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ADVANCED COLD SPRAY ADDITIVE MANUFACTURING FACILITY

Unleashing the Remarkable Additive Manufacturing Potential of Cold Spray

CFI Infrastructure project

Co-PI: Prof. Steve Yue, Dr. Dominique Poirier

McGill UNIVERSITY

National Research Council Canada
Conseil national de recherches Canada

Canada

Background : McGill-NRC Cold Spray Facility (2007-2022)

Outcomes:

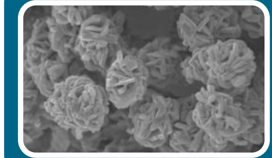
- NRC performed more than 80 R&D projects with a value of over $18M, and attracted leveraging capital investments
- McGill and other academic institutions obtained over $3M in R&D grants training 25 HQP
- NRC and/or McGill established partnership with 30 companies, 18 academic institutions and 5 OGDs from 6 countries

- NRC led or is leading the development of several cold spray applications
  - Dimensional restoration of aircraft engine parts transferred to the P&WC (contributed to mature the technology from TRL2 to TRL9)
  - CSAM Industrial R&D Group – contributed to the development and validation of cold spray powders, cold spray sensors, repair applications and additive manufacturing applications
  - Continued development with industry partners : electric motors, nuclear waste canister protection, bond coats for thermal barrier coatings for gas turbines, repair of hydro turbines, solid-state batteries, etc.
- Publications : R&D perform in the NRC-McGill cold spray facility led to (2007-2018):
  - 94 journal papers and book chapters (ranking 2nd in world with 4.5% of all publications in cold spray).
  - 1550+ citations (ranking 3rd in the world with 7.2% of all citations of cold spray papers).

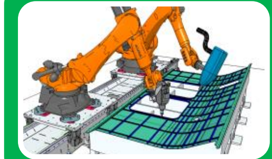
Unleashing the Remarkable Additive Manufacturing Potential of Cold Spray

New CFI grant of $7.8M in procurement process and to be installed at NRC-Boucherville

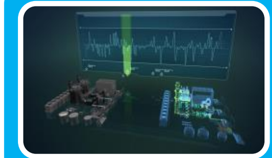
Vision: Develop an entire technology, centered around cold spray, enabling large dimension additive manufacturing of advanced alloy structural components and parts combining metal based smart and structural materials.



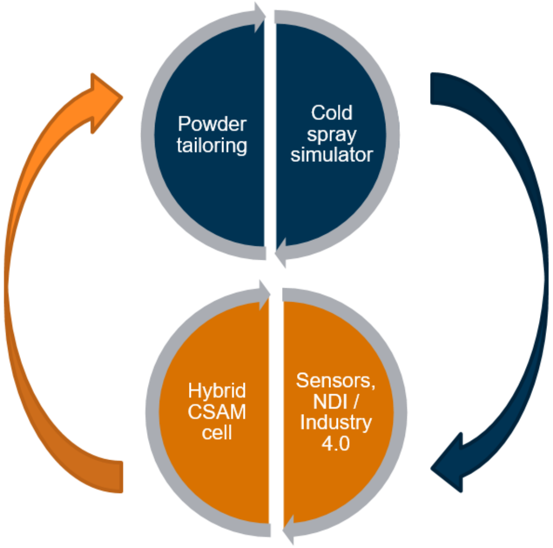
Radically improve the cold spray process by concentrating on understanding and controlling powder feedstock characteristics with a unique powder tailoring facility, including a unique cold spray simulator, yielding effective deposition of next generation materials.



Develop a hybrid facility combining cold spray, laser technologies and advanced machining making possible the fabrication of net shape 3D parts or 3D components on parts with proper dimensions and material properties.



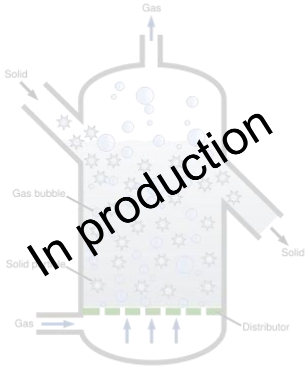
Adapt and develop a comprehensive set of sensors and non destructive inspection tools enabling big data acquisition for analytical technologies and AI approaches at the forefront of the Industry 4.0 strategy for full digitisation to deploy optimization, prediction and real-time process control capabilities.



Powder Tailoring Facility

Ultrasonic Atomizer
To produce custom powders from rods or wires

Magnetron Reactor
To coat powders



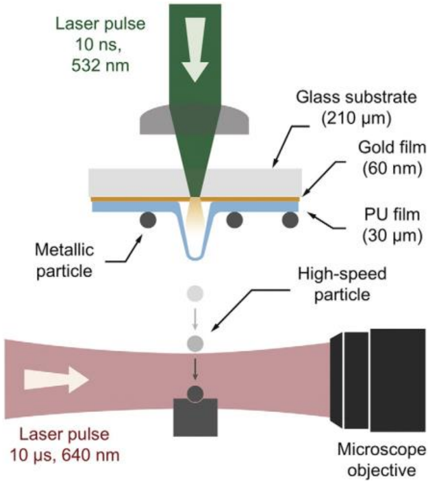
Fluidized Bed Furnace
To heat treat the powders and rapidly quench

