

# Advancements in Cold Spray Expeditionary Repair and Additive Manufacturing

Cold Spray Club Meeting  
Gallipoli Italy  
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# Presentation Outline

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- 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



QUALITY IN  
AEROSPACE  
AS9100D  
NSA Certified



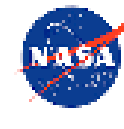
Large Business of the year 2023



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 full high-pressure capability



All systems support robotic or handheld operation

Dragonfly – compact portable system with full high-pressure capability



# VRC Cold Spray Systems

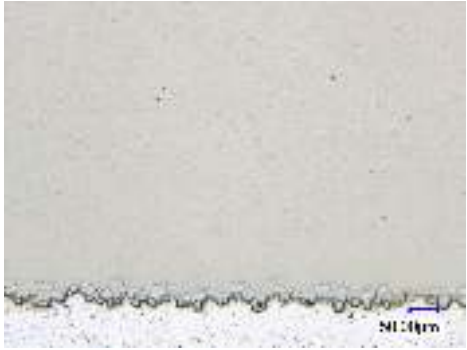
## VRC FireFly – Lightweight and Highly Portable Medium Pressure-High Temperature System

- 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

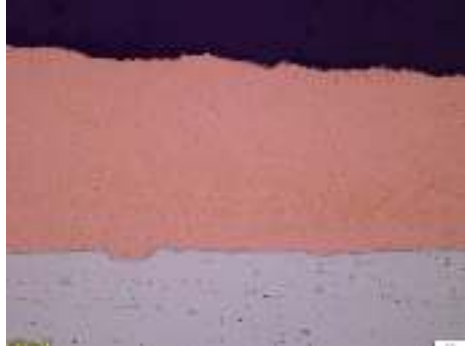


