Cold Spray Emerging Industrial Repair Developments

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Cold Spray Action Team Meeting
Worcester, MA
June 20, 2018

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Outline

- Why Cold Spray is Gaining Traction
- Manufacturing Sustainability
- Cold Spray Market
- Emerging Applications
  - Chrome Replacement
  - Weld Protection Overlay
  - Shaft Repair
  - Steel & Cast Iron Repair
  - Active Leak Repair
- Wrap-up

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Arbegast Materials Processing & Joining Laboratory

Technologies

- Cold Spray
- Friction Stir Welding
- Laser Powder Deposition
- Plasma Transfer Arc Wire Deposition
- Fused Deposition Modeling 3-D Printing
- Stereo Photo Lithography 3-D Printing
- Plasma Electrolytic Oxidation
- Direct Write Printing w/ Photonic Curing
- Atmospheric Plasma Nano-Spray
- Tungsten Filament Physical Vapor Deposition

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VRC Metal Systems

- 7th Fastest Growing Private Manufacturing Company in 2017

Inc. 500 #413 2017

- ✓ Equipment Sales
- ✓ Consumables
- ✓ Training
- ✓ Research & Development
- ✓ Turkey System Design
- ✓ Specialty Manufacturing
- ✓ Service and Support Agreements
- ✓ Licensing & Partnerships

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Why Cold Spray is Gaining Traction

- **Amazing Properties**
  - ✓Highest Strength Spray Process Available
  - ✓Solid-State Process w/ Metallurgical Bonding
  - ✓No Strength Knockdown…
  - ✓No Thickness Limitation
  - ✓Offers Structural Repair Capabilities

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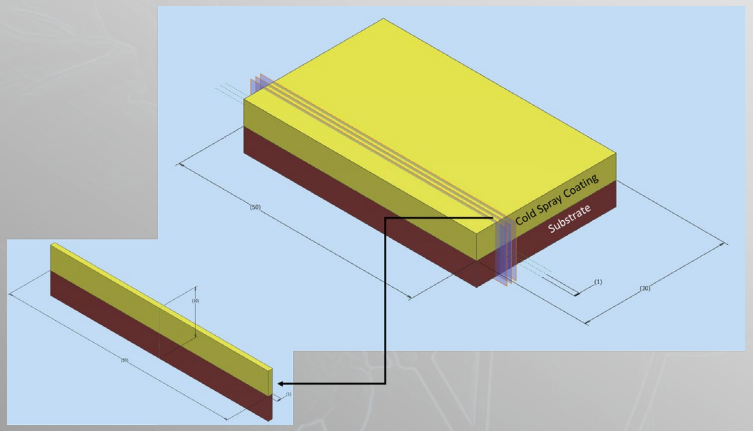
Cold Spray has High Adhesion Strength

- Tensile testing shows adhesive/cohesive strengths of selected Cold Spray Coating & Substrate Combinations are far in excess of 70 MPa (10 ksi) epoxy strength



Coating Material	Substrate Material	Maximum Stress
IN625	304 stainless	229 MPa

cohesive failure within coating

- Testing performed at Johns Hopkins University in collaboration with Dr. Dan Sordelet at Caterpillar, Inc.

