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Reducing Hazardous Materials in Weapons Systems: Advances in Waterjet Applications and Cold Spray Technologies

September 10, 2020

SERDP DOD • EPA • DOE | ESTCP

Welcome and Introductions

Rula A. Deeb, Ph.D.
Webinar Coordinator

SERDP
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Webinar Agenda

- **Webinar Logistics** (5 minutes)
  Dr. Rula Deeb, Geosyntec Consultants
- **Overview of SERDP and ESTCP** (5 minutes)
  Mr. Timothy Tetreault, SERDP and ESTCP
- **Multipurpose 3D Waterjet for Machining and Stripping Coatings on Weapon Systems** (25 minutes + Q&A)
  Mr. Frank Campo and **Mr. Mark Miller**, U.S. Army Benet Laboratories
- **Repair Process Development Using Cold Spray Deposition** (25 minutes + Q&A)
  Mr. Aaron Nardi, U.S. Army Research Laboratories
- **Final Q&A session**

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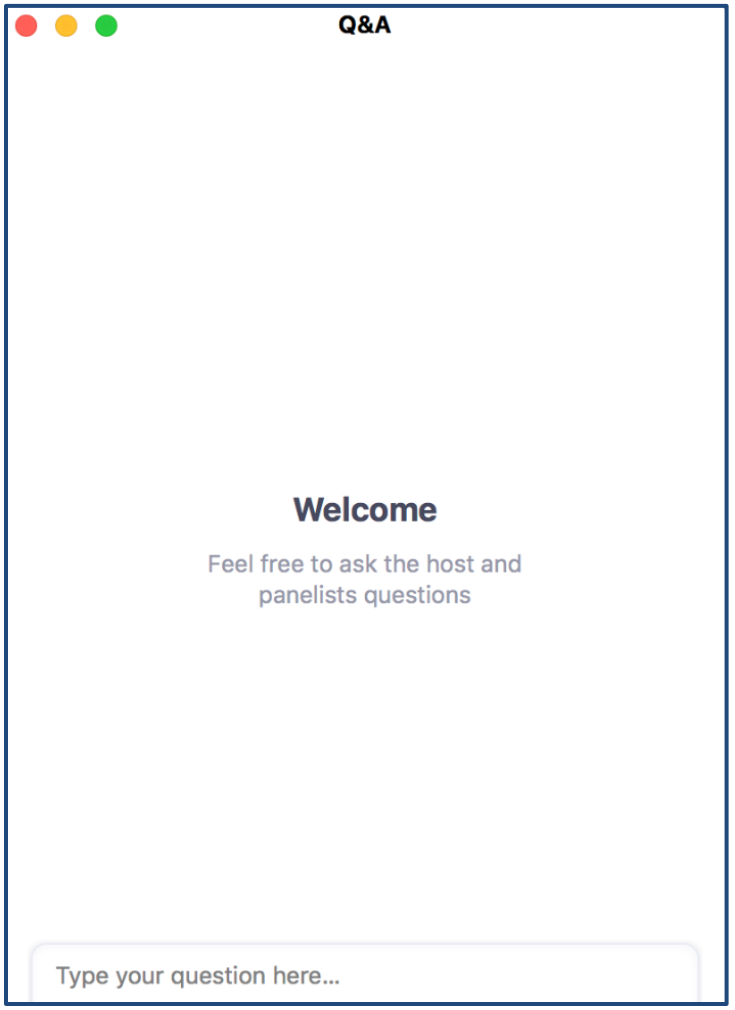

SERDP and ESTCP Overview

Timothy Tetreault
SERDP and ESTCP

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SERDP

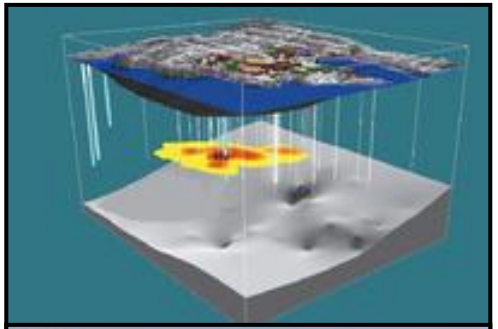
- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced technology development to address near term needs
  - Fundamental research to impact real world environmental management

ESTCP

- Environmental Security Technology Certification Program
- Demonstrate innovative cost-effective environmental and energy technologies
  - Capitalize on past investments
  - Transition technology out of the lab
- Promote implementation
  - Facilitate regulatory acceptance

Program Areas

- Environmental Restoration
- Installation Energy and Water
- Munitions Response
- Resource Conservation and Resiliency
- Weapons Systems and Platforms





Weapons Systems and Platforms

- Major focus areas
  - Surface engineering and structural materials
  - Energetic materials and munitions
  - Noise and emissions
  - Waste reduction and treatment in DoD operations
  - Lead free electronics

SERDP and ESTCP Webinar Series

Date	Topic
September 24, 2020	Munitions Mobility and Burial in Underwater Environments
October 8, 2020	Managing AFFF Impacts to Subsurface Environments and Assessment of Commercially Available Fluorine-Free Foams (**Part 1)**
October 22, 2020	Managing AFFF Impacts to Subsurface Environments and Assessment of Commercially Available Fluorine-Free Foams (**Part 2)**
November 5, 2020	Pathways under Non-Stationary Conditions and Their Implications for Wildlife and Human Exposure on Department of Defense Lands
November 19, 2020	Abiotic Degradation of Chlorinated Solvents in Subsurface Environments

For upcoming webinars, please visit

http://serdp-estcp.org/Tools-and-Training/Webinar-Series

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Save the Date

SERDP • ESTCP
SYMPOSIUM

A three-day symposium showcasing the latest technologies that enhance DoD's mission through improved environmental and energy performance

December 1-3, 2020

Registration for the virtual event is open!

Multipurpose 3D Waterjet for Machining and Stripping Coatings on Weapon Systems

Frank Campo Mark Miller

U.S. Army Benet Laboratories

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Agenda

Background review of previous programs

- SERDP: WP-1426
  - Explosive Bonding/Chromium Elimination and Cannon Life Extension
- ESTCP: WP-201111
  - Explosive Bonding/Chromium Elimination and Cannon Life Extension
- ESTCP: WP-201618
  - Green Machining of Weapons via Waterjet Technology

Review of current program

- ESTCP: WP19-D4-5115
  - Multi-purpose 3D Waterjet for Stripping Coatings on Weapon Systems
- Technical progress and results
- Conclusions
- Benefits to DoD

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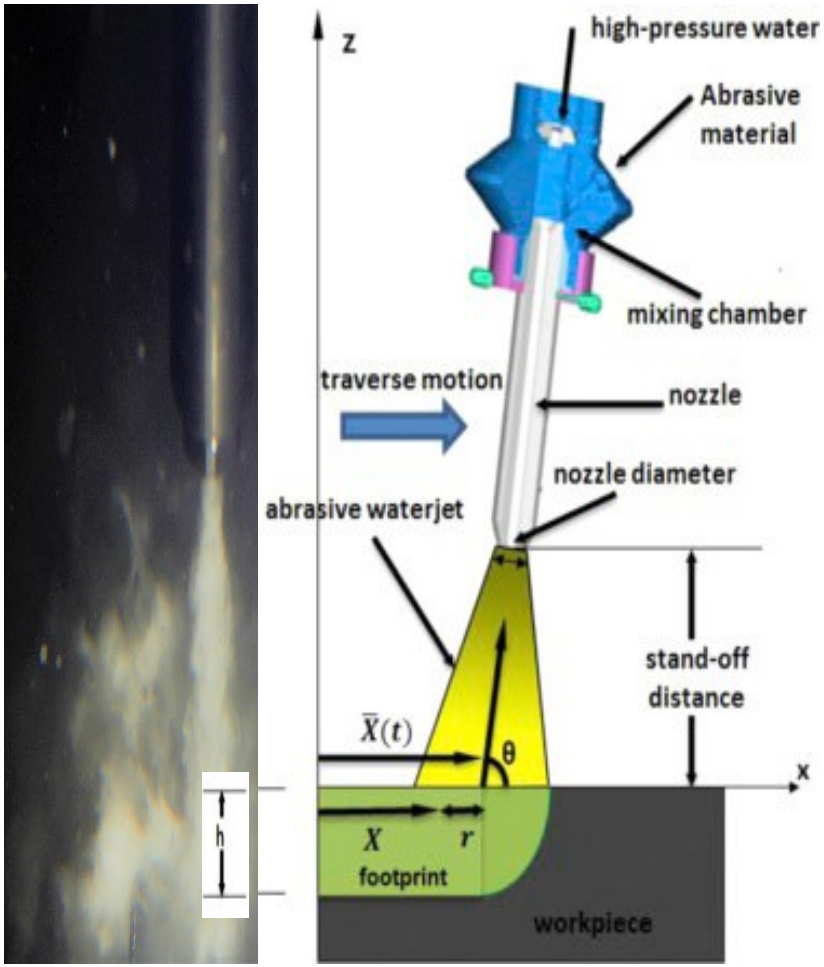
Objectives

- Technology focus
- Demonstrate use of cavitation/waterjet stripping
  - Green machining process
  - Remove coatings from gun barrels
- Validate the processes by performing cavitation/waterjet stripping on coated gun barrels
- Surface finish specifications per drawing
- Avoid use of toxic chemicals such as short chain chlorinated paraffin (SCCP)



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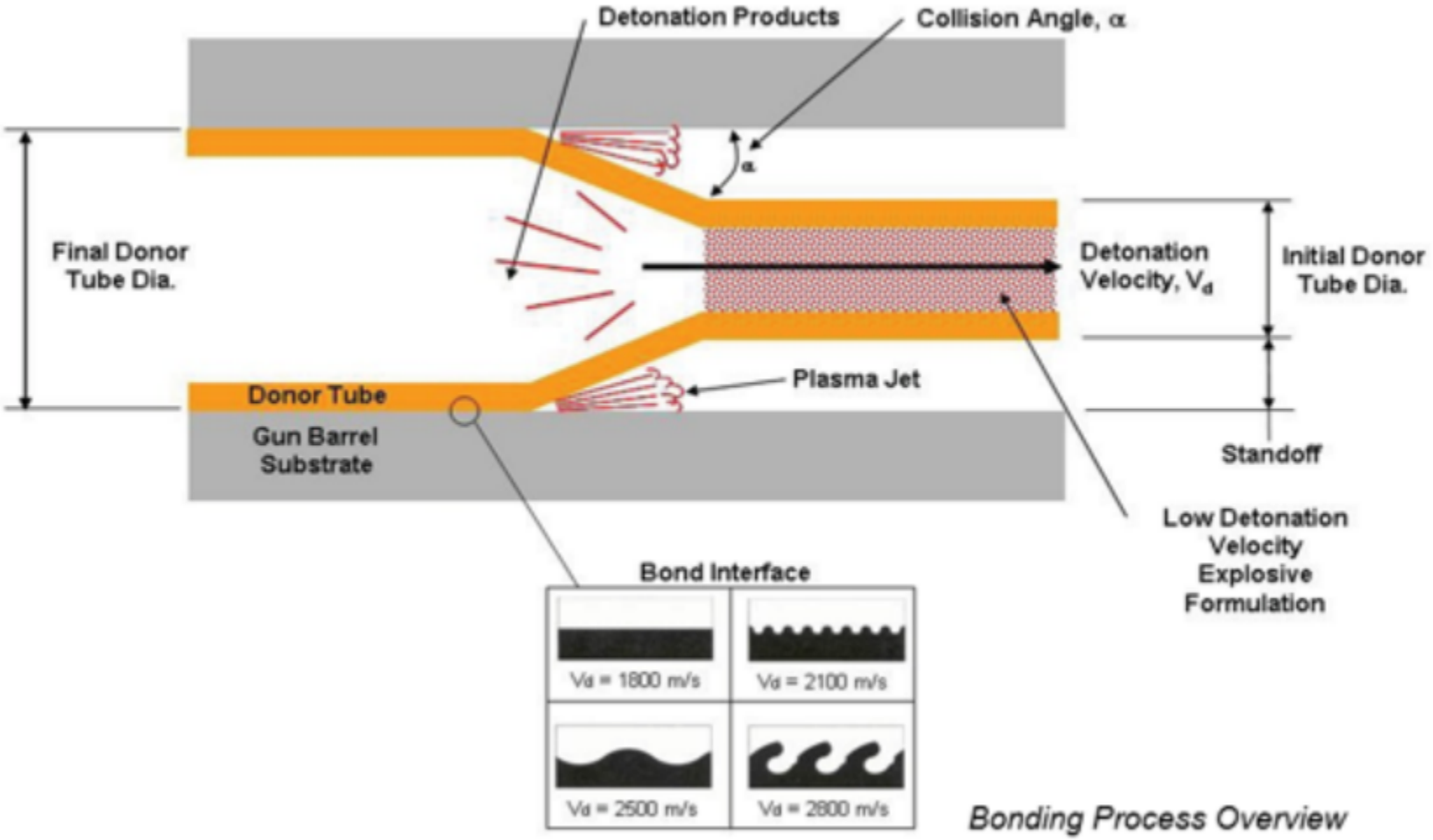
Background – Prior Programs