# VRC Cold Spray Systems

## FireFly Unblended N2 Sprayed Powders Developed



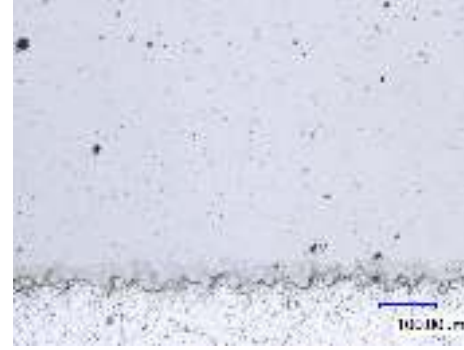
Pure Nickel



Pure Copper



F357 Aluminum



Stellite 21



Stellite 6

## FireFly Blended N2 Sprayed Powders Developed



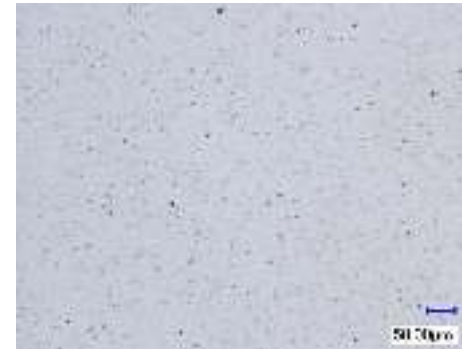
Ni-Chrome Carbide



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



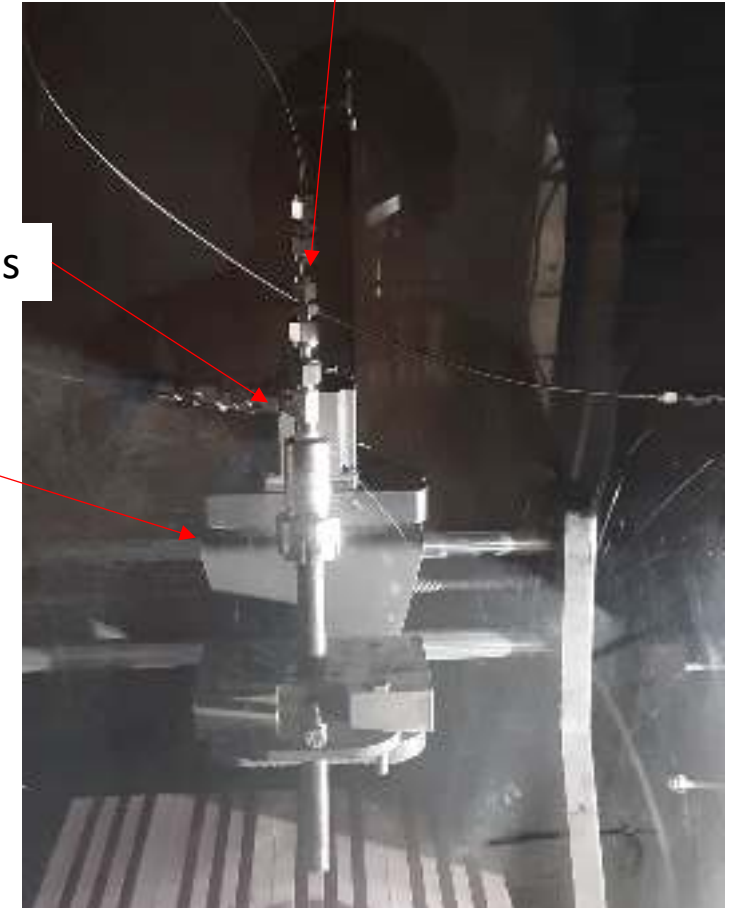
3 axis CNC  
platform

## Process Basics

- Purge sealed enclosure with N<sub>2</sub>
- Spray H<sub>2</sub> venting outside in controlled manner
- Purge sealed enclosure with N<sub>2</sub>

Main Gas

From PF





# Hydrogen Cold Spray

- Successfully sprayed a range of materials

- Copper
- Inconel 625
- Nickel
- 316ss
- 17-4PH
- 6061
- F357

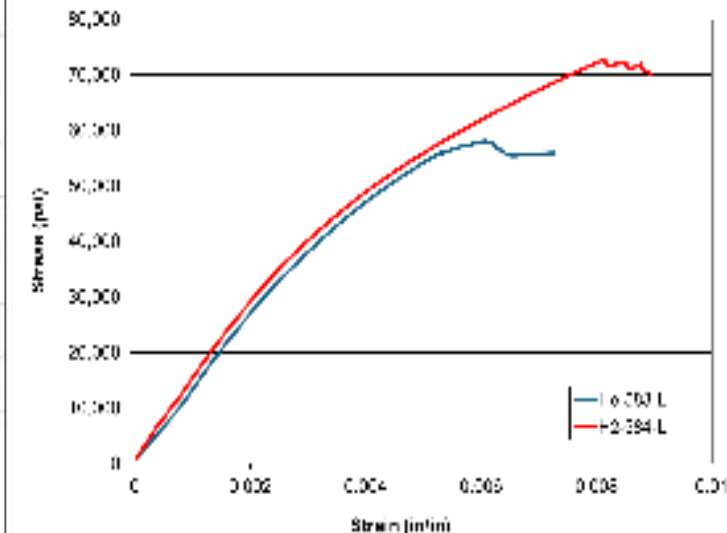
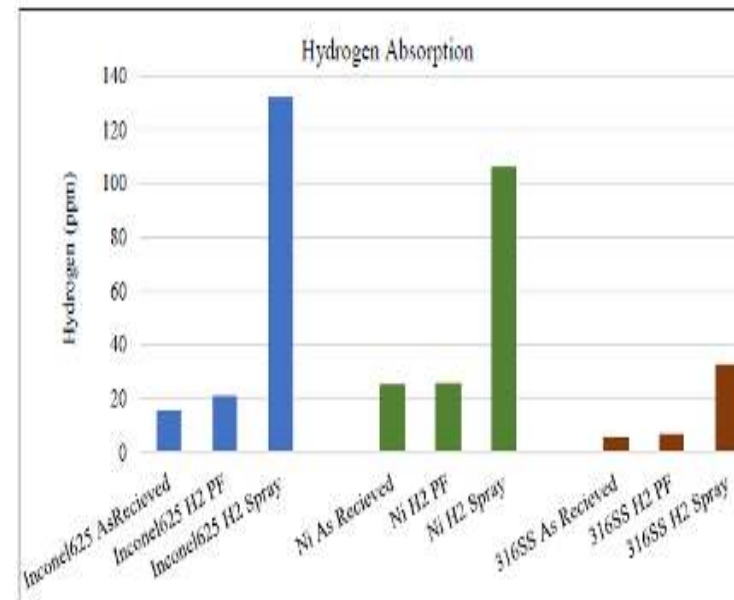
The rate of absorption and embrittlement is critical to understand

