 HV depending on composition
- Design optimized clad agglomerate powders show the best overall properties including higher DE, good toughness, and excellent wear performance

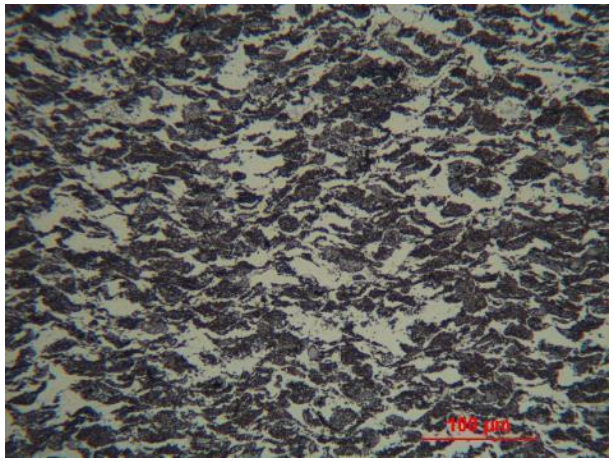
Mechanical Blend



Spray Dried and Sintered

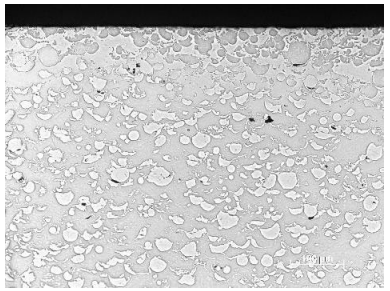


Combined Processing
Spray Dried + Coated



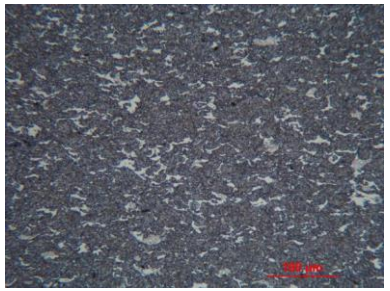
Wear and Impact Protection (WIP) Powder Family

- 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



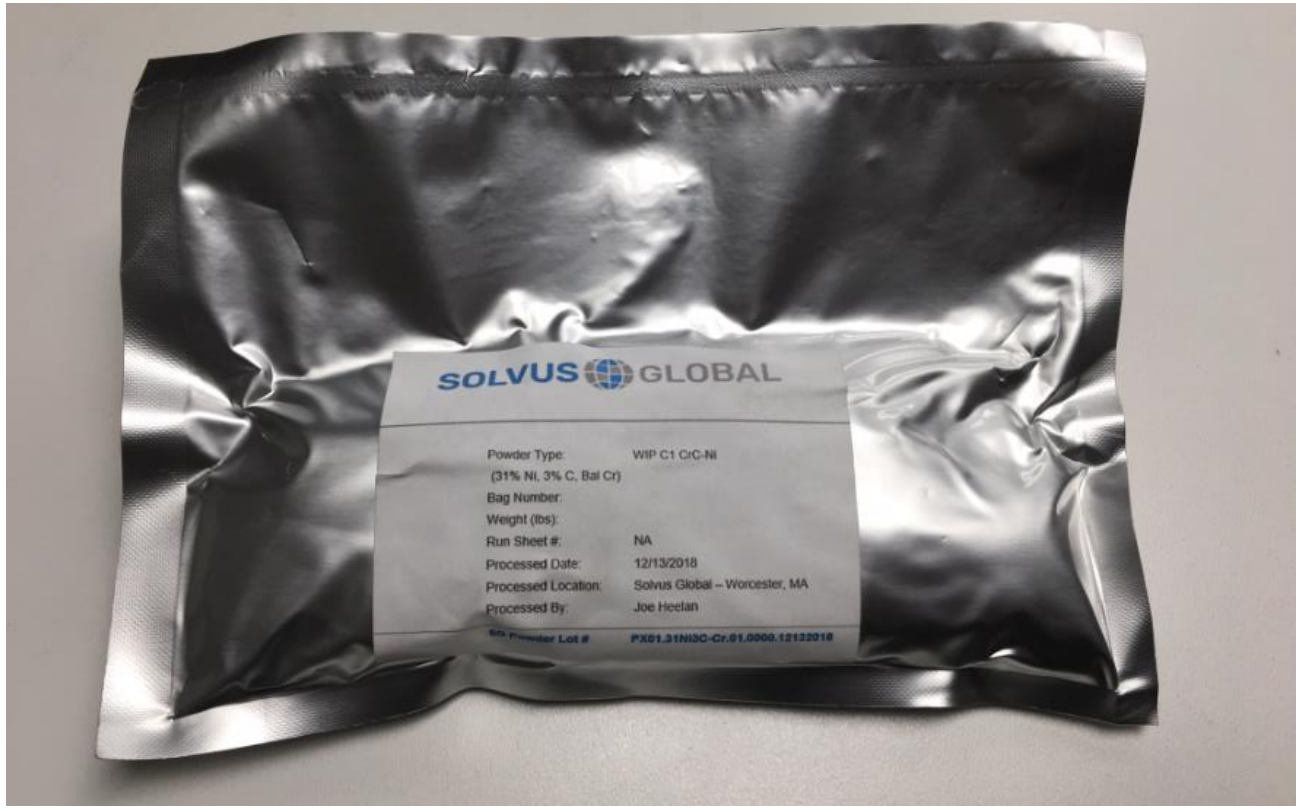
- WIP-F1
  - This material is very similar to WIP-C1 and C2 but is completely iron based for applications where EH&S concerns about nickel based deposits may be present
  - More work needs to be done to characterize the properties, especially wear performance, of this material
  - Once further data is 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
  - Deposits must be ground, but can be ground with SiC or diamond
  - All powders have been produced using production robust processes



Powder Blending Production Scale-up

Powder Classification	Material 1	Material 2	Blended Composition
WIP - C1	Ni (-45 µm/+16 µm)	CrC-NiCr (-45 µm/+11)	31% Ni, 3% C, Bal Cr
WIP – C2	Ni20Cr (-45 µm/+16 µm)	CrC-NiCr (-106 µm/+45)	26% Ni, 3% C, Bal Cr
WIP - BC1	Ni (-45 µm/+16 µm)	CrC-NiCr (-106 µm/+45)	41% Ni, 2.6% C, Bal Cr



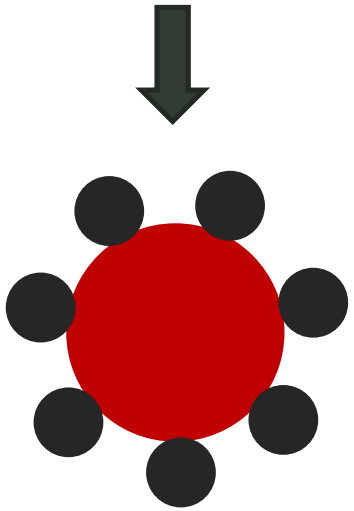
Capabilities	Description
Batch Capacity	5 lbs
Mixing Rate	10 lbs / hour
Packaging	Inert + vacuum sealed

Solvus Global blended powder packaged in vacuum sealed mylar bags in inert gas

Granulation Production Scale-up

Granulation is a process which can be used to attach small fine particles to larger course particles to make mixed agglomerates.