SERDP/ESTCP: Explosive Bonding



Bonding Process Overview

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Background – Prior Programs

SERDP/ESTCP: Explosive Bonding (EB)

Proposed demonstration site: Yuma Proving Grounds (YPG)

- Preliminary proof of principle endurance testing
  - Promising results when conducted side by side to a chrome plated barrel
- Baseline: Condemned chrome barrel
- At more than 4 times the rounds fired, the EB tube was less than 1/3 worn when compared to baseline

Preliminary Testing
Medium Caliber Test Range

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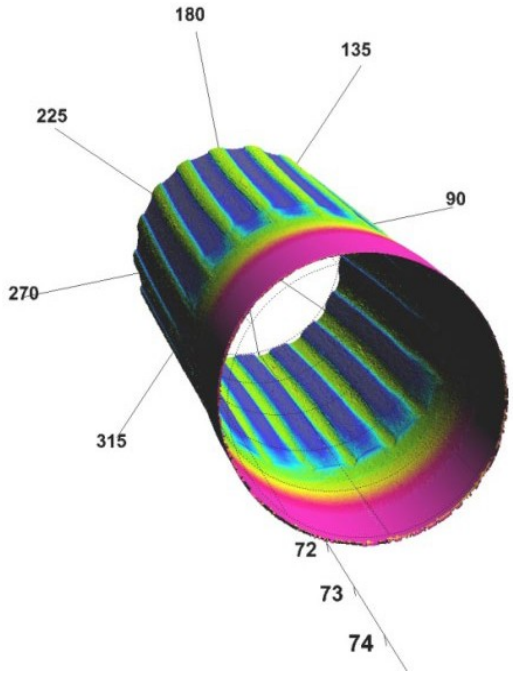
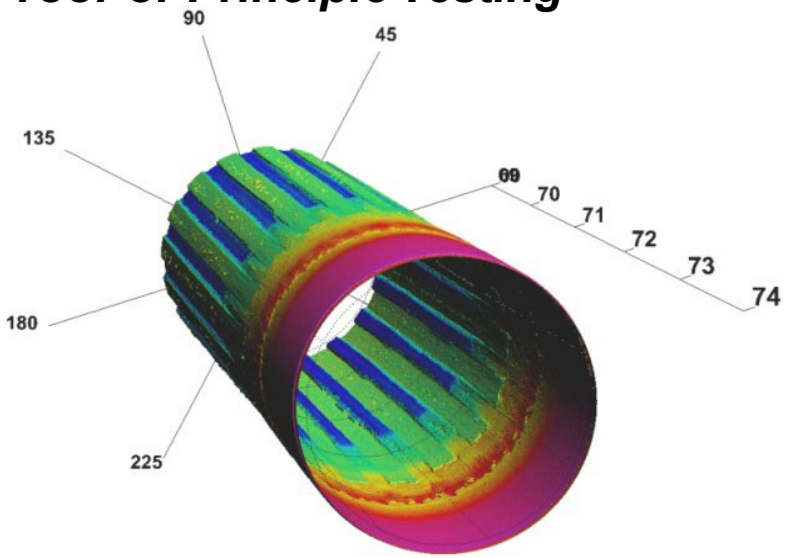
Background – Prior Programs

SERDP/ESTCP: Explosive Bonding

Medium Caliber EB Barrel Liner Proof-of-Principle Testing



EB Liner survived over four times



Production chromium tube - condemned

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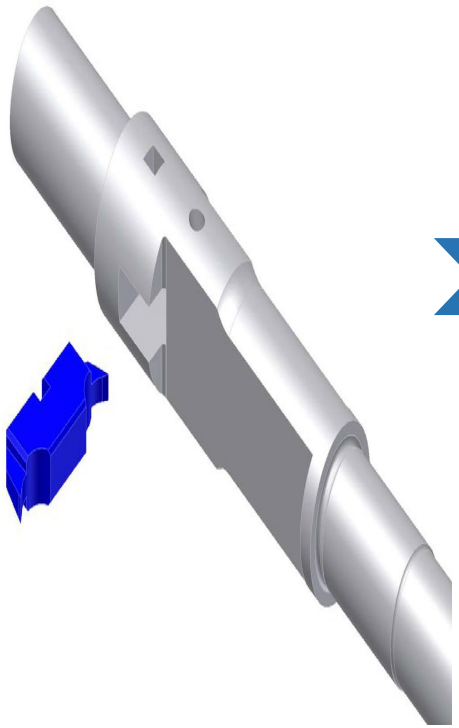
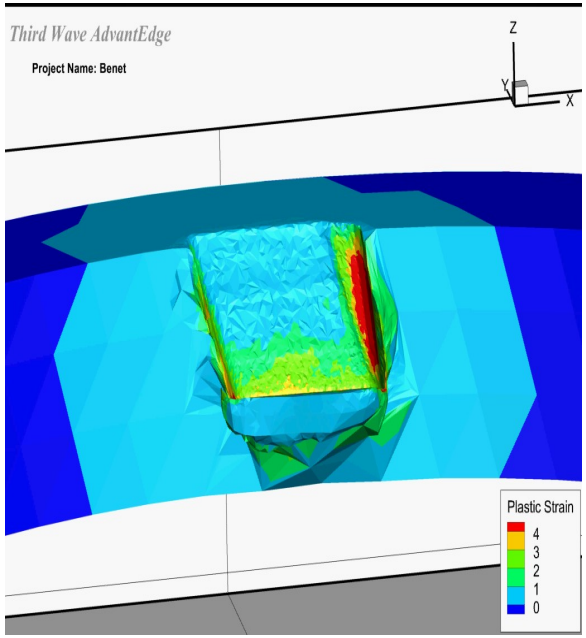
Background – Prior Programs

Barrels were rifled using 2-point cutters not practical for any production quantities



Modeling-simulation virtual rifling



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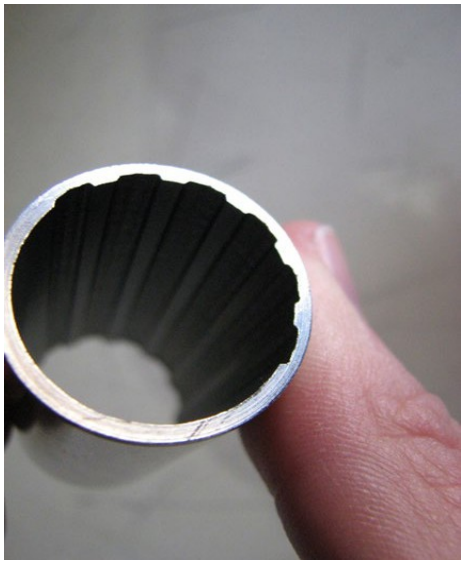
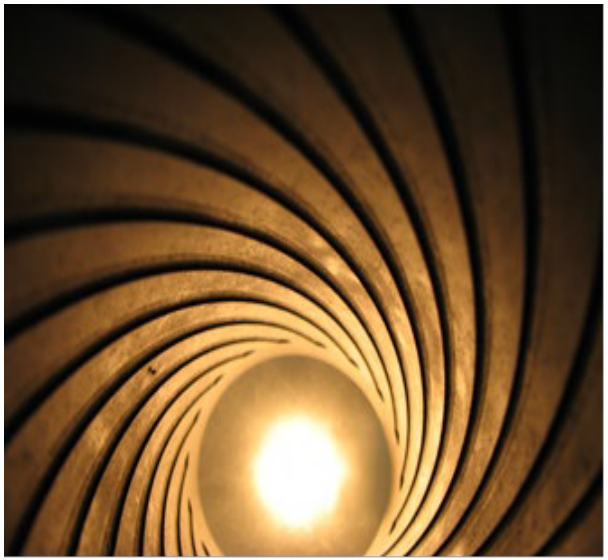
Background – Prior Programs

Green Machining of Weapons via Waterjet Technology



Waterjet Rifled Steel Tube

Waterjet Rifled Glass Tube



Waterjet Rifled Barrel

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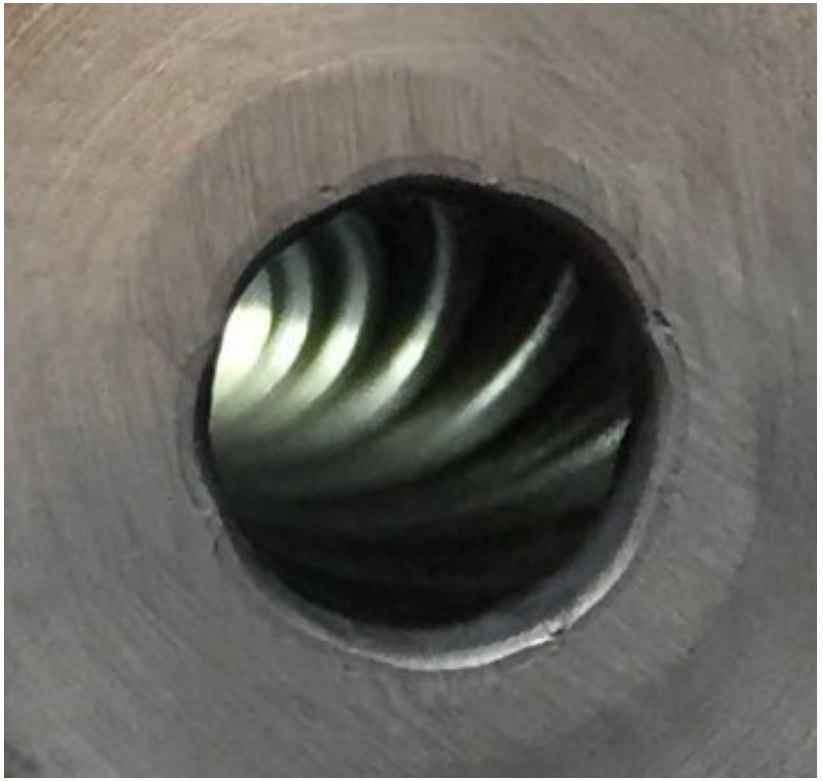
Background – Prior Programs

