Advancements in Cold Spray Expeditionary Repair and Additive Manufacturing

Cold Spray Club Meeting

Gallipoli Italy

June 26th, 2025

Contact Information:
Aaron Nardi – CTO VRC Metal Systems LLC
aaron.nardi@vrcmetalsystems.com
860-841-8337

Presentation Outline

- Introduction
- Equipment developments
- Materials and process developments
- Applications for cold spray

About VRC Metal Systems, LLC

- Founded in 2013 to commercialize R&D in high pressure hand operated cold spray ARL-SDSM&T
- Manufacturing technology company with a focus on metals advanced manufacturing
  - high pressure cold spray, wire-DED AM, friction stir welding, Electro-spark deposition (ESD)
- Headquartered in Box Elder, SD, with locations across the US
- Over 100 systems sold operating in 9 different countries

Lockheed Martin Missiles and Fire Control Exceptional Small Business Award 2023

NSAI Certified

Large Business of the year 2023

Small Business Exporter of the year

Working with our Government partners

Working with our Commercial partners

Working with our Research partners

VRC Capabilities and Services

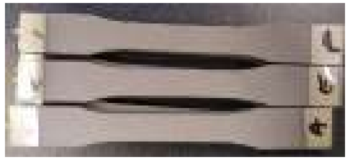
Cold Spray System Engineering & Manufacturing

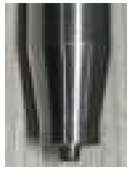



Automation/Integration for CS and Advanced Manufacturing



Advanced Manufacturing R&D/ Applications Development


Cold Spray Consumables Sales and Prototypes Nozzles/Applicators



Services

Repair, Coatings, CSAM, Wire-DED, FSW/FSP Services & ESD



Point-of-Need Services



Operations Support Services


VRC Cold Spray Systems

Gen IV – Stationary system with highest spray conditions, multiple feeders, advanced data acquisition and analysis

Raptor – Stationary or portable system with ful high-pressure capability

All systems support robotic or handheld operation

Dragonfly – compact portable system with full high-pressure capability

VRC Cold Spray Systems

VRC FireFly – Lightweight and Highly Portable Medium Pressure-High Temperature System

- 100 - 500 (6.9-35 bar) psi pressure
- 700°c temperature capable
- Cool-Touch applicator body <40°c
  - Multiple nozzle/applicator options
- Advanced powder feeder design
  - Feeding of very fine powders (down to 1-5 micron)
  - Simple cleaning
  - Reduced PF carrier gas (down to 25 SLPM)
- Operates on single phase 220/240V-30 Amp
- Hand or Robotic Operation (4.7 kg applicator)
- Special line of powders enabling deposition of advanced materials

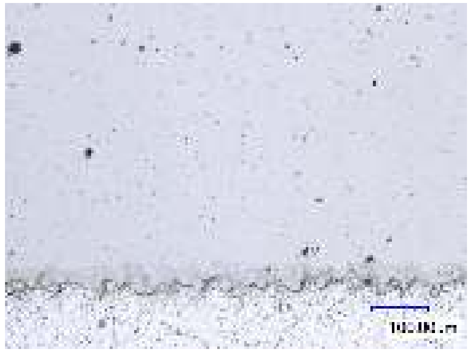
VRC Cold Spray Systems

FireFly Unblended N2 Sprayed Powders Developed

Pure Nickel

Pure Copper

F357 Aluminum



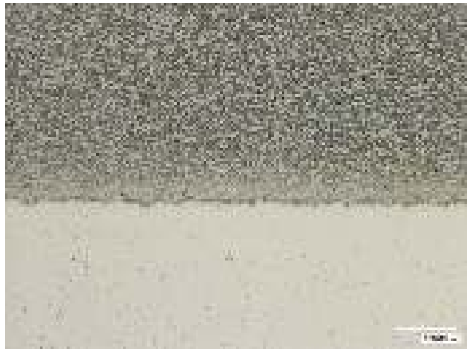
Stellite 21

Stellite 6

FireFly Blended N2 Sprayed Powders Developed

Ni-Chrome Carbide

316SS Blend



Tungsten Carbide-Ni

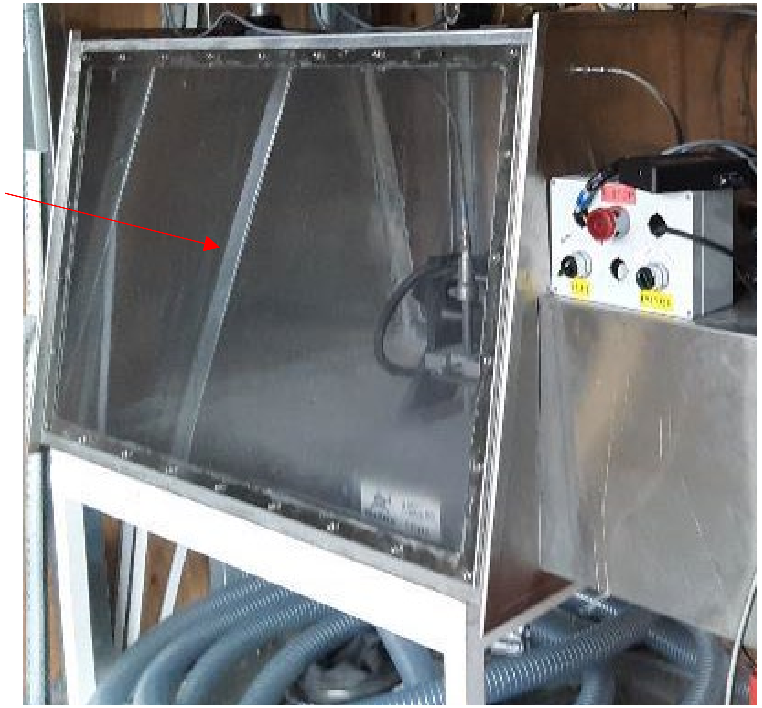
Stellite 21-Tribaloy T400

Specialized Bondcoats

Hydrogen Cold Spray

- VRC and ARL developed a concept to use hydrogen safely in a cold spray process
  - Submitted a patent application for the process
- Developed prototype hardware to validate process