High Energy Sieving
To classify powders

Particle Size and Shape Analyzer

Cold Spray Simulator

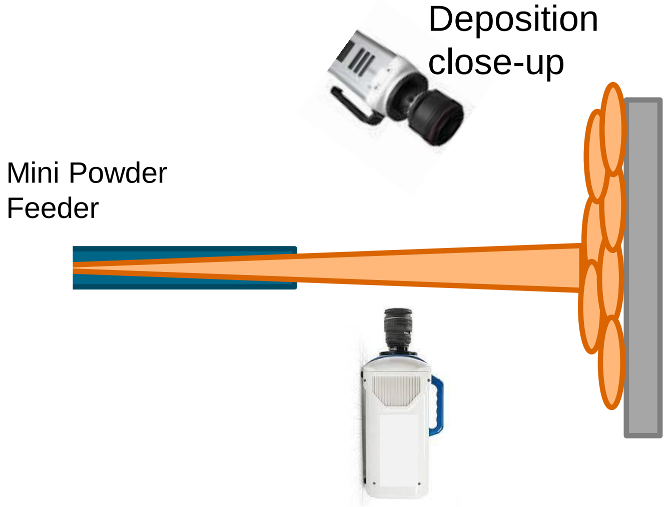
Direct particle impact observation



Credit: In-situ observations of single micro-particle impact bonding

Ultra High speed framing camera (12 frames at up to one billion frames per second) will capture flight velocity, impact (3-5 frames) and rebound (if any)

High throughput cold spray observation



High speed cameras to study particle-on-particle deformation
+ Infrared camera (heat transfer)
+ Schlieren imaging (gas flow)
Ultra high speed camera to look at particles in the jet

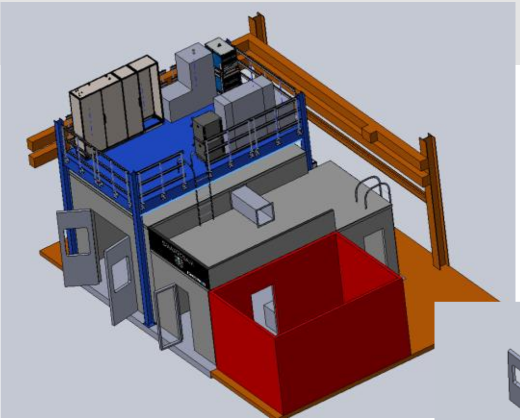
Hybrid CSAM Cell

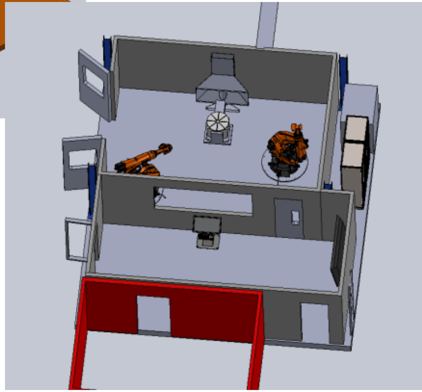
Cell components

- Two KUKA robots
- Plasma Giken Cold Spray Gun (PCS-100)
- Robot Machining – deburring and finishing
- Ablation Laser system for surface work
- Fully instrumented

Digital Twin

- AI assisted model of entire cold spray system fed by data from all equipment in the Cold Spray Cell





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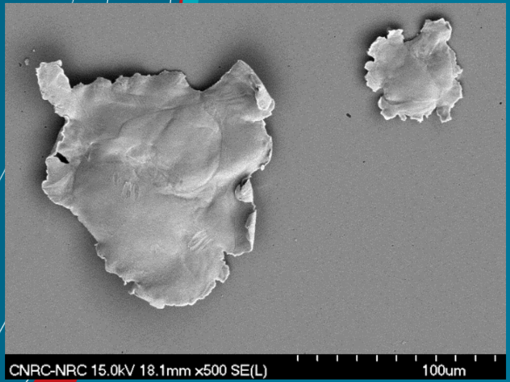
How to improve soft particle adhesion on hard substrates in cold spray

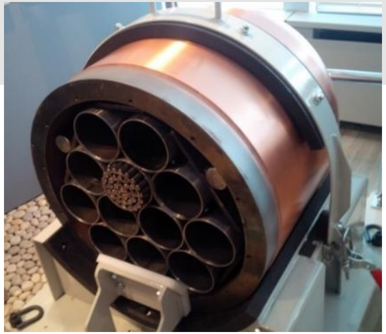


October 2023

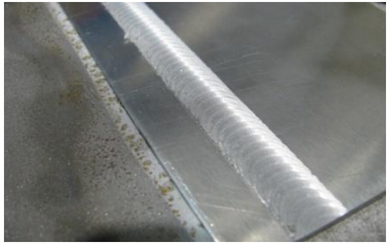
D. Poirier[a], J.-G. Legoux[a], B. Guerreiro[a], F. Caio[b], L. Pouliot[b], J.D. Giallonardo[c]

[a] National Research Council of Canada
[b] Polycontrols
[c] Nuclear Waste Management Organization (NWMO)

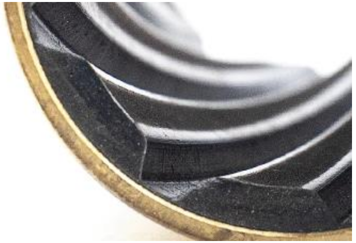
Soft Particle Deposition on Hard Substrates
Some Applications



- Corrosion protection of steel, such as for Nuclear Used Fuel Containers (UFCs) (Cu on steel)



- Localized metal addition technique to facilitate welding (Al on steel)