Waterjet Rifled Profiles

Medium Caliber Profile



Small Caliber Profile

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Technical Approach

- Design and fabricate cavitation stripping head for inside gun barrels
- Test on truncated coated gun barrels
- Perform microstructure, SEM and EDS analysis of stripped steel
  - Confirm process does not affect steel microstructure and mechanical properties
- Determine cavitation and waterjet stripping parameters required to remove refractory metal coatings
- Test on full length barrels

***Notes**: SEM = Scanning Electron Microscope; EDS = Energy-Dispersive X-Ray Spectroscopy*

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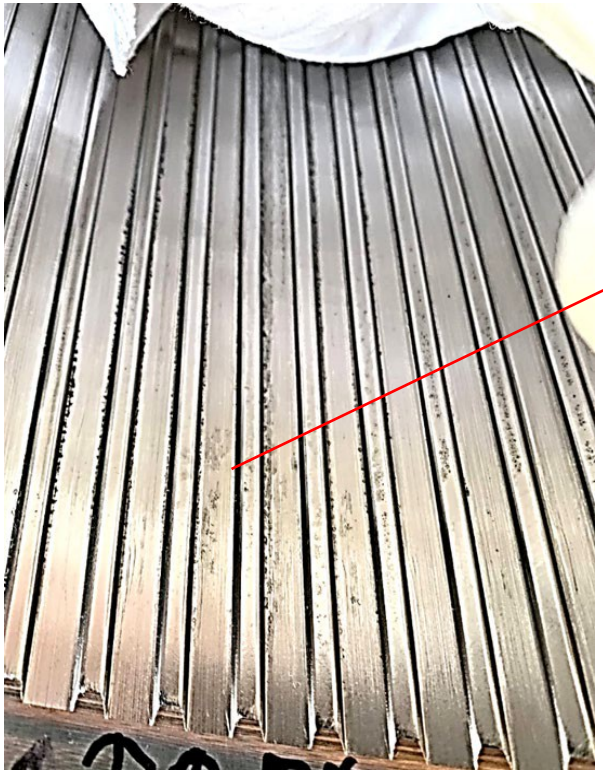
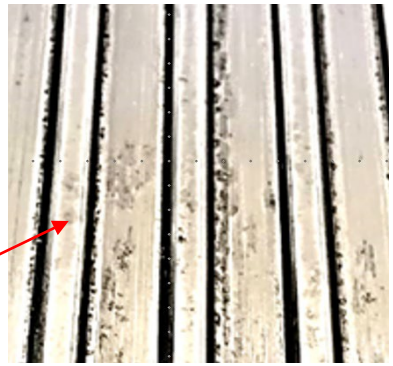
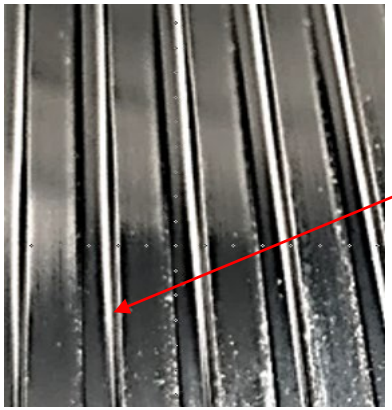
Results/Technical Progress

Cleaning of Residue on Gun Barrels



Before Waterjet Cleaning





Cleaned Tube

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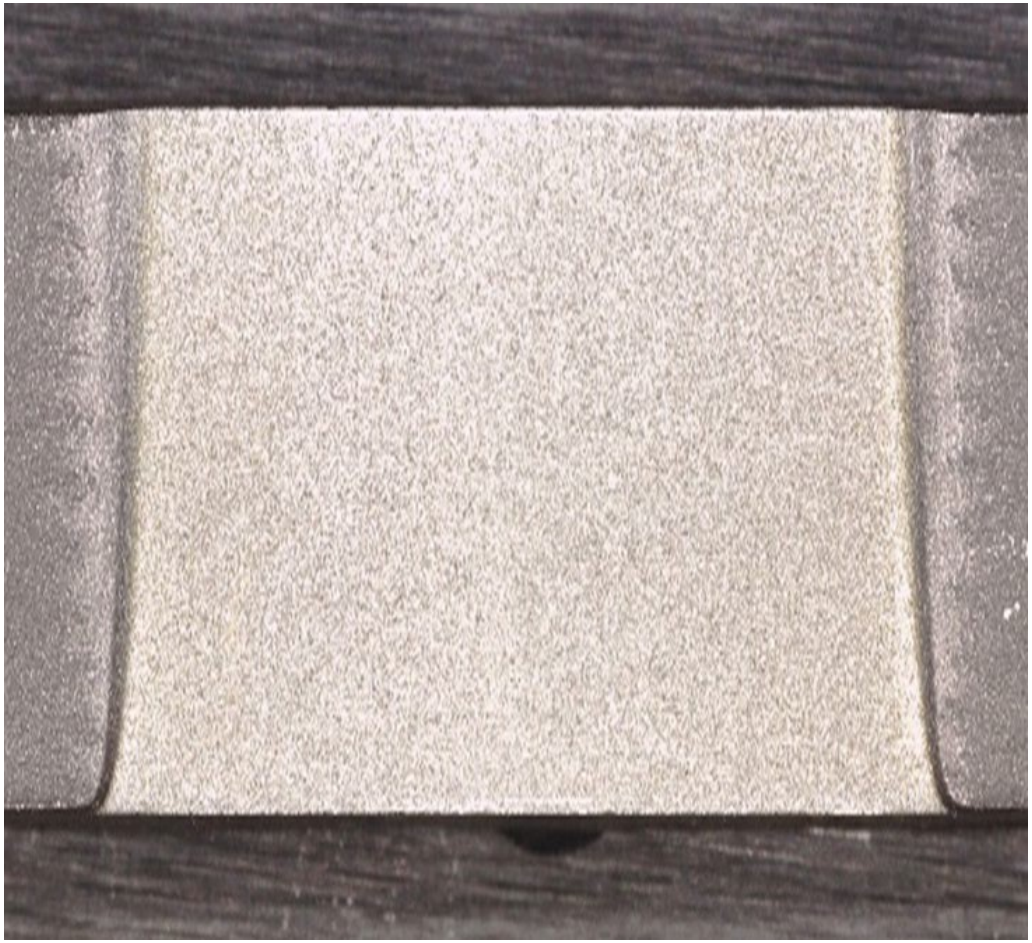
Results/Technical Progress

Waterjet Stripping of Coated Coupons



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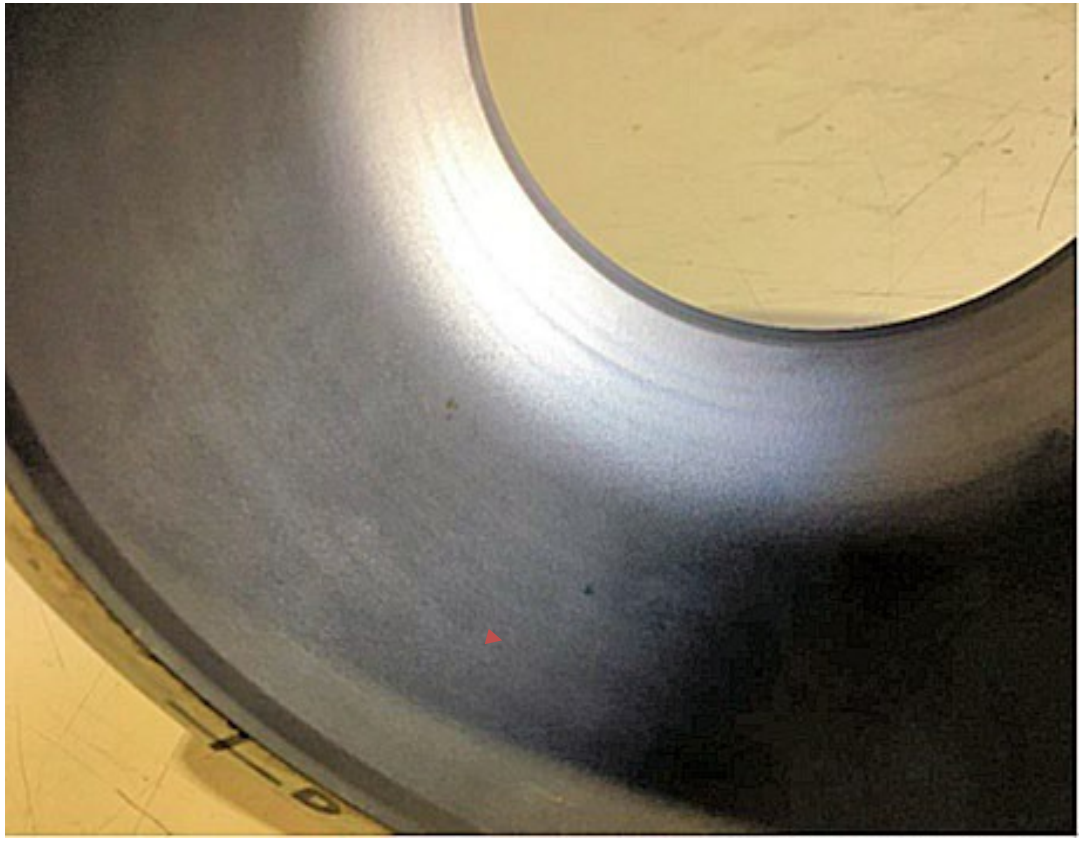
Results/Technical Progress

Waterjet Honing



Waterjet honing improves surface finish

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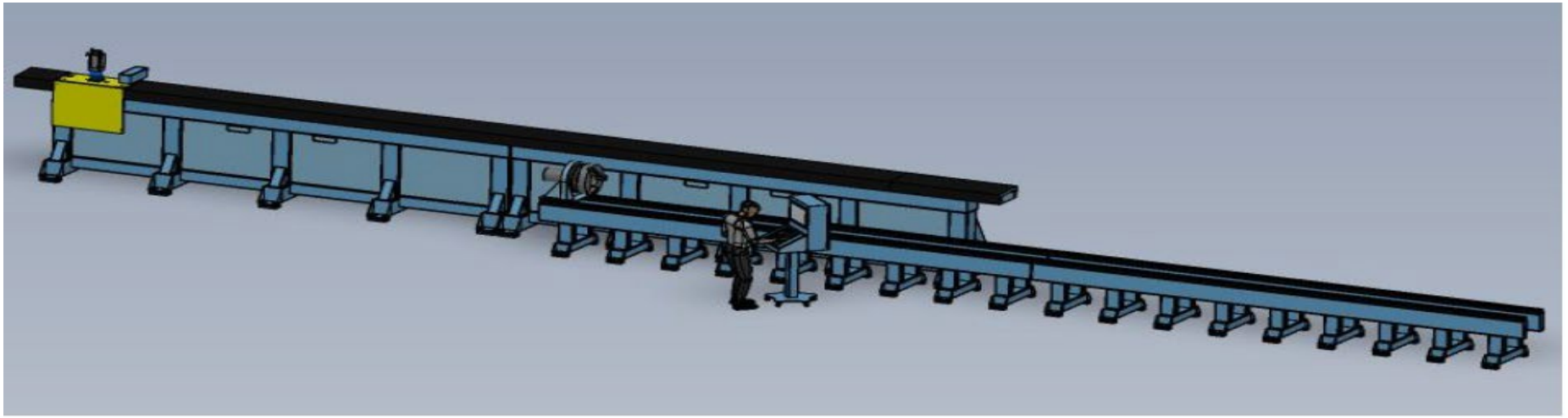
Results/Technology Transitioning