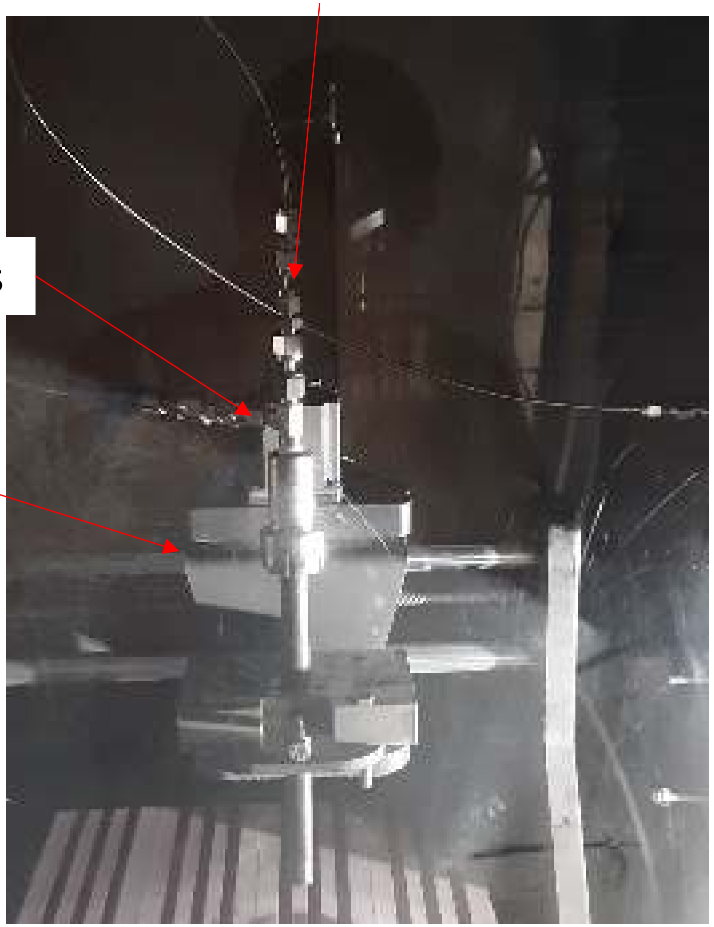
Sealed glovebox enclosure



From PF

Main Gas

3 axis CNC platform



<u>Process Basics</u>

- Purge sealed enclosure with N2
- Spray H2 venting outside in controlled manner
- Purge sealed enclosure with N2

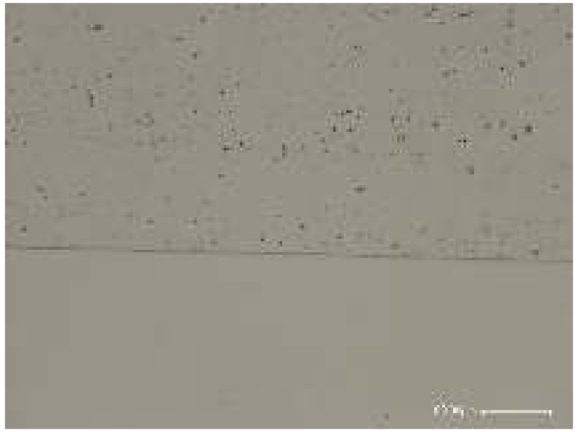
Hydrogen Cold Spray

- Successfully sprayed a range of materials
  - Copper
  - Inconel 625
  - Nickel
  - 316ss
  - 17-4PH
  - 6061
  - F357

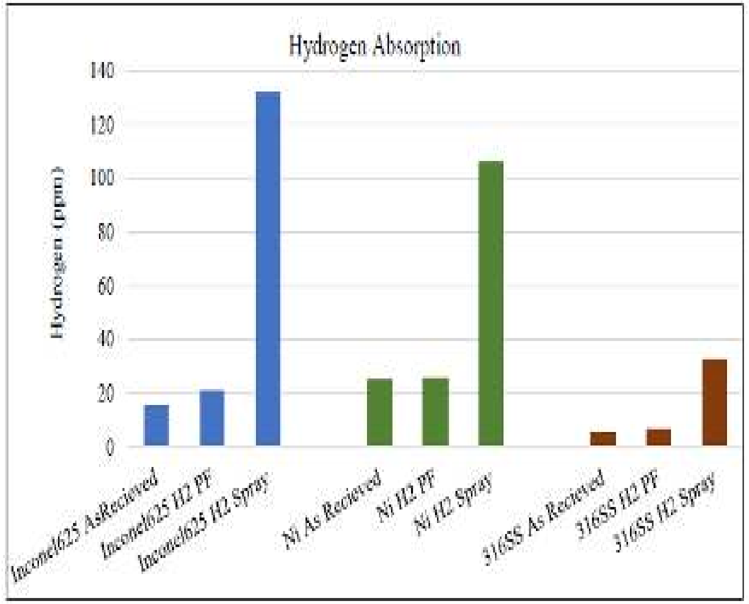
The rate of absorption and embrittling is critical to understand