- Titanium
- Tantalum
- Niobium
- Chromium

Inconel 625, He 425 psi, RT



Inconel 625, H2 425 psi, RT



# Heat Treating of H<sub>2</sub> 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



Inconel 625

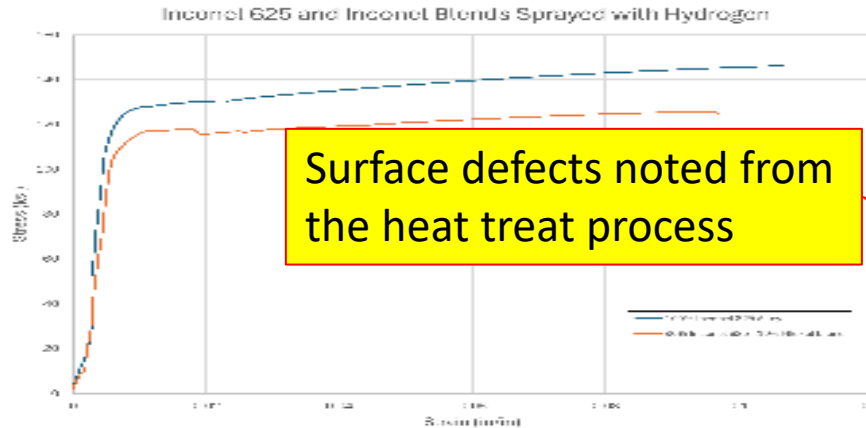
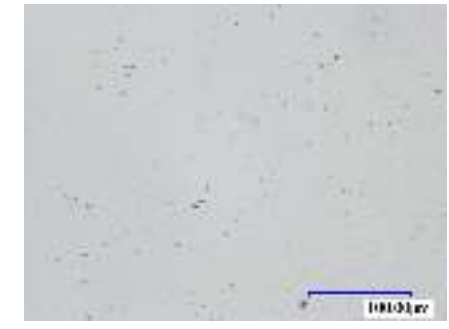
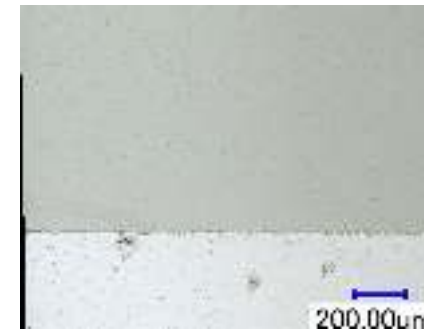
As Sprayed



Heat Treated



Inconel 625 +  
10% Nickel

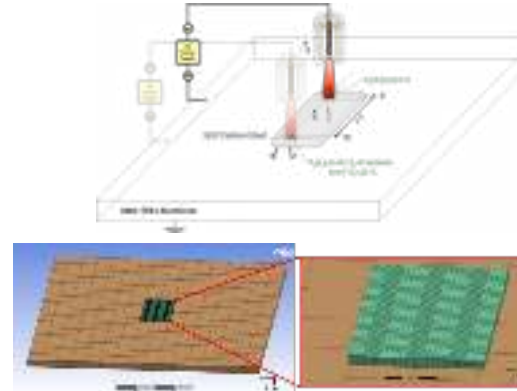


Material	UTS ksi (MPa)	YS ksi (Mpa)	Modulus msi (Gpa)	Elongation (%)
Inconel 625	143 (986)	119 (820)	29 (200)	8.1
Inconel 625-10% Nickel Blend	127 (876)	113 (779)	25 (172)	5.5
Solution and peak age Inconel 625 Sheet (Handbook)	177 (1220)	120 (827)	29 (200)	37

