Development of thick copper coating for nuclear waste container

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Development of Thick Copper Coating for Nuclear Waste Container

Presented at NACSC 2016 Edmonton

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Abstract

Since several years the National Research Council (NRC) is mandated by the Nuclear Waste Management Organization (NWMO) to develop cold sprayed thick copper coating intended to act as a corrosion barrier over a used fuel container developed for deep geological storage of Canada's spent nuclear fuel. The container consists of a carbon steel structural core covered by a copper corrosion barrier. It has been evaluated that in order to for the copper coating to perform its role of a corrosion barrier it needs to be 3 mm thick. Also to sustain load under Deep Geological Repository (DGR) conditions the adhesion strength higher than 20 MPa and ductility above 15 % elongation should be obtained from the copper coating. This paper will present advances in the Cu coating development for long term corrosion protection of steel container intended for DGR.

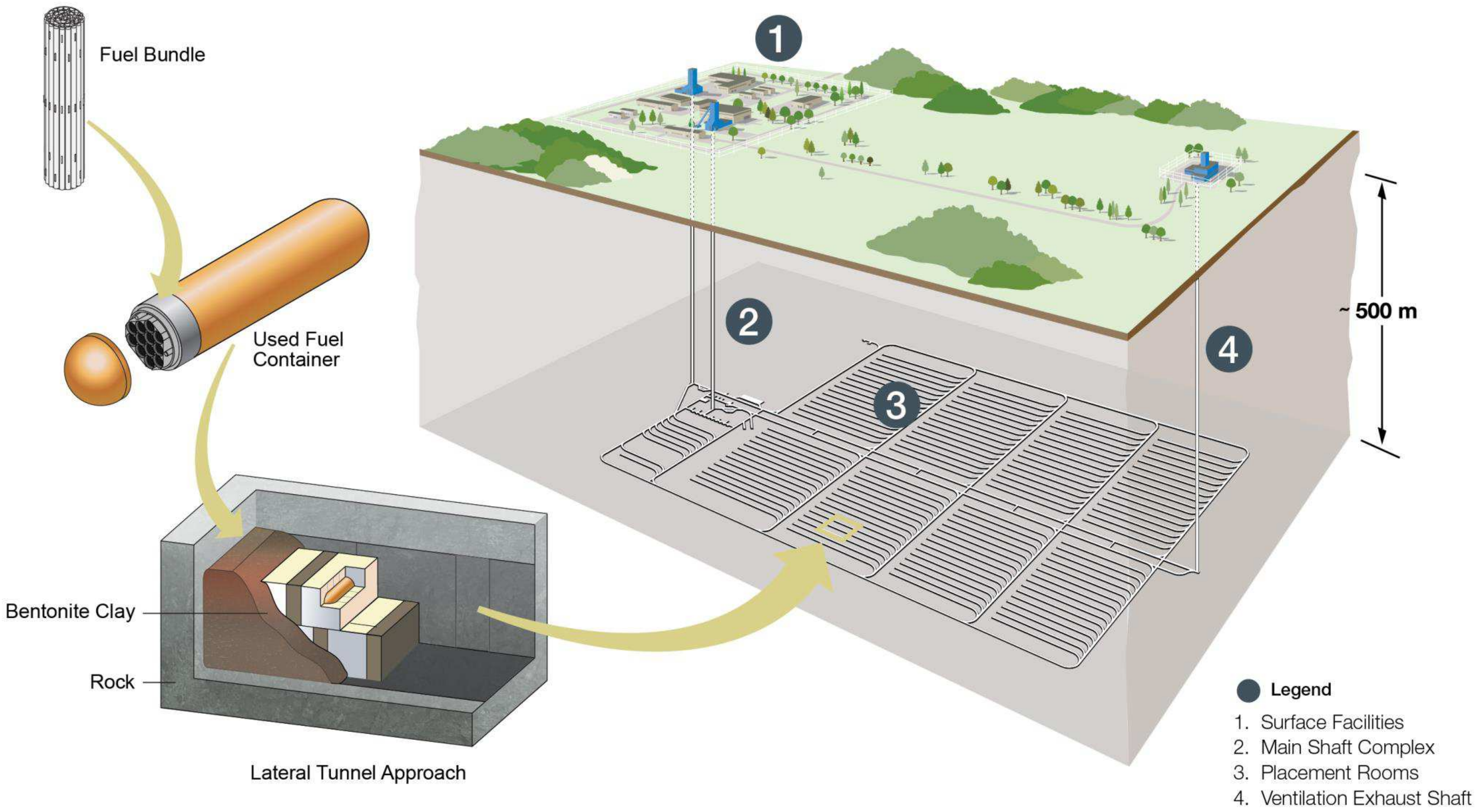
Copper is often considered as one of the easy material to be processed by cold spray this statement can be misleading in the case of the deposition of thick Cu coating deposited on massive steel structure. Experimental result on key parameters affecting adhesion will be presented and discussed with emphasis on the case of production massive parts. Particle velocity have shown to play a major role in the development of an adherent coating, up to now proper adhesion of copper over steel has only been obtained while using helium as propelling gas in order to develop particle velocities above 800 m/s. Surface conditions such as roughness and temperature have also shown great influence on the interfacial fracture strength. The coating build up rate linked to the ability to move the parts is also playing a major role on the adhesion strength. Finally the thermal history of the part being coated influences adhesion, results of thermal modelling will be described and the development of a representative sample holder based on those results will be presented.

Outlines

- Application
- Requirements
- Coating development
- Coating optimization
  - Surface conditions
    - Roughening
    - Spray angle
  - Buildup rate
  - Thermal History

- Summary

NWMO Deep Geological Repository Approach



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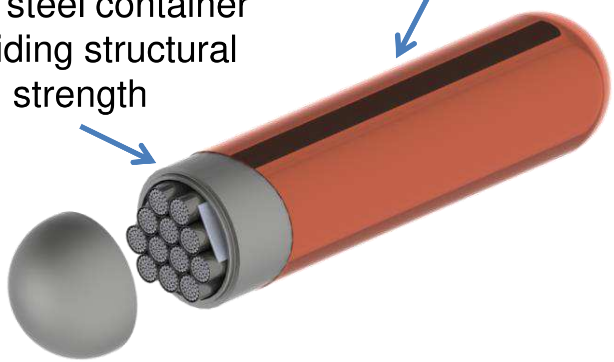
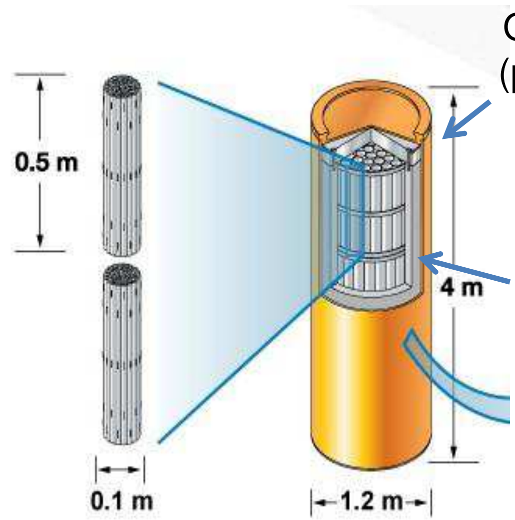
Corrosion Protection of Used Fuel Containers (UFCs)