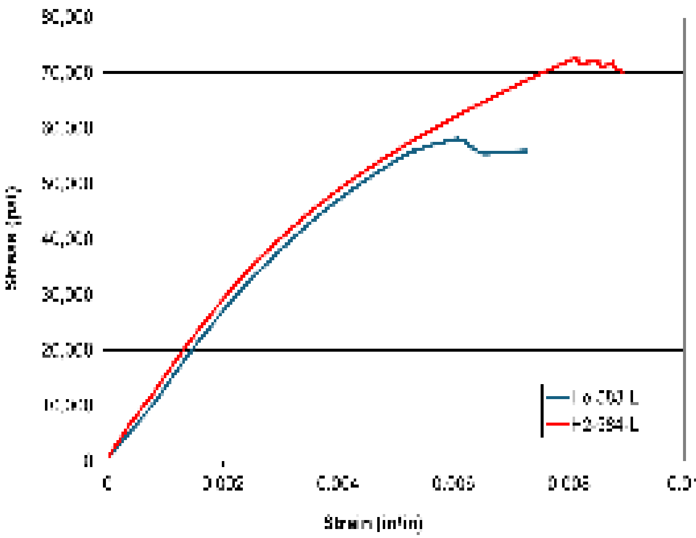
- ~~Titanium~~
- ~~Tantalum~~
- ~~Niobium~~
- ~~Chromium~~

Inconel 625, He 425 psi, RT



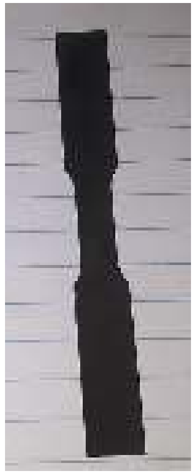
Inconel 625, H2 425 psi, RT

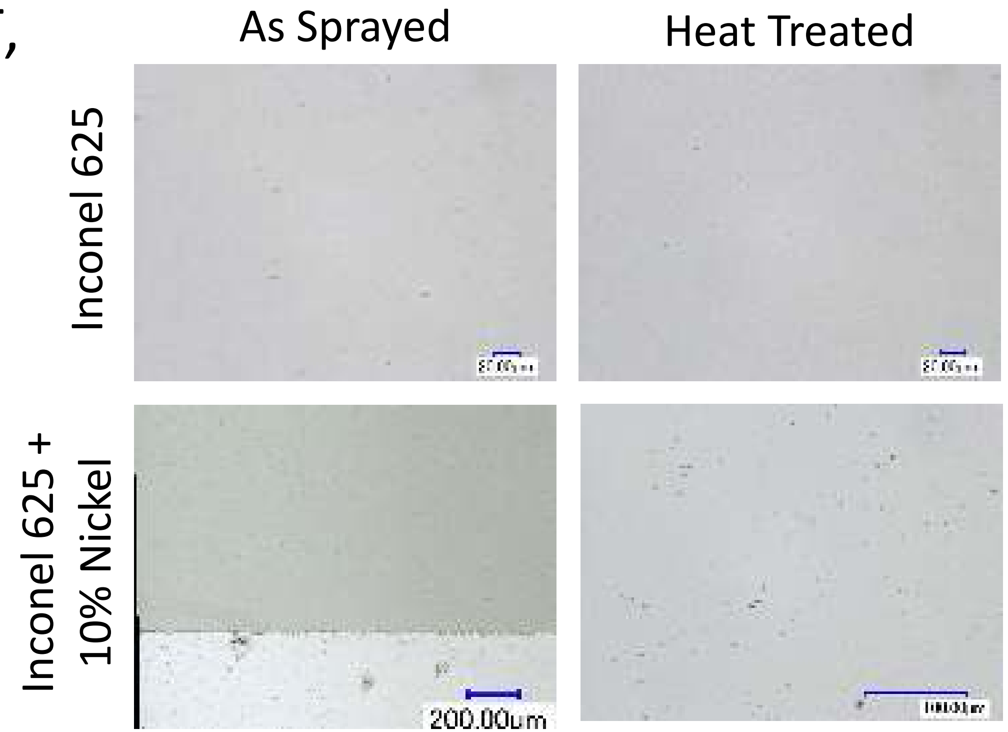


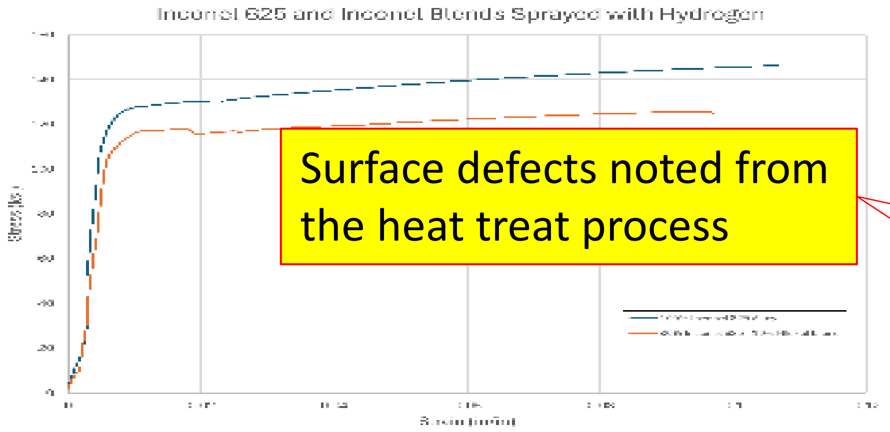


Heat Treating of H2 Sprayed Inconel 625

- Inconel 625 and Inconel 625 blend sprayed with RT, 450 psi Hydrogen
- Heat treated using a three stage process (partially protective atmosphere)
  - Solution treating to dissolve carbides
  - Aging step 1 for 8 hours
  - Aging step 2 for 8 hours
- Very thin sheet tensile coupons extracted