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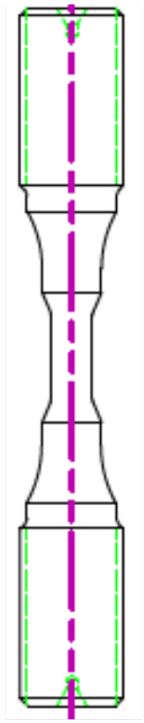
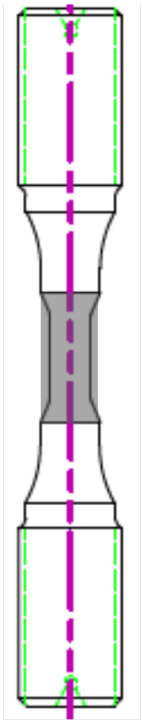
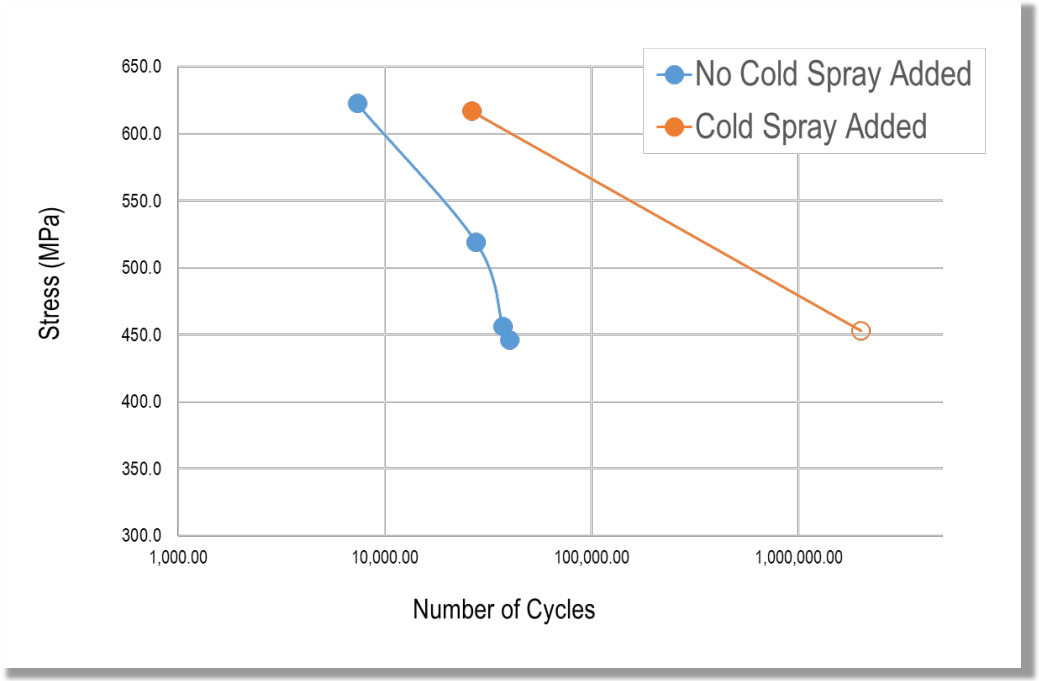
Cold Spray Adds to Fatigue Strength



No Cold Spray Added



~1 mm thick Cold Spray Added



Note: Stresses calculated at the reduced underlying base material cross-sectional thickness to maintain an equivalent load based comparison.

*Worked performed in collaboration with Dr. Dan Sordelet at Caterpillar

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Why Cold Spray is Gaining Traction

- **Cost Savings**
  - ✓Repair vs. Replace
  - ✓Life Extension with Superior Surface Properties
- **Reduced Downtime**
  - ✓Spray and Immediately Re-machine
  - ✓Minimal Distortion

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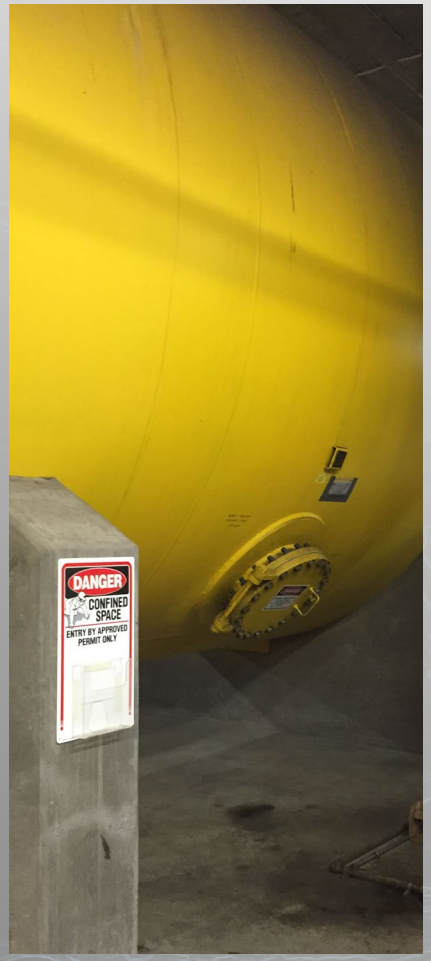
Example Industrial Needs



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Manufacturing Sustainability

1. Low environmental impact
   - *No toxic fumes*
   - *Waste materials are recyclable – powder & gas*
2. Displacement of polluting alternatives
   - *Examples: weld overlay and chrome plating*
3. Life Extension
   - *By applying thin layers of more exotic materials*
4. Lower Emissions & Energy Savings
   - *By repairing items instead of scrapping them*

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GREEN Thoughts about Repair

- To Produce 1 Ton of Steel or Cast Iron
  - ~2 metric tons of CO_2 emissions
  - ~560 kW-hr of electricity
- Cost to Produce a Steel/Iron Part
  - $1.5-$20 USD/kg
- Cast Iron Scrap Price
  - $0.06-$0.13 USD/kg
- ***Note: Materials like Aluminum, Magnesium, Titanium, Copper/Bronze, etc. are even more compelling…***

Recycling is Good, BUT Repairing is MUCH Better!