Mark II



- 2.7 tonnes when filled
- 3 mm thick Cu
  - significant reduction in copper contribution costs
- Elimination of creep concern

Mark I



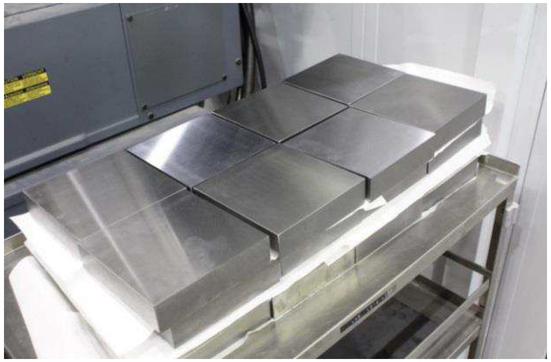
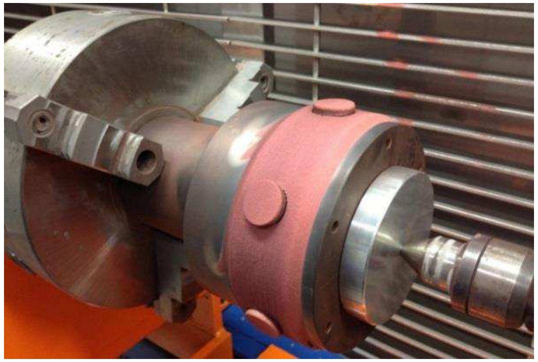
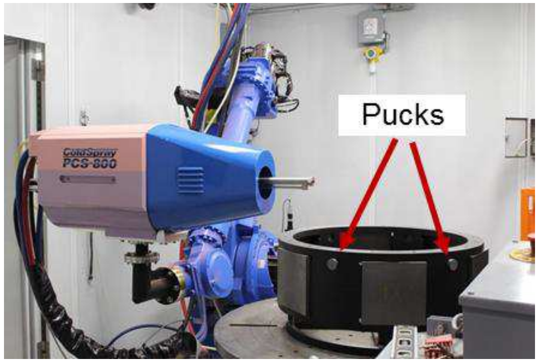
- Over 25 tonnes when filled
- Cu extra thickness required due to manufacturing considerations
- 1 mm nominal gap between the copper and steel due to copper creep consideration → challenging

Coating Development - Methodology

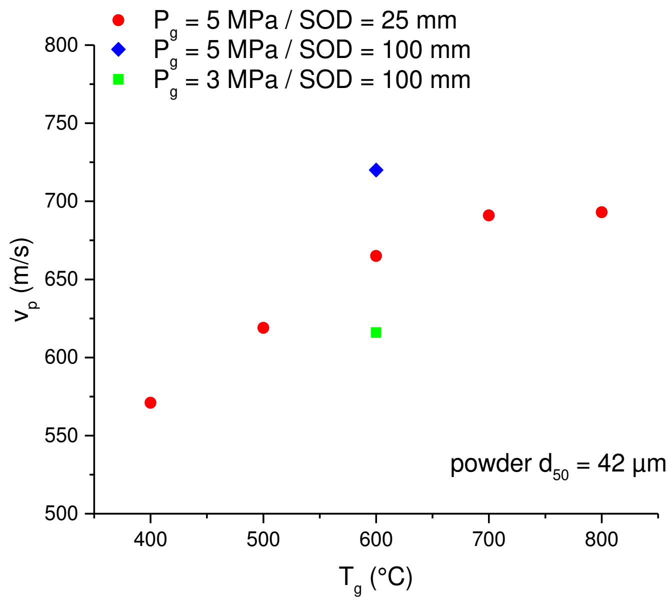
Variables to investigate:

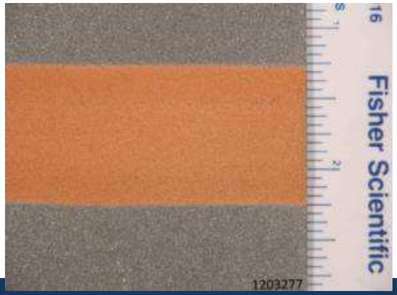
- Feedstock
  - Powder morphology, composition and size
- Substrate
  - Surface preparation
  - Part temperature
- Process parameters
  - Gas Temperature
  - Gas pressure
- Robot parameters
  - Gun traverse speed
  - Step Size
  - Standoff distance
- Post heat treatment
  - Temperature
  - Time

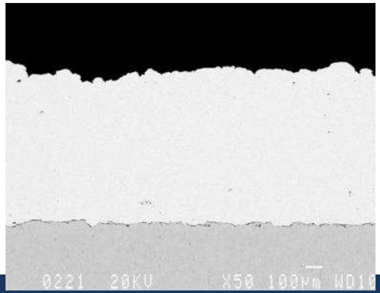
Properties	Requir.	Target
Elongation (%)	10	≥ 15
Adhesion (MPa)	20	≥ 60
Porosity (%)	n/a	≤ 1

Coating Development – Results I







- Particle velocities toward 750 m/s with optimised N_2 conditions (850 m/s for He)
- Well within window of deposition for Cu (~ 400-1100 m/s*) → dense coatings obtained
- Required adhesion (>60 MPa) achieved with He bond coat

*Schmidt, T. et al (2009). J. Therm. Spray Technol., 18 5-6, 794-808

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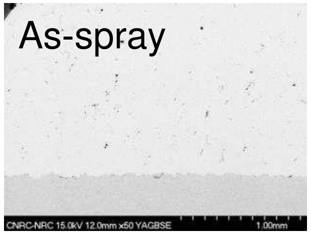
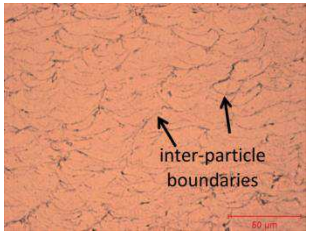
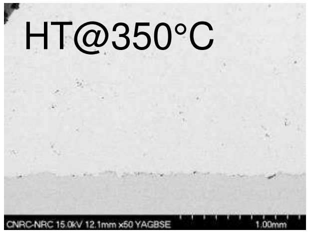
Coating Development – Results II

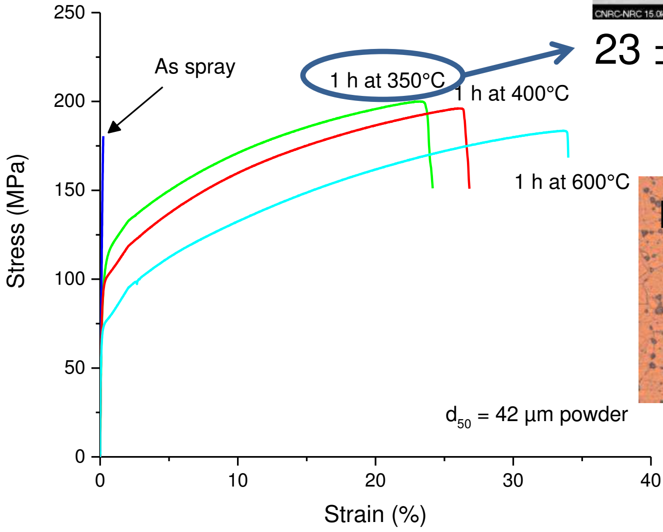
- Annealing is required to recover coating ductility