- Bearing surfaces (brass on steel) Theimer et al. JTST, 2019

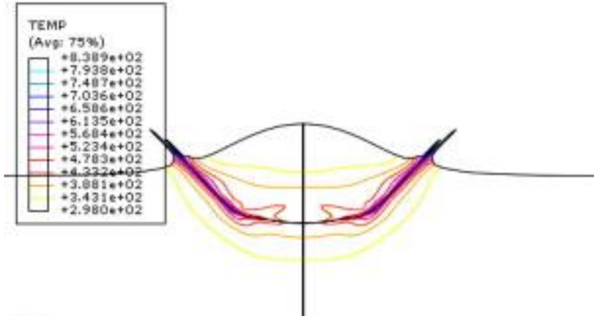
Bonding Mechanisms

- **Mechanical anchoring f(geometry, size and quantity of hooks and anchoring sites found at the substrate surface)** Nastic et al. JTST, 2017

- **Metallurgical bonding f(interfacial deformation, contact pressure and temperature variation)** Nastic et al. JTST, 2021

→ maximized when both particles and substrate deform

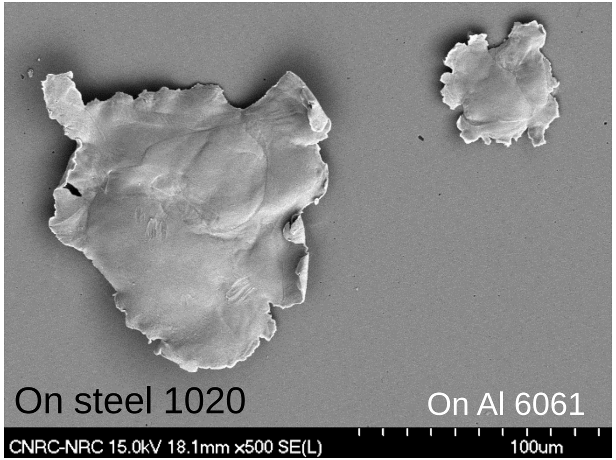
Goldbaum et al. JTST, 2011, Bruera et al. Surf Coat Technol, 2023

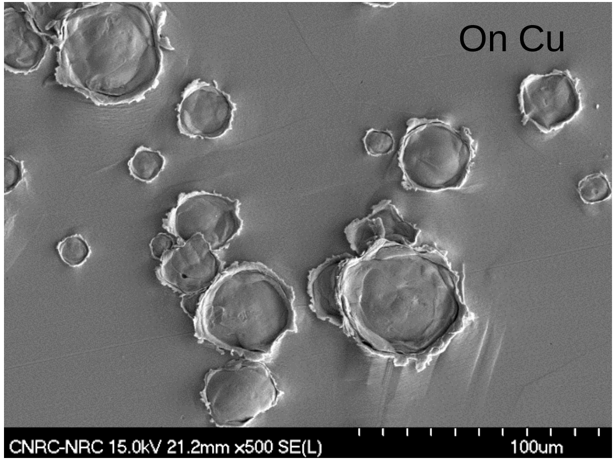


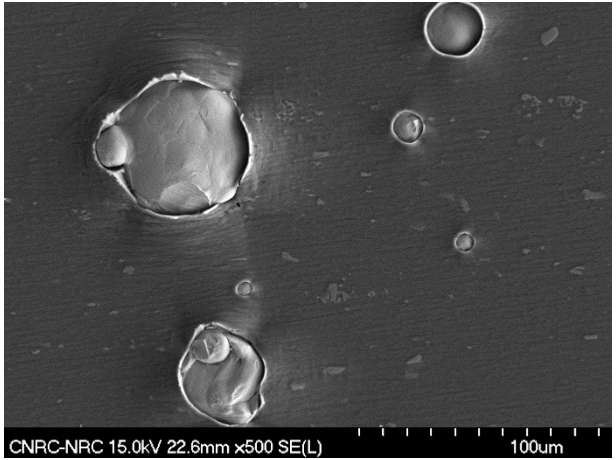
Bae G. et al, Acta Mat., 2008.

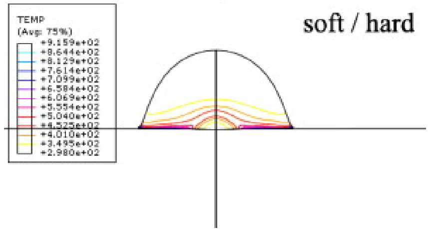
Influence of Substrate Hardness on its Deformation

