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Defining Powder Specifications for Cold Spray Deposition of High Performance Copper on Steel Substrates

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Phuong Vo¹ and Jason D. Giallonardo²

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² Nuclear Waste Management Organization, Toronto, Canada

Cold Spray Action Team Meeting, Worcester Polytechnic Institute (Worcester, MA), June 25-26, 2019

Outlook

- Cold Spray Additive Manufacturing team at NRC
- Nuclear Waste Management in Canada and where cold spray fits in
- Powder specification
- He vs laser
- Final heat treatment
- Final scale-up and properties

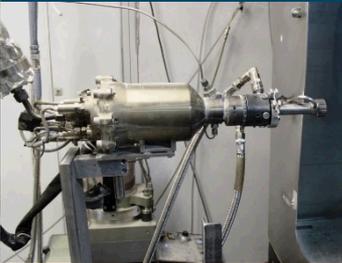


Cold Spray Additive Manufacturing Team at NRC

40+ experts



**Plasma Giken
(PCS 100, 800 and 1000)**
P: 50 bar (725 psi)
T: 800 and 1000°C



**Oerlikon Metco
(formely CGT)
KINETIKS 4000**
P: 40 bar (580 psi)
T: 800°C



**Oerlikon Metco
(formely CGT)
KINETIKS 3000**
P: 40 bar (580 psi)
T: 600°C



**Inovati
KM-CDS 2.2**
P: 10 bar (145 psi)
T: 600°C



**Centerline
SSM-P3300
(upgraded to P-series)**
P: 8 bar (116 psi)
T: 500°C



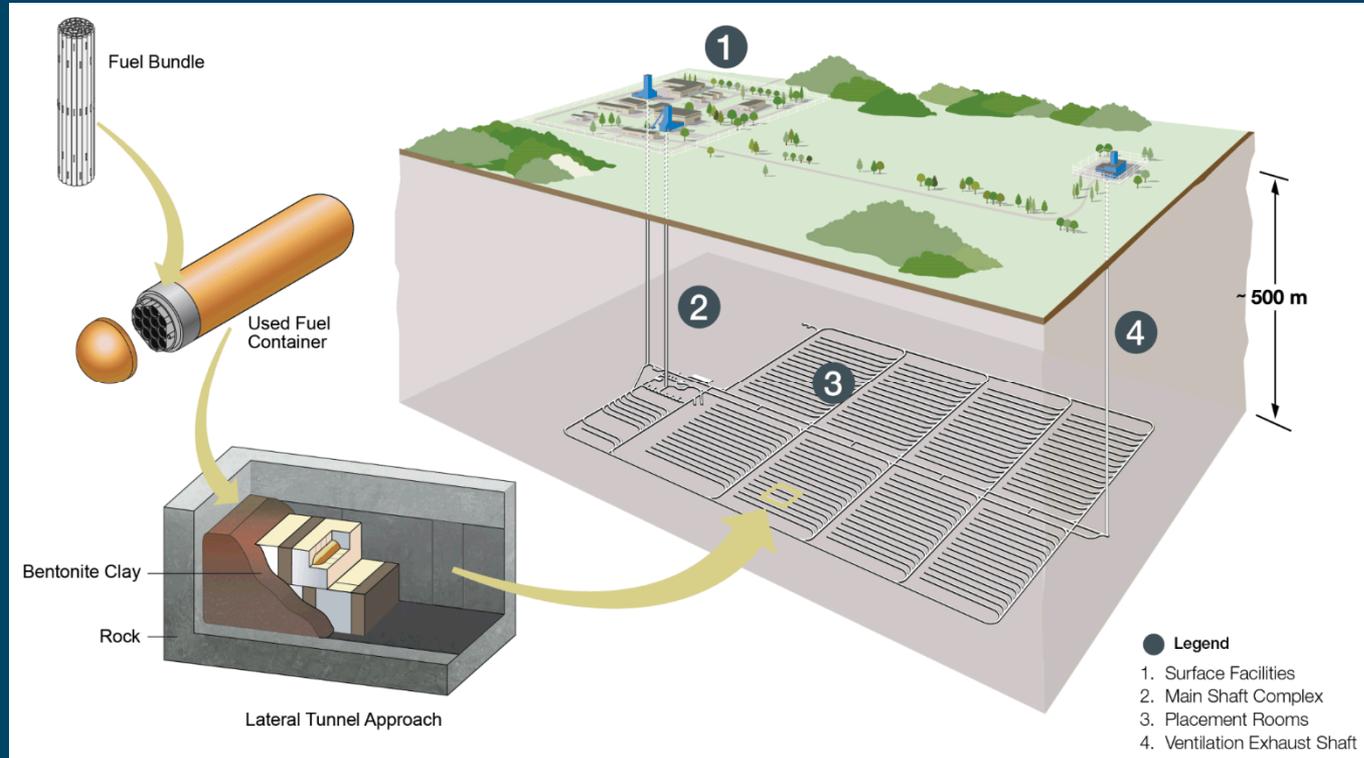
**Centerline
Waverider
(Shock-wave Induced Spraying)**
P: 40 bar (580 psi)
T: 800°C



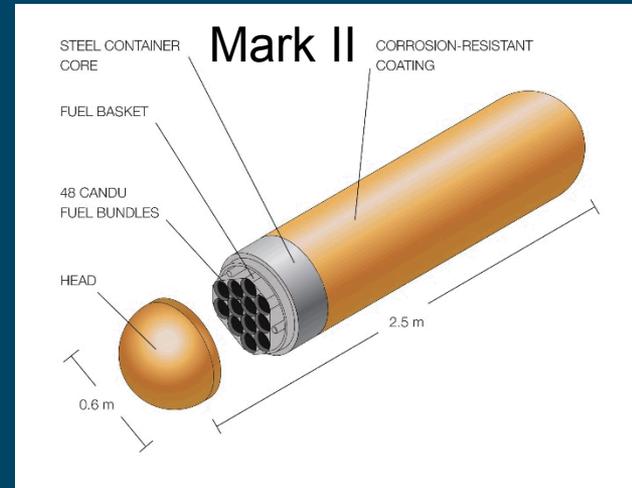
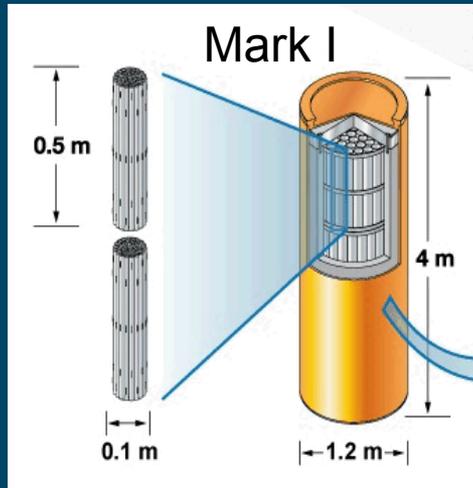
INTRODUCTION & OBJECTIVES