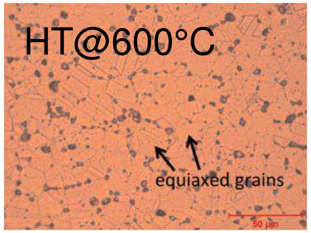


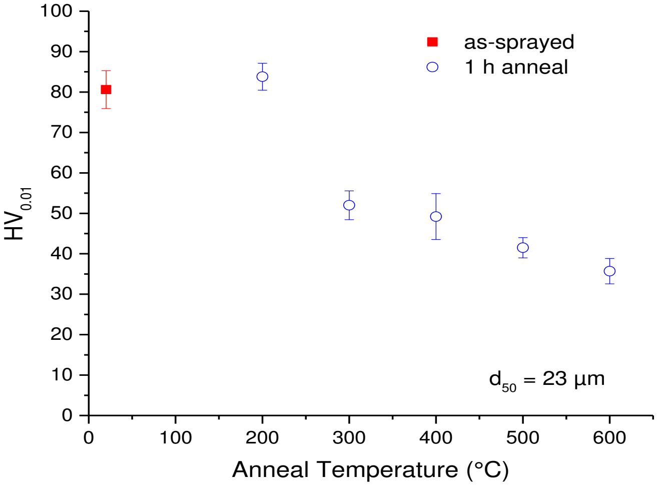




23 ± 3% ductility







Coating cohesive strength (HT@350°C): 67 ± 5 MPa

Effect of Annealing on Machining

As Sprayed Condition

Post Annealed Condition

Coating Development – Reference Conditions

- 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 N_2-spray at 5 MPa and 800 °C, and
  - Post-deposition heat treatment at 350°C for 1 hour.

Properties	Requir.	Target	Obtained
Elongation (%)	10	≥ 15	23 ± 3
Adhesion (MPa)	20	≥ 60	67 ± 5
Porosity (%)	n/a	≤ 1	~ 0

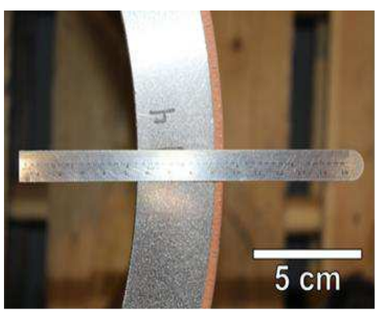
Coating Validation and Scale-Up

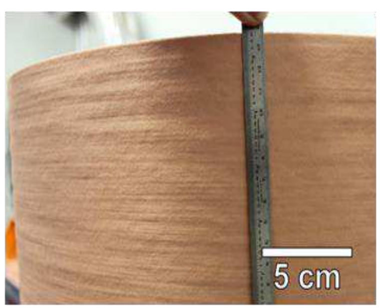
Coating validation on UFC representative materials and shapes:

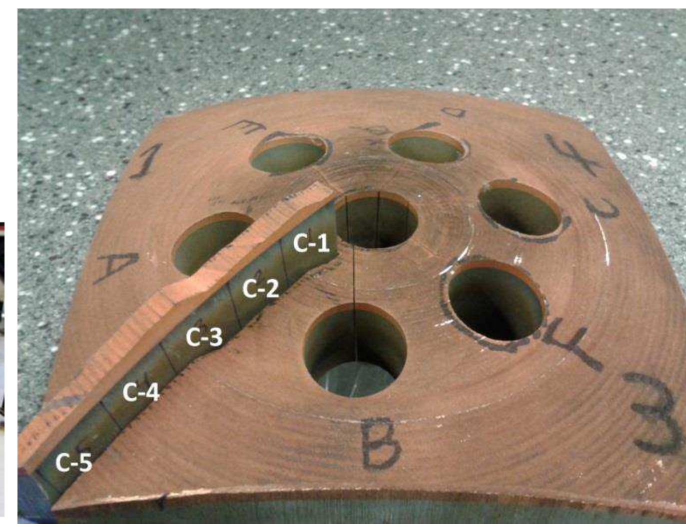
- Larger surfaces
- Curved surfaces
- Hemispherical surfaces

Adjustments →

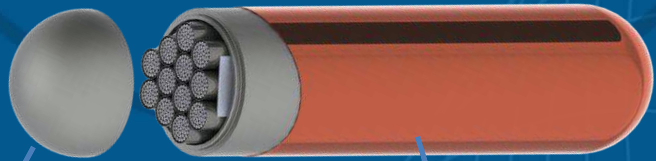
Substrate Handling
Powder feedrate
He gas consumption







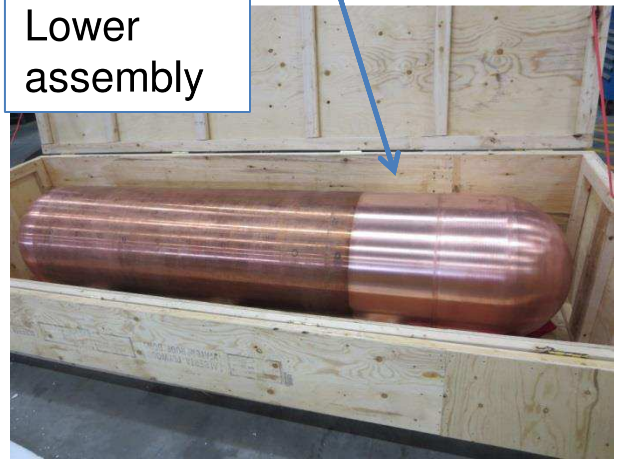
Process Demonstration
Full-scale UFCs Components