Machine Concept: Waterjet Stripping



Waterjet technology enables Army to meet modernization goals

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Conclusions

- This innovative technology and machine will be introduced in the DoD industrial base
- ESTCP supporting the process technology, leveraged by ManTech and NDCEE programs
- Reduction in Weapon Systems Operations and Support costs
- Anticipate numerous uses and applications for waterjet stripping and machining technology

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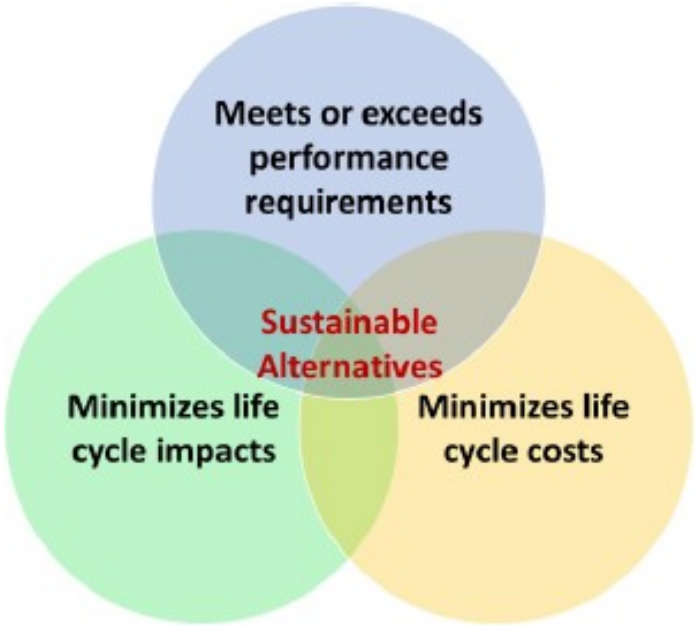
Benefits to DoD

DoD Sustainability and Life Cycle Costs

Technology - Innovation Green - Manufacturing

- Sustainable alternative technology
  - Modernize manufacturing within DoD
  - Machine/strip/clean weapons using water
  - Program supports Army weapon systems throughout life cycle
- DoD Sustainability Analysis Guidance* outlines key elements
  - Life cycle costs
  - Impacts
  - Performance of a system over its useful life



Key Elements of Sustainable Alternatives

** https://denix.osd.mil/esohacq/home/dod-guidance/dod-sustainability-analysis-guidance/*

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Benefits to DoD

DoD Modernization and Sustainability

- Secretary of Defense Memorandum on Cr^{6+} elimination
  - Fosters alternative coating technology
- EPA guidance on reduction of SCPPs
  - Reduced usages of metal working fluids
- Directly supports and may be the key enabler for the Army's modernization priority
  - Long-range precision fires
- May extend life cycle of weapon systems in the sustainment phase deferring disposition

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Acknowledgments

ORMOND

Precision waterjet finishing and stripping

DEVCOM ARMAMENTS CENTER

High Energy Metals, Inc.

High Technology Weapon Manufacturing

WATERVLIET ARSENAL 1813

Tube manufacture & post processing

VRC METAL SYSTEMS

LTC Laser Techniques Co. Laserbased NDT and QC Systems

Laser bore inspection

U.S.ARMY

NAVSEA WARFARE CENTERS Indian Head EOD Technology Division

BENÉT LABS

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For additional information, please

https:/www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Surface-Engineering-and-Structural-Materials/WP19-5115

Speakers Contact Information

frank.e.campo.civ@mail.mil; 518-266-4770

mark.d.miller194.civ@mail.mil; 518-266-4177

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Q&A Session 1

Repair Process Development Using Cold Spray Deposition

Aaron Nardi
U.S. Army Research Laboratories

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Agenda

- Cold spray process overview
- Physics of acceleration and bonding
- Consolidation and mechanical properties
- Unique material solutions developed
- Equipment comparison
- New equipment development
- Conclusions
- Benefits to DoD

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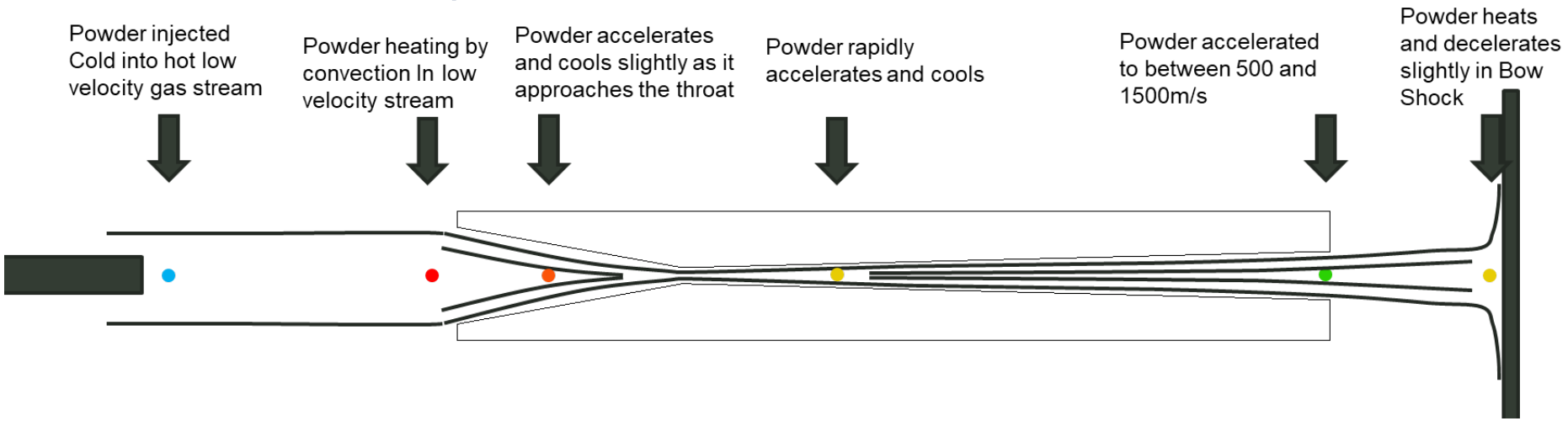
The Cold Spray Process

- Solid state impact of powder particles
- Plastic deformation causes cold welding
- He, N_2 or air used as process gas
- Major benefits
  - Exceptional properties
  - Microstructure control
  - Dissimilar materials
  - Low heat input



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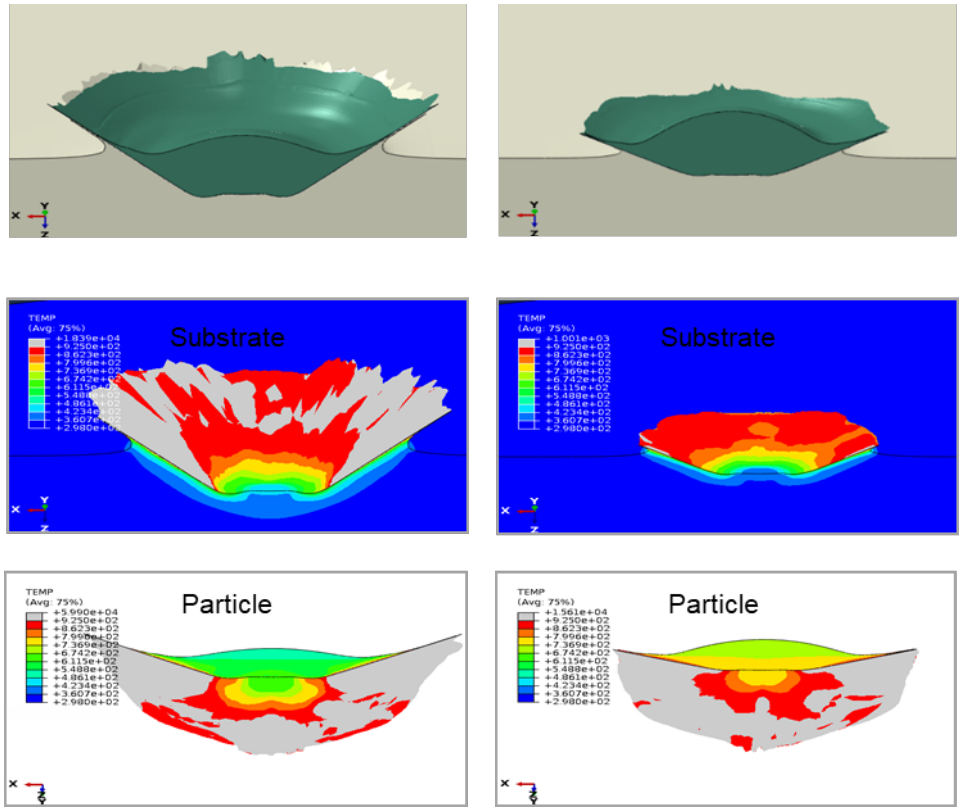
Particle Impact and Bonding

Multistep Process

- Impact with surface
- Shock wave from impact location toward edge of impact ejecting material
- Adiabatic heating of interface
  - Plastic flow of material localizes
- Strain localization and heating
  - Shear instability
  - High levels of plastic flow at the interface