Deep geological repository for used nuclear fuel

NWMO Deep Geological Repository Approach



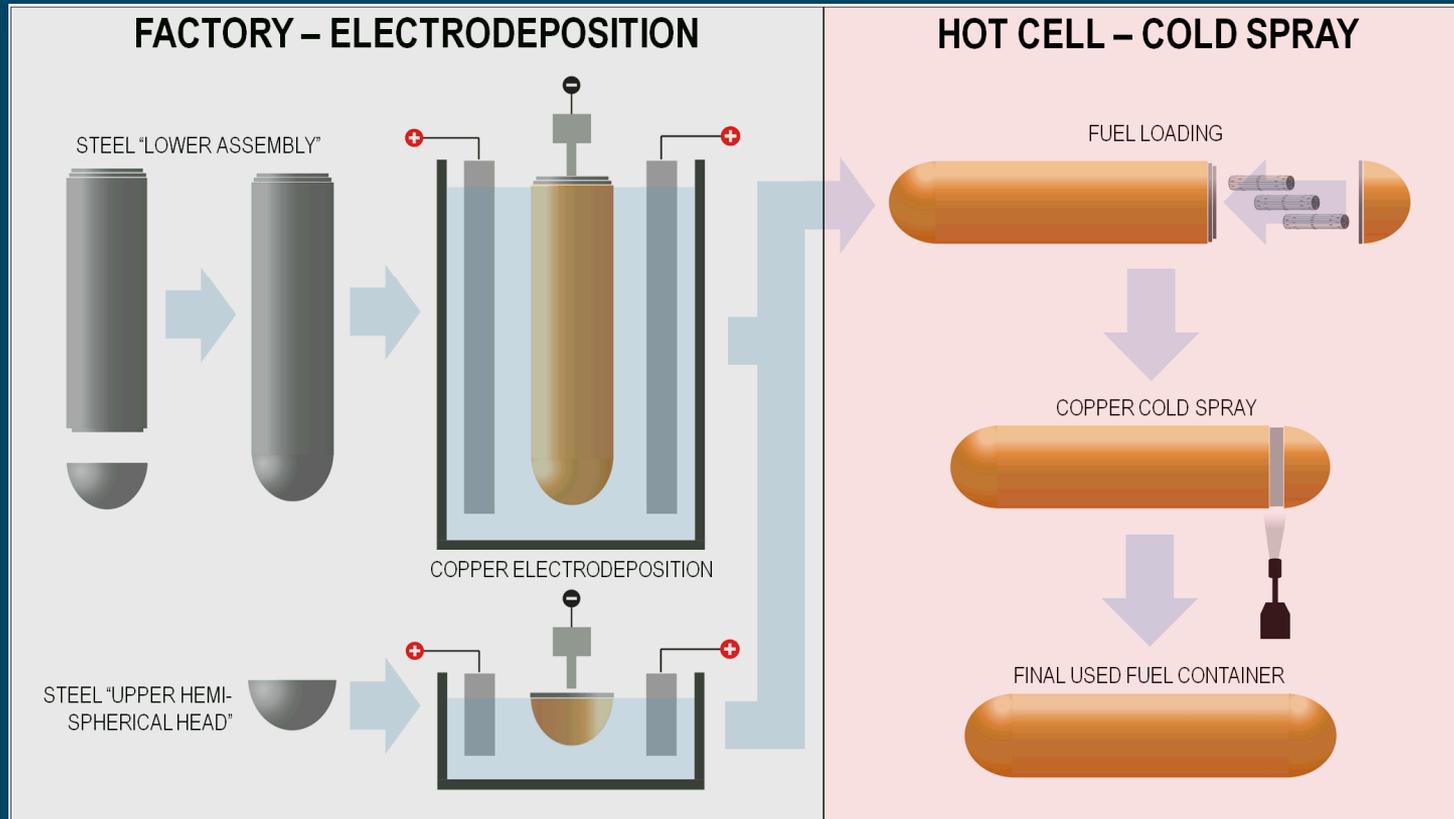
Corrosion Protection of Used Fuel Containers (UFCs)



- Steel structural vessel with 25 mm Cu overpack
- Over 25 tonnes when filled with 288 fuel bundles
- 1 mm nominal gap between the copper and steel
 - Copper creep consideration

- Steel structural vessel with 3 mm exterior Cu coating
- 2.7 tonnes when filled with 48 fuel bundles
- Significant reduction in copper contribution costs
- Elimination of creep concern

Corrosion Protection of Used Fuel Containers (UFCs)



Deposit Requirements and Reference Conditions

Areas of research:

- Powder
- Surface preparation
- Cold spray process parameters
- Post-heat treatment

Properties	Requir.	Target
Elongation (%)	10	≥ 25
Adhesion (MPa)	20	≥ 60
Porosity (%)	n/a	≤ 1

Reference conditions:

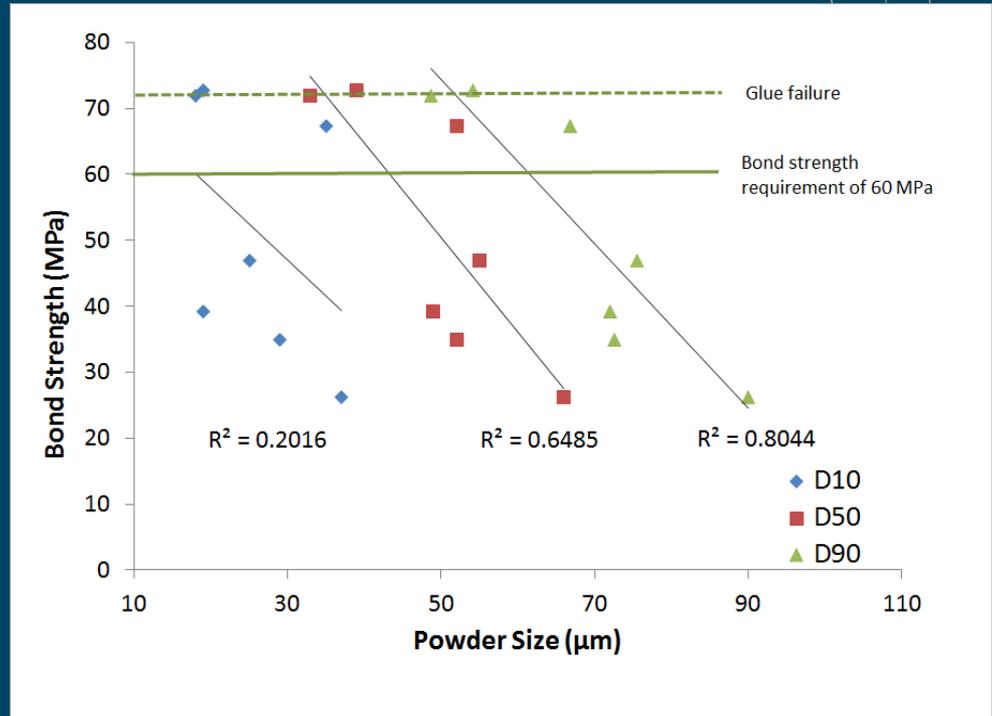
- 10-70 μm spherical low oxygen copper powder;
- 25.4 mm min. thick A516 grade 70 steel, grit blasted with 24 grit to remove millscale;
- 100 μm bond coat, applied with He-spray at 5 MPa and 800 °C,
- 3 mm top coat, applied with N₂-spray at 5 MPa and 800 °C, and
- Post-deposition heat treatment at 350°C for 1 hour.

POWDER SPECIFICATION

- Powder size
- Powder composition

Effect of Powder Size on Adhesion

D90 < 60 μm was recommended to ensure meeting the application requirement of 60 MPa bond strength.

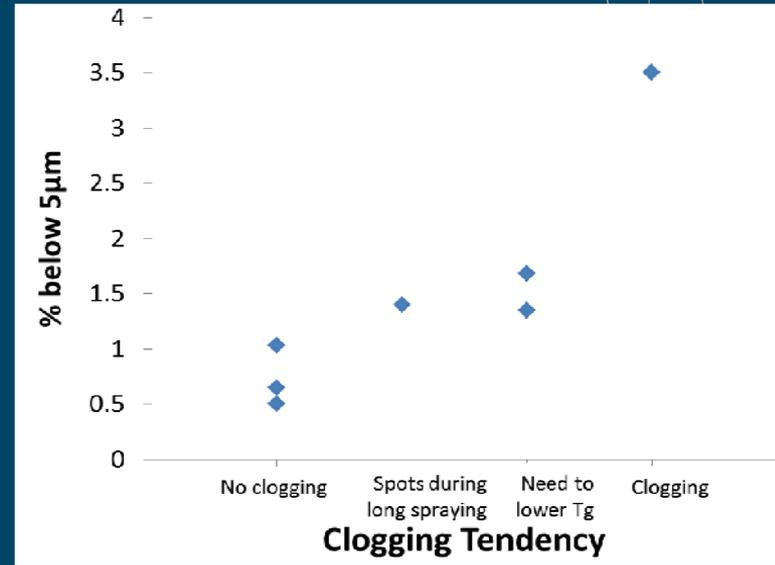


*Constant spray conditions, different powder lots

Particle Size Distribution - Fine

Very fine particle particles can stick to the cold spray system nozzle and/or injector, causing clogging.

Among the various powders tested, powders with 1vol% or less of their particles below 5 μm ($D_{01} > 5 \mu\text{m}$) have not shown any powder clogging issues.



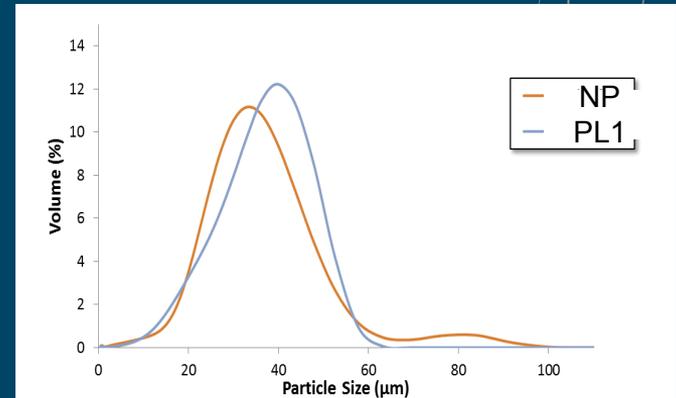
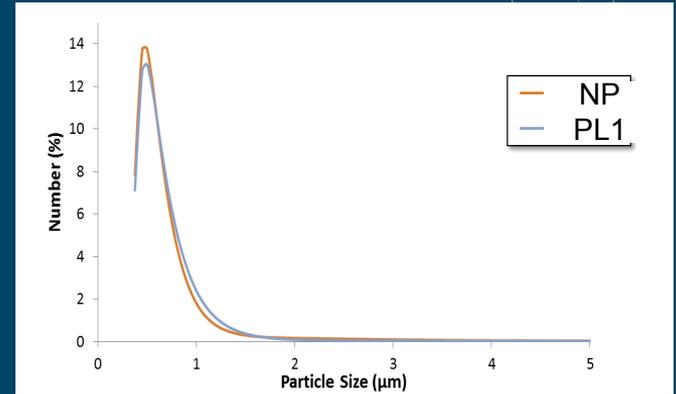
* There is still some variability in the results which make us believe powder hardness and/or powder surface state also impact powder tendency for clogging.