- Mechanical cladding
- Clad composite powders

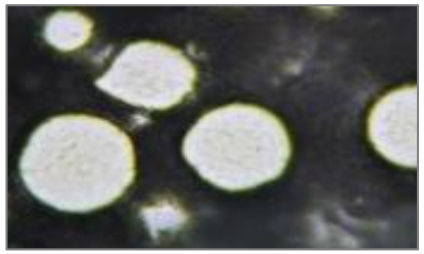


Process Scale-up at Solvus Global

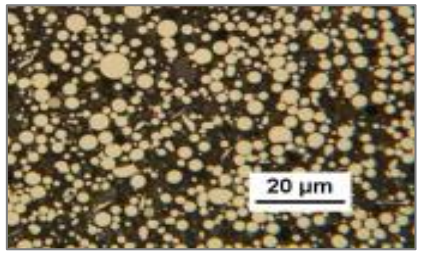
Lab Scale (~200 grams)

Small Bench Scale (~2kg)

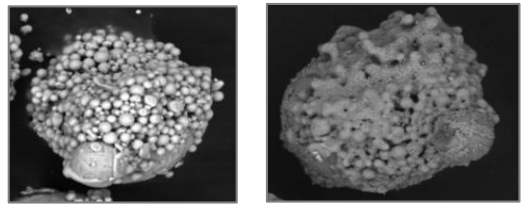
Production Scale (10-50 kg)