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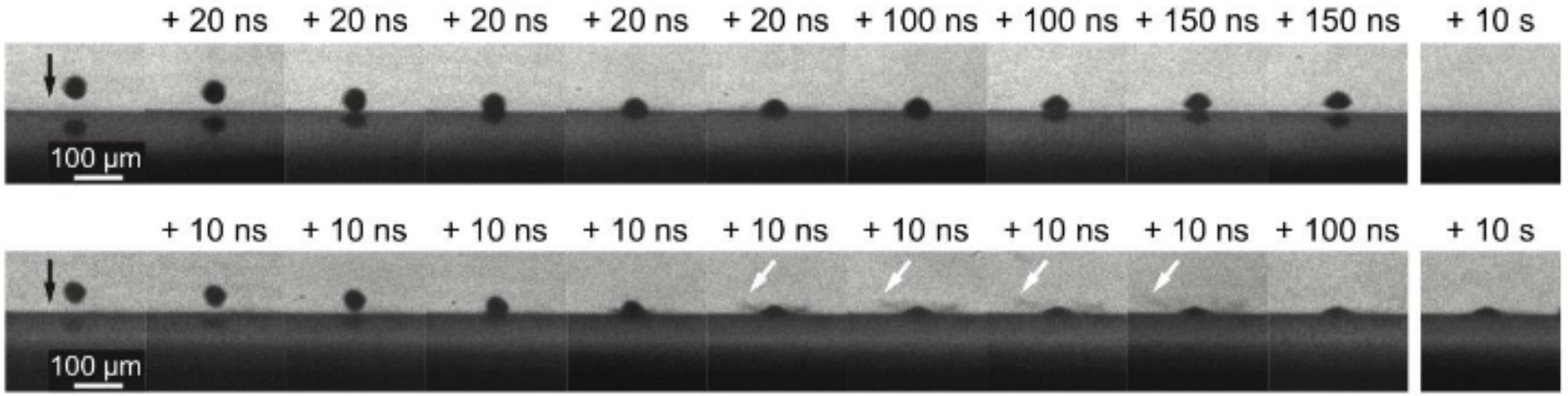
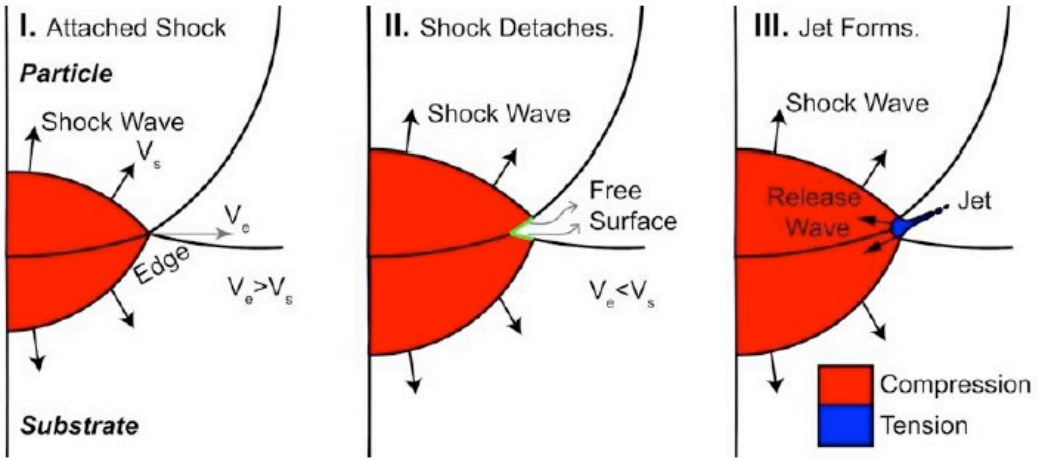
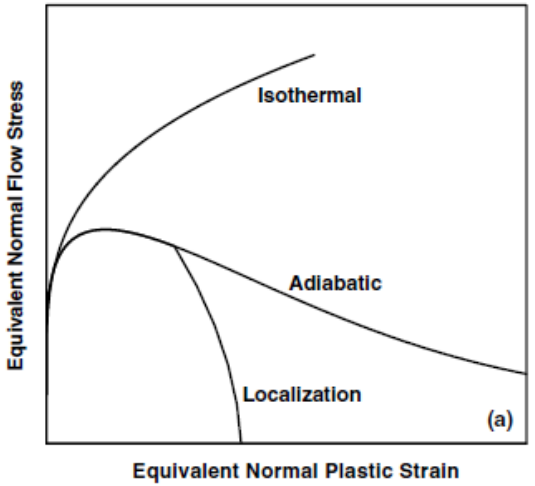
Particle Impact and Bonding

Multistep Process





Hassani Theory



Assadi Theory

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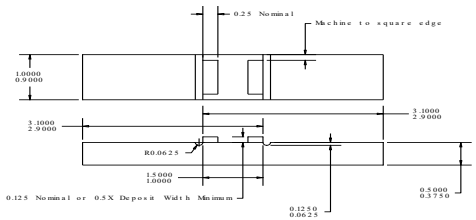
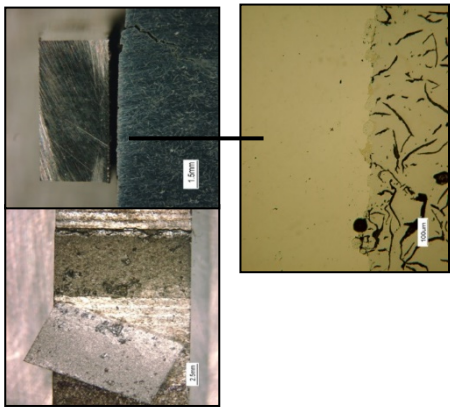
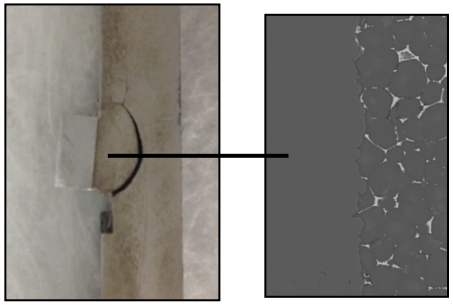
Bond Strength and Testing

Lug shear bond strength testing uses a die to shear the cold sprayed deposit from a substrate eliminating glue

Material Couple	Using bondcoat or other bonding procedures developed
6061 aluminum on ZE41A Magnesium	22 ksi
Stellite 6 applied to Gray Cast Iron	25 ksi
Like-on-Like Aluminum (6061 on 6061, 7075 on 7075) (He)	20-30 ksi
Like-on-Like Aluminum (6061 on 6061, 7075 on 7075) (N2)	10-20 ksi
Ta and Ta Alloys to 40 HRC Steel (He)	35-50 ksi
WIP-C1, C2, W1 on hardened steel (He)	30-50 ksi
WIP-C1, C2, W1 on hardened steel (N2)	20-30 ksi
7075 applied to 50 HRC steel	15-20 ksi







***Note**: HRC = Rockwell C Scale Hardness*

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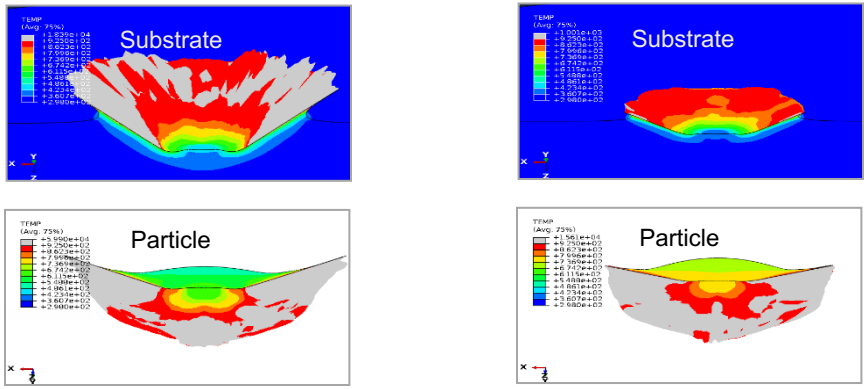
Inter-particle Bonding

Influence on Ductility

Helium Sprayed, CVR = 1.58 **Nitrogen Sprayed, CVR = 1.45**

Deformed shapes

Temperature contours



Model and data show effect of velocity regardless of similarity in CVR

***Note**: CVR = Critical Velocity Ratio (velocity of the particle / critical velocity for bonding)*

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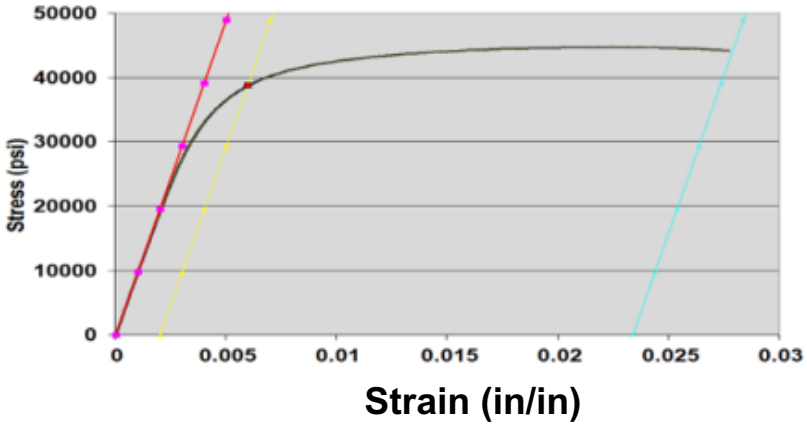
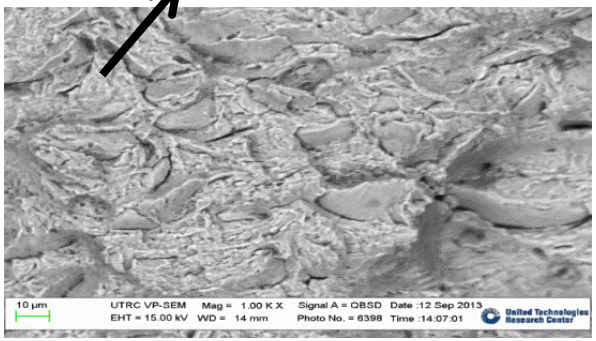
Inter-particle Bonding

Influence on Ductility

Helium Sprayed



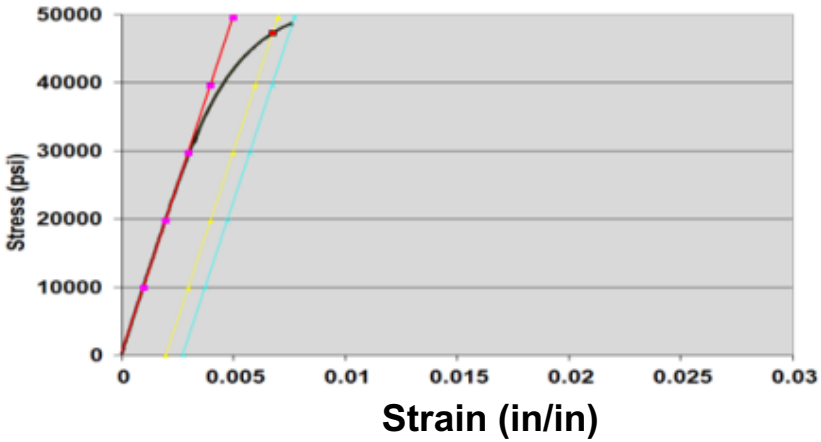
Dominated by trans-particle fracture



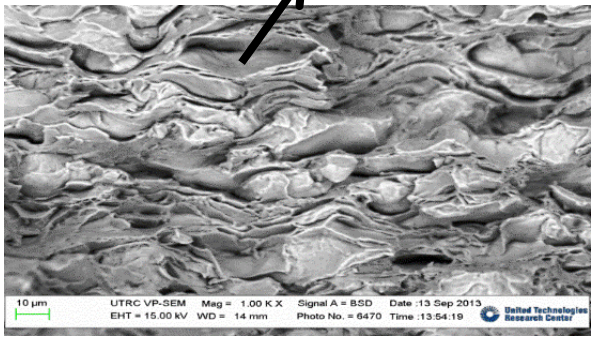
(d_p = 40 µm ,T_{p0} = 236°C , V_0 = 980 m/s)

Fracture Surfaces

Nitrogen Sprayed



Dominated by inter-particle fracture



(d_p = 40 µm ,T_{p0} = 427°C, V_0= 635 m/s)