Characterization of the Fines in CS Powders

- D10 is not sufficient
- Particle size distribution displayed in volume tend to “hide” the fines

Powder	%below 5	D10	D50	D90
NRC ID	μm	(μm)	(μm)	(μm)
NP	2.4	18	33	49
PL1	1.3	18	36	50



Effect of Powder Composition on Ductility

	EDL143	7G17F1	CEF221	EEI052
	µg/g	µg/g	µg/g	µg/g
Ag	14	11	15	13
Al	688	20	0.8	0.8
Co	0.2	0.2	<DL	0.2
Cr	0.5	0.3	0.2	<DL
Fe	43	7	6	6
In	<DL	<DL	<DL	11
Mg	8	0.4	<DL	<DL
Mn	2	0.2	0.2	0.1
Na	2	2	2	2
Ni	<DL	3	3	3
Si	1550	5	14	13
Sn	7	8	14	35
Ti	19	<DL	<DL	<DL
Zn	<DL	3	<DL	<DL
Total	2334	60	54	93

Below detection limit : As, Au, Bi, Cd, Hg, Pb, Sb, Se, V

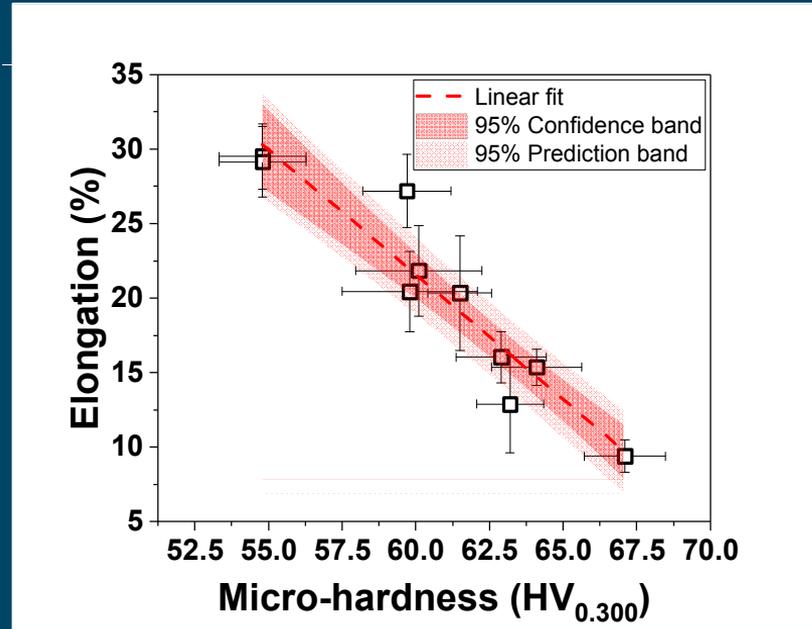
Elongation and micro-hardness (before and after HT at 350°C/1h/air) for coatings prepared with different powders. All coatings were prepared on Al6061 rods

Powder lot	Elongation (%) after HT	As-sprayed micro-hardness (HV _{0.300})	HT micro-hardness (HV _{0.300})
EDL143	7.6±0.5	139.9±5.5	70.4±1.6
7G17F1	21.9±1.5	87.5±3.0	66.2±1.4
CEF221	39.2±1.4	89.5±2.5	67.5±1.3
EEI052	36.0±2.9	99.4±4.5	73.7±1.6

Powder properties

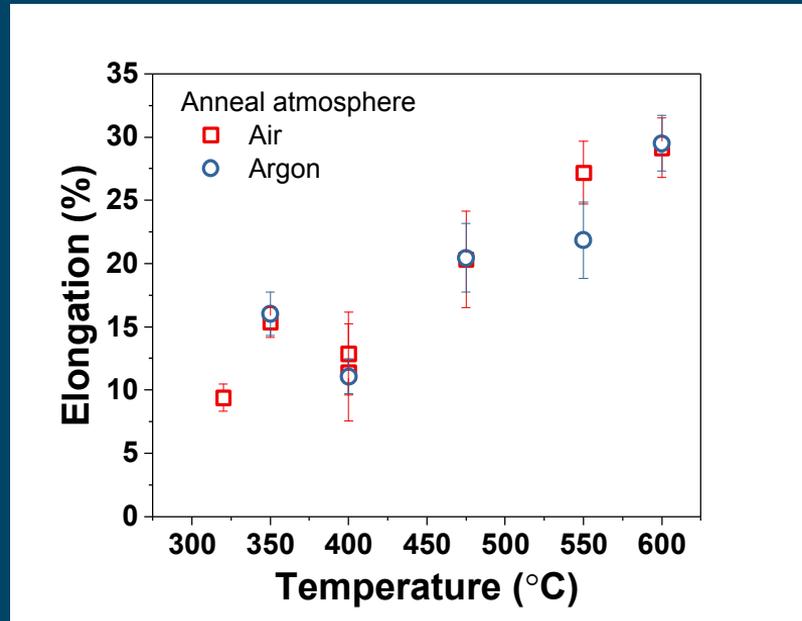
Powder	D50 (µm)	O ₂ (ppm)	Hardness (HV _{0.01})
EDL143	43	111	57.0 ± 1.9
7G17F1	38	282	55.7 ± 8.5
CEF221	32	185	48.6 ± 2.4
EEI052	22	409	52.9 ± 4.7