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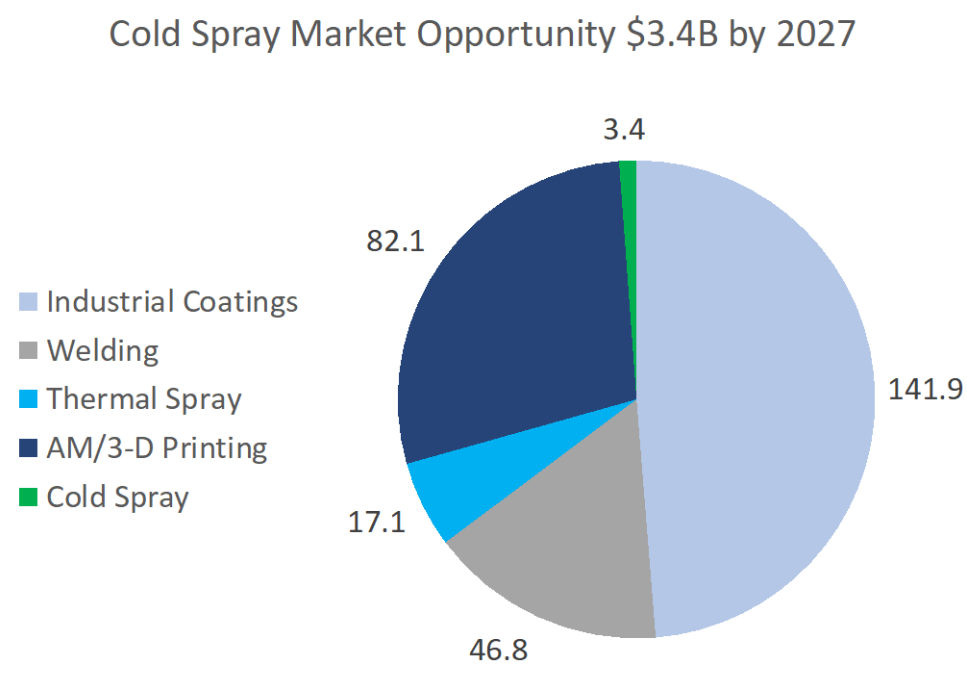
Cold Spray Market

- VRC estimates that the **worldwide cold spray market** is currently ~$110M USD and will grow to $3.4B with a **CAGR** of **41%** for the period **2018-2027.**



- Global **Thermal Spray Market** was $8.1B in 2017, growing at a CAGR of 7.8% *(Mordor Intelligence Report, Mar. 2018)*
- Global **Industrial Coatings Market** to reach $105.5B by 2022, growing at a CAGR of 6.1% *(www.prnewswire.com)*
- Global **Welding Market** to reach $32.6B by 2022, growing at a CAGR of 7.5% *(globenewswire.com)*
- Global **AM/3-D Printing Market** to reach $32.8B by 2023, growing at a CAGR of 25.8% *(www.marketsandmarkets.com)*