Carbide powder



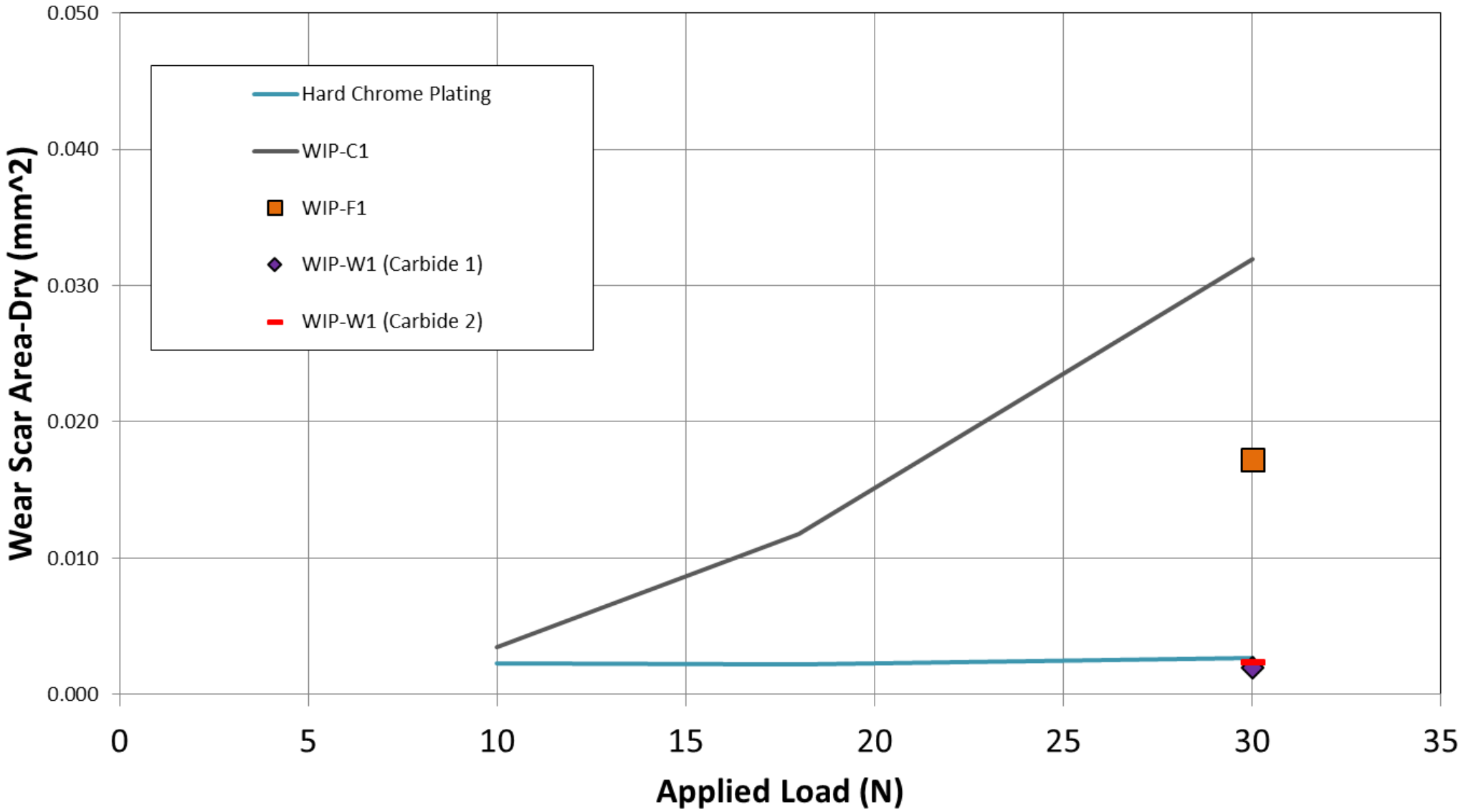
Additional Metal Matrix Powder



Powder particles after granulation

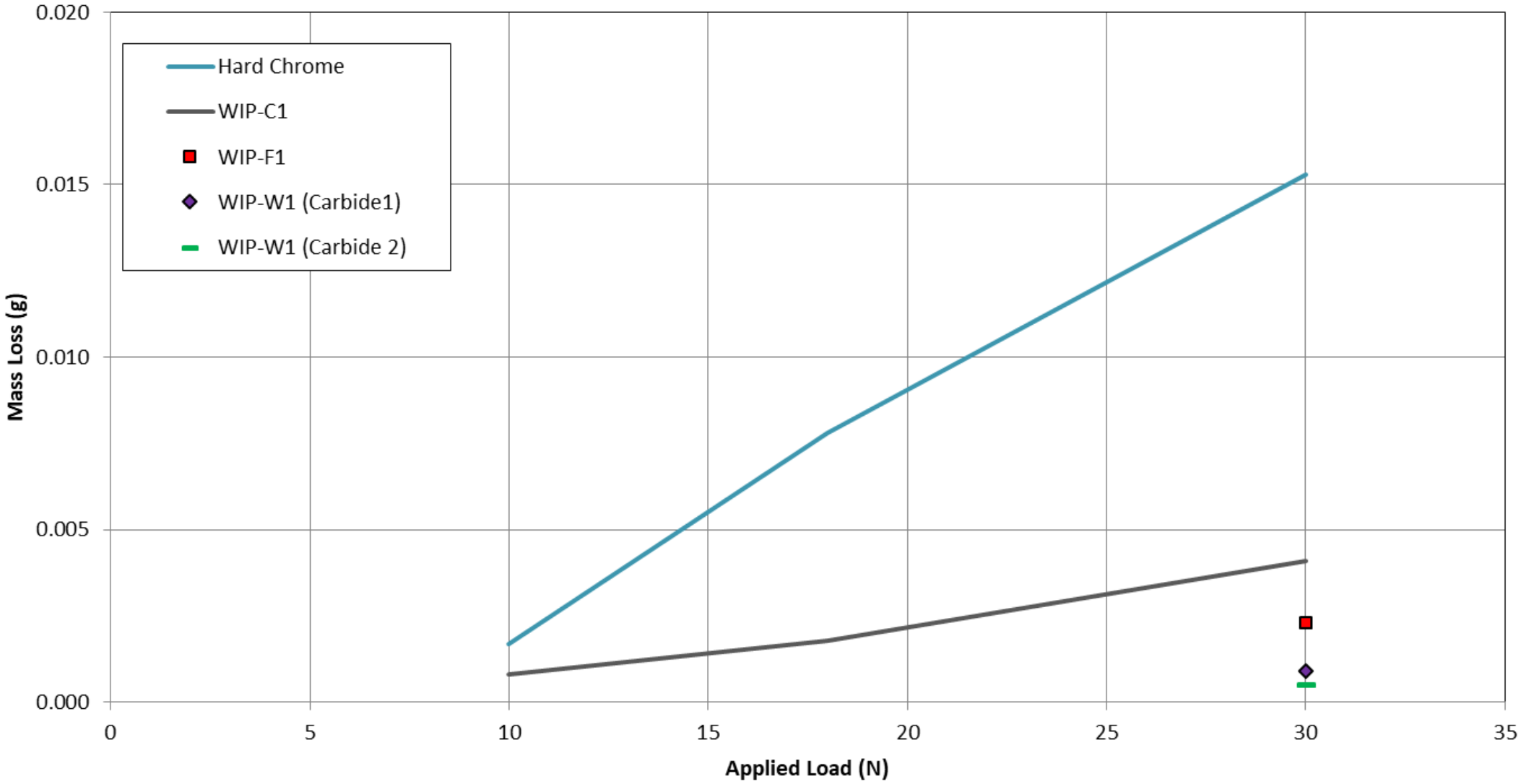
Ball on Flat Reciprocating Wear

0.375 in 52100 Ball, No Lubrication

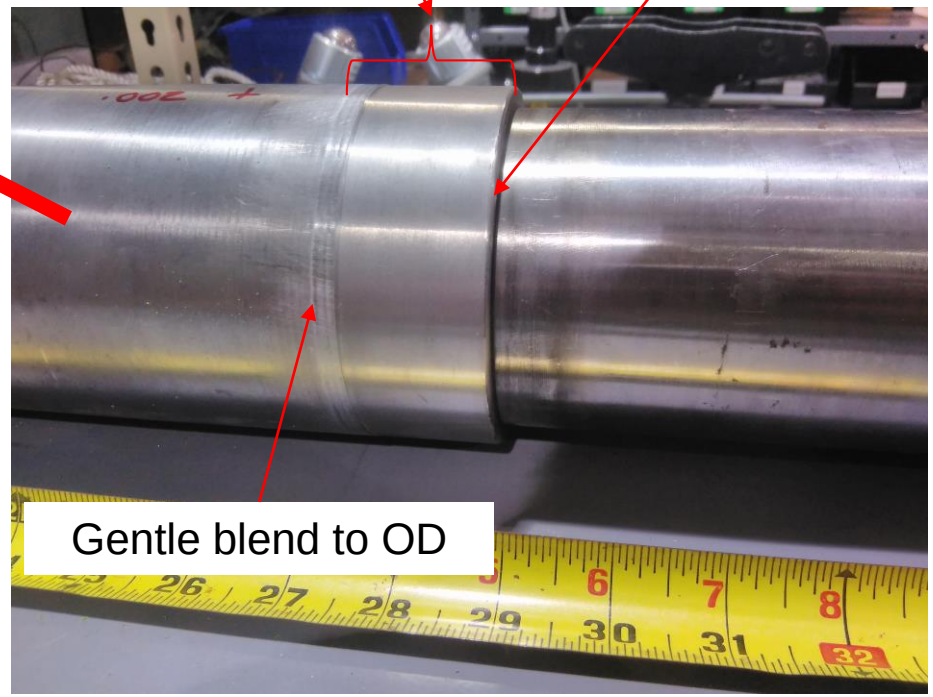


Ball on Flat Reciprocating Wear

0.375 in Al2O3 Ball, No Lubrication



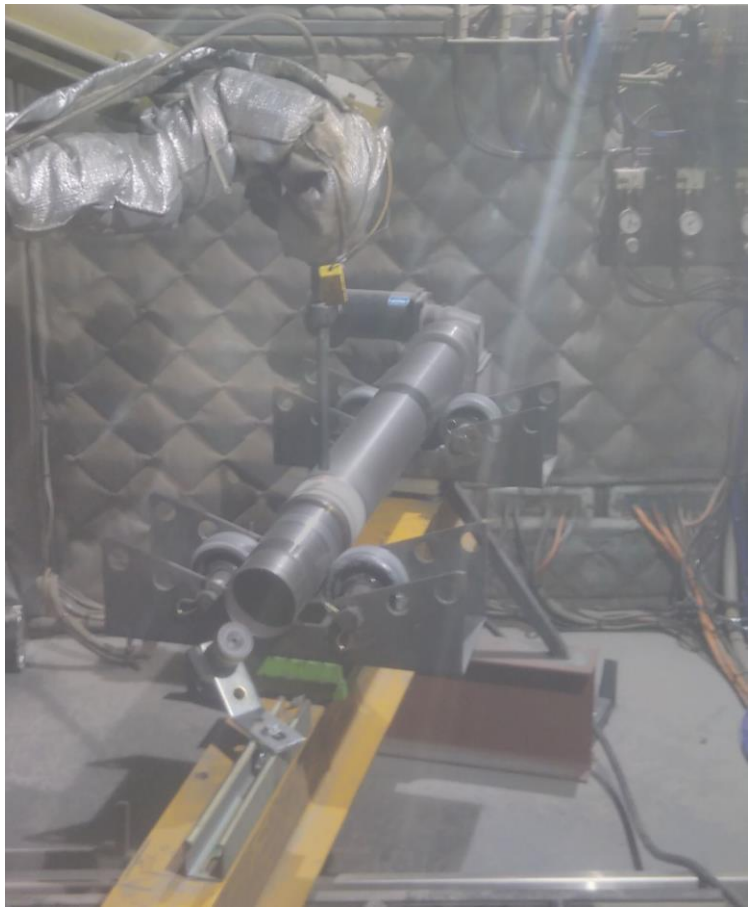
Ball Screw Actuator Cover
Letterkenny Army Depot



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

Ball Screw Actuator Cover
Letterkenny Army Depot

Spray Processing



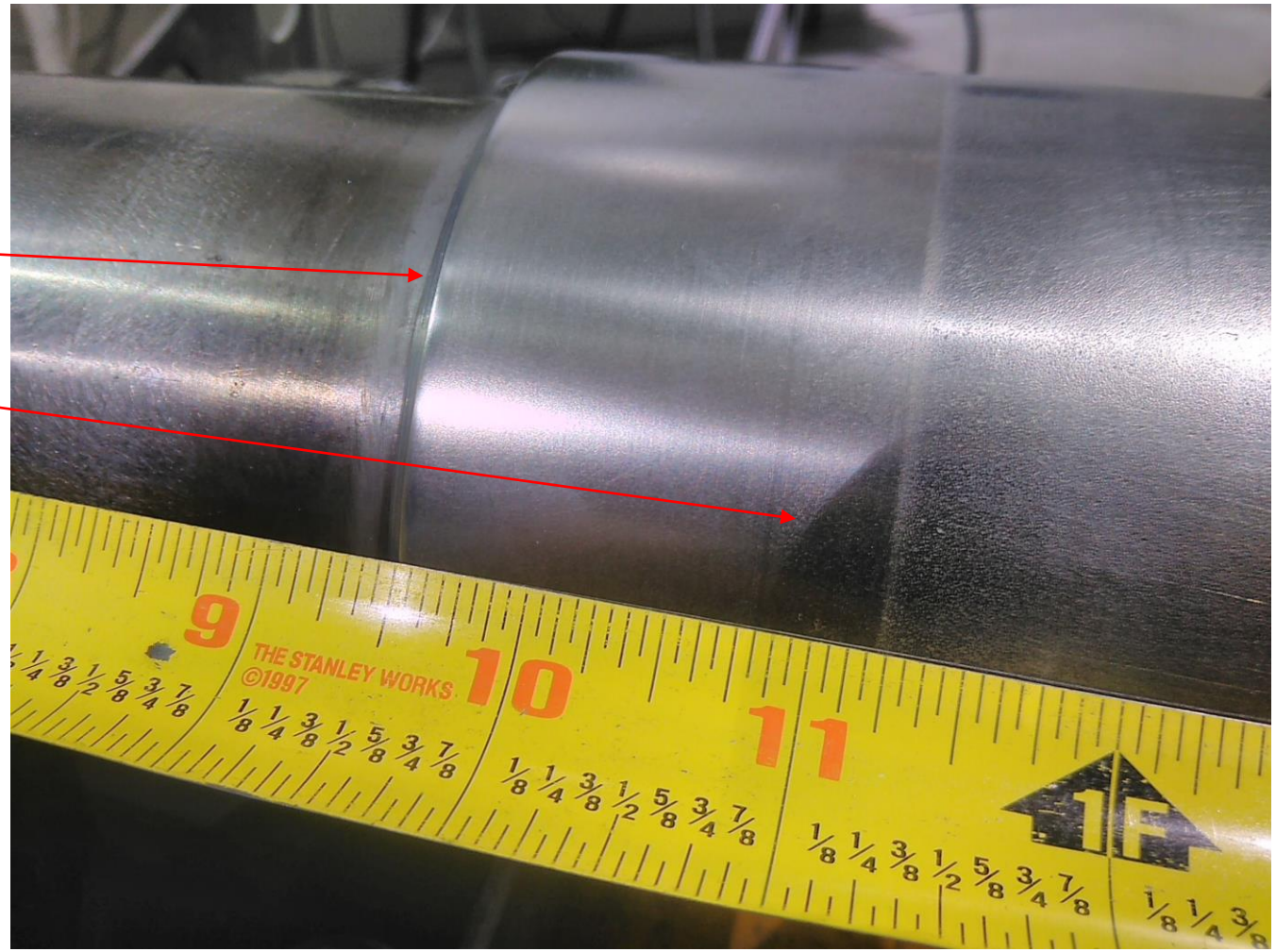
Sleeve (masking still on)
after spray / before machining