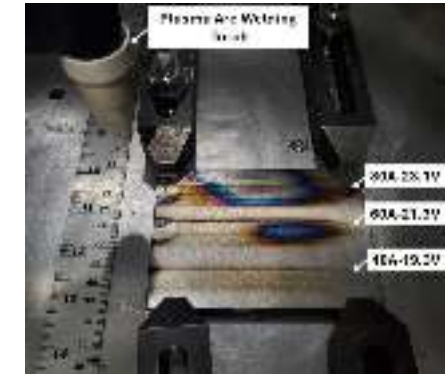
# Hybrid Processing at VRC

## 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**

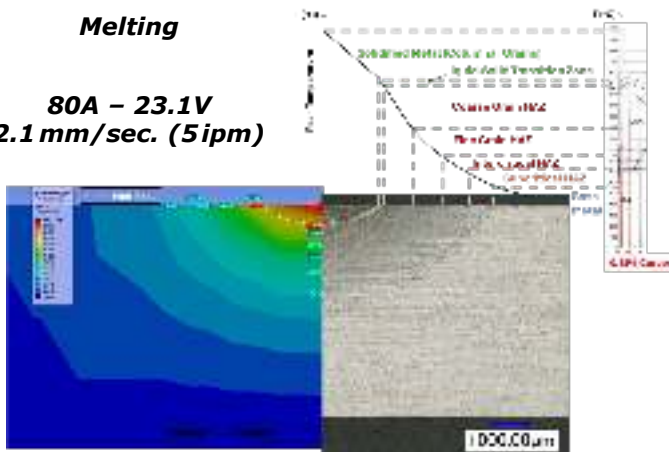


**PAH Experiments**

## Calibration of PAH Process using 1017 Carbon Steel

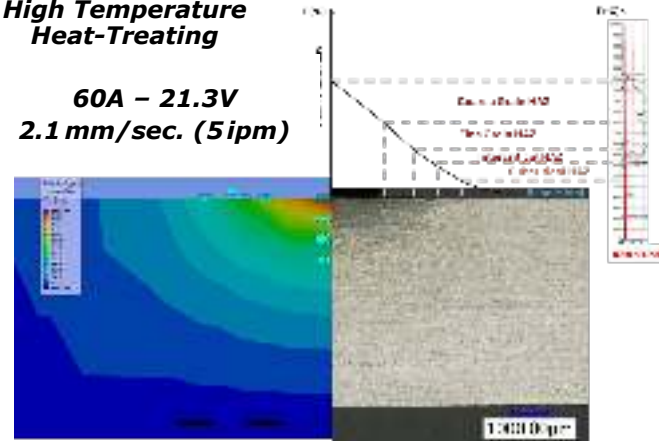
### **Melting**

**80A – 23.1V**  
**2.1 mm/sec. (5ipm)**



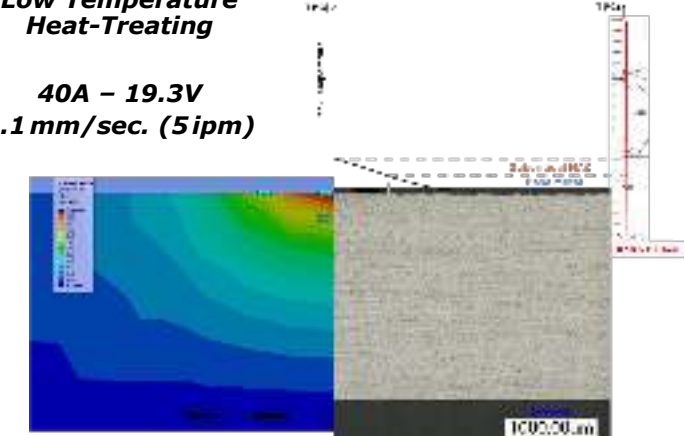
### **High Temperature Heat-Treating**

**60A – 21.3V**  
**2.1 mm/sec. (5ipm)**



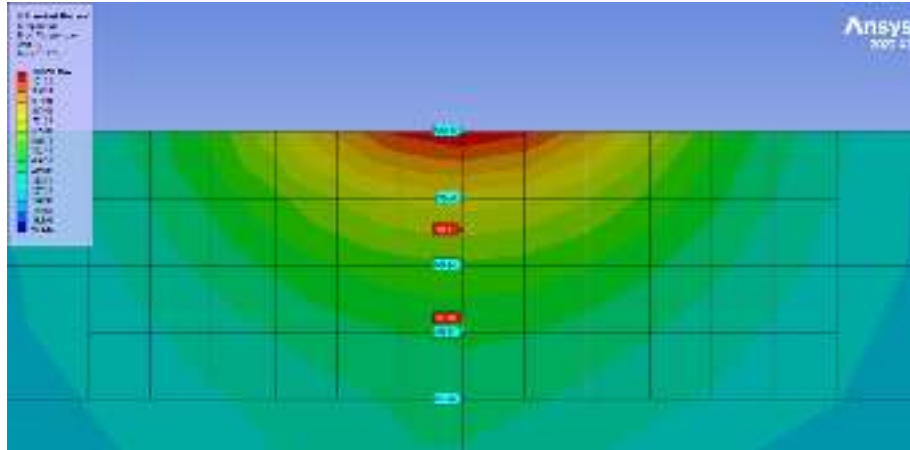
### **Low Temperature Heat-Treating**

**40A – 19.3V**  
**2.1 mm/sec. (5ipm)**

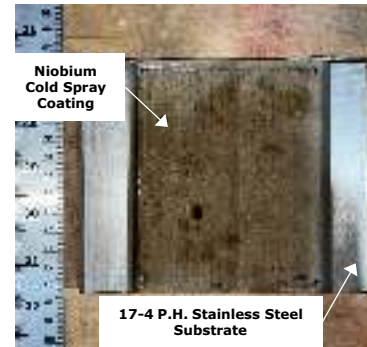