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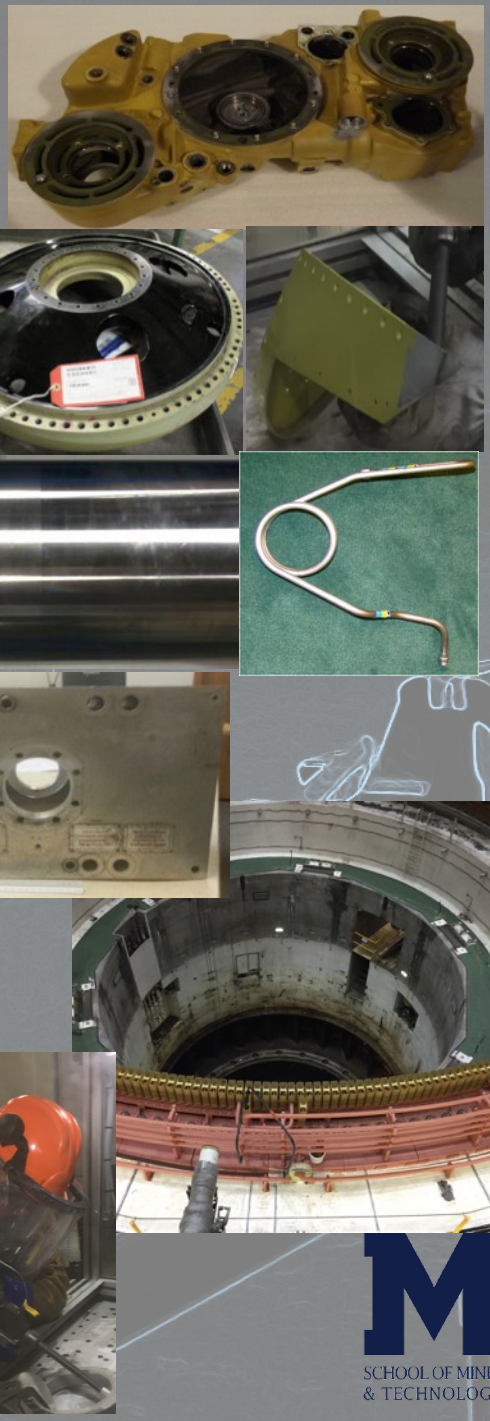
Applicable Industries

- **Aerospace & Defense**
  - Planes, Helicopters, Ships, Submarines, Ground Vehicles, etc.
  - Use: Restoring wear & corrosion damage
- **Commercial Shipping**
  - Shafts, pumps, valves, tanks, hatches, structural members
- **Power Generation**
  - Power Turbines, Boilers, Condensers, Separators, Nuclear Containment, etc.
- **Heavy Industry, Mining, Oil & Gas**
  - Shaft journals, Bushings, Bores, Seals, Castings, Mating Surfaces, etc.
  - Dissimilar Metal Coatings
- **Electronics**
  - PVD targets, Copper contacts, Hermetic sealing
- **Industrial**
  - Mill Rolls, Gears, Holding Tanks, Farming Equipment



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Applications Under Consideration

Broad scope general industry needs:

- Hard Chrome Replacement
- Cast Iron Repair
- Weld Protection Overlay
- Shaft Repair
- Active Leak Repair

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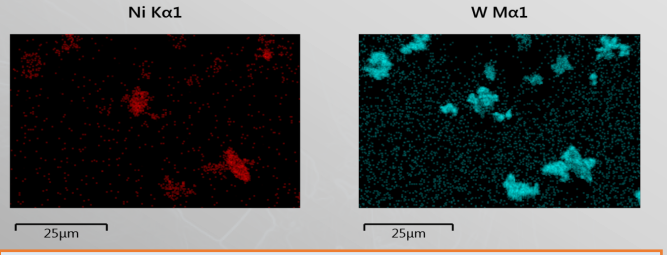
Chrome Replacement

- 85 vol% WC +15 vol% CpNi
- [Proprietary Powder Developed at SDSM&T]



Nitrogen Carrier Gas
WC Nozzle -VRC NZZL0085
600°C Applicator Temperature
950psi System Pressure

Volume % Carbide

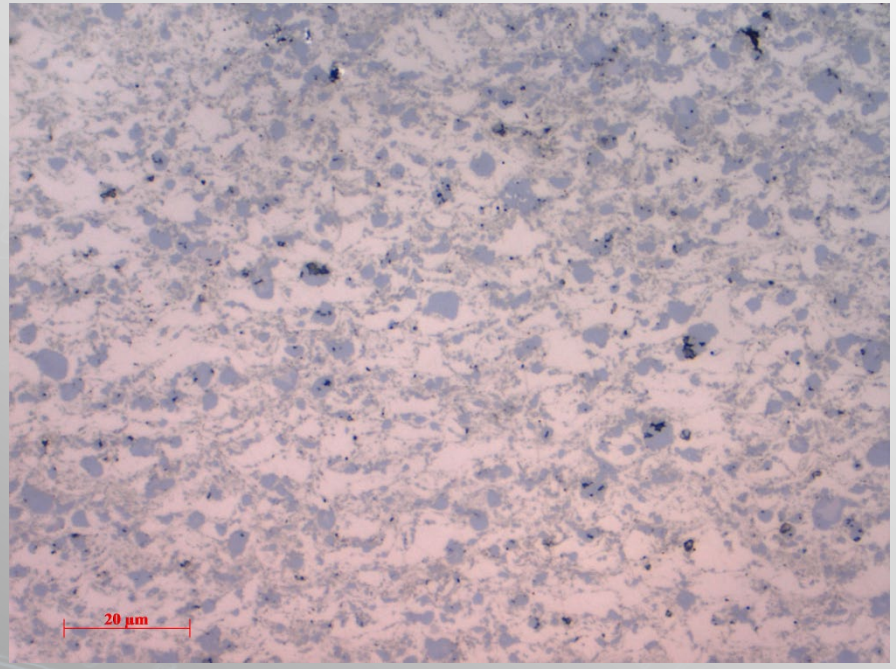
77% ± 4% WC (coating)