Steel sleeve set screwed in place
used as masking
OD < OD - buildup thickness

Ball Screw Actuator Cover
Letterkenny Army Depot

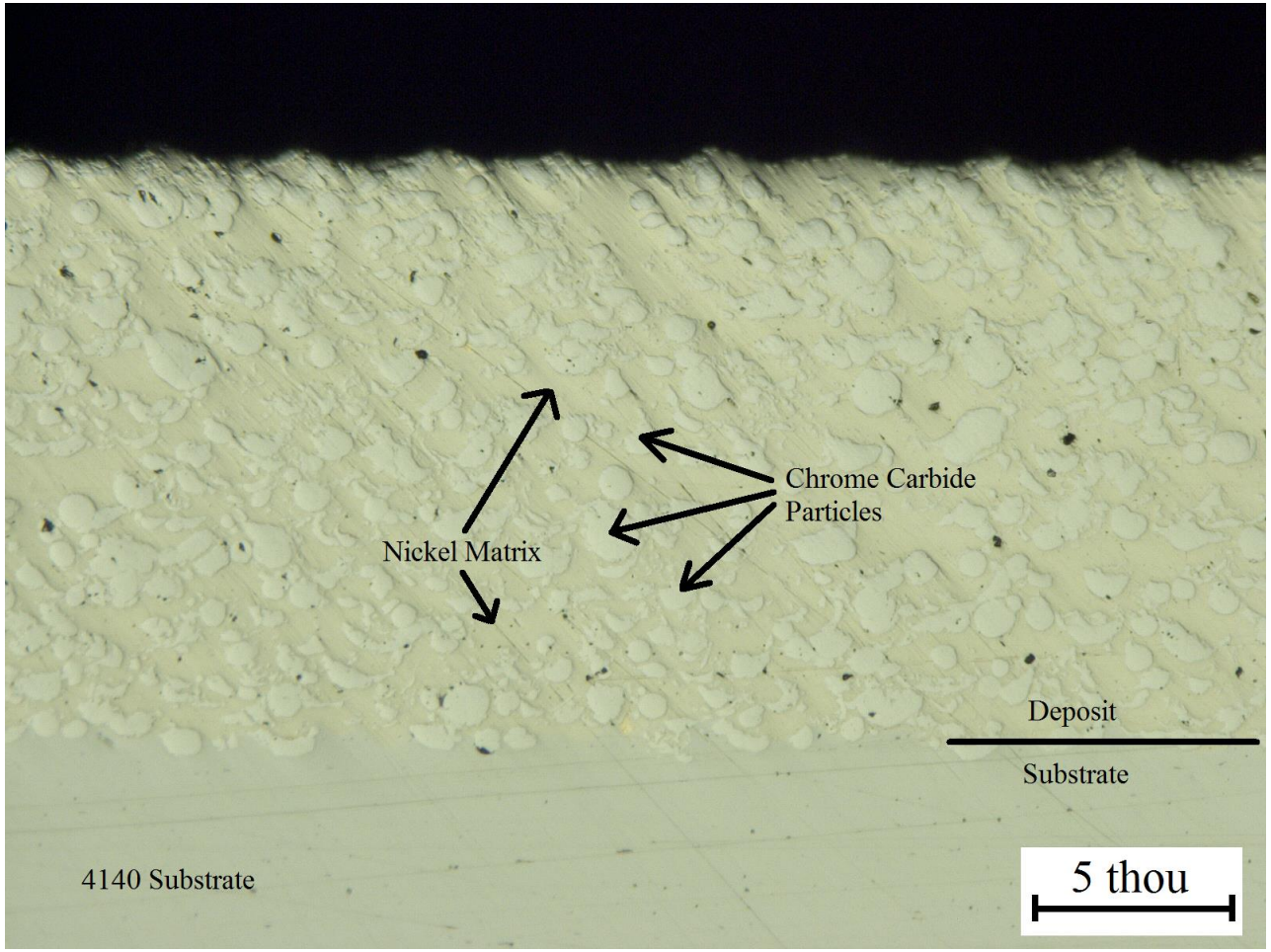
Finish Machining

- Single point turned then sanded to achieve desired roughness
- Lead edge chamfered to allow for seal engagement
- Meets drawing allowable diameter matching requirement at trailing edge



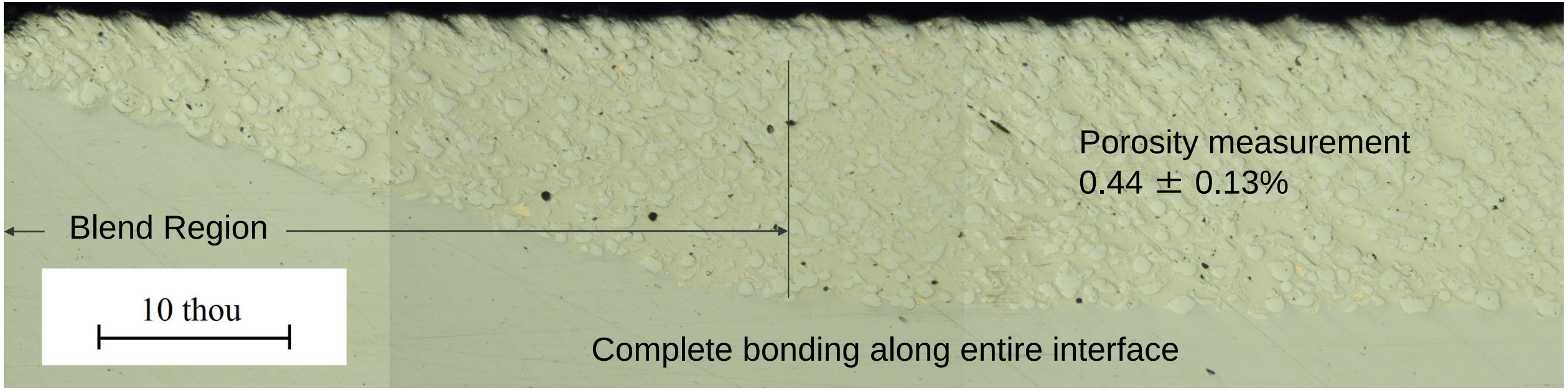
MICROGRAPHS AND POROSITY

- Cross section of a mockup piece.
- Complete bonding along interface
- Porosity measured to be 0.44 ± 0.13%
- Lug Shear testing on 4340 (40-44HRC) results in 28 ksi bond strength