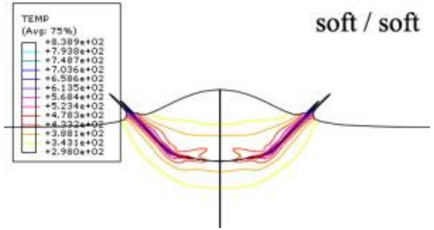
Cu powder impacts

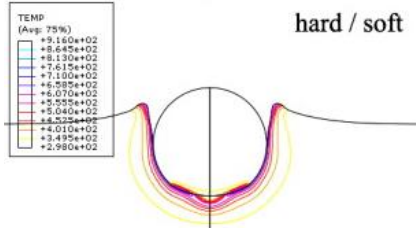






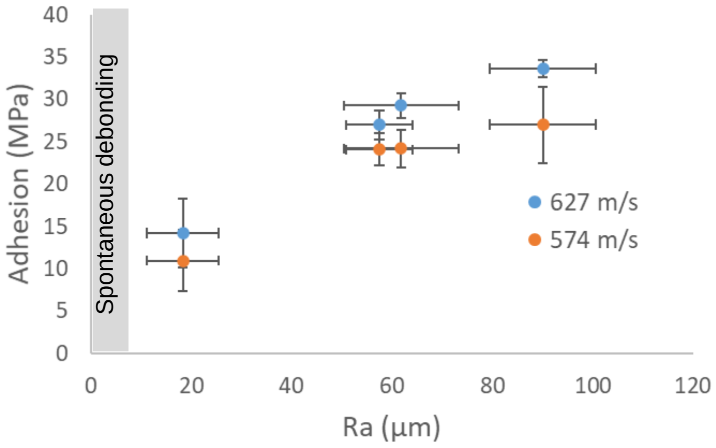


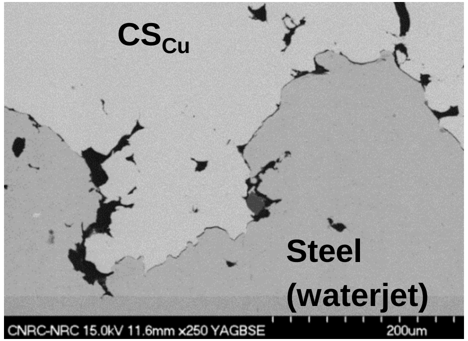




Modelling. Bae G. et al, Acta Mat., 2008.

Adhesion on Hard Substrates – Cu on Steel





PCS800, SOD 30mm
Tg, Pg = (600°C, 3.4MPa)
or (800°C, 4.9MPa)

Adhesion increases as roughness increases but eventually levels off → there is a limit to mechanical anchoring

Standard spraying conditions under nitrogen do not allow to meet adhesion requirement.

Metallurgical bonding needed

↓

Substrate deformation needed

Study Objective

Investigate methods to improve adhesion via substrate deformation:

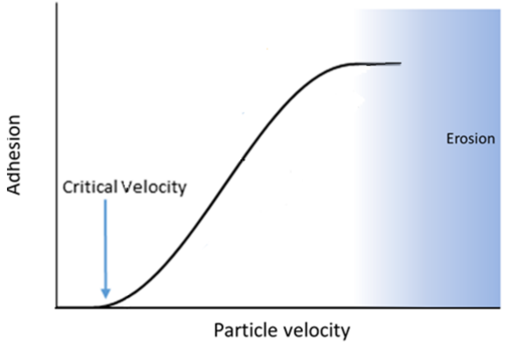
- Increase in-flight particle speed by the use of He as propelling gas
- Increase substrate temperature with high power laser

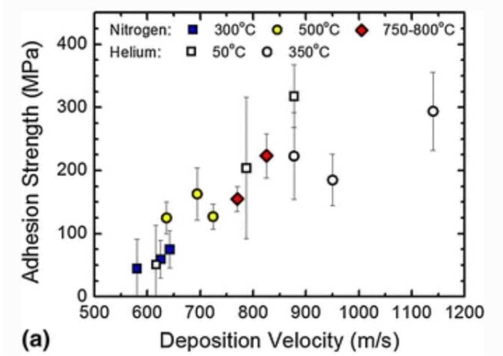
*As both methods aim to improve coating adhesion, the use of He or laser was limited to a bond coat and reference spraying conditions were used for coating buildup.