Surface defects noted from the heat treat process

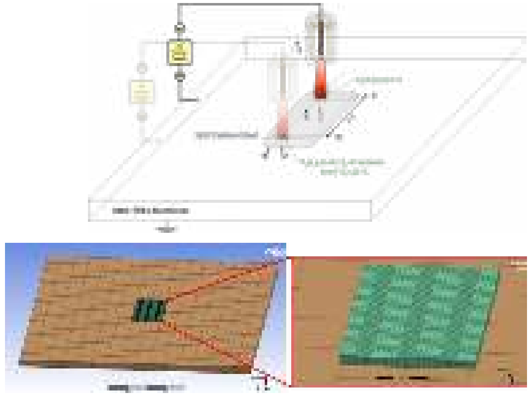
Material	UTS ksi (MPa)	YS ksi (Mpa)	Modulus msi (Gpa)	Elongation (%)
Inconel 625	143 (986)	119 (820)	29 (200)	8.1
Inconel 625-10% Nickel Blend	127 (876)	113 (779)	25 (172)	5.5
Solution and peak age Inconel 625 Sheet (Handbook)	177 (1220)	120 (827)	29 (200)	37

Hybrid Processing at VRC

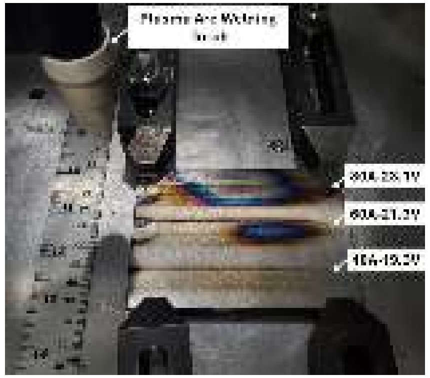
Use of a Plasma Transferred Arc to heat cold spray Ex-Situ

Benefits

- Highly safe and efficient
- No reflectivity issues
  - Material type
  - Surface roughness
- Robust supply chain
  - Lower cost
  - More options



FEA Modeling of PAH Process

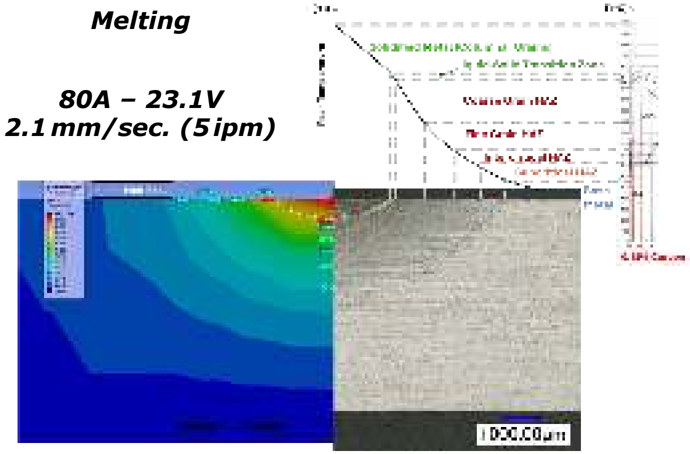


PAH Experiments

Calibration of PAH Process using 1017 Carbon Steel

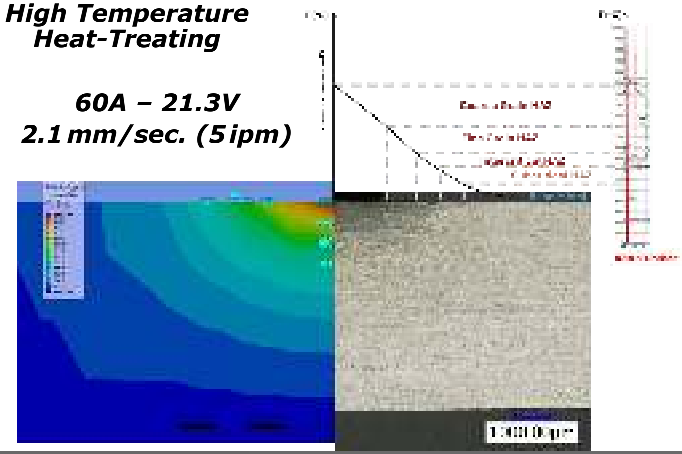
Melting

80A – 23.1V
2.1 mm/sec. (5 ipm)