Hardness-Ductility Relationship For One Powder



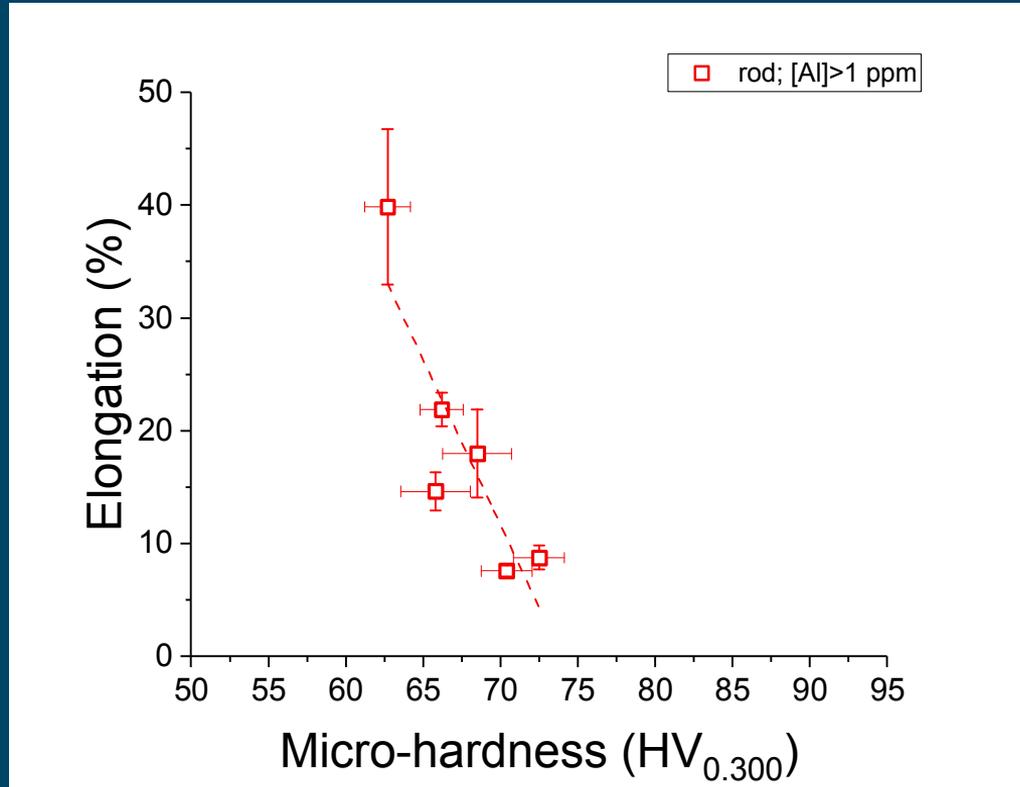
- Heat treatments were performed in the range 300-600°C for 1h.
- For one powder, the ductility is closely correlated to the hardness of the deposited copper.

Effect of Heat Treatment Atmosphere

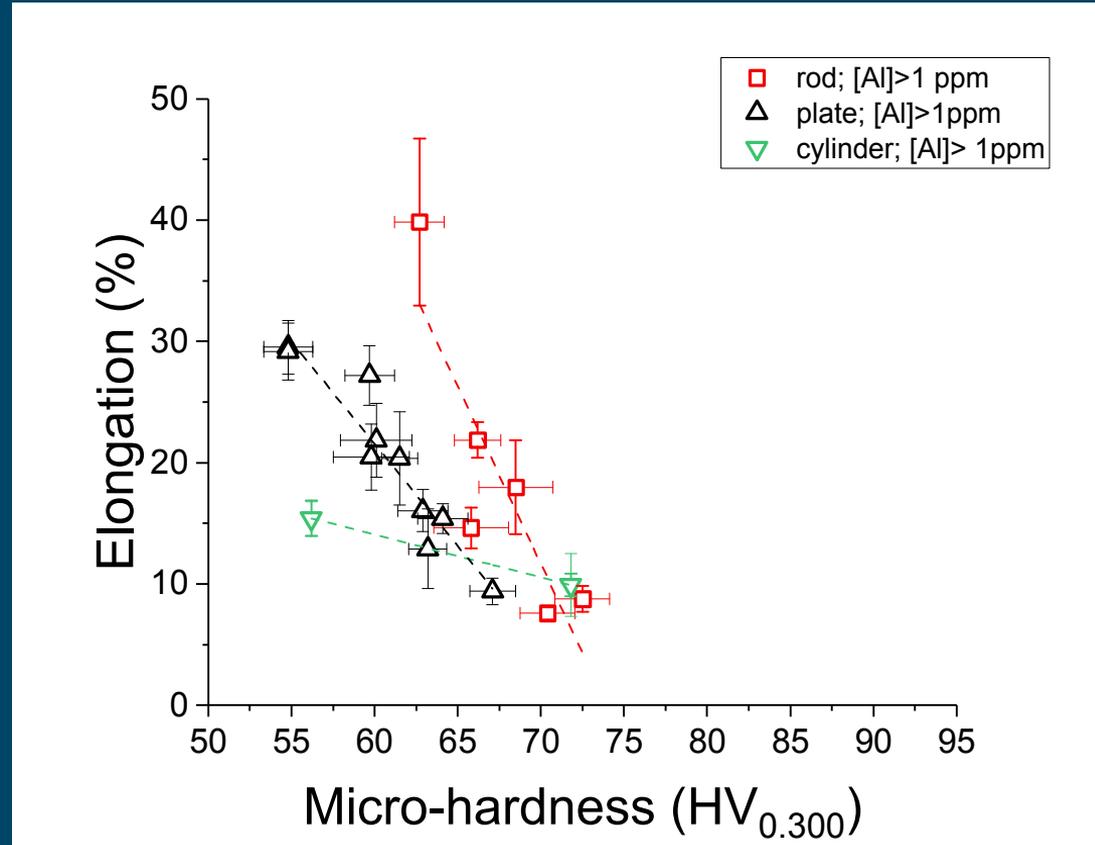


Performing the heat treatment in air have no influence on final properties.