Fully coated head

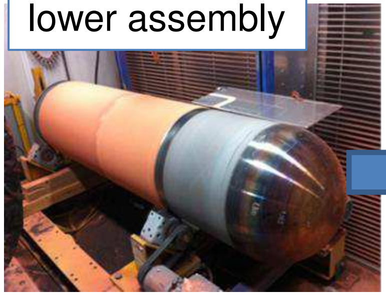
Head

Lower assembly

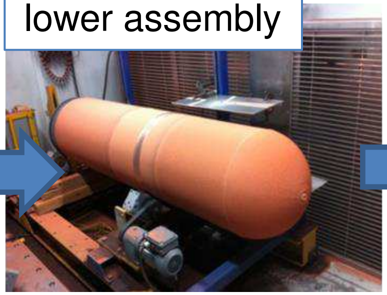


Short-sized container

Partly coated lower assembly

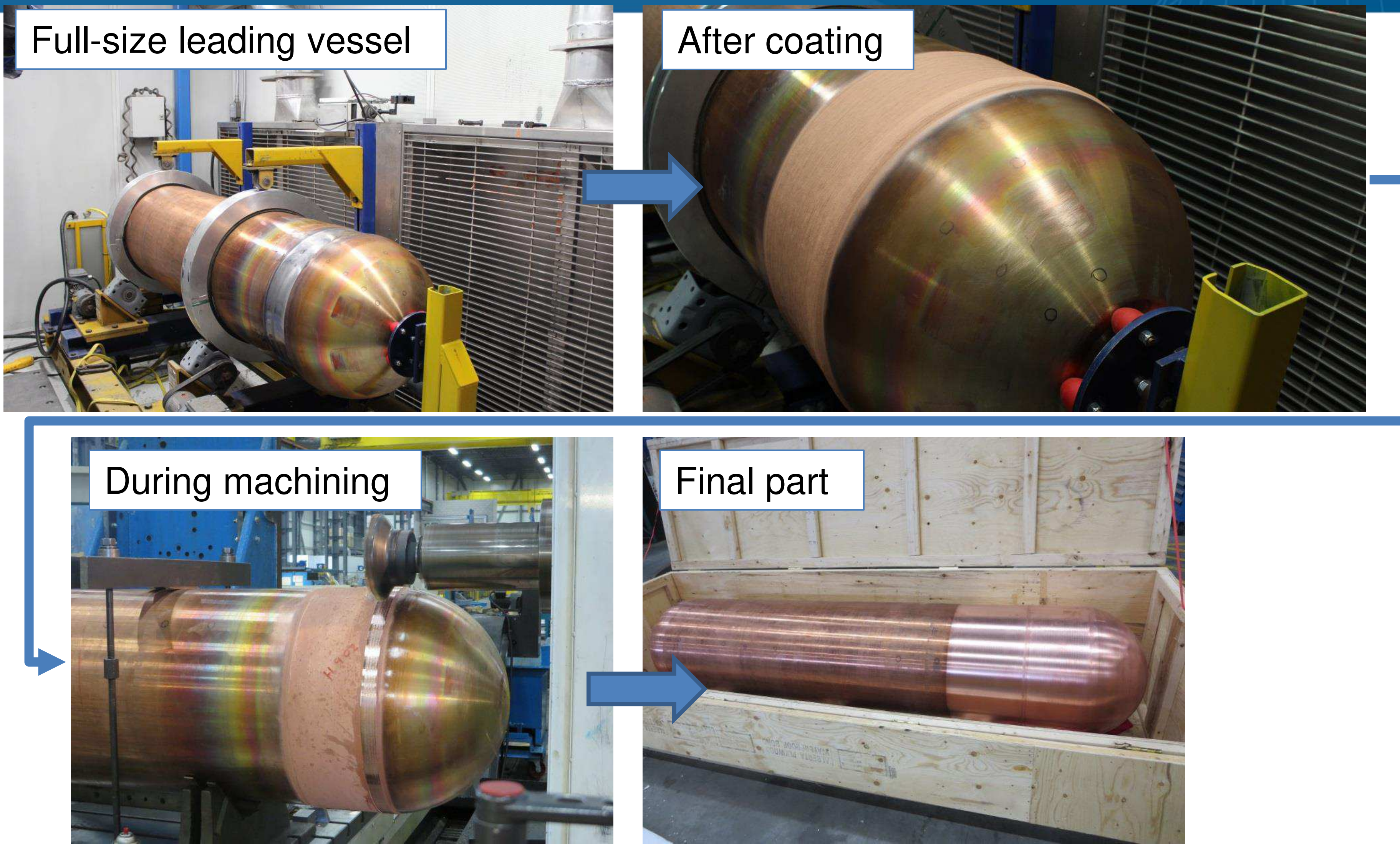


Fully coated lower assembly



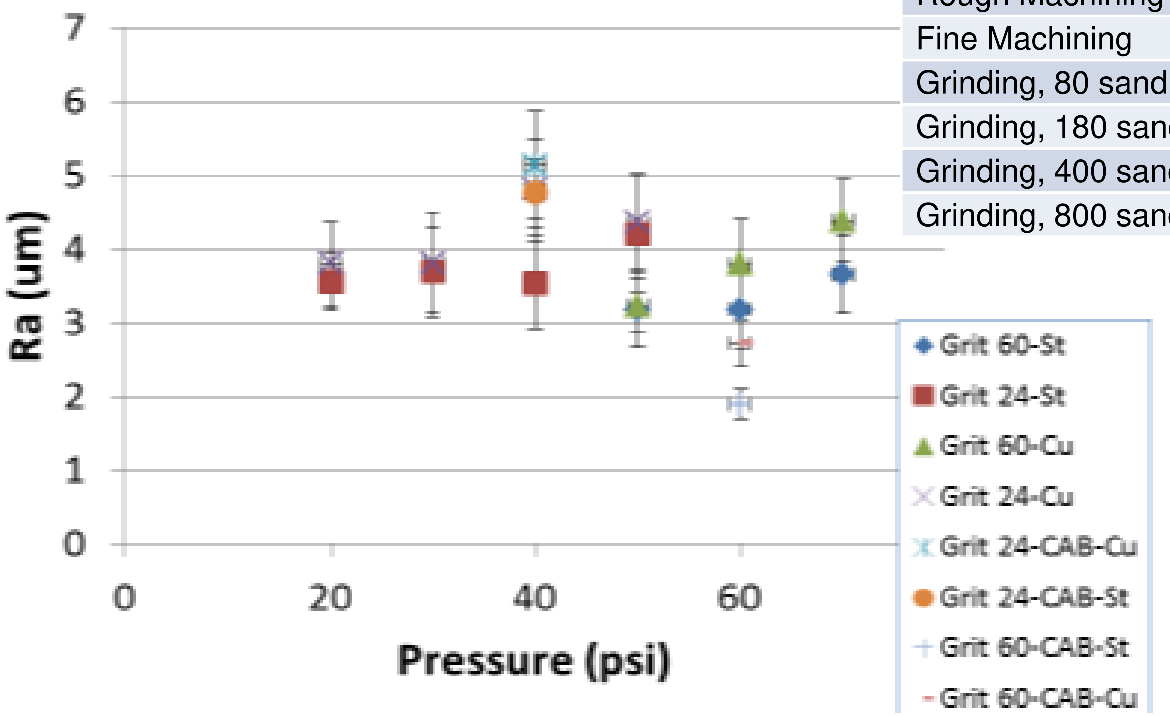
Machined lower assembly

Process Demonstration
Weld Closure Zone



Effect of Surface Preparation

Surface Treatment	ID	Ra (µm)
Grit Blasting with grit 24, pressure of 40 psi	GB24	4.8±0.5
Grit Blasting with grit 60, pressure of 60 psi	GB60	1.9±0.2
Rough Machining	Rough	2.2±0.3
Fine Machining	Fine	0.15±0.03
Grinding, 80 sand paper	P80	1.5±0.2
Grinding, 180 sand paper	P180	0.7±0.1
Grinding, 400 sand paper	P400	0.8±0.8
Grinding, 800 sand paper	P800	0.19±0.05



Different Ra values are obtained using sand blasting, machining and polishing techniques