## Use of a Plasma Transferred Arc to heat cold spray Ex-Situ

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**

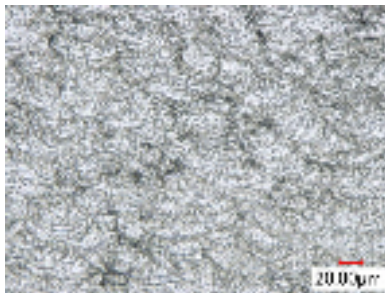


**Plasma Arc Heat-Treated (PAH) Niobium Cold Spray Coating**

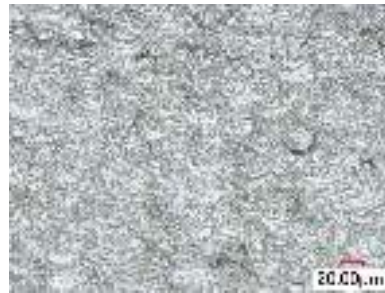
1,082 °C  
700 °C  
500 °C  
455 °C



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



**As Sprayed Niobium**



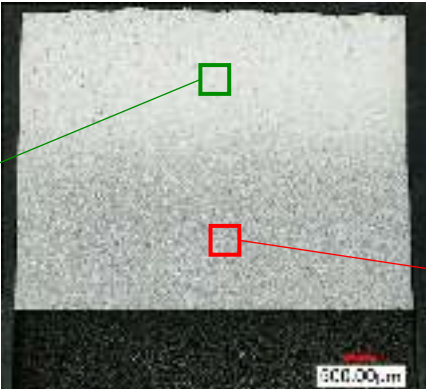
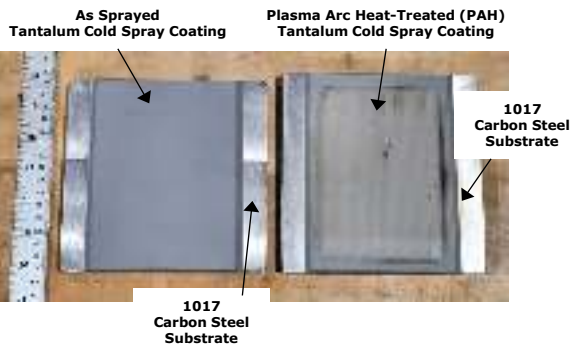
**PAH Niobium**

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

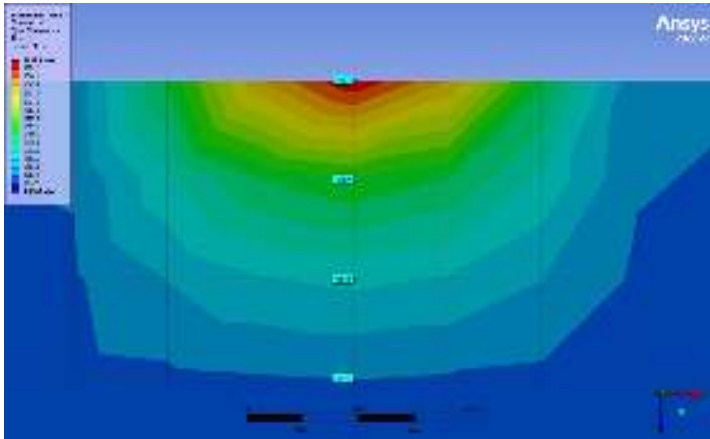
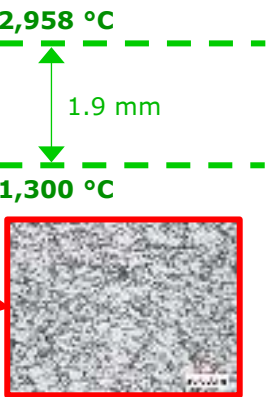