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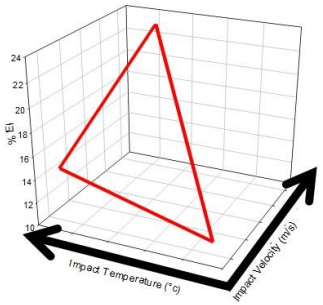
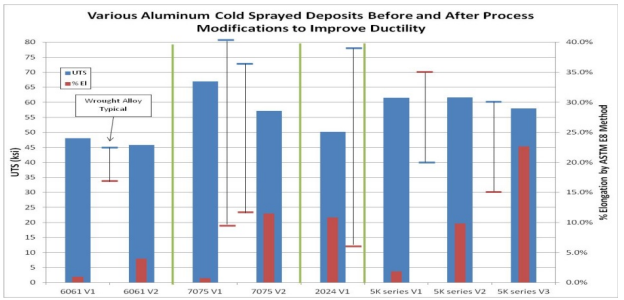
Inter-particle Bonding and the Influence on Fatigue

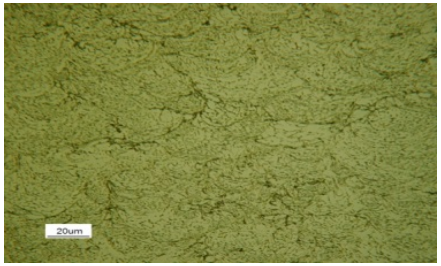
- Modification of process parameters and powder processing conditions can achieve improved deposit properties

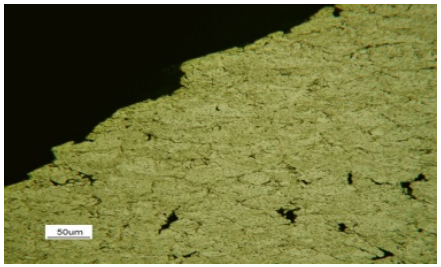




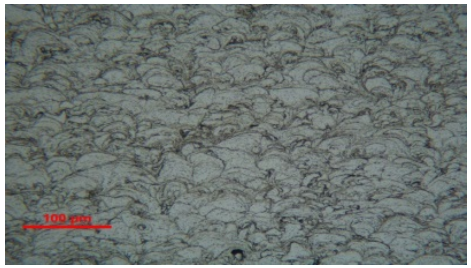
Unstrained

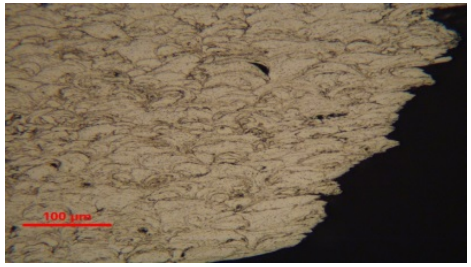
High Plastic Strain



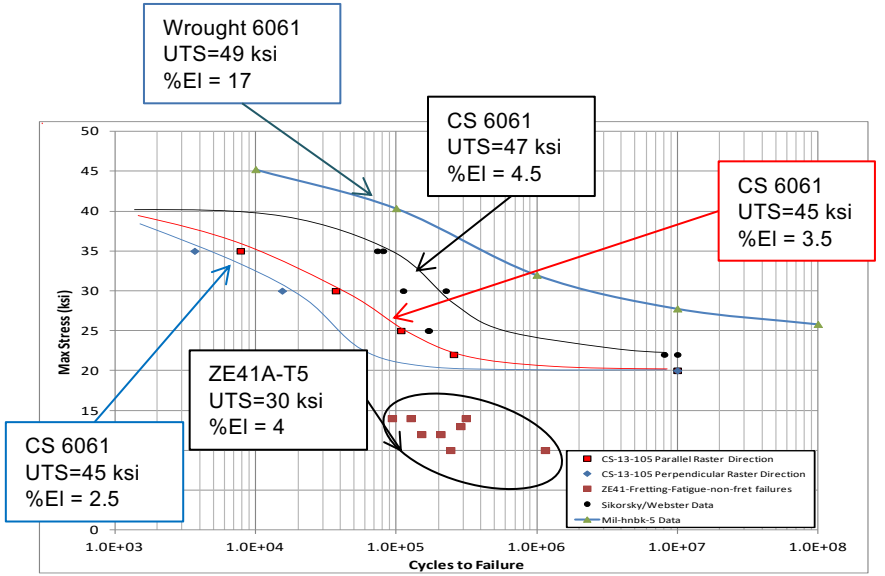


CS6061, UTS = 45ksi, % El = 3.5%





CS5056, UTS = 58ksi, % El = 22%



***Note**: UTS = Ultimate Tensile Strength*

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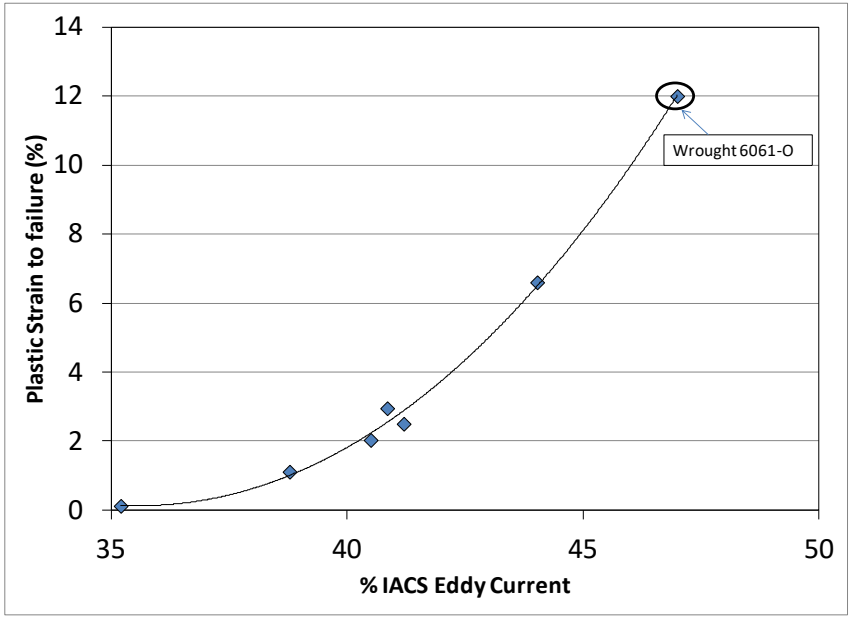
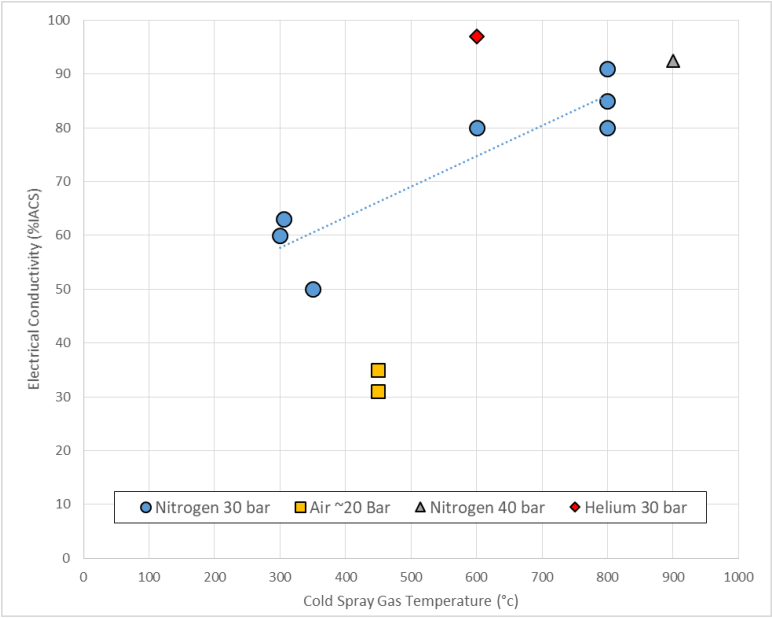
Inter-particle Bonding and NDT

- Electrical conductivity can measure aggregate defects between particles
  - Eddy Current is a simple method of measuring conductivity

Conductivity data of helium sprayed aluminum under multiple spray conditions all using processed powder



Copper conductivity data from literature, multiple sources



Note: *NDT = Non-Destructive Testing*

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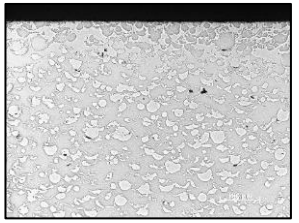
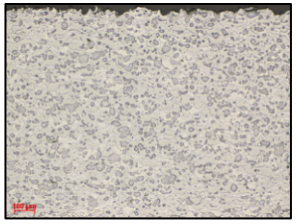
Wear and Impact Protection (WIP) Powder Family

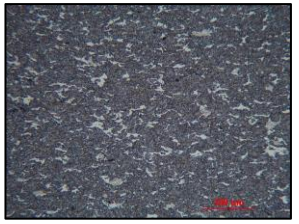
- WIP-C1 and WIP-C2
  - Deposits being rolled out into several applications
  - Most robust set of data and spray conditions of all WIP materials
  - Vendors set up to produce commercially → easier procurement
  - Deposits demonstrated with helium and nitrogen with good quality
  - Deposits can be machined by milling, turning, or grinding



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



- WIP-W1
  - Greatest potential for direct chrome replacement in most applications
  - The data generated has shown excellent wear
  - Deposits must be ground
    - Can be ground with SiC or diamond
  - All powders have been produced using production robust processes



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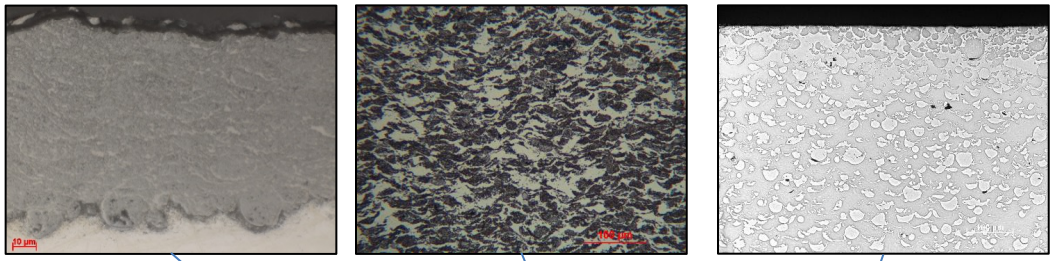
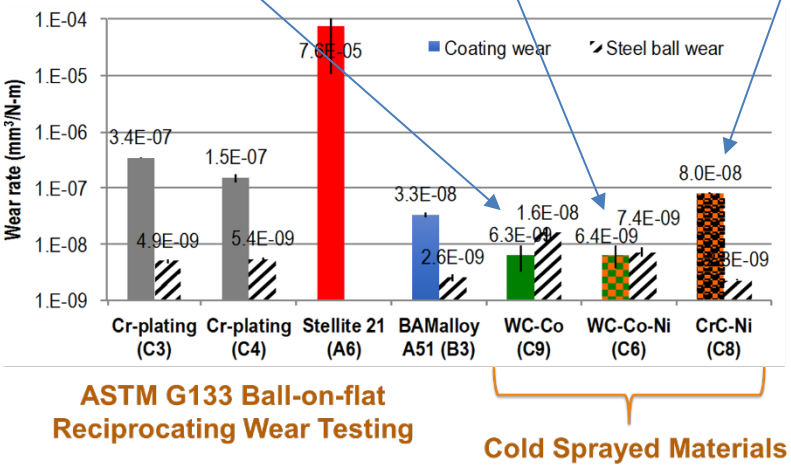
WIP-C1 Wear Data Comparison