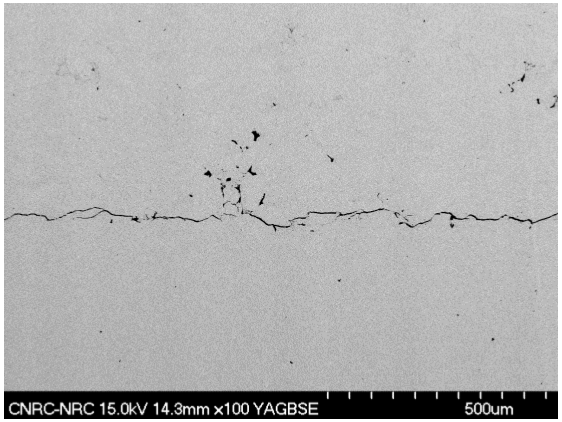
Effect of Surface Preparation

Trial	Coating Thickness (mm)	Surface Treatments	Bond Strength
1 (1501301csB) (1502021csB)	~2.9 ~1.5	GB24*	Spontaneous debonding
2 (1501301csB) (1502021csB)	~2.9 ~1.5	GB60*	Spontaneous debonding of 2(2.9mm) and 1 samples (1.5mm)
3 (1502022csB)	~ 1	GB60	Spontaneous debonding of 2 samples
5 (1502023csB)	n/a, 1 targeted	Rough and Fine Machining	Spontaneous debonding
6 (1502031csB)	n/a, 1 targeted	P800 and P400	Spontaneous debonding
7 (1502032csB) (1503102csB)	~ 1 ~ 1	GB60	Spontaneous debonding
8 (1503102csB)	~ 1	GB24	4.9 ± 0.9 MPa (A†)
9 (1504152csB)	~ 0.5	GB24	10 ± 1 MPa (A) (5 samples)

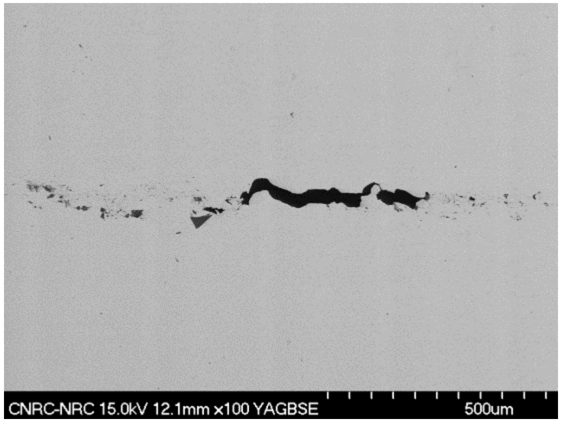
- Coatings were produced using only N2.
- Only the rougher surfaces obtained with coarse grit blasting enable the production of thick (3 mm) coatings
- While using N2 only the adhesion remains very limited

Effect of Spray Angle on Flat Samples

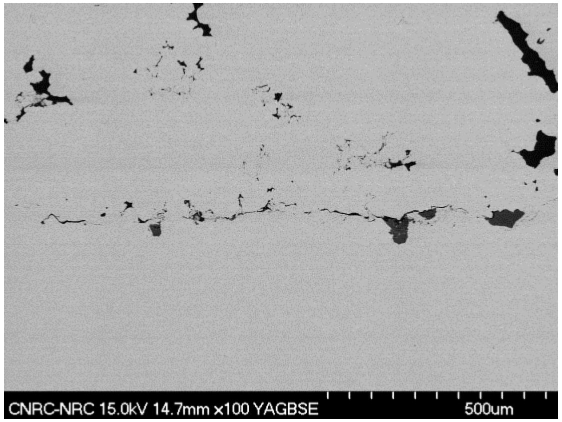
5 º



10 º

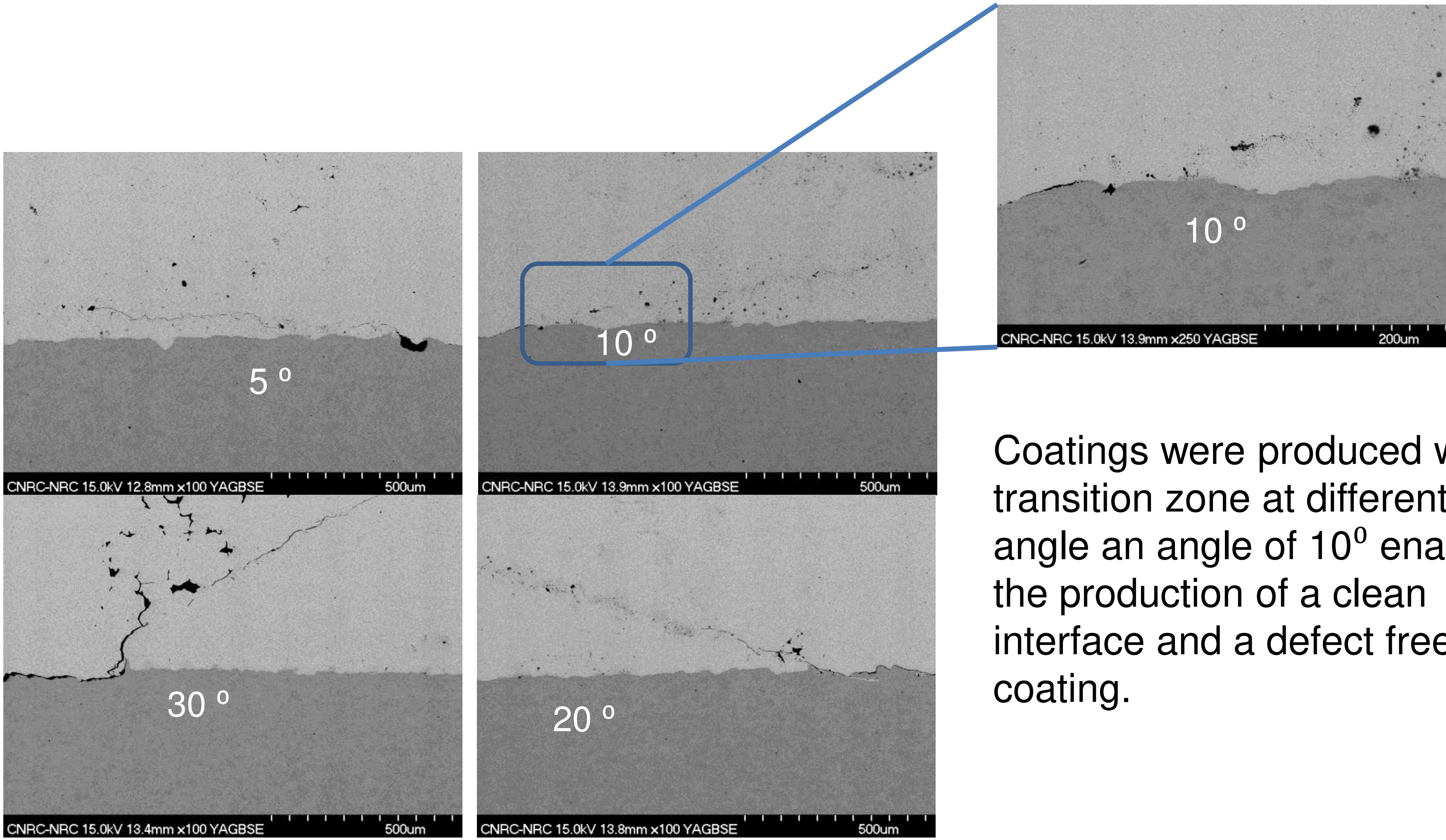


30 º



Coatings were produced on electrodeposited copper at different impinging angle
At 30º the coating quality is affected