Hardness

827 ± 32 HVkrs

ASTM G65 Dry Abrasion Resistance

Vol. Loss: -2.1 ± .3 mm³



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Prepared by: Michael Carter, Ph.D. Candidate (SD Mines)

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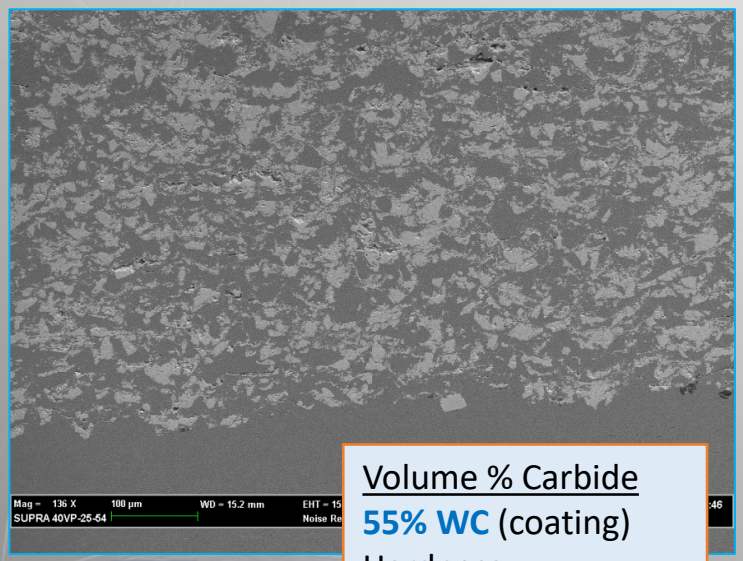
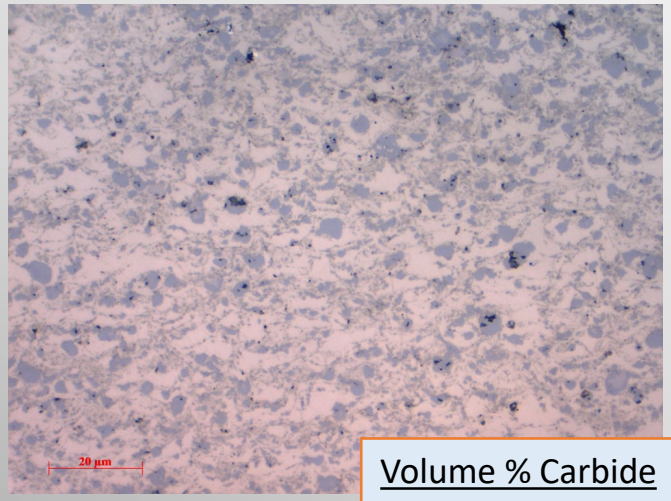
Comparison to Previous CS Chrome replacement coatings

- 5 times smaller WC feature size
- 2X increase in hardness
- 10x reduction in wear rate



100 um

Volume % Carbide
55% WC (coating)
Hardness
499 HVkrs
ASTM G65 Dry
Abrasion Resistance
Vol. Loss: -27.2 mm³



20 um

Volume % Carbide
77% WC (coating)
Hardness
827 HVkrs
ASTM G65 Dry
Abrasion Resistance
Vol. Loss: -2.1 mm³

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Comparison CS micro Ni-WC to Cr Plate

ADVANTAGES

- No limit to part size
- Spot Repairable
- Not thickness limited
- No toxic fumes
- High speed application
- Similar hardness
- 4X reduction in wear
- Similar corrosion resistance
- Rapid Deposition

DISADVANTAGES

- One part at a time
- Line of sight application
- Surface requires post grinding/machining & polishing
- Likely more expensive on initial application