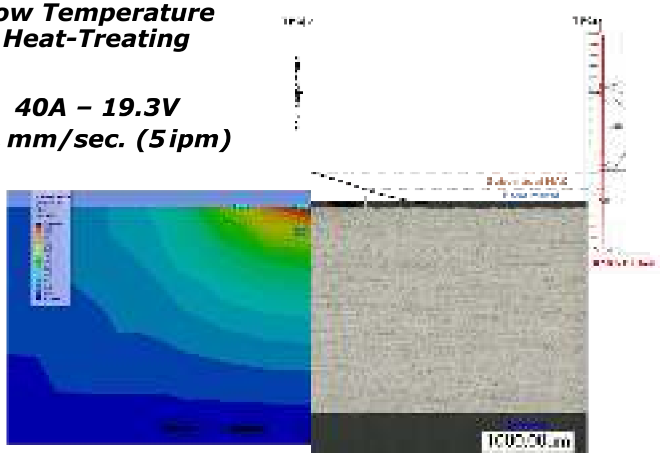
High Temperature Heat-Treating

60A – 21.3V
2.1 mm/sec. (5 ipm)



Low Temperature Heat-Treating

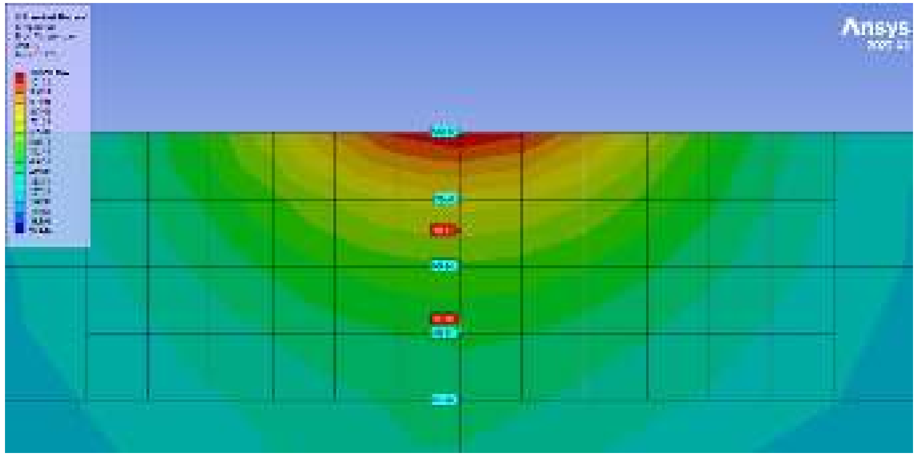
40A – 19.3V
2.1 mm/sec. (5 ipm)



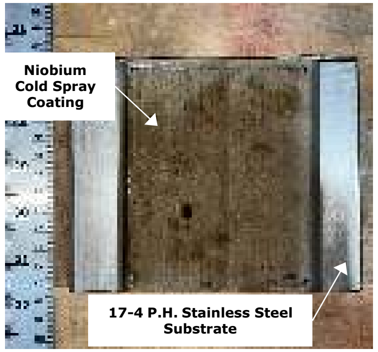
Hybrid Processing at VRC

Use of a Plasma Transferred Arc to heat cold spray Ex-Situ

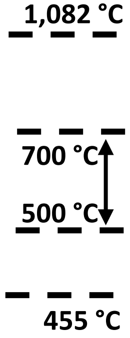
Goal: Strengthen and Increase Ductility of Niobium Cold Spray Coating



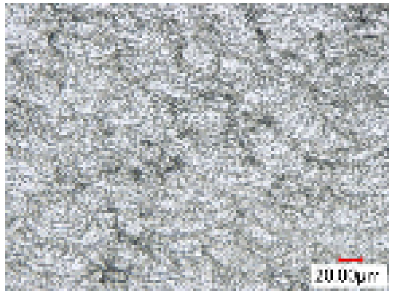
FEA predicted through-thickness temperature distribution in the middle of the Plasma Arc Heat-Treating process



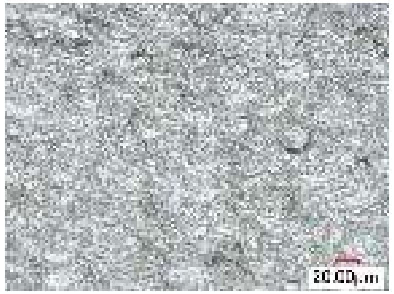
Plasma Arc Heat-Treated (PAH) Niobium Cold Spray Coating



Cross-Section of Plasma Arc Heat-Treated Niobium Cold Spray Coating



As Sprayed Niobium



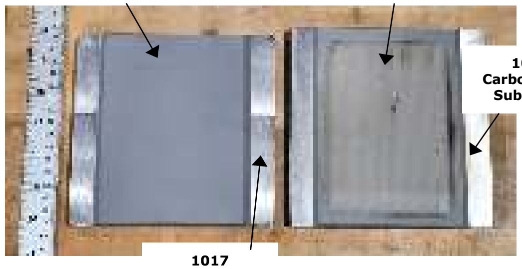
PAH Niobium

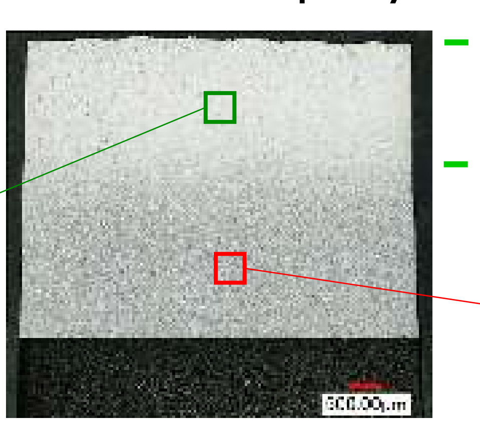
Material	Ultimate Tensile Strength	Yield Strength	Elongation	Hardness
Niobium – As Sprayed	90 ksi (621 Mpa)	60 ksi (414 Mpa)	<1%	182 HV
Niobium After Furnace Heat Treatment	105 ksi (724 Mpa)	85 ksi (586 Mpa)	5-8%	205 HV
Niobium Plasma Arc Heated	109 ksi (752 Mpa)	87.6 ksi (604 Mpa)	4.9	196-242 HV