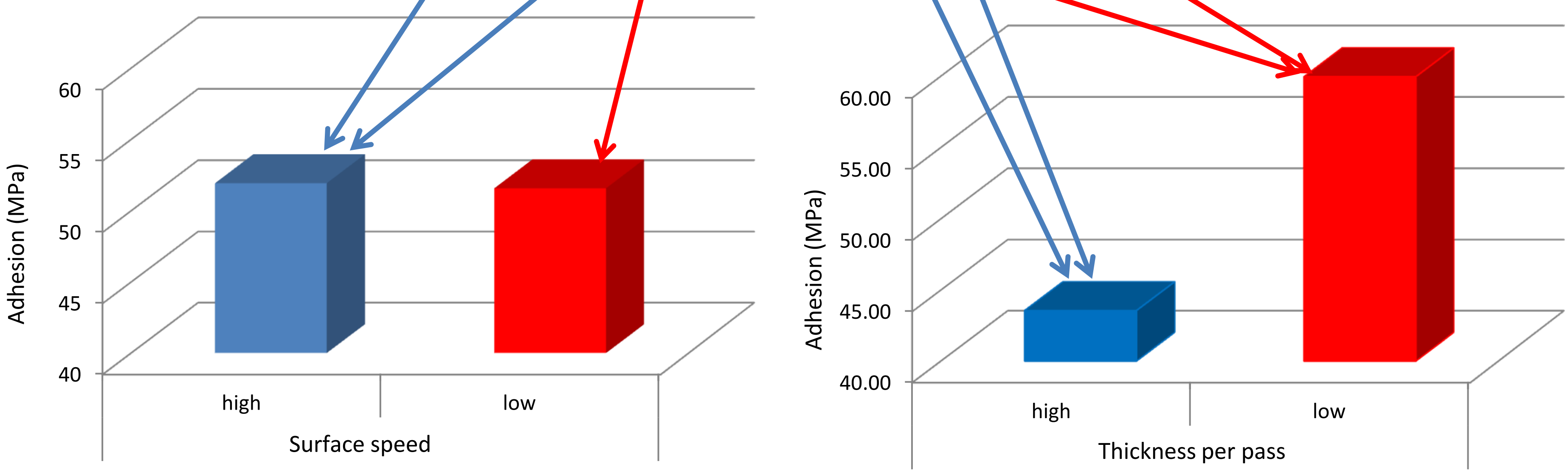
Effect of Spray Angle on Machined Plate



Coatings were produced with transition zone at different angle an angle of 10^0 enables the production of a clean interface and a defect free coating.

Effect of Deposited Thickness per Pass

spray run #	RPM	feed rate	surface speed	thickness/pass	adhesion
	min^{-1}	g/min	cm/s	µm	MPa
1510152	225	160	180	206.9	38.26
1510161	38	12	30	87.2	54.31
1510153	38	74	30	558.9	48.85
1507073	225	75	180	92.7	65.6



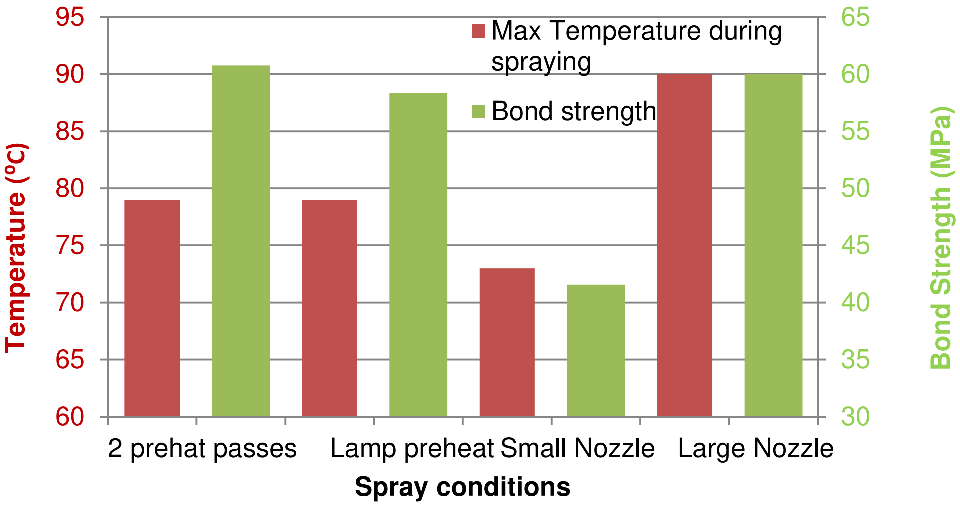
Effect of Feed Rate
Increasing Productivity

Spray conditions 4.9 Mpa, 800 ºC	
One adhesion pass	Process gas helium
	Particle feed rate 12g/min
Build up passes	Process gas N_2
	Particle feed rate 75 g/min
Adhesion	67.9 MPa

Similar results have been obtained while spraying short cylinders

Process Adjustment
Spray Rate

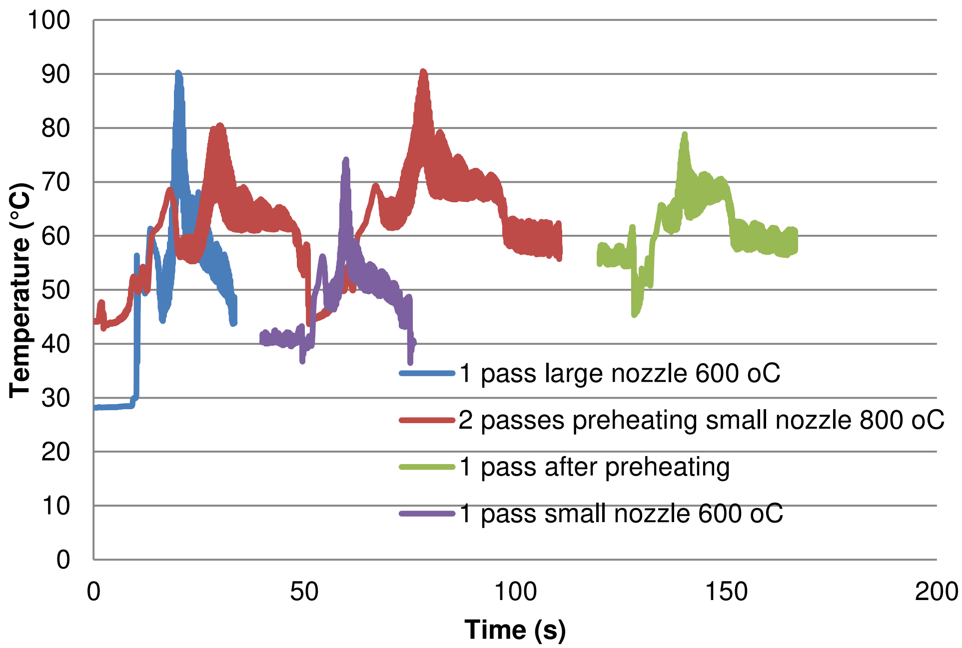
- Need to minimize gas consumption (mainly He)
- Using smaller nozzle reduces He flow rate: 5300 LPM → 2100 LPM.
- Particle velocities are similar
- Bond strength is lower. Surface temperature on particle impingement was potentially lower with the smaller nozzle → lower gas mass flow.
- Need to control surface temperature.