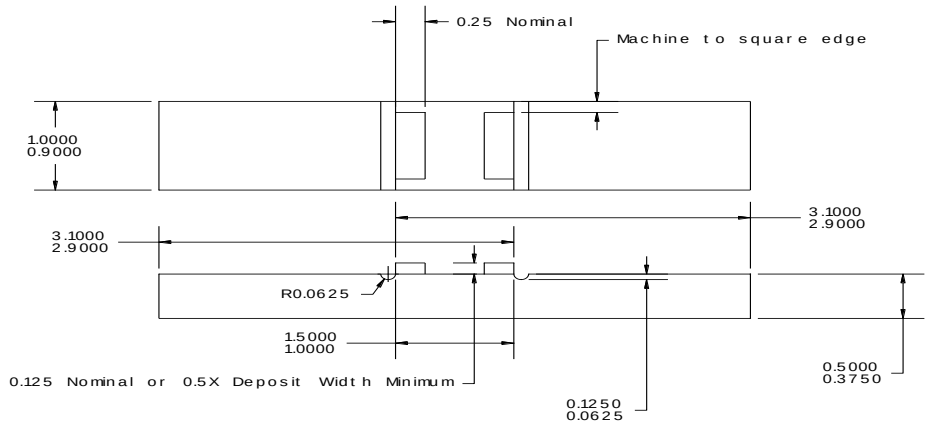


Ball Screw Actuator Cover, Mock Part Evaluation

Letterkenny Army Depot

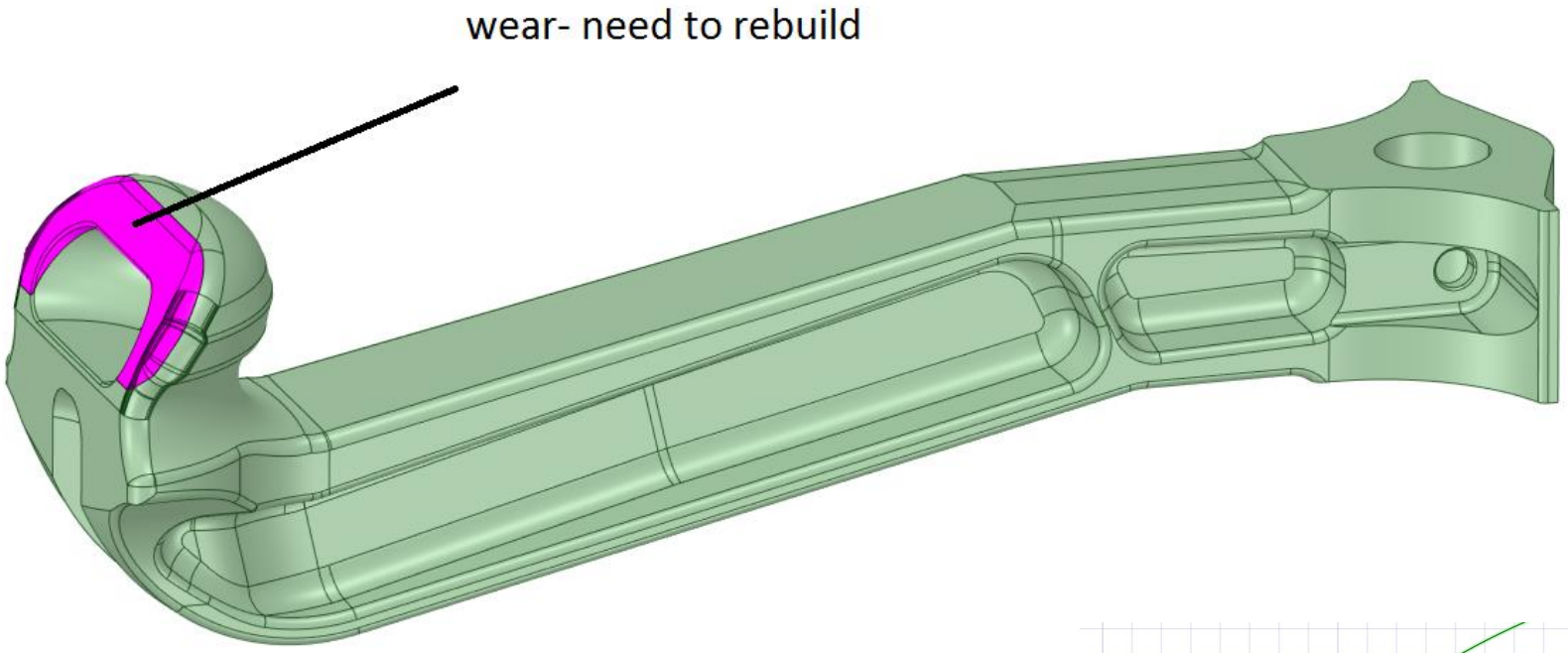


- Deposition process was performed with WIP-BC1 followed by WIP-C1
- Lug Shear testing was performed on 4340 (40-44HRC) which closely represents part material
- Results → 28 ksi bond strength

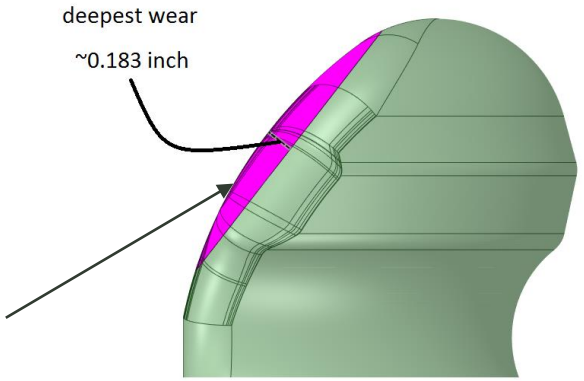


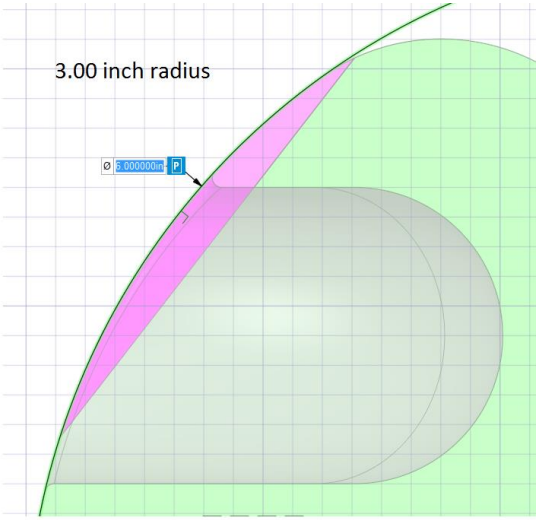
Arresting Hook Repair
NAVAIR-PAX River

Surface wear due to adhesive/abrasive wear



Material to be added

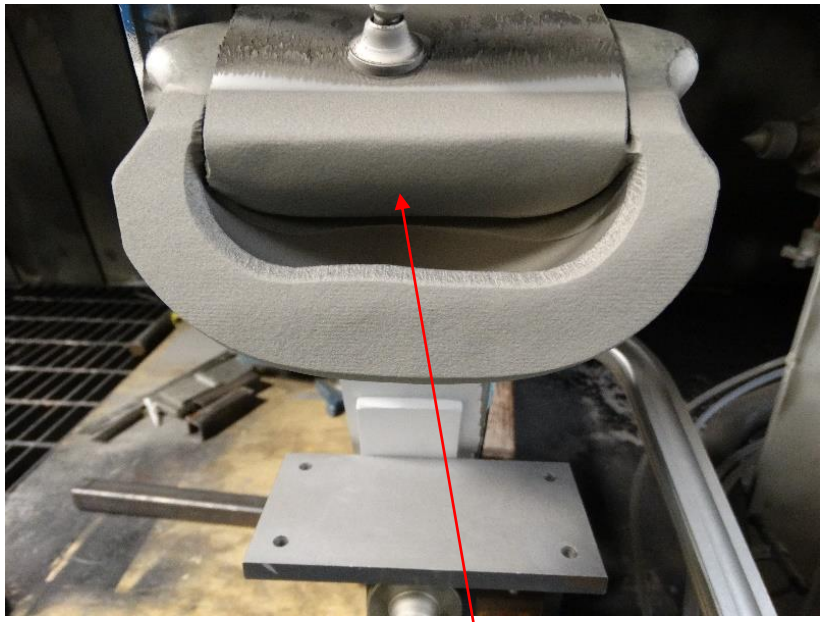




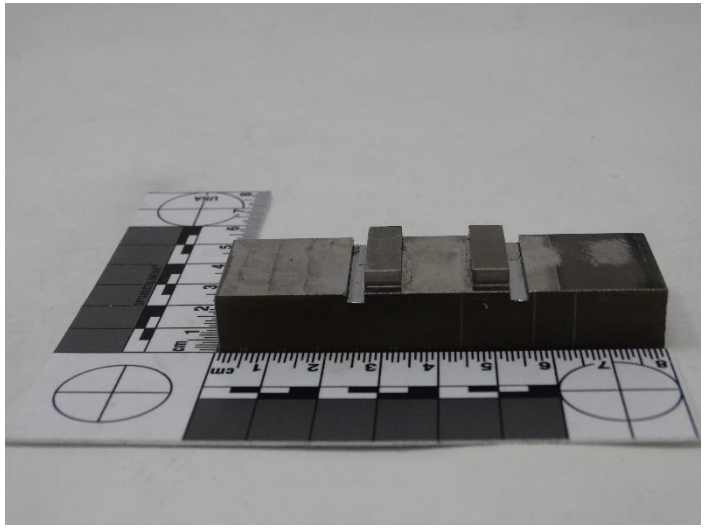
ARL Cold Spray Process Development

- **Cold Spray Process**
  - VRC Gen 3 21 kW System
  - Gas: Helium
  - High Pressure, High Temperature spray condition
- **Powder**
  - WIP-BC1 bond coat
  - WIP-C1 top coat
  - Selected for good wear, bonding, and toughness properties
- **Testing**
  - Porosity: <0.5%
  - Lug Shear Adhesion: 38 ksi average