Hybrid Processing at VRC

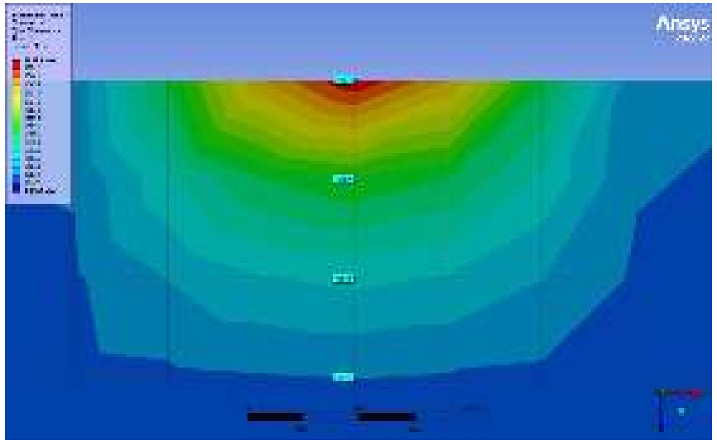
Use of a Plasma Transferred Arc to heat cold spray Ex-Situ

Goal: Toughen the Tantalum Cold Spray Coating





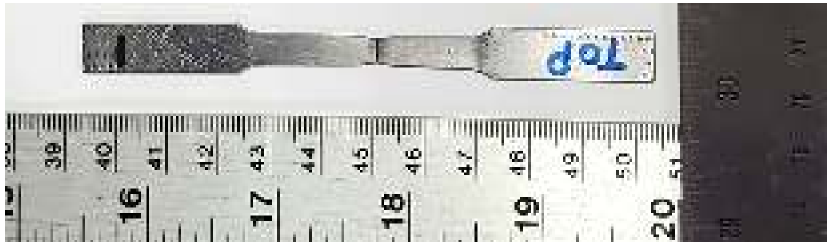
Cross-Section of Plasma Arc Heat-Treated Tantalum Cold Spray Coating



FEA predicted through-thickness temperature distribution in the middle of the Plasma Arc Heat-Treating process

As Sprayed Tantalum Tensile Coupons

PAH Tantalum Tensile Coupons



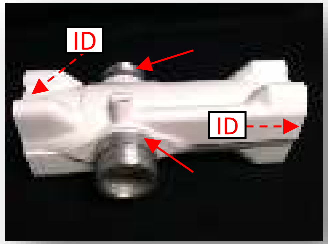
Material	Ultimate Tensile Strength	Yield Strength	Elongation
Wrought Tantalum	25-45 ksi (172-310 Mpa)	15-40 ksi (103-276 Mpa)	30-50%
N2 CS Tantalum	53 ksi * (364 MpPa)	-	<<1%
N2 CS Tantalum – Duplex Annealed	75 ksi (515 Mpa)	68 ksi (470 Mpa)	42%
N2 CS Tantalum – Plasma Arc Heated	80 ksi (553 Mpa)	75 ksi (517 Mpa)	32%

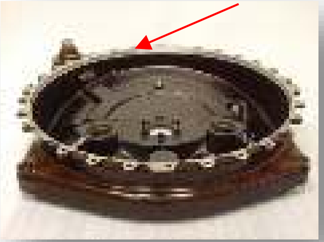
* The UTS of Tantalum - As Sprayed material has low ductility leading to premature tensile failure

Applications for Cold Spray

- High-cost part repairs
  - structural, non-structural, cosmetic or functional

Wear, thermal, etc.