Measuring Surface Temperature During Spraying

- Measurement using an infrared camera.
- Gun traveling over the sphere surface
  - Without powder
  - Nitrogen as the process gas.

It was assumed that the effect of temperature when using He would be proportional to what is measured using nitrogen.



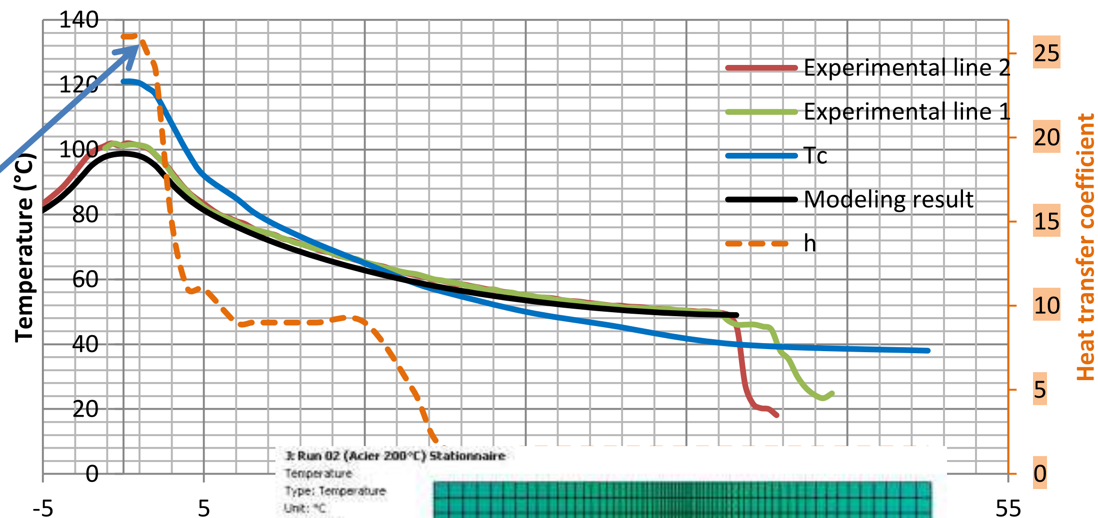
Different trials show that higher temperature can be reached if preheating is applied to the part.

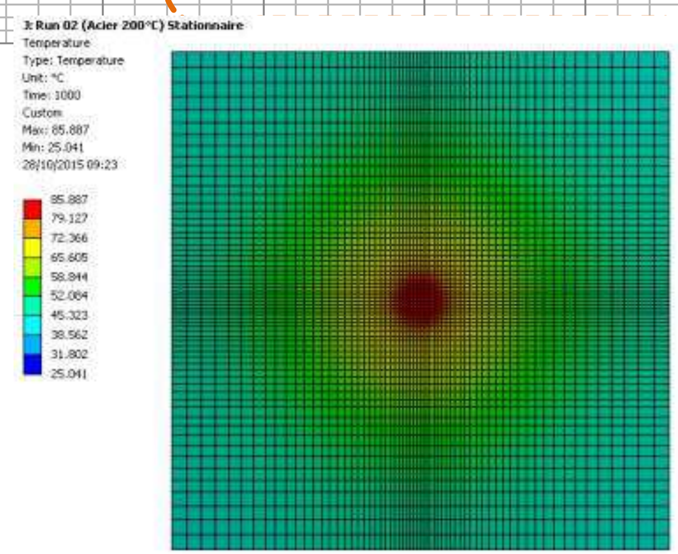
Thermal Modeling
Acquiring the Heat Transfer Parameters

$Q = h \cdot A \cdot (T_c - T_p)$

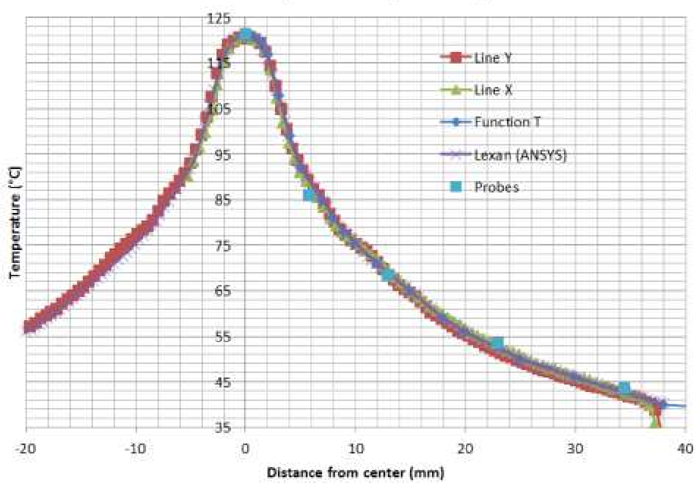
Q = heat transferred
H = convection coeficient
A = Surface area
T_c= gas temperature
T_p = part temperature

Steel 516 (200°C, 4.9 MPa)

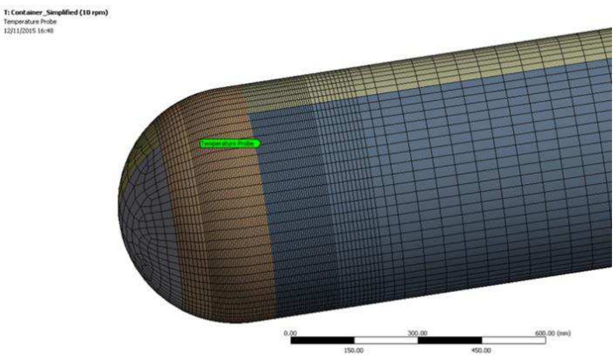


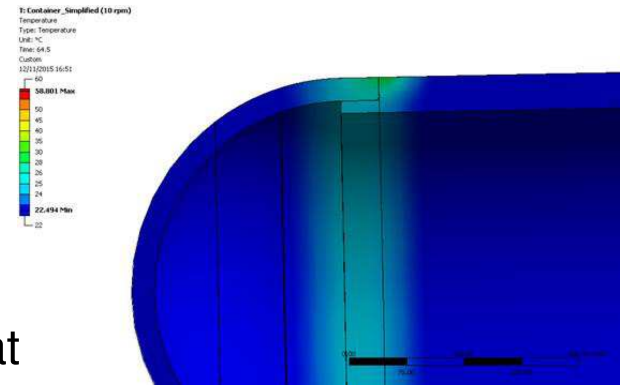


Lexan (4.9 MPa, 200 °C)