He Bond Coat

Effect of Particle Speed on Adhesion

Polished Substrate



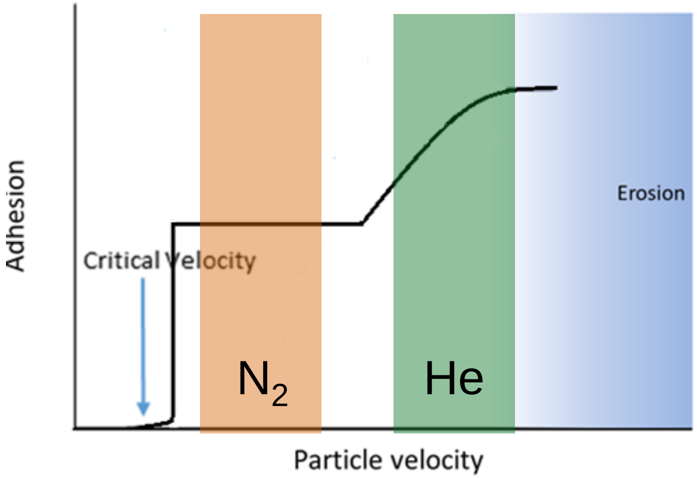


Goldbaum et al. JTST, 2011

Higher velocities improve adhesion strength

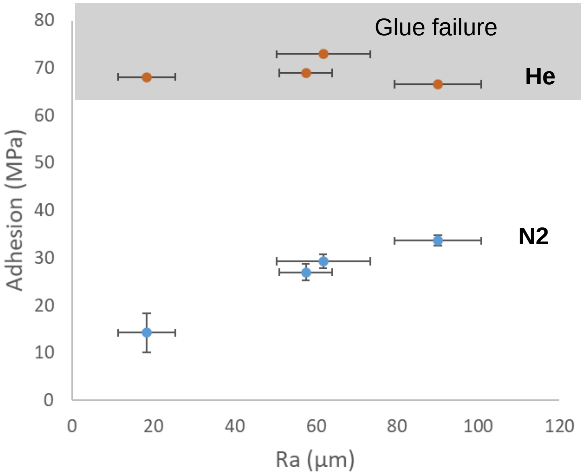
N_2: 600-700m/s
He: 900-1150m/s

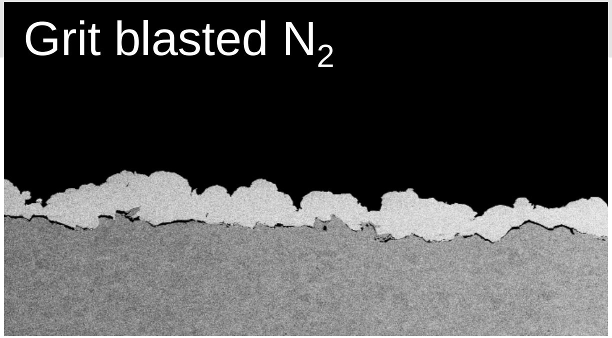
Roughened Substrate

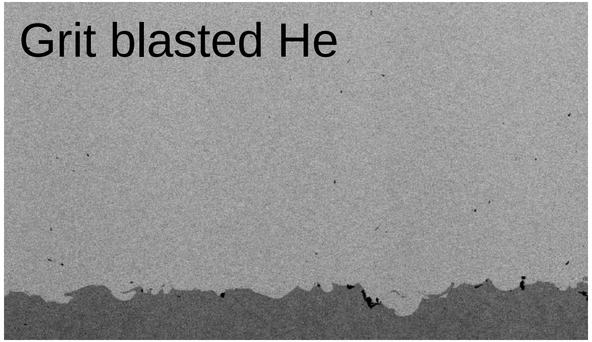


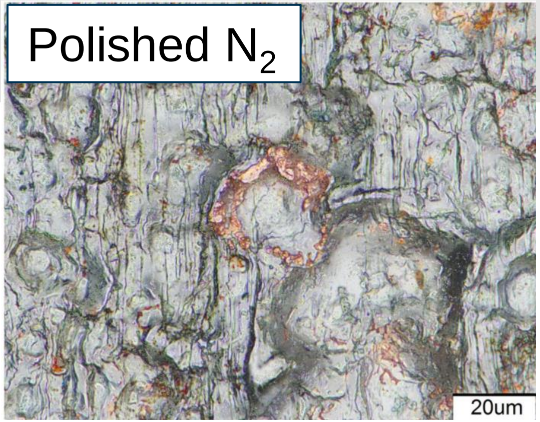
Cu on Steel - He

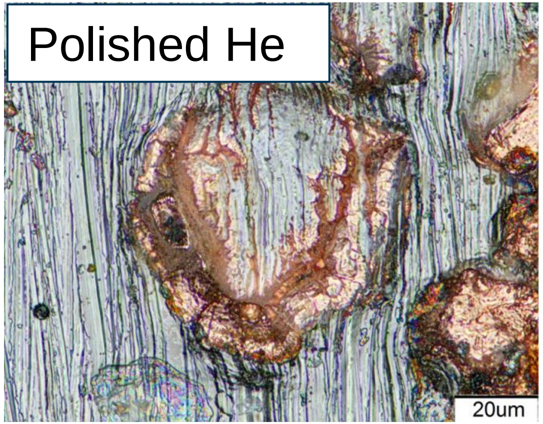
Adhesion values higher than glue bond strength are obtained using helium as propelling gas.







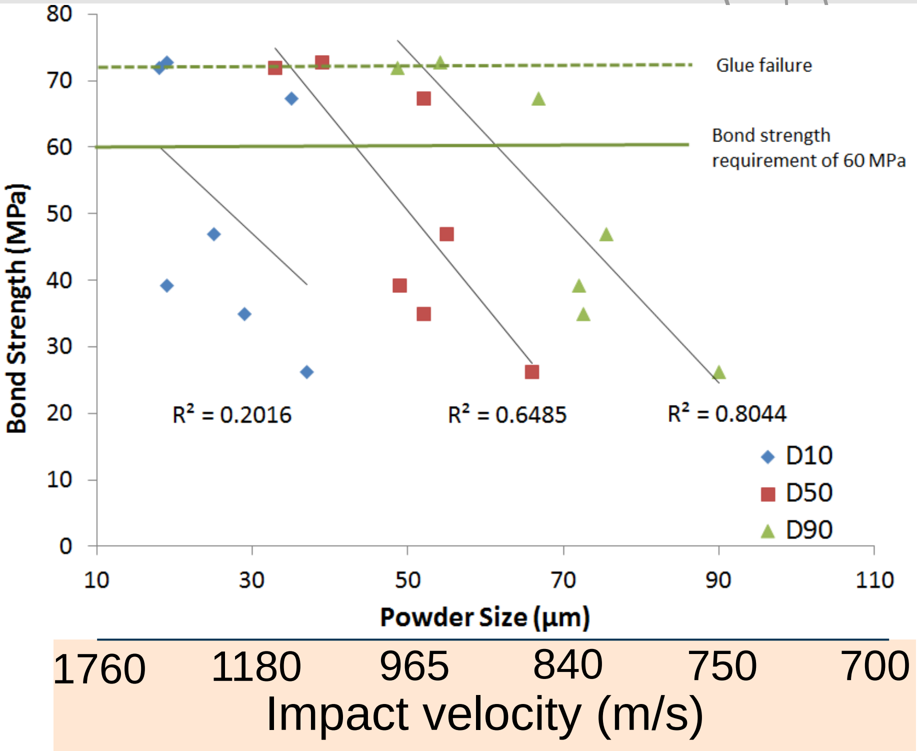




Effect of Powder Size on Velocity and Adhesion

*As powder size increases, impact velocity decreases, as well as adhesion

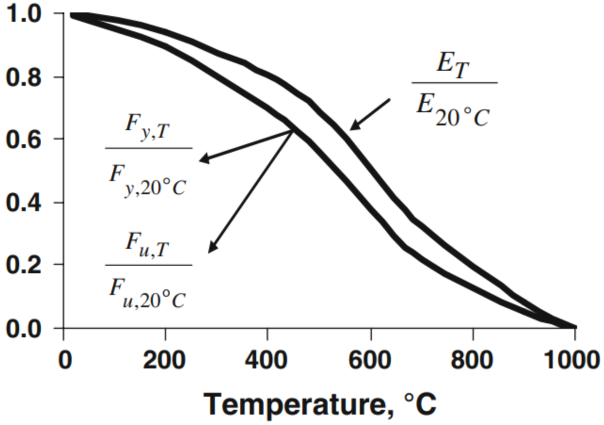
PCS800, 800°C, 5MPa, SOD 30mm
He, Powder D90 < 60µm