Helium selected due to unknowns about application requirements



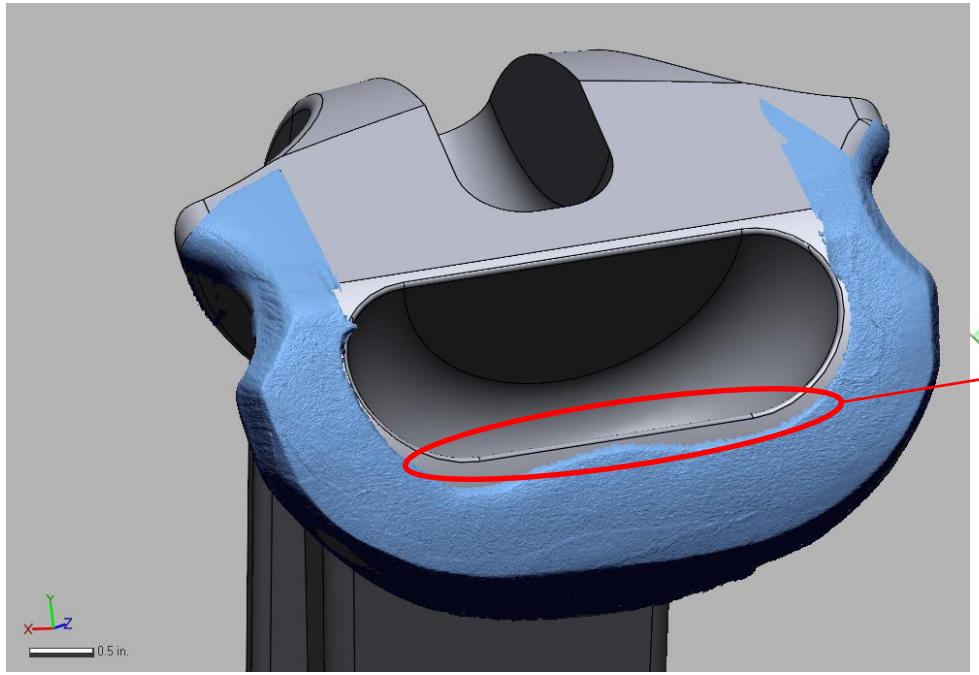
Sheet metal masking created to protect pocket



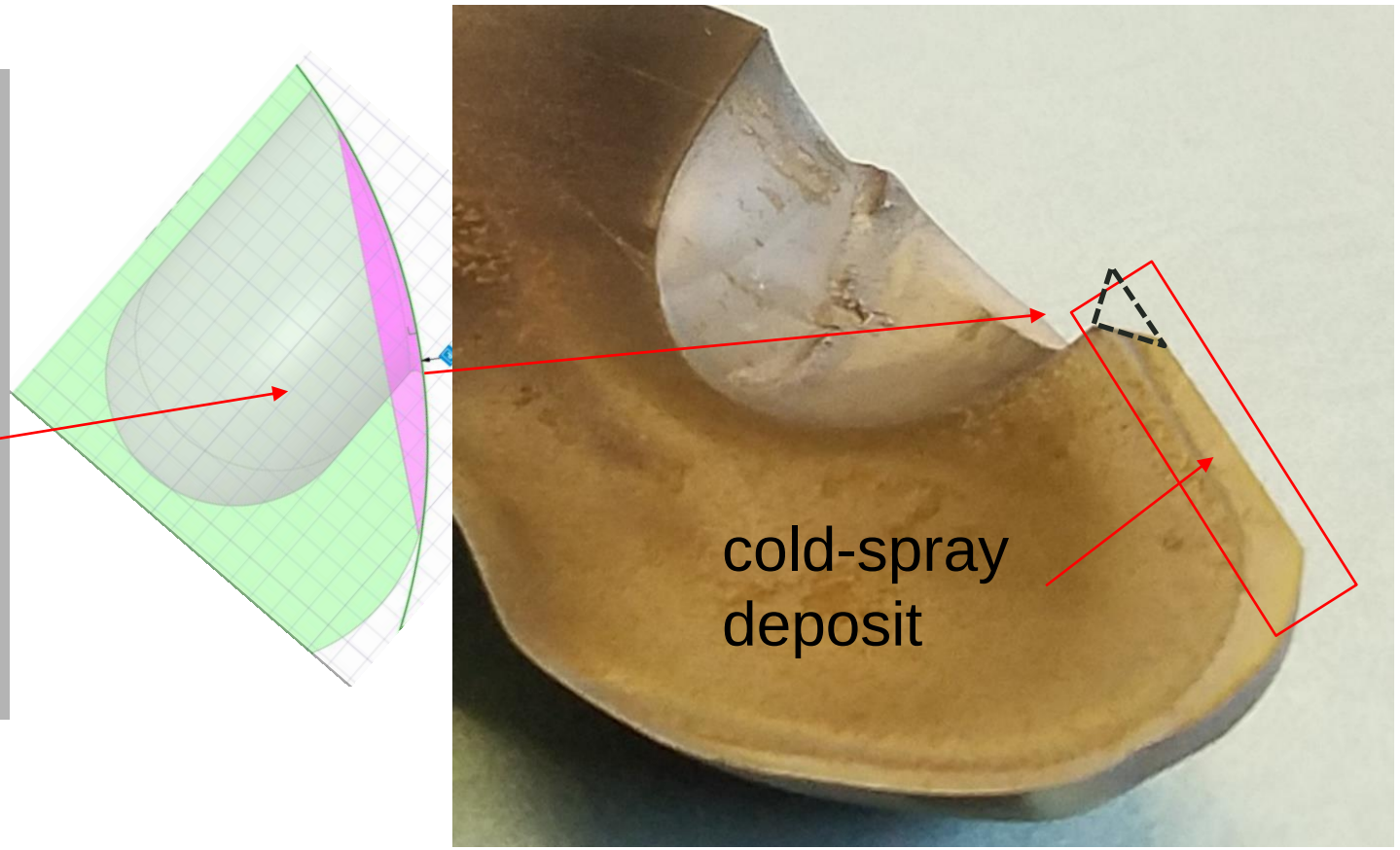
Significant material mixing at interface

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



Potential ID Coating Applications

Potential parts to be repaired

- Landing gear cylinders
- Hydraulic cylinders
- Valve bodies
- Shipboard hydraulic accumulators
- Main Rotor Dampers

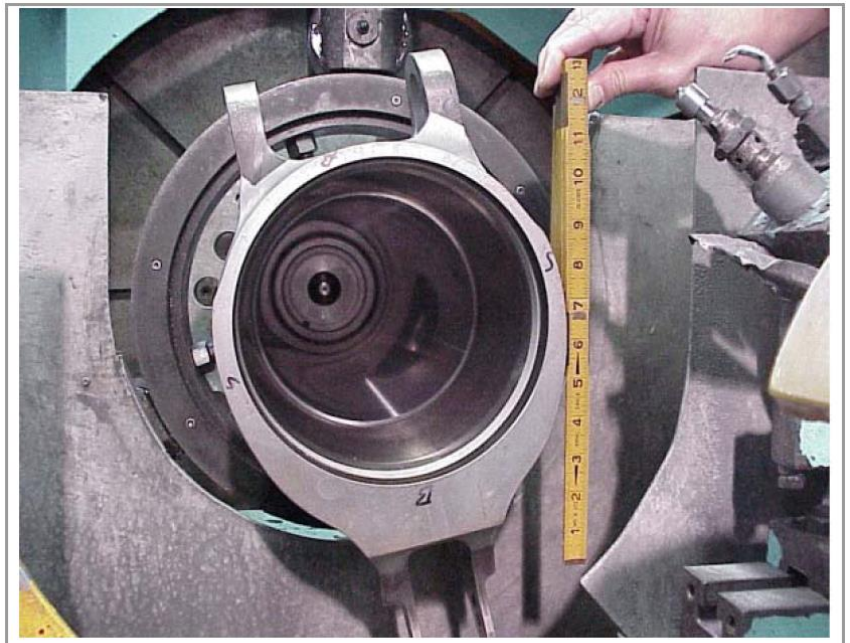


Figure 1-4 P-3 main landing gear outer cylinder ID chrome plated at NADEP JAX.