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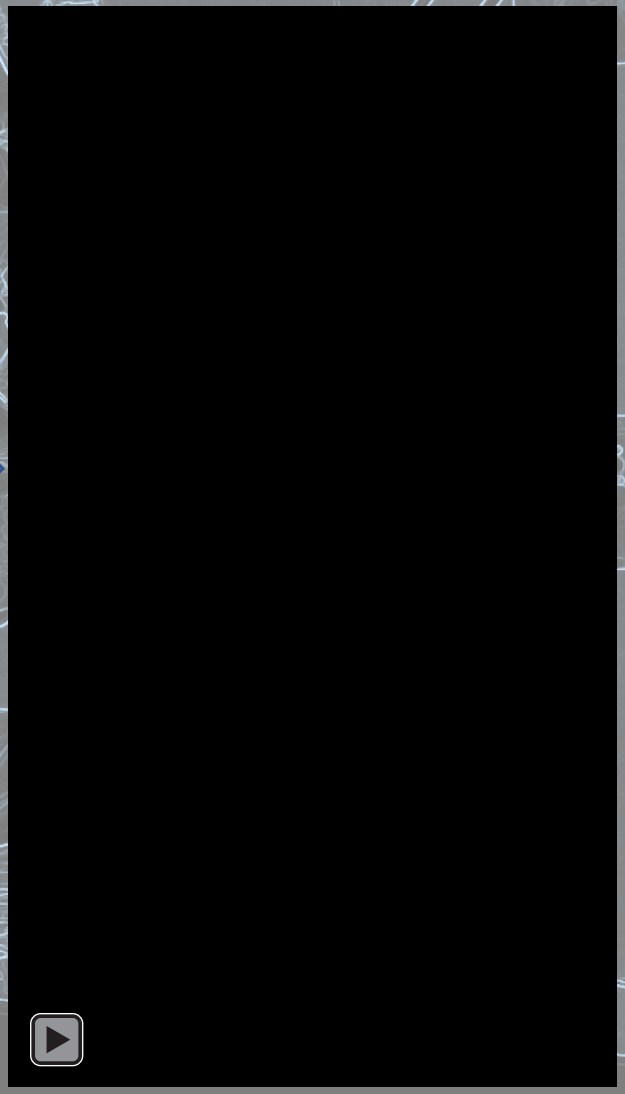
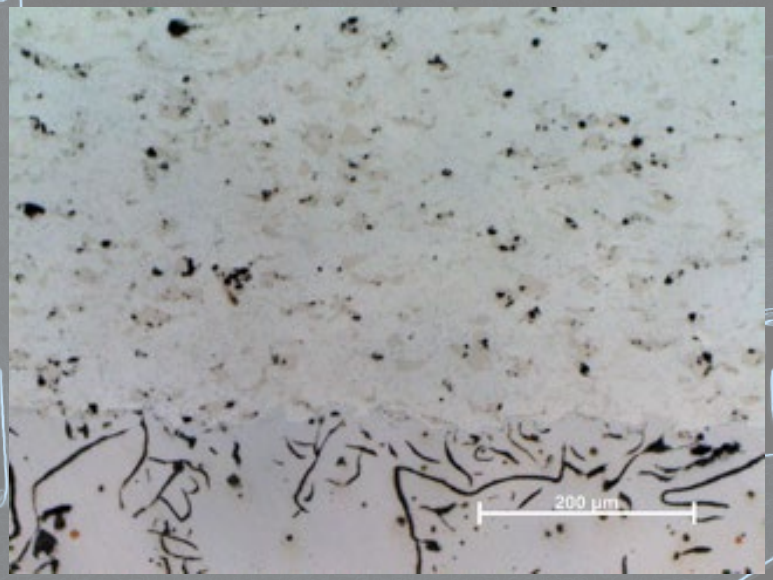
Cast Iron Damage Repair