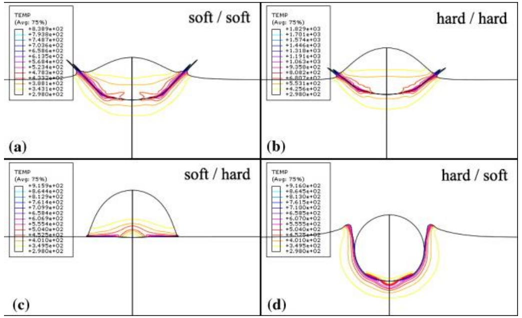
Laser Assisted Bond Coat

Effect of Substrate Preheating on Adhesion

S355 steel

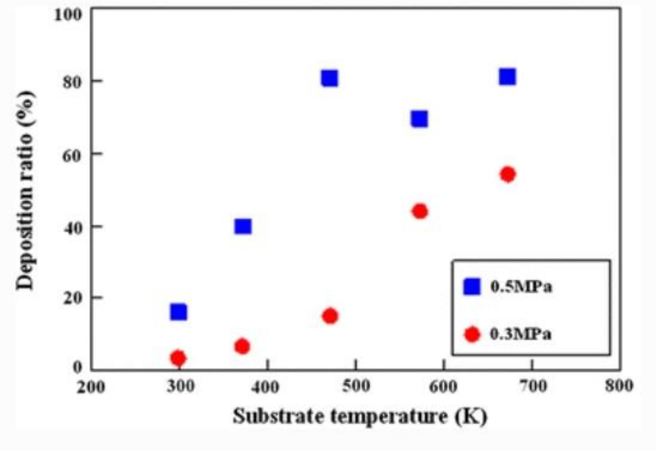


Dwaikat et al. Fire Tech, 2010.



Bae G. et al, Acta Mat., 2008.

Cu on steel



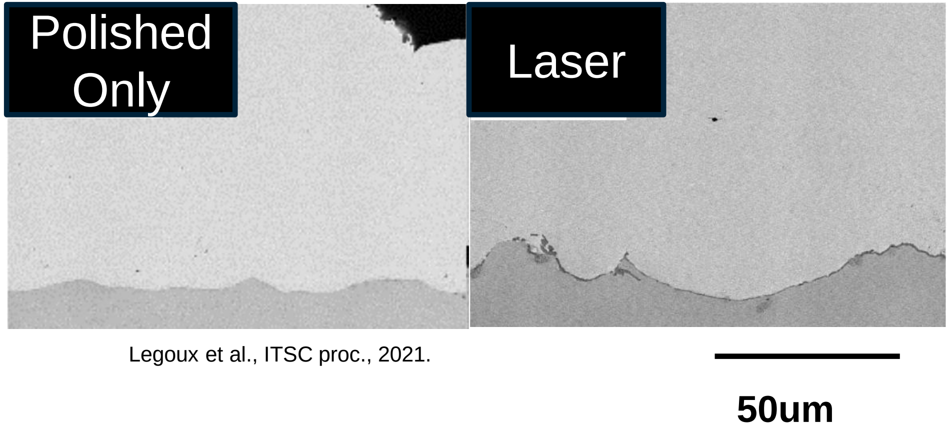
Fukumoto et al. JTST, 2007.

<u>Laser</u> could soften the steel and allow Cu penetration → good coating adhesion

Laser Heating & Interface Engineering

Advantages of a localised and fast heating
- More effective than heating the whole part
- Minimal substrate oxidation

Using a laser to heat the substrate while spraying enables to replicate the interface produced while using He: Embedding Cu particles into the steel surface.



Legoux et al., ITSC proc., 2021.

Parameter Optimization

Laser Power

- 2 to 4 kW were tested
- To maximize (?)

Step size

- 1 mm 13 MPa
- 3 mm > 69 MPa (Glue)
- ≥ 4 mm, decreasing adhesion

Laser Position

- (4,3) and (7,2) > 69 MPa (Glue)
- (8,2) 36 MPa

Traverse speed

- Influence T_{max}, $T_{depth\ profile}$ and oxidation
- Overall heat manag. considerations

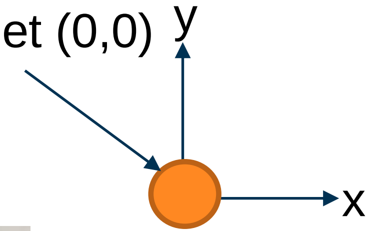
Spray Conditions

Process Gas:	Nitrogen
Gas Temperature:	800˚C
Gas Pressure:	4.9 MPa
S.O.D.:	30 mm

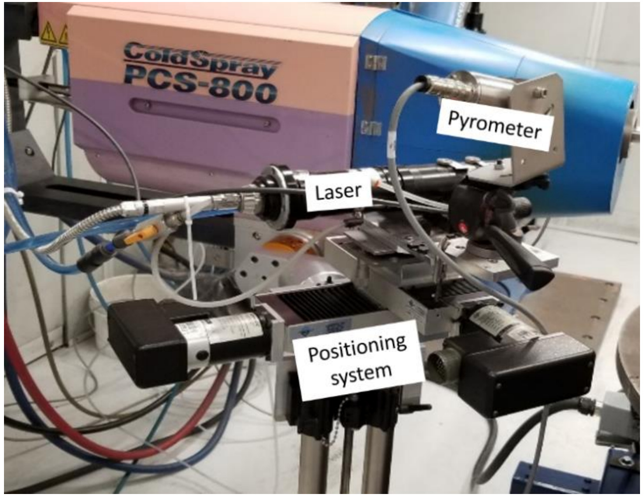
Laser/Particle Jet Positioning (Lab)