## Use of a Plasma Transferred Arc to heat cold spray Ex-Situ

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



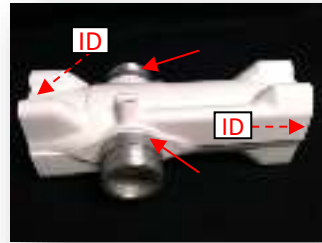
Material	Ultimate Tensile Strength	Yield Strength	Elongation
Wrought Tantalum	25-45 ksi (172-310 Mpa)	15-40 ksi (103-276 Mpa)	30-50%
N2 CS Tantalum	53 ksi * (364 MpPa)	-	<<1%
N2 CS Tantalum – Duplex Annealed	75 ksi (515 Mpa)	68 ksi (470 Mpa)	42%
N2 CS Tantalum – Plasma Arc Heated	80 ksi (553 Mpa)	75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



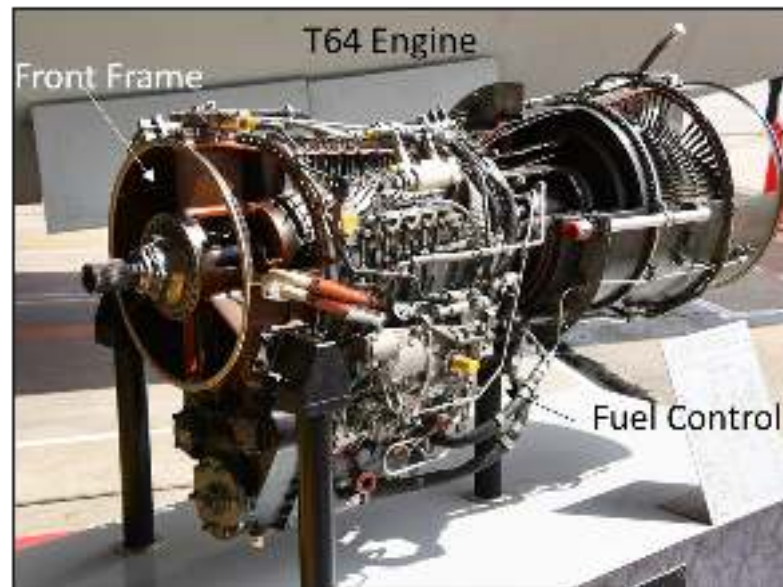
- CSAM of large format shell structures



# High-Cost Part Repair



## T64 Engine Components for FRC East



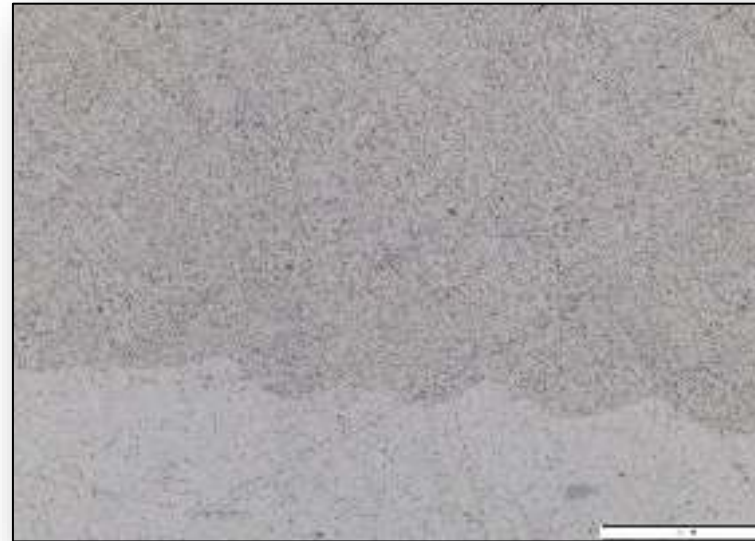
- Cast aluminum housing repairs
- VRC developed helium and nitrogen solutions that exceeded baseline performance in fatigue
- Helium Sprays selected by NAVAIR to ensure optimum fatigue performance