410 SS + CrC
helium
on Gray
Cast Iron





17-7 SS + CrC
nitrogen
HRC 34
on Gray Cast Iron

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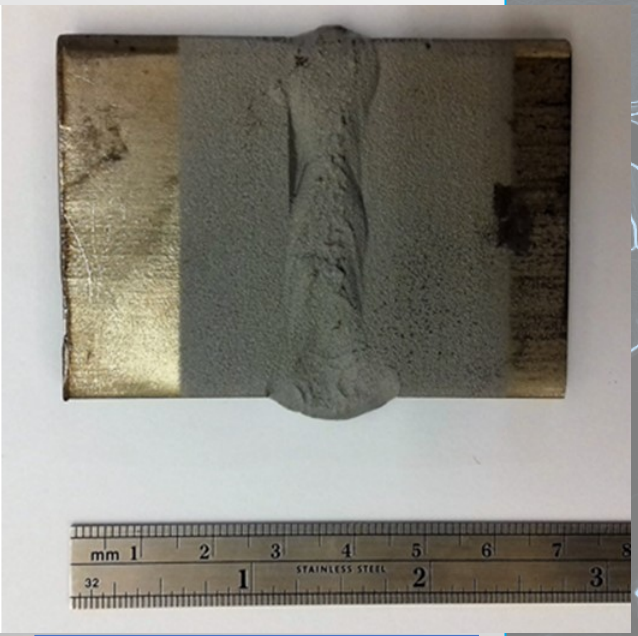
Weld Protection Overlay

- Cold Spray as a Weld Overlay Corrosion Protection Method
- Per ASTM G36 – Demonstrated Stress Corrosion Cracking Resistance in a Boiling Magnesium Chloride Solution when cold spray was applied.

1) Welded 304L plate



2) Welded 304L plate, sprayed with cold spray

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Prepared by: Morotolaoluwa Alabi, M.S. Student (SD Mines)

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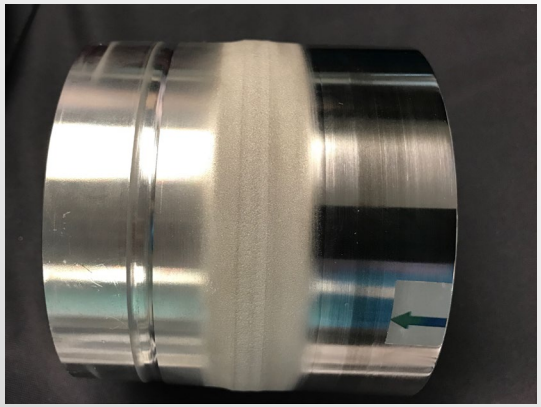
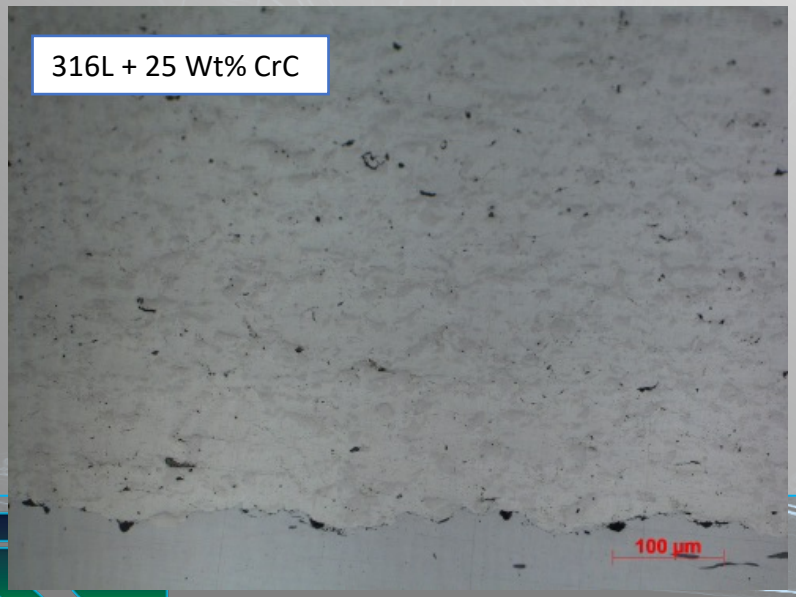
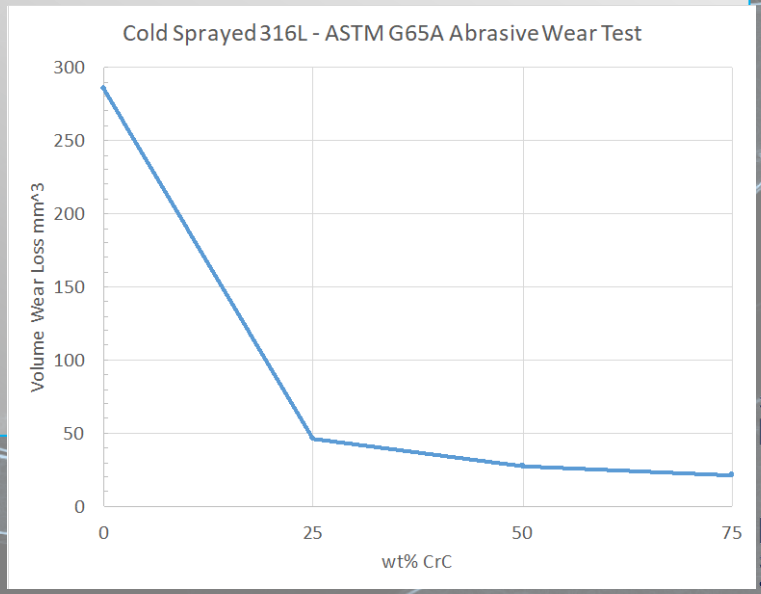
Shaft Repair