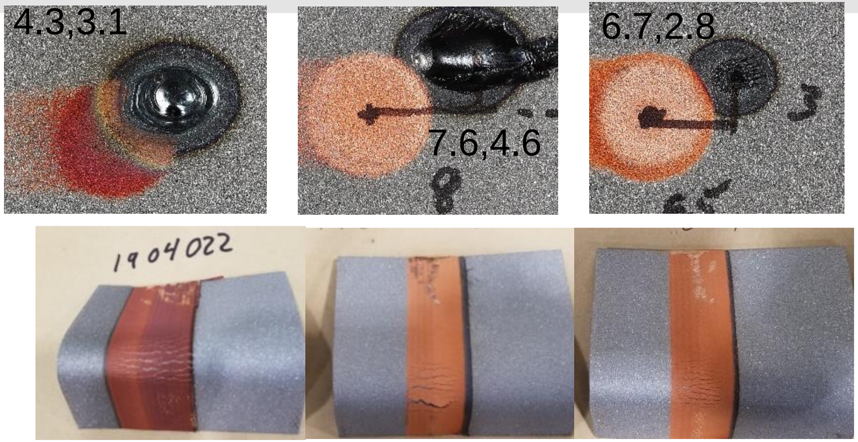
Legoux et al., ITSC proc., 2021.

Particle jet (0,0)



Experimental set-up

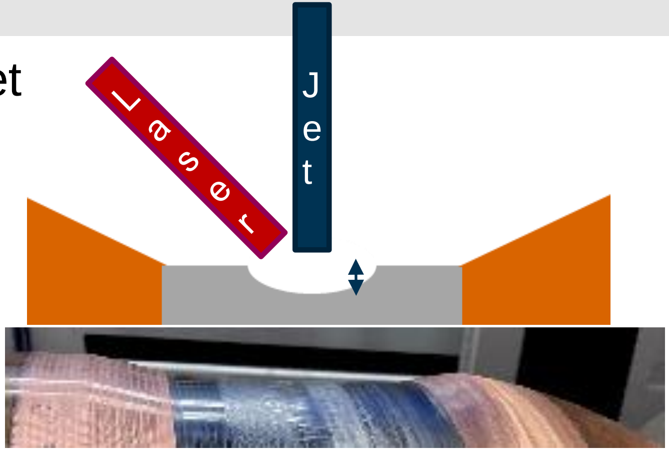




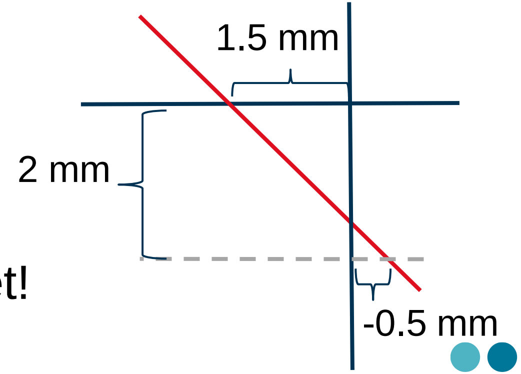
Optimal at 5±1mm, 1.5±0.5mm
Adhesion > 60 MPa

Stand-Off Distance Adjustment on a Real Part

1.5±0.5 mm gap targeted between laser and particle jet



Machining of the weld cap → surface that is up to 2 mm deeper, i.e. SOD in machined area is 2 mm more than at the unmachined sides.