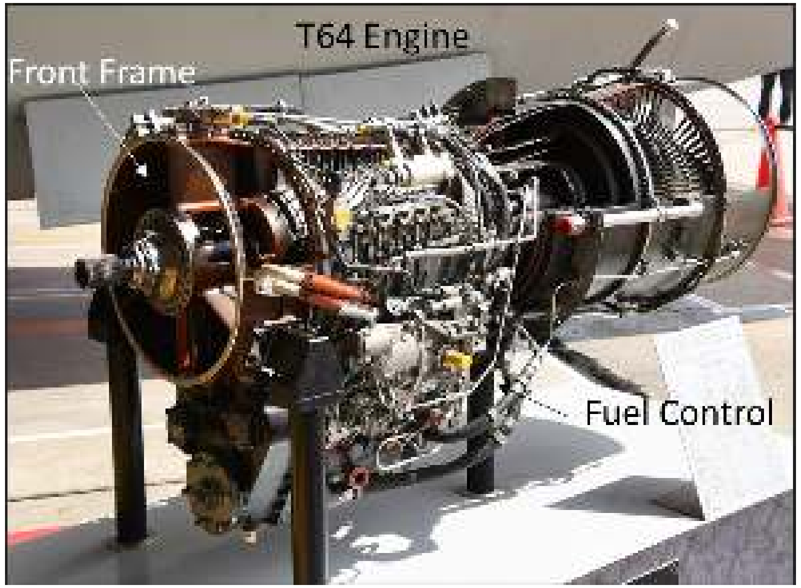

- Repairs on parts with high removal or transport costs



- CSAM of large format shell structures

High-Cost Part Repair

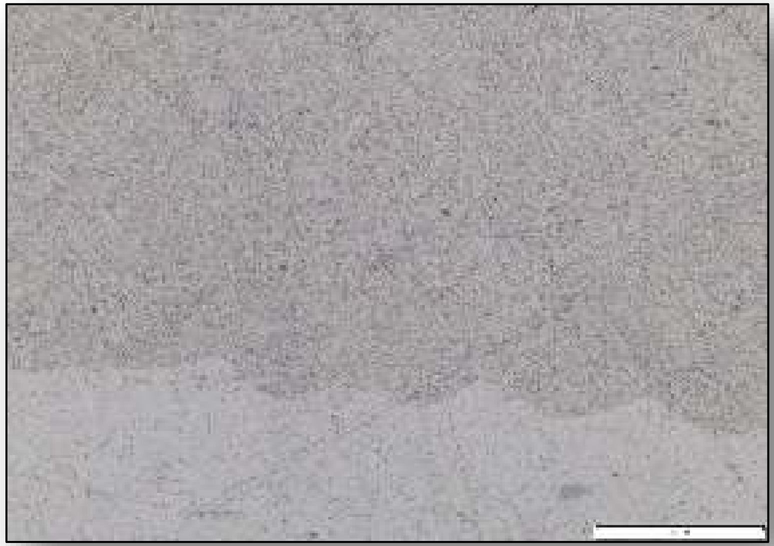
T64 Engine Components for FRC East



- Cast aluminum housing repairs
- VRC developed helium and nitrogen solutions that exceeded baseline performance in fatigue
- Helium Sprays selected by NAVAIR to ensure optimum fatigue performance

T64 Fuel Control Repair

Witness	Pre	Post
Adhesion	12.8 Glue	11.7 Glue
Porosity	0.01 %	0.01 %
Hardness	95.5 HV	95.9 HV




Witness	Pre-Witness	Post-Witness
Adhesion	10.5 ksi Glue	11.3 ksi Glue
Porosity	0.43%	0.25%
Hardness	103.7 HV	103.0 HV


T64 Fuel Control Repair

Witness	Pre	Post
Adhesion	12.8 Glue	11.7 Glue
Porosity	0.01 %	0.01 %
Hardness	9	

Similar commercial applications on cast aluminum and magnesium have been performed with nitrogen using F357 and 5056 blends providing lower cost solutions

Witness	Pre	
Adhesion	10.5 ksi Glue	11.3 ksi Glue
Porosity	0.43%	0.25%
Hardness	103.7 HV	103.0 HV

Maritime Repairs

On-Ship Shaft Repair

- Corrosion damage repaired in place on submarine with Ni based repair material
- Saved **<u>5 months</u>** in drydock
- Hardware used
  - Dragonfly™ cold spray system
  - Vark™ Portable wet dust collector



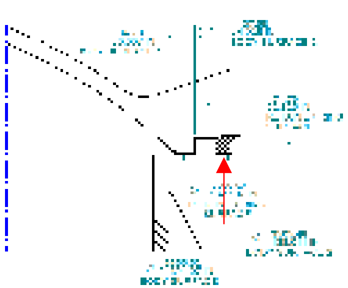

Point of Need Rudder Shaft Repair

- First repair performed in customer facility spraying 126 kg of CuNi based powder in 28 hours to avoid additional **<u>6 months</u>** of drydock time
- VRC hardware used
  - Raptor™ portable cold spray system
  - Vark™ Portable dust collector
- Second rudder repaired on ship 1 year later after failure noted during deployment



Hydropower Repair

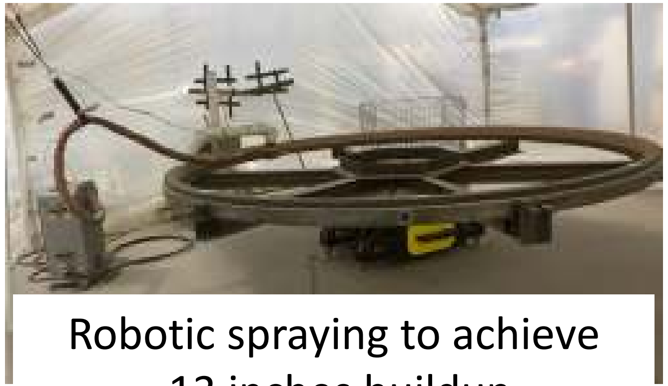
- Largest hydropower ball valve on the east coast of the US
- Worked with PNNL and Voith Hydro Inc. to repair sealing surface for retainer ring with bronze material VRC CU03



Temporary spray room assembled

Before machining prep

Machined in prep for spray



Robotic spraying to achieve .13 inches buildup

After spraying

Nuclear Repair

- Worked with VZU in Pilsen Czeck Republic to repair steam lancing in a steam turbine parting face
- Multiple challenges overcome and CS was successfully qualified
- CS repair performed with VRC and VZU at Temelin power plant

Large Format CSAM

Leading Edge Proof-of-Concept Developments

- Developed in collaboration with ARL and Boeing with path plan optimizations developed by Dr. Isaac Nault at ARL