- 304 Stainless Shaft Repair Example with 316 SS + 25% CrC using Nitrogen
- 75/25 Wt% CrC (N2) - HRC 32
- 316L - (with He)
  40.1 ksi ± 2.5 ksi [276 MPa]
  1.5%±0.5% Elongation







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Active Leak Repair

- Water leaking at 100 psi

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Prepared by: Oladimeji Oladepo, MS Student (SD Mines)

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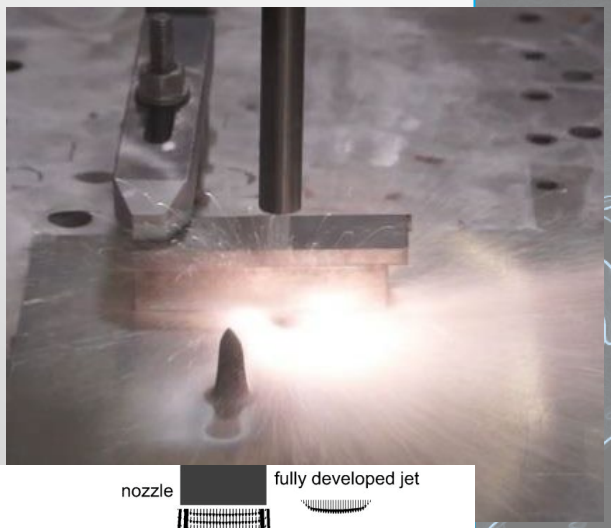
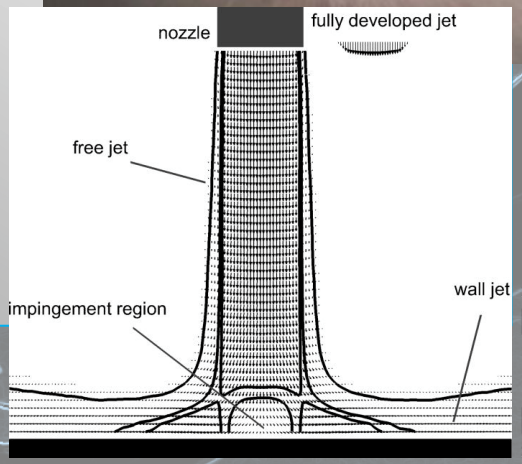
Active Leak Repair Explained

- Why does it work?
- It works for two reasons:

1. A high pressure cold spray impinging jet creates a high pressure stagnation zone on the part when the nozzle is reasonably close to the substrate, which can overcome the leak pressure.
2. The particles achieve full strength immediately on impact, and knock debris and fluid out of the way to create a direct solid-state bond with the substrate, unlike fusion processes which have to cool and solidify before reaching full strength.

Patent-Pending
(Licensable through VRC)





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Wrap-up: Cold Spray Repair Candidates

1. **High Value**
   - If there is no big savings, its hard to justify a big capital investment
2. **Minimal Total Material Loss**
   - The majority of the part is intact and in good condition
3. **The capability exists to re-machine part features**
   - Is the equipment or expertise available to grind or re-machine the part after cold spray?
4. **Unavailability of replacements**
   - When spares are not available even a cheap part can become critical
5. **When a coating spot repair is needed**
   - Many times a large part must be completely recoated if a repair is needed using other processes (e.g. plating, thermal spray, etc.)
6. **A part is not weldable, or is an exotic material**
7. **A thick material deposit is needed**

Final Comments

- **SD Mines** remains focused on **cold spray applications** and **commercialization** of this "game changing" technology.
- **VRC** has built a **remarkable team** to bring cold spray **equipment** and **services** to market.
- **We are doing millions of dollars of development work every year, and have the experience and resources to make your cold spray application a success!**

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Thank you for your attention!

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