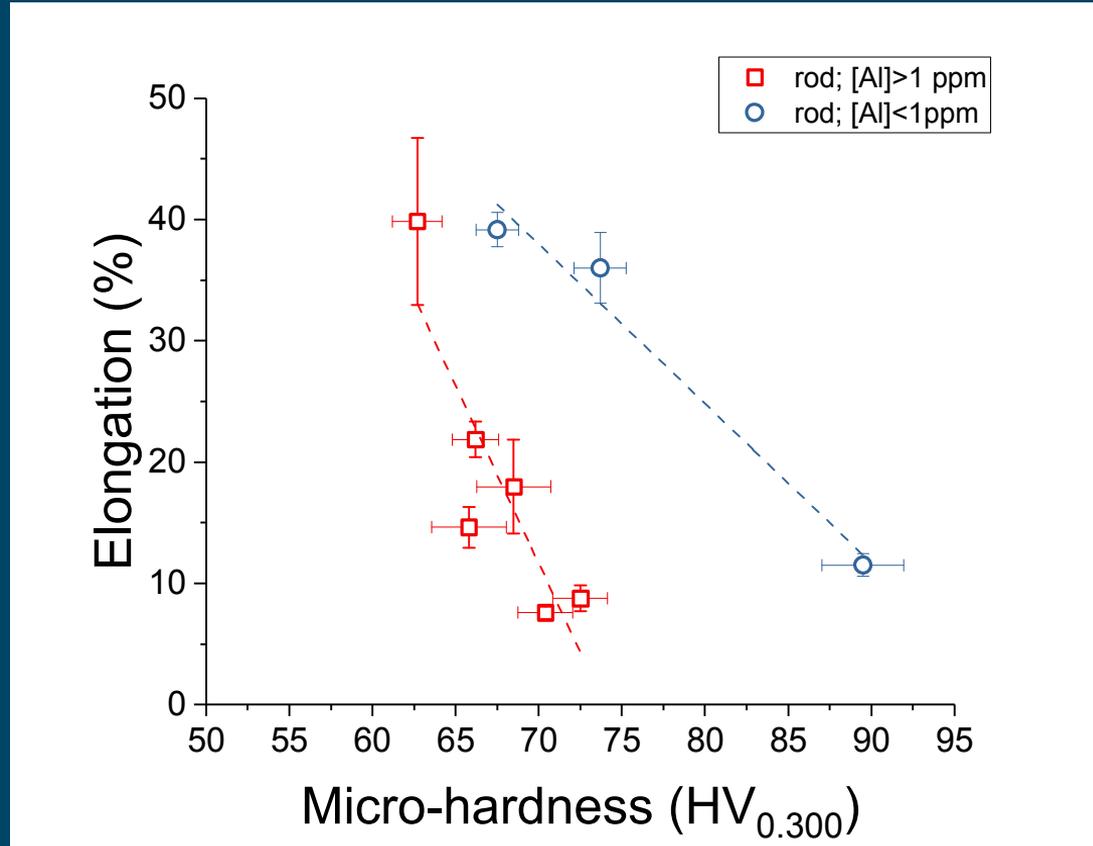
Hardness vs Ductility Relationship for Typical Purity



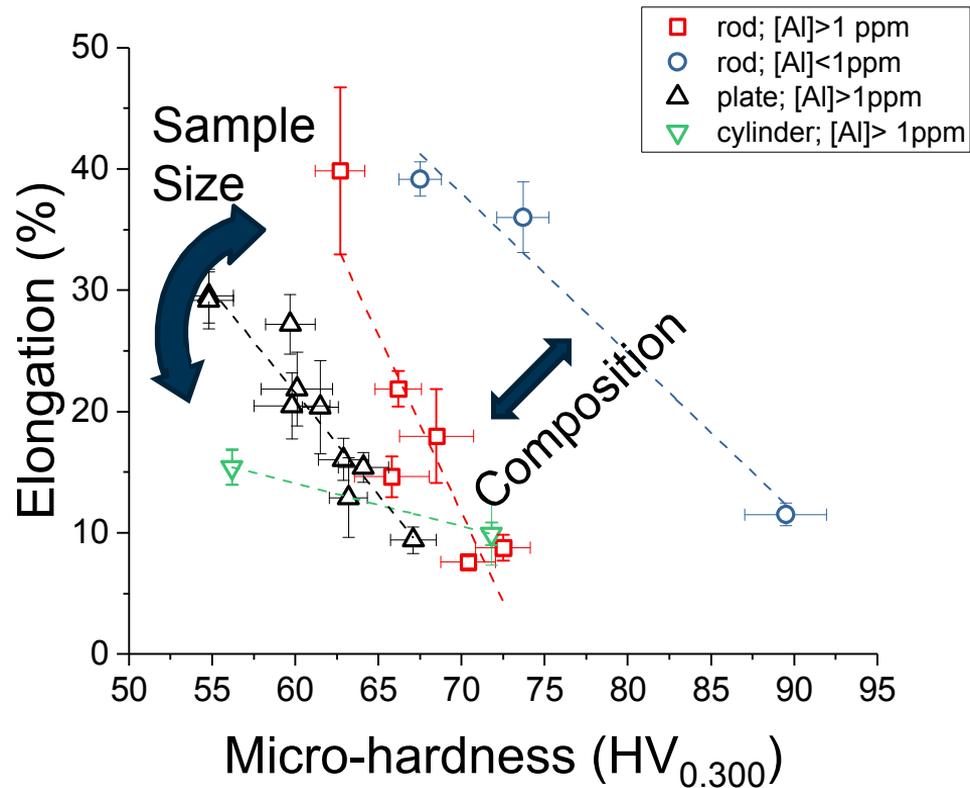
Effect of Sample Size on Hardness-Ductility Relationship