Spray Dried and Sintered

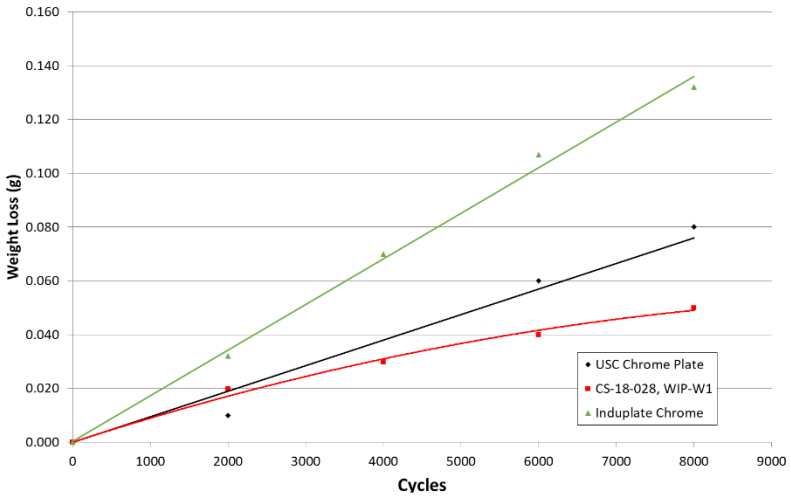
Combined Processing Spray Dried + Coated

Mechanical Blend





- ASTM g133 ball on flat reciprocating wear testing
  - Temp and pressure matching application
  - Lubrication as seen in application
- Taber abrasion testing
  - Pure 2 body abrasion
  - Hardness dominates wear rate



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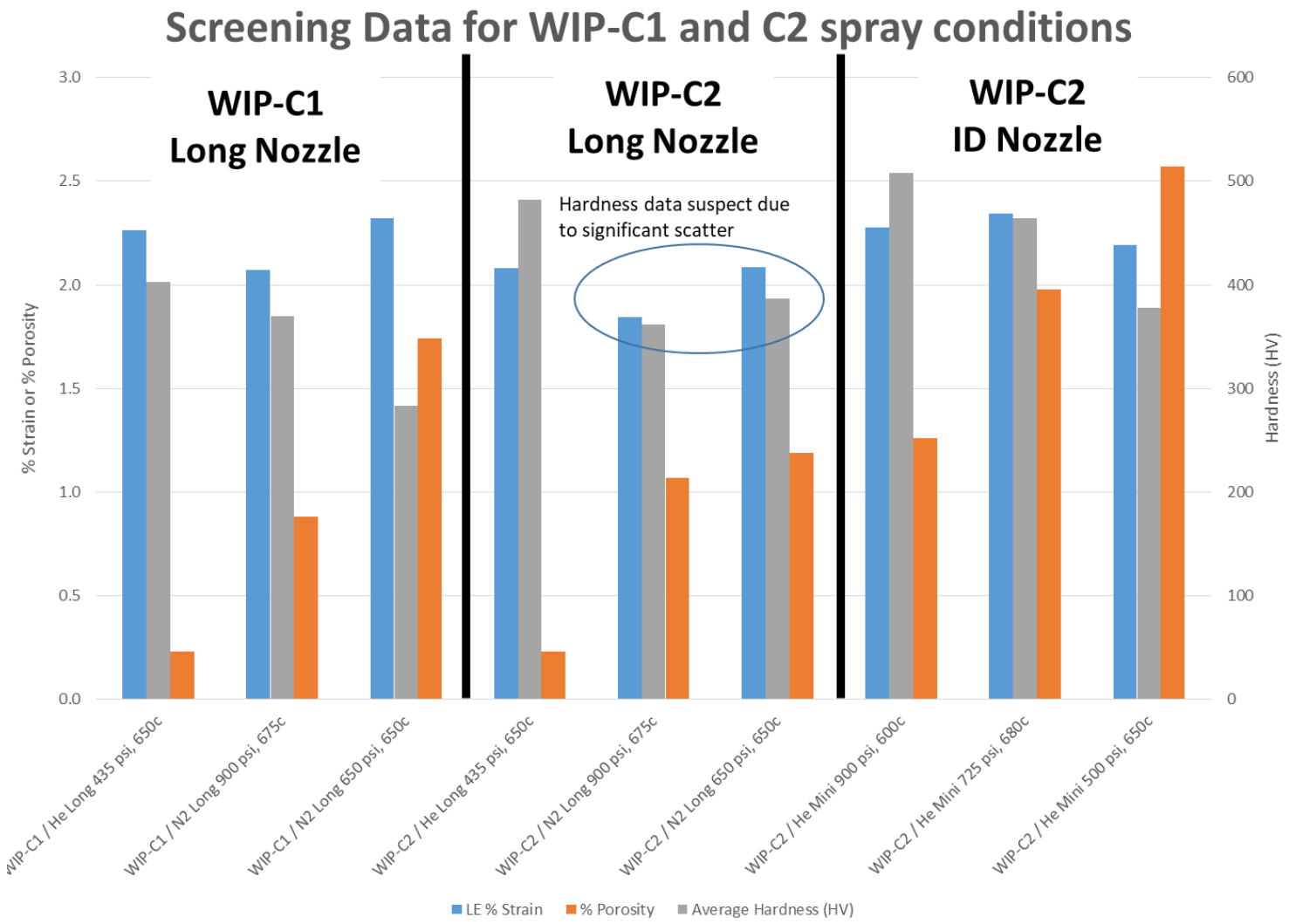
WIP Mechanical Property Comparison



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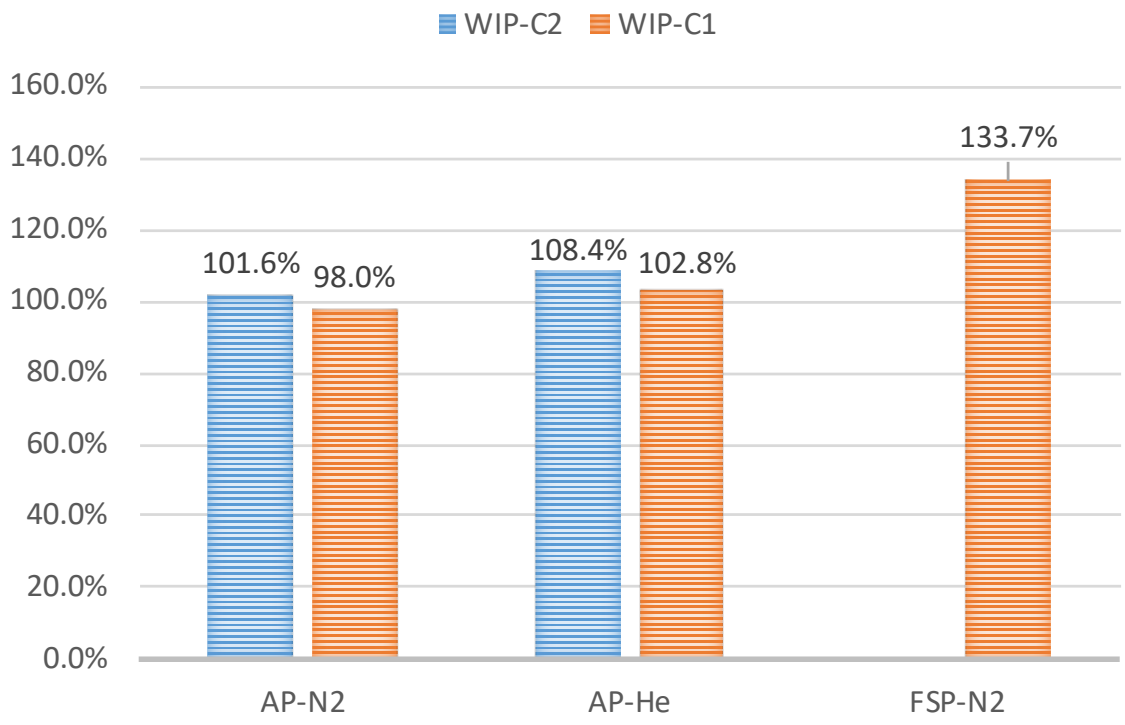
WIP-C1 and C2 Ballistic Performance

- Percentage of ballistic performance restoration indexed to 100% of base metal
- Repair depth 1 mm onto thinned 6.3 mm thick HHS for a 12-inch x 12-inch panel
- Using armor piercing (AP) rounds and fragment stimulating projectile (FSP) rounds
- 8-22 shots per condition (152 total)

Cold Spray Ballistic Results vs. HHS V50 Baseline



***Notes**: HHS = High Hard Armor Steel*

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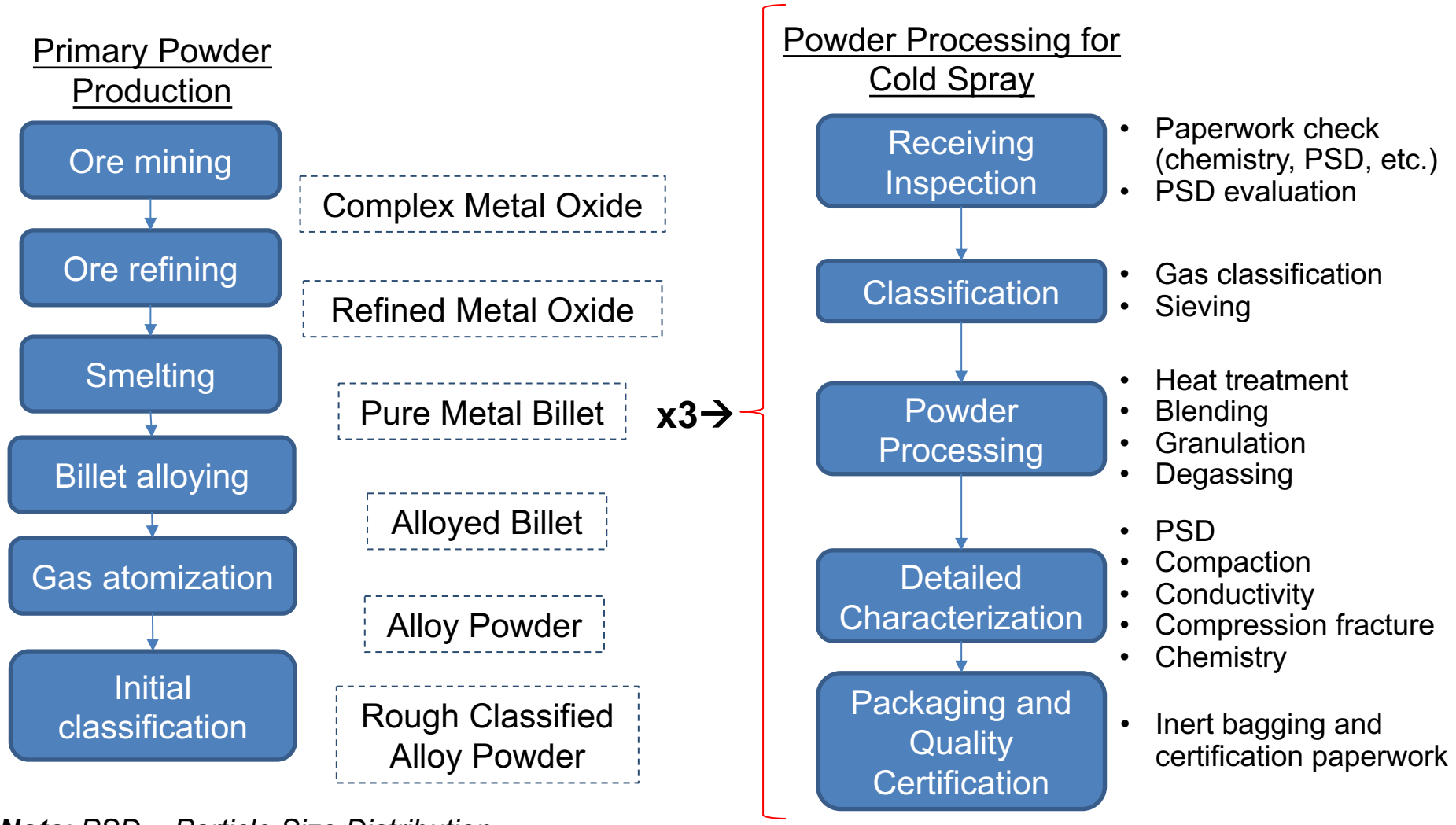
Powder Production and Suppliers