Images from From WP-1151 Final Report

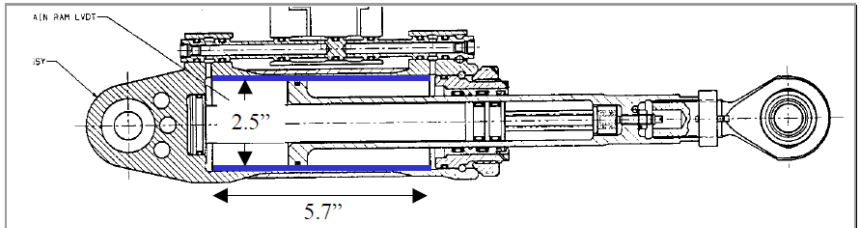


Figure 1-7. F/A-18 E/F aileron servocylinder, manufactured by HR Textron - Courtesy Boeing.

SERDP Project WP-1151 ID Chrome Replacement

Work performed as part of SERDP in early 2000 to look at dry processes to replace Chrome plating for ID applications

Low angle HVOF identified as an option, but development was focused on plasma due to limitations with HVOF

- Limited aspect ratio
- Moderate bond strength
- Good hardness but lower than conventional spraying

Figure 1-1. ID coating by HVOF.

Plasma ID Torches

- Insensitive to aspect ratio within reason
- Limited to ~2.4 inches
- Low bond strength
- Moderate hardness

Figure 2-2 Praxair SG-2700 gun (front) and Sulzer Metco F-210 gun (center) in front of the 3" ID, 18" long sample holder (back).

SERDP Strategic Environmental Research and Development Program

Investigation of Plasma Spray Coatings as an Alternative to Hard Chrome Plating on Internal Surfaces

SERDP Project WP-1151 Final Report

Keith O. Legg
Rowan Technology Group
Libertyville, IL

Bruce D. Sartwell
Naval Research Laboratory
Washington, DC

Jean-Gabriel Legoux
National Research Council Canada – Industrial Materials Institute
Boucherville, Canada

Montia Nestler and Christopher Dambra
Sulzer-Metco
Westbury, NY

Daming Wang and John Quets
Praxair Surface Technologies
Indianapolis, IN

Paul Natishan
Naval Research Laboratory
Washington, DC

Philip Bretz
Metcut Research Inc.
Cincinnati, OH

Jon Devereaux
Naval Air Depot
Jacksonville, FL

June 20, 2006

SERDP PROJECT WP-1151 ID CHROME REPLACEMENT

- One outcome from this project was the qualification of a Triballoy T-400 Coating for the H-60 Damper application
  - 7.2% porosity
  - 4 ksi bond strength
  - 450 HV hardness

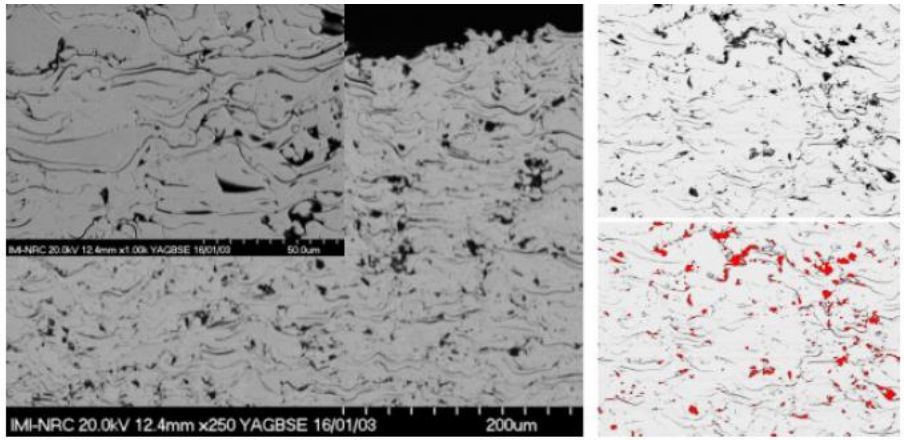


Figure 4-10 Cross sectional microstructure of T400. Right – porosity map with porosity in red.

ID plasma spray has now been successfully tested and qualified for helicopter blade dampers on CH-53 and H-60 helicopters (see Figure 8-2). The cylinder ID coating is T400.

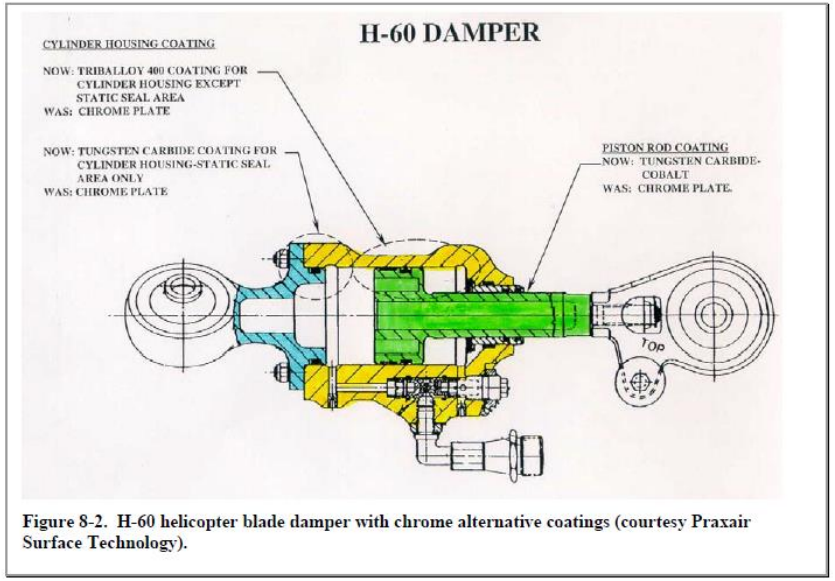
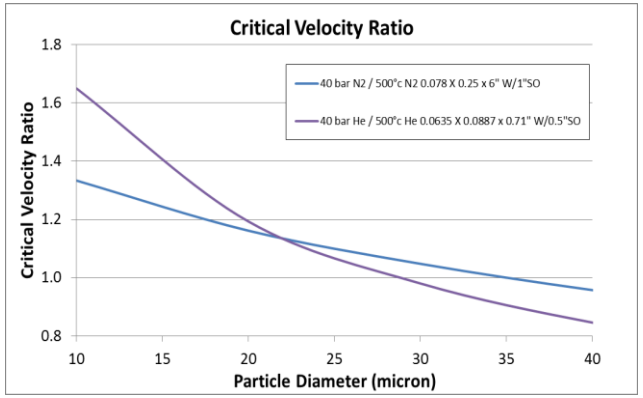
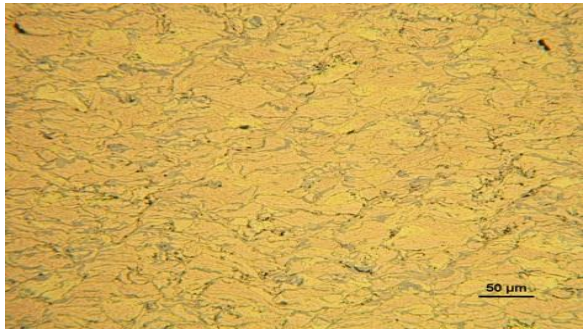


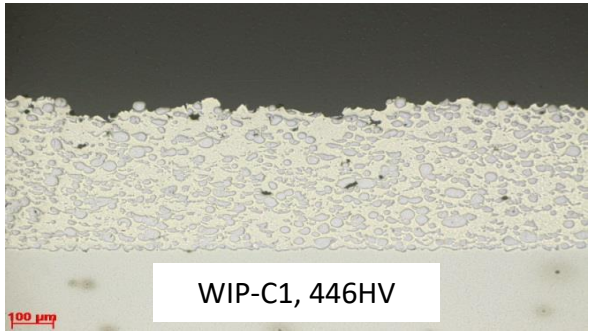
Figure 8-2. H-60 helicopter blade damper with chrome alternative coatings (courtesy Praxair Surface Technology).