Effect of Powder Purity on Hardness-Ductility



Hardness Ductility Relationship

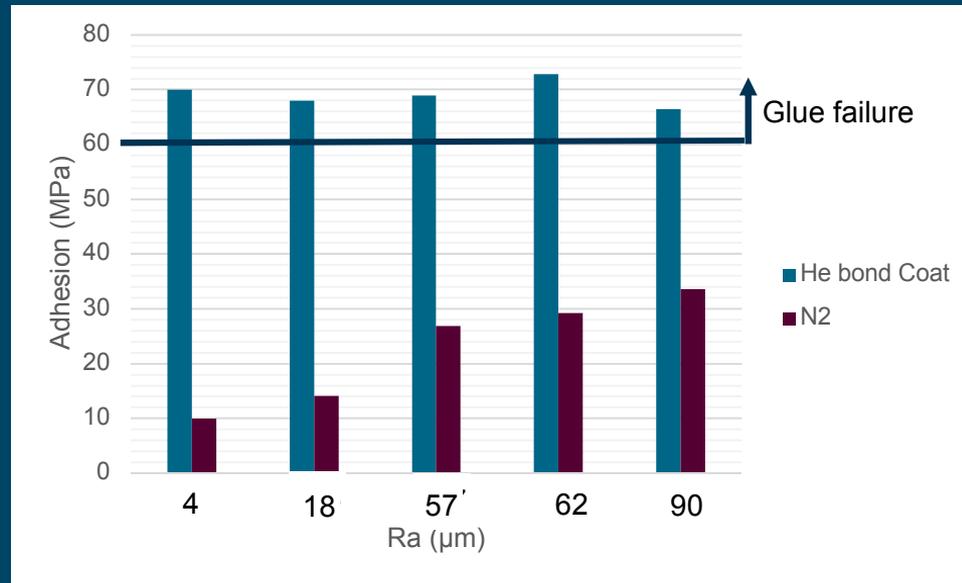


HE ELIMINATION

- Adhesion vs surface roughness
- Laser assistance

Adhesion

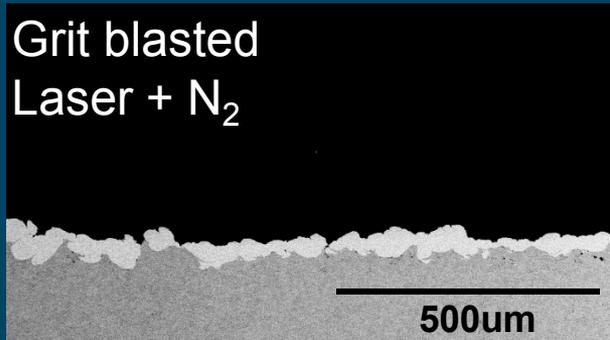
Adhesion values higher than glue bond strength are obtained using helium as propelling gas.