***Note**: PSD = Particle Size Distribution*

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High Pressure Cold Spray

- Supersonic nozzle, powder introduced upstream of throat (SSUT)
- Stationary, heater integrated in gun
  - CGT, Plasma Giken, Impact

- Supersonic nozzle, powder introduced upstream of nozzle
- Portable and handheld capable, heater separate from gun
  - VRC

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Low Pressure Cold Spray

- Supersonic nozzle, powder introduced downstream of throat
  - Centerline, Russ Sonic
- Sonic nozzle, powder introduced upstream of throat
  - Inovati

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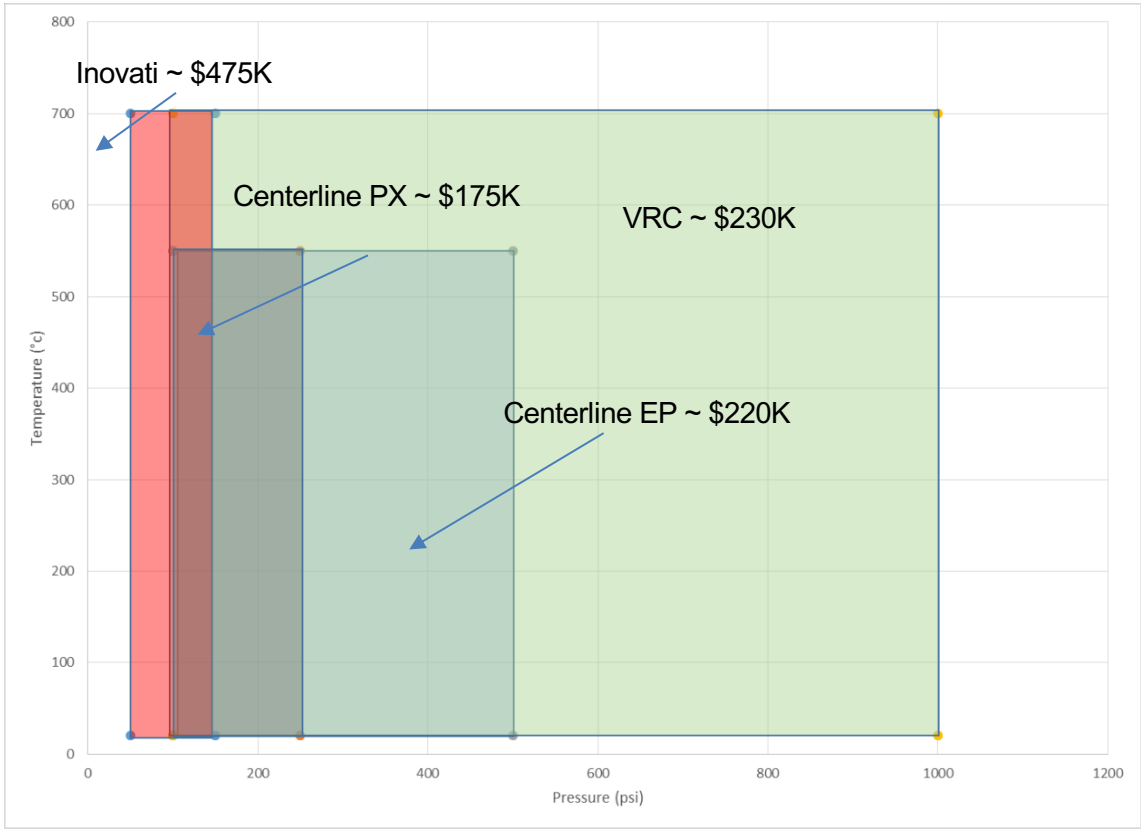
Cold Spray System Comparison

Case Study 6061 Aluminum

- Inovati
  - CVR range
    - 0.58 to 0.77
  - Velocity range
    - 460 to 575
  - Temperature range
    - 13 to 97
  - DE range
    - 0% to 4.2%
- VRC
  - CVR range
    - 0.65 to 1.47
  - Velocity range
    - 550 to 1209
  - Temperature range
    - -85 to -10
  - DE range
    - 1.9% to 100%



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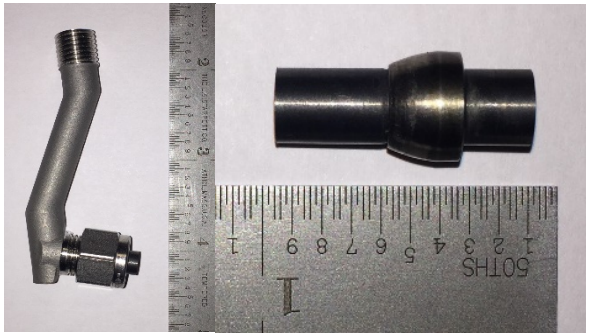
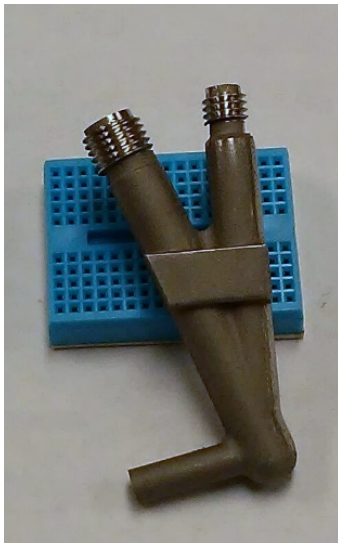
ID Nozzle Development

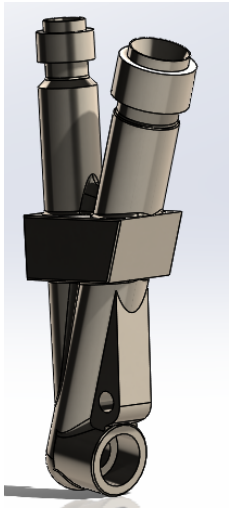


Single injection design for use with carbide nozzle
- 1.6-inch min. bore
- 0.5-inch standoff

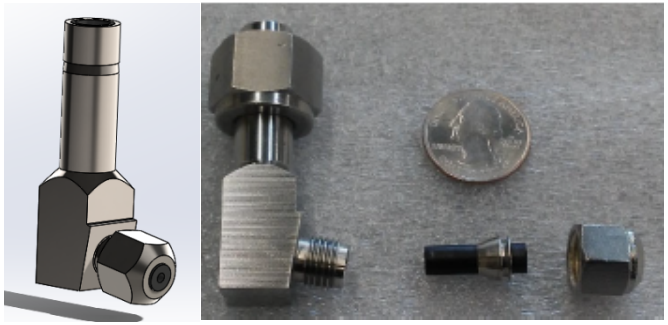
Single injection large bore design
- 4-inch min. bore
- 0.5-inch standoff



Dual injection design with integral Cobalt-Chromium Alloy 3D printed nozzle
- 1.5-inch min. bore
- 0.5-inch standoff



Dual injection design with carbide insert
- 1.5-inch min. bore
- 0.5-inch standoff



Single injection design for spraying aluminum
- 1.8-inch min. bore
- 0.5-inch standoff

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ARL Led OSD DMS&T

- Mobile hospital system
  - Expected completion June 2021
- Deployable cold spray cell
- Connex 1: Complete work cell unit
  - Robot
  - Cold spray system
  - Dust extraction and makeup air
  - Wall mounted system user inputs
  - Separate operator control room
- Can be used alone at locations with power gas supply, power, and shop areas
- Connex 2: Auxiliary unit
  - Air or nitrogen generation and storage
  - Power generation
  - Powder storage
  - Work area for specimen and part prep or simple test and evaluation
- Provides auxiliary support for forward operating locations

***Notes**: DMS&T = Defense-Wide Manufacturing Science &Technology; OSD = Office of the Secretary of Defense*

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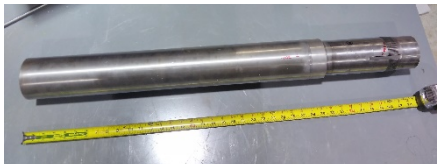
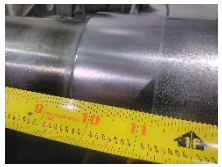
Repair Success Stories

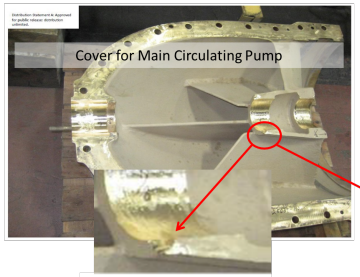
Apache Mast Support
Ni-Plate replacement

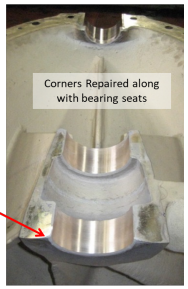
Patriot Pivot Compression Actuator
Ni-Plate replacement





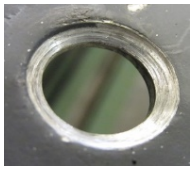
Patriot Ballscrew Actuator Cover
Cr-Plate replacement





Nimitz Class Carrier Pump
Bronze repair

TD-63 Actuator Repair
6061 repair



B-1 FEB Panel Repair
2024 repair

B-1 Hydraulic Line Repair
Titanium repair

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Conclusions

- High pressure cold spray deposits can achieve bond strength capable of carrying structural loads
- Properly developed spray processes can deposit materials with high inter-particle bonding
  - Increased ductility and fatigue performance
- Wear coatings have been developed which outperform chrome in critical applications
- Equipment improvements allow for:
  - Mobile repairs
  - Deposits on IDs as small as 1.6 inches

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Benefits to DoD

- Repair of components that can not be repaired using other techniques
- Surface modification to enhance performance
- Cost savings through component reuse and lower cost coating deposition
- Reducing logistics train through near or infield repairs and improved performance

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For additional information, please visit

https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Surface-Engineering-and-Structural-Materials/Coatings/WP19-5120

Speaker Contact Information

aaron.t.nardi.civ@mail.mil; 301-787-3859

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Q&A Session 2

The next webinar is on September 24, 2020

Munitions Mobility and Burial in Underwater Environments

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Survey Reminder

Please take a moment to complete the survey that will pop up on your screen when the webinar ends

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