Build of High-Quality CS Material

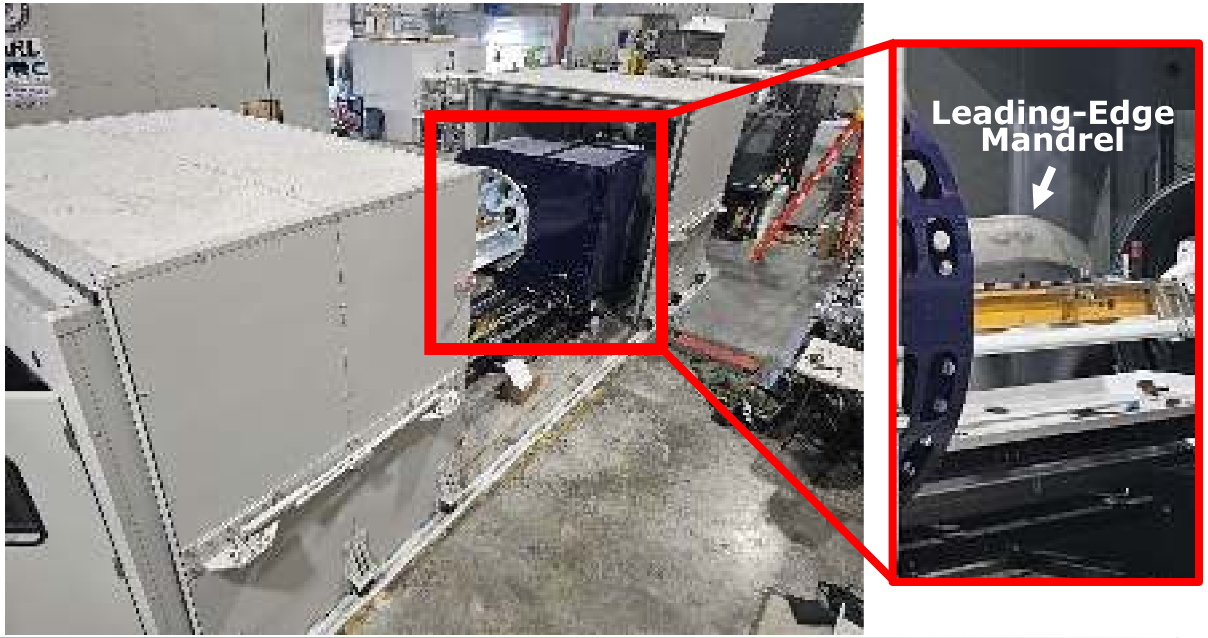

Release of Erosion Strip


Ready for Vacuum Heat Treat

Large Format CSAM

Production Scaleup

- Army/Boeing approved qualification plan for Chinook CSAM Nb repair doubler
  - Controlled manufacturing plan being finalized
  - Production to start in 2028
- CSAM cell is integrated with Gen IV cold spray system and helium recovery
  - Test tensile blocks made to validate system performance



Large Format CSAM

Production Scaleup

- Army/Boeing approved qualification plan for Chinook CSAM Nb repair doubler
  - Contro
    finalize
  - Produc
- CSAM ce
  cold spra
  recovery
  - Test tensile blocks made to validate system performance

VRC worked with collaborators from other cold spray OEM's, aerospace OEM's, and government representatives to finalize AMS 7057 - Cold Spray Additive Manufacturing (CSAM) Process

Summary

- High pressure cold spray provides high density, high bond strength, and highly cohesive repair and production solutions
- Point of need repairs using HPCS can return significant cost savings
- CSAM of large-scale shell structures is a powerful manufacturing method for many different materials
- Hydrogen gas shows promise for CSAM and cold spray in general
  - further development underway to produce commercial system
- Plasma non-isothermal processing shows excellent potential for ex-situ material processing
- Advanced materials developed to enable new low-cost FireFly system to apply advanced material solutions

Thank You!!

Contact Information:

Aaron Nardi – CTO VRC Metal Systems LLC
aaron.nardi@vrcmetalsystems.com
860-841-8337

Useful Web Pages:

https://coldspray.com
https://vrcmetalsystems.
com

Friction Stir Processing of CS Aluminum

VRC Acquires Friction Stir Welding Equipment / Personnel

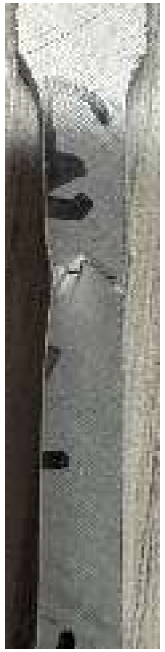
Friction Stir Processing of CS Aluminum

VRC METAL SYSTEMS

VRC Acquires Friction Stir Welding Equipment / Personnel

2024 helium sprayed to achieve deposit with high mechanical properties

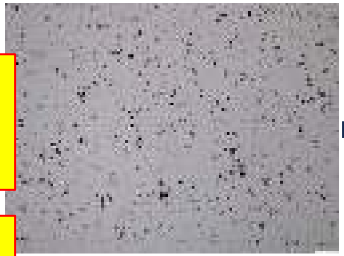
Material	UTS ksi (MPa)	YS ksi (Mpa)	Elongation (%)
HT 2024 He sprayed	55 (379)	41 (283)	5
HT 2024, He sprayed, FSP	62 (427)	46 (317)	11
Wrought 2024 plate at equivalent heat treat condition	62 (427)	40 (276)	21.6



6061 nitrogen sprayed at moderate condition to rapidly consolidate material – targeting a porous deposit

Material	UTS ksi (MPa)	YS ksi (Mpa)	Elongation (%)
N2 CS 6061 as FSP	28.7 (198)	17.5 (121)	12.5
Wrought 6061-T6	45 (310)	40 (276)	17

Likely time @ temperature caused drop in strength



Initial reheat-treatment study → 40 ksi UTS, 39 ksi Yield with > 20% Elongation