Cold Spray ID Coating Nozzle Development

- Designed to have comparable or higher deposit characteristics compared to nitrogen spraying
- Materials which can be sprayed effectively using nitrogen can be sprayed effectively using this nozzle with helium
  - Bronze, Nickel, Copper, blends, etc.
- Provides improved ability to spray materials sensitive to cold working and requiring additional heat
  - Cermets (WC-Co, Cr3C2-NiCr, etc.)

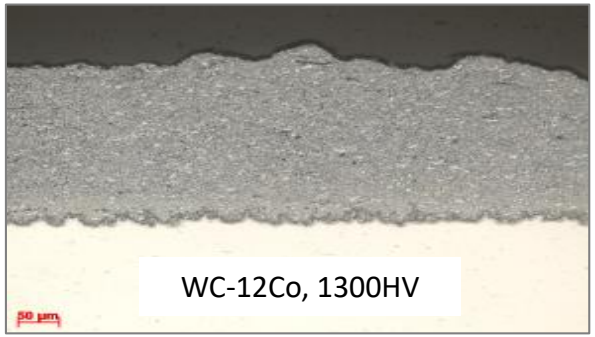






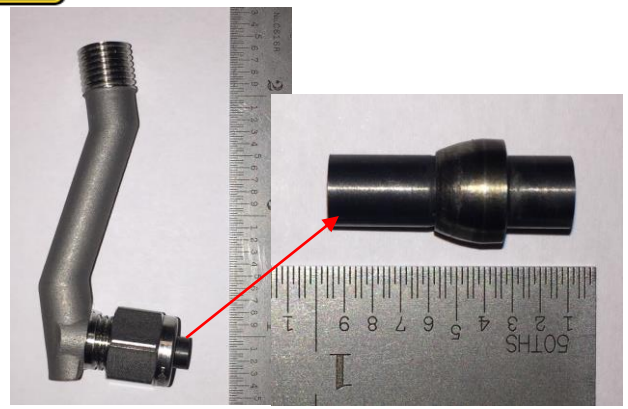
WIP-C1, 446HV

CrC-35NiCr, 880HV

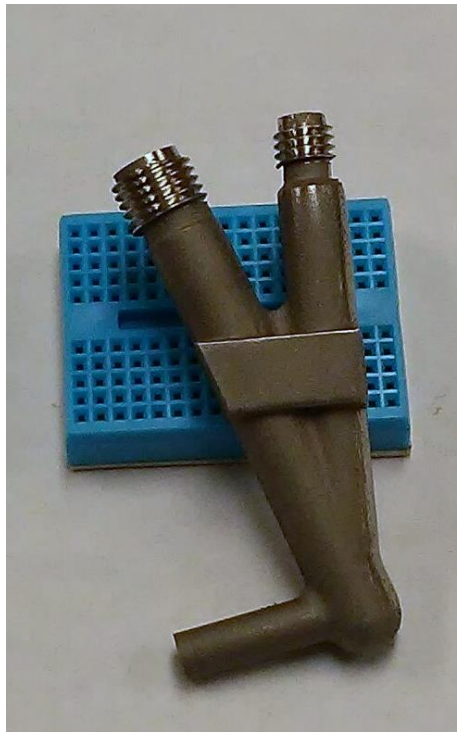


WC-12Co, 1300HV

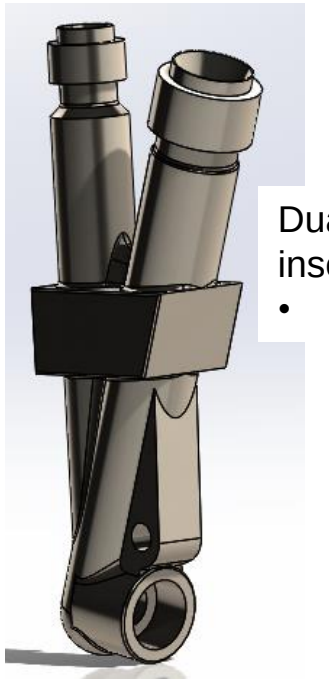
Alternate ID Applicator Designs



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

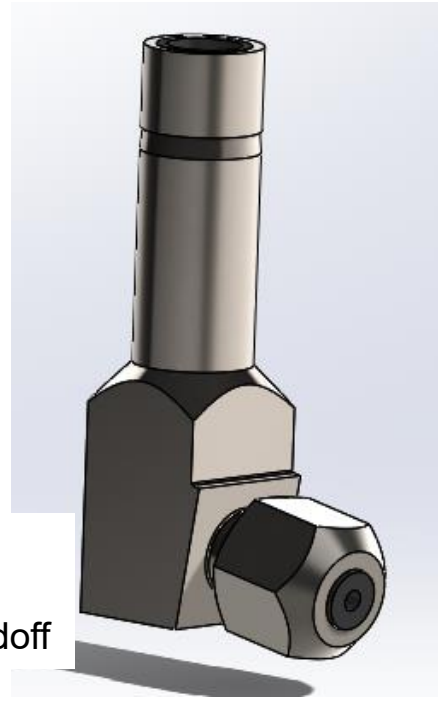


Dual injection design with integral Co-Cr nozzle
- 1.5 in minimum bore, 0.5” standoff



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

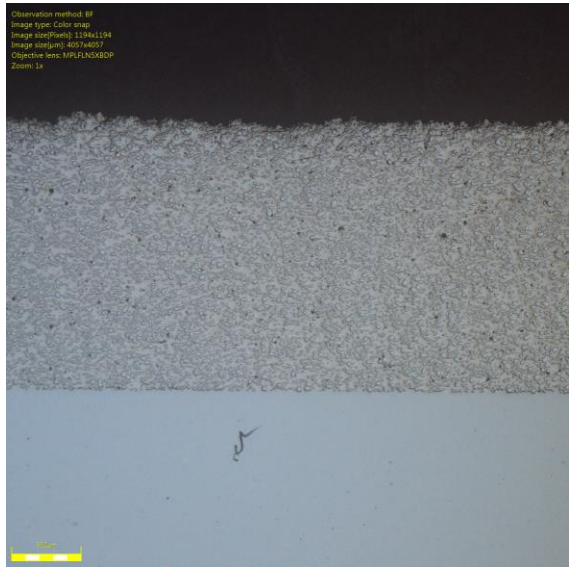
Single injection large bore design
- 4 in minimum bore, 0.5” standoff

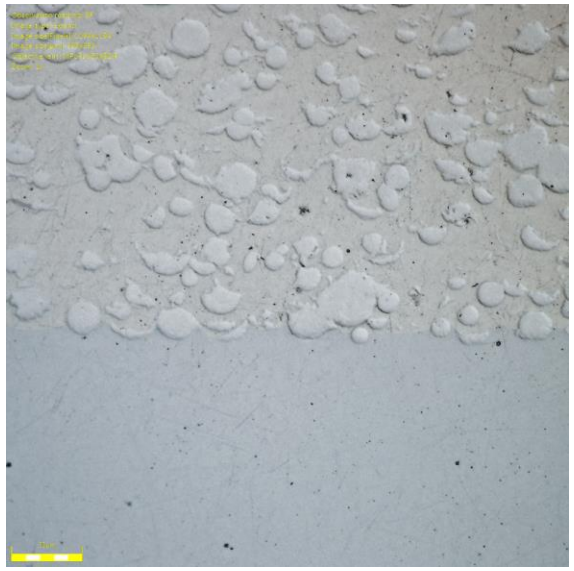


Single injection design for spraying aluminum
- 1.8 in minimum bore, 0.5” standoff

ID Nozzle Performance with WIP-C1

- Mini-nozzle dual injection trials with WIP-C1
- Low coating porosity < 0.5%
- Lug Shear bond strength of 26 ksi average to low carbon steel
- Hardness 400-500 HV
- Expected wear performance comparable to long nozzle based on comparable hardness and density





Thank You

Questions?