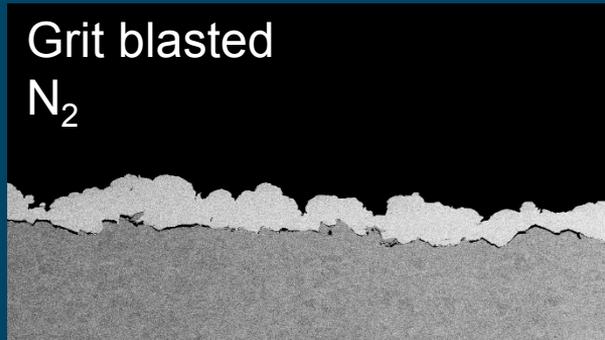
Interface Engineering

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

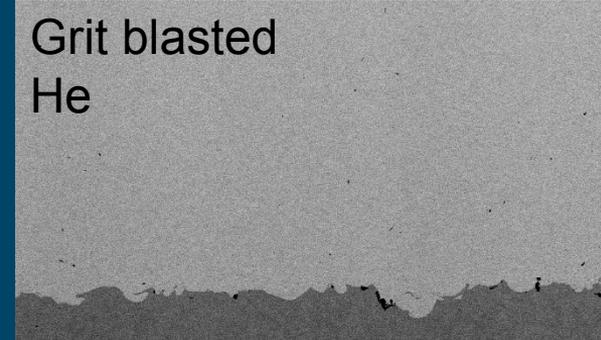
Grit blasted
Laser + N₂



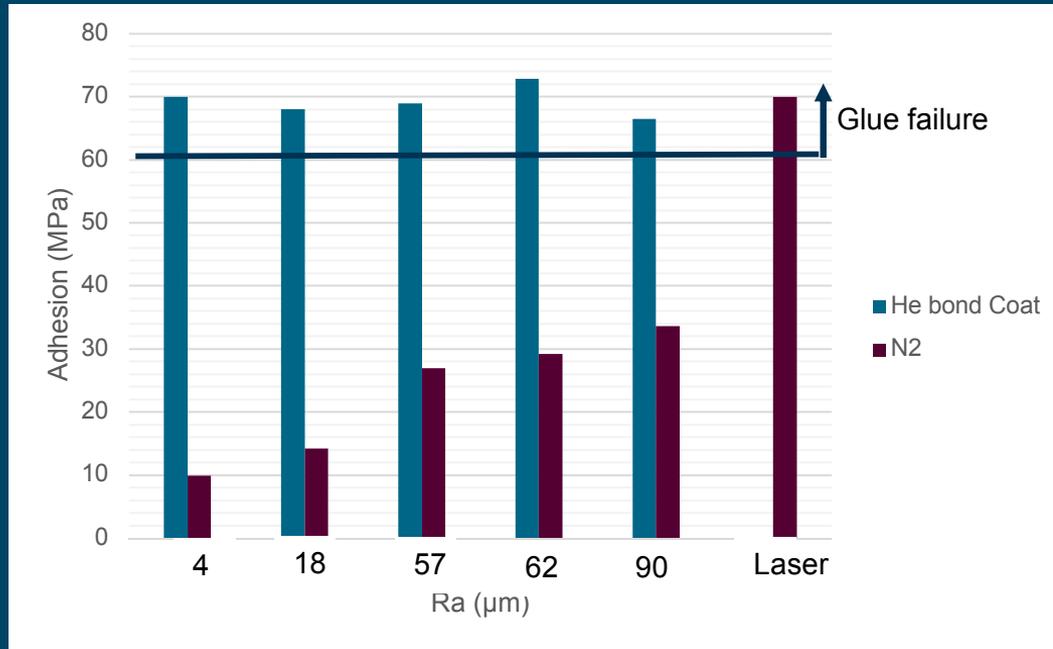
Grit blasted
N₂



Grit blasted
He

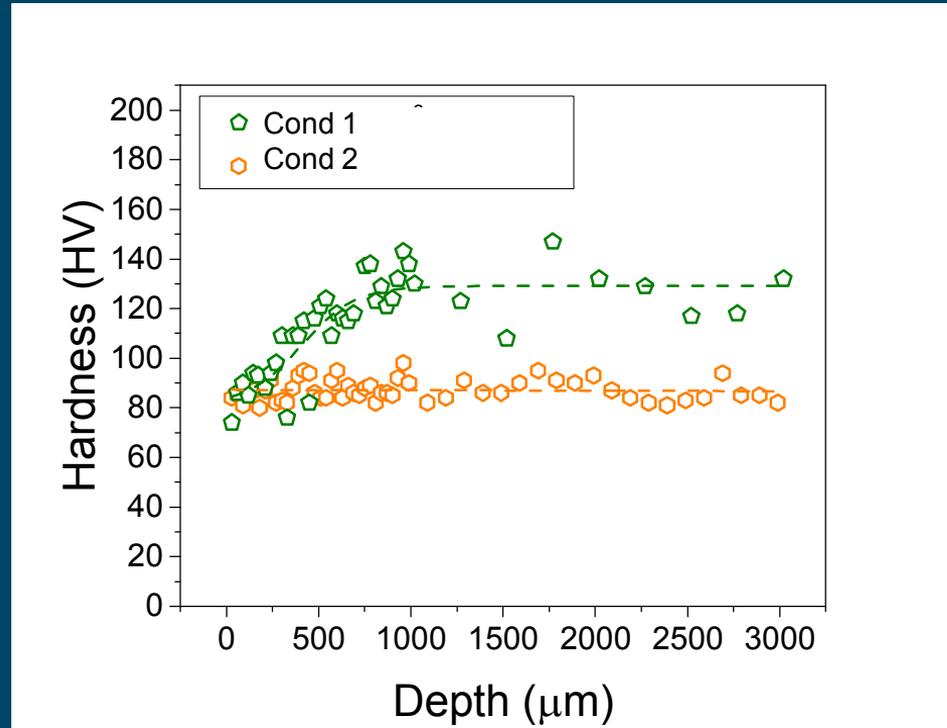


Adhesion Values Using Laser Assistance



LASER ASSISTANCE TO POST DEPOSITION HEAT TREATMENT

Example of Non Contact Heat Treatment



Final Properties vs Requirements

Properties	Requir.	Target	Status
Elongation (%)	10	≥ 25	Met
Adhesion (MPa)	20	≥ 60	Qualified with He, in progress with laser
Porosity (%)	n/a	≤ 1	Met

SCALE-UP

Demonstration - Weld Closure Zone

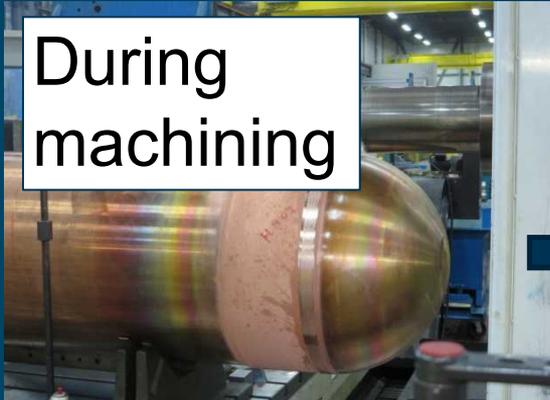
Full-size leading vessel



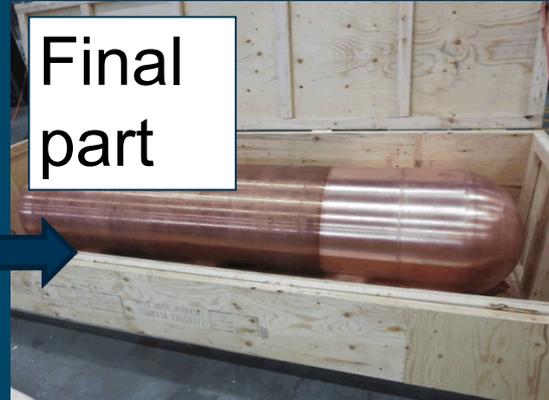
After coating



During machining



Final part



Full-Scale External Pressure Test

The copper-coated UFC was able to withstand the maximum theoretical pressure (45MPa) that could be exerted on the container under a predicted worst-case scenario during the next glaciation.

The copper coated UFC failed at 54.4MPa, which is in the range of the predicted collapse load from the computer modelling performed on the steel UFC (copper coating is not expected to provide any structural rigidity).



Penn State
Advanced
Research Lab
(ARL) High
Pressure Test
Facility (HPTF)

Process Automation



Manual Sandblasting

Surface prep



Oven heat treatment

Annealing



High power lamp

Preheating

Laser

Robotized Abrasion



The Brand

POLYCSAM

COLD SPRAY ADDITIVE MANUFACTURING
INDUSTRIALIZATION FACILITY



National Research
Council Canada

Conseil national de
recherches Canada

POLYCONTROLS

What Poly/CSAM Has to Offer

- A unique technology platform able to address ALL of the following manufacturing steps in a digital manufacturing environment:
 - Surface preparation
 - Coating/buildup by Cold Spray
 - Local, laser-based thermal treatment (no impact nor damage to substrate)
 - Robotic machining & surface finishing
 - State-of-the-art sensor technologies
 - Extensive data logging & analytics
 - Machine learning
- Capability to handle industrial-scale components
- Pre-production, and production back-up services
- Significant de-risking (CapEX)
- Much reduced time-to-implementation/time-to-market
- Complete training programs (operators, engineers, students)
- **In summary: Poly/CSAM is meant to boost cold spray additive manufacturing into full-scale production !**

Slide 35

A7

In summary: PolyCSAM is meant to boost cold spray additive manufacturing into full-scale production.

Author, 5/22/2019

What Poly/CSAM Will Look Like



Compressors & chillers

Robots mounted on an 8m linear rail

Dust collection system

Gold Spray AM
n
x 6m – 29pi x 20pi)

Slide 36

A8

the yellow text will not be visible on a projector

Author, 5/22/2019

A9

This composite picture is visually confusing. Better to use the CSAM meeting layout with one picture.

Author, 5/22/2019

Conclusion

The collaboration between NRC team and NWMO has enabled the development of a cold spray weld closure zone coating process as a fabrication step for the containment of used nuclear fuel for deep geological repository. Specifically, the following steps were achieved.

- A powder spec has been developed.
- The process has been industrialized.
- Non contact techniques are being developed and will be implemented.
- Demonstration of process capability in serial production planned to start end 2019.

THANK YOU

Jean-Gabriel Legoux • Jean-Gabriel.Legoux@nrc-cnrc.gc.ca