# 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





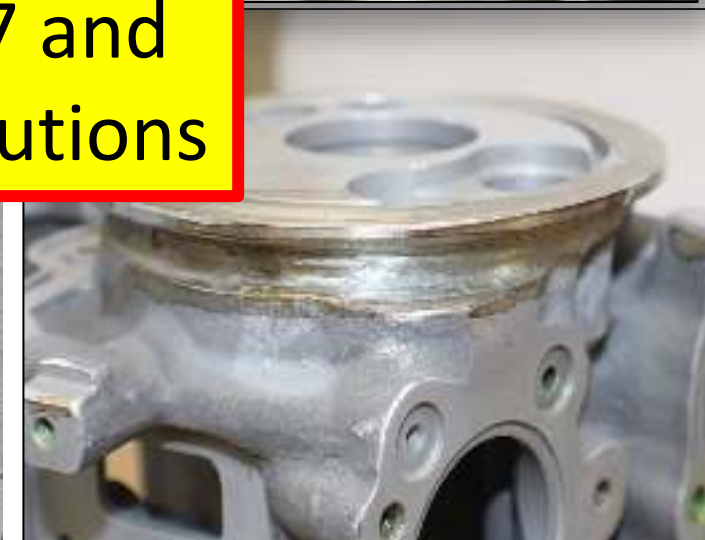
# T64 Fuel Control Repair



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



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



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

# Maritime Repairs

## On-Ship Shaft Repair

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



## Point of Need Rudder Shaft Repair

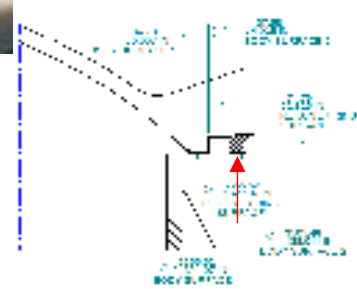
- First repair performed in customer facility spraying 126 kg of CuNi based powder in 28 hours to avoid additional **6 months** of drydock time
- VRC hardware used
  - Raptor™ portable cold spray system
  - Vark™ Portable dust collector
- Second rudder repaired on ship 1 year later after failure noted 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 CU<sub>03</sub>



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 Czech 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



Photo: left - welded repair, right - CGS Coating

The visual quality difference between the repair by welding on the left (visible weld joint and unfinished groove) and the CGS coating after machining on the right.

### Repair of Dividing Plane of High-pressure Turbine Vessel (1000 MW NPP TEMELIN, Czech Republic, 2024)

**VZU PLZEŇ**

- Between October 23 and 26, a specialized repair was conducted on a damaged section of the dividing plane in the high-pressure component during the shutdown.
- Two test samples taken on the left were prepared to evaluate and select the optimal repair method, comparing the performance of traditional weld repair versus CGS spray technology.
- The repair process, illustrated from left to right, involved the following steps: defect identification, surface preparation, manual grinding using a turbine grinder, CGS spray application, and finishing to achieve the final surface.



100 µm

### Mobile CGS technology

**VZU PLZEŇ**

**Key Features:**

- Exceptional adhesion with a gradient interface between the substrate and coating, avoiding sharp transitions.
- Enables part repairs with no limitations on coating thickness.
- Allows joining of materials that cannot be welded.
- Eliminates the formation of a heat-affected zone (HAZ).
- Induces compressive stress within the applied layer.

**Technology principle**

- Uses cryogenically compressed nitrogen up to 80 bar.
- Accelerates particles to velocities several times the speed of sound.
- Upon impact, particles convert kinetic energy into thermal energy, welding material deposition.

**Commonly used materials**

- Fe-Ni based alloys
- Cu, Al, Zn based alloys
- Titanium



Identification of defect - surface

Hard preparation of coated area

Added material by CGS technology

Surface after finishing



The repair procedure from left to right (identifying the defect -> surface preparation - manual preparation with a turbine grinder -> actual CGS spraying -> final finishing by coating).

**Key Benefits of CGS Technology:**

- Does not impact or alter the base material.
- Allows for the application of coatings in any desired thickness.
- Enables rapid repairs.
- Eliminates the need for post-repair heat treatment or grit blasting.



### THE COLD SPRAY PROCESS

**VRC METAL SYSTEMS**

TERMINIC PARTICLE DEPOSITION



The diagram illustrates the Cold Spray Process, showing the flow of nitrogen gas from a source through a control valve and a spray gun to the application point. It also shows the resulting particle stream and the deposition of material onto the substrate.



# 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
  - Control finalize
  - Production
- CSAM ce cold spray 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





- 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!!

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## Contact Information:

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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 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