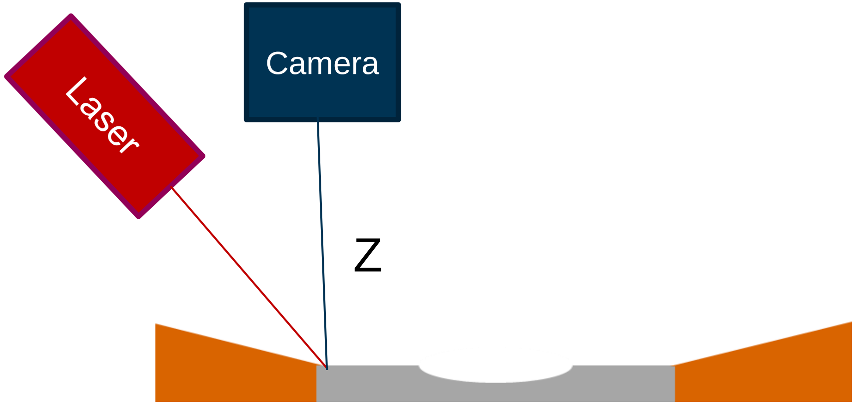
Laser at about 45°

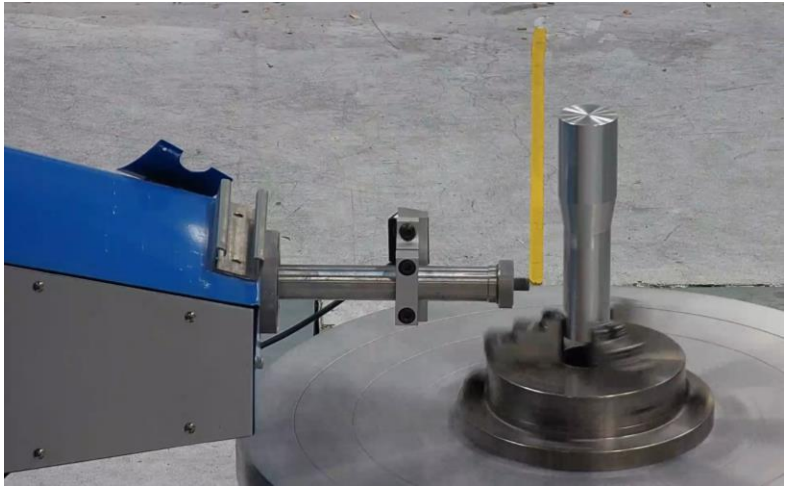
2 mm deeper = -0.5 mm gap → laser is behind the gas jet!

Dynamic Stand-Off Control

Objective: Automatically control SOD at ± 0.5 mm to ensure proper laser/particle jet positioning.

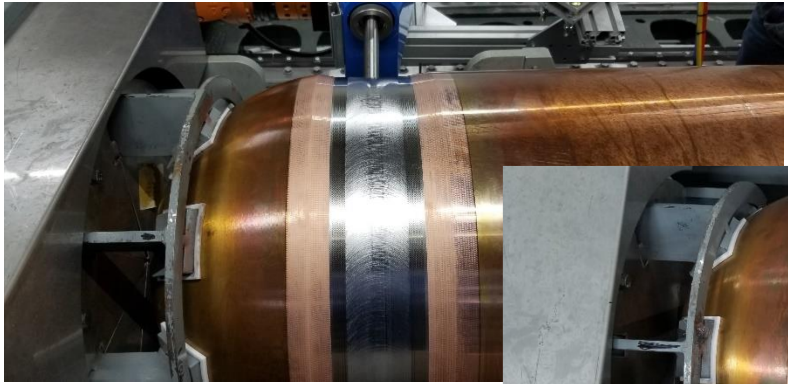
- Use of laser triangulation to monitor SOD.
- Development of a feedback loop to adjust robot position in-situ and thus keep SOD constant.





Processing a Used Fuel Container

Cold spray process for corrosion protection of UFCs is successfully demonstrated in a simulated production environment (18 bands)

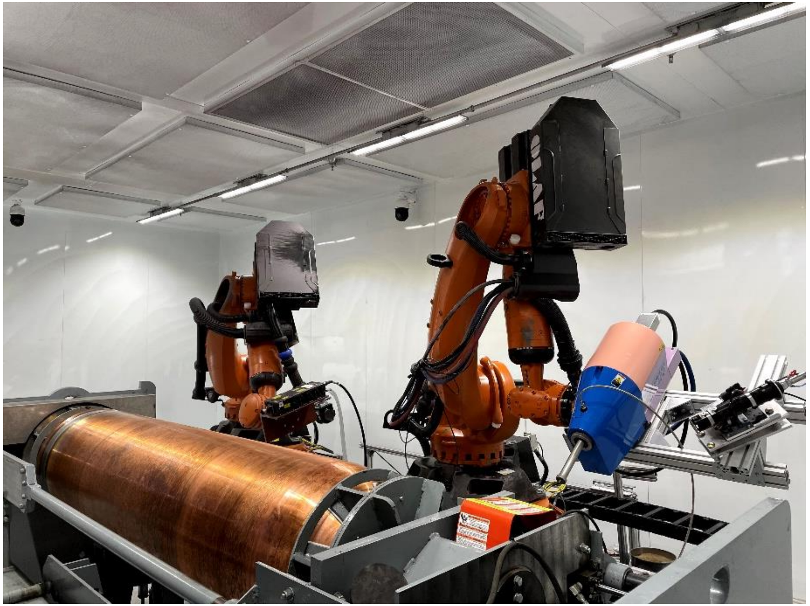


Laser Cleaned Surface

Laser Assisted Adhesion Layer

Final Coating (7.5 mm thick)

Used Fuel Container Production at PolyCSAM



- ➢A unique technology platform able to address ALL of the following manufacturing steps in a fully digital manufacturing environment:
  - •Surface preparation
  - •Coating/buildup by Cold Spray
  - •Local, laser-based treatment (no impact nor damage to substrate)
  - •Robotic machining & surface finishing (9-axis robotic system)
  - •State-of-the-art sensor technologies
  - •Extensive data logging & analytics
  - •Machine learning-based process control
- ➢Capability to handle industrial-scale components (ex: UFC length >2.5 m weight > 7000 kg)
- ➢Production scale-up & back-up services
- ➢Significant de-risking (CapEX)
- ➢Much reduced time-to-implementation/time-to-market
- ➢Training programs (operators, engineers, students)

POLYCSAM
COLD SPRAY ADDITIVE MANUFACTURING INDUSTRIALIZATION FACILITY

Summary

Soft particle adhesion on hard substrate can be drastically improved by increasing substrate deformation.

2 methods investigated:

	Pros	Cons
Increase particle speed (He)	-Easy set up	-Non-renewable resource
Substrate heating (softening with laser)	-Lower costs -Multiple uses (e.g. post heat treatment)	-Laser alignment -Specific to a pair substrate/laser -Possible phase transform. in the substrate

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THANK YOU

Dominique Poirier • Senior Research Officer • Dominique.Poirier@nrc-cnrc.gc.ca