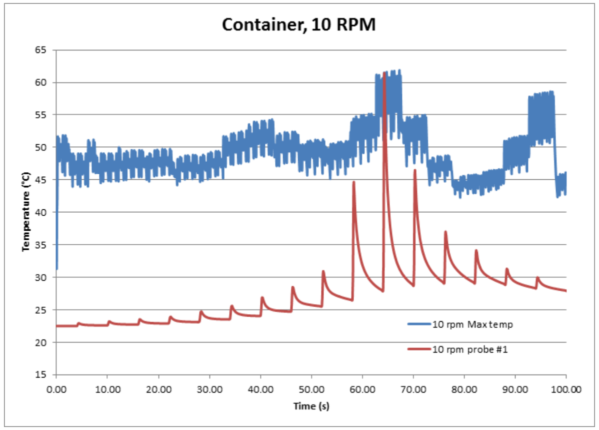


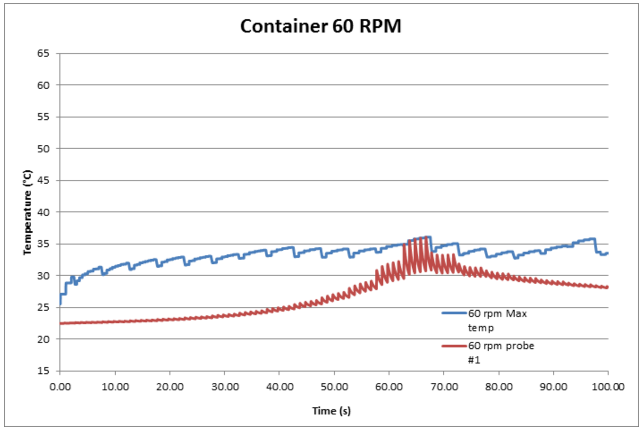
Thermal Modeling
Simulating Real Parts Thermal History





Simulation shows that rotation rate (surface velocity) affects the surface temperature and thus the thermal history of the part being coated





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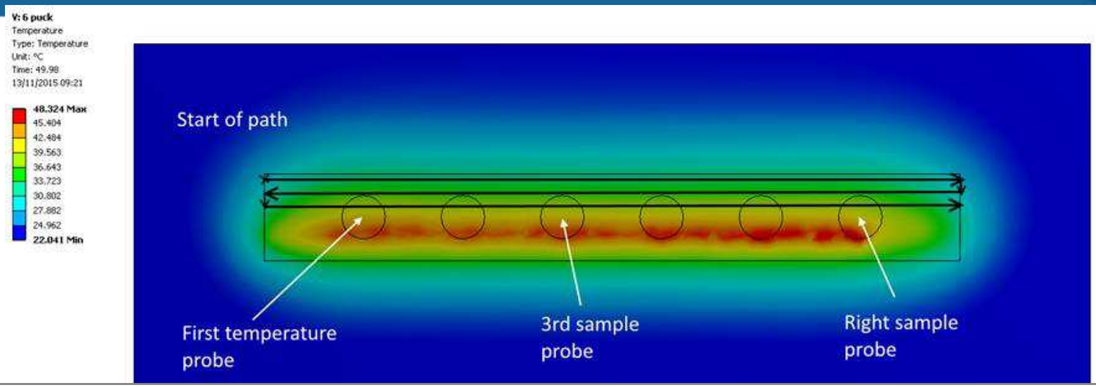
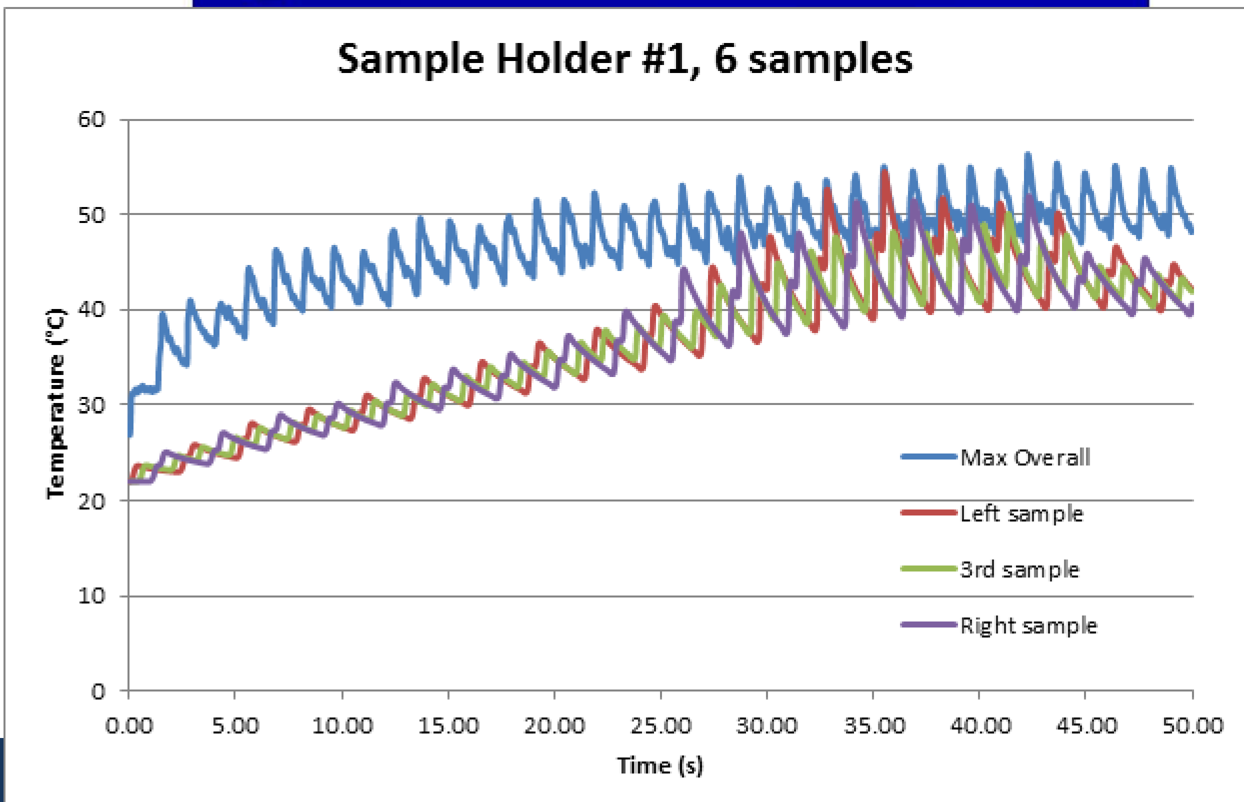
Thernal Modeling
Design of Sample Holder





Simulation shows that using a massive sample holder (22in X 8 in, 1 in thick) enables to simulate relatively closely the thermal history of the large components.

Validation pull tests on cylindrical samples have confirmed the representativity of the sample holder.

Summary

- A cold sprayed thick copper coating has been developed to fulfill the need of corrosion protection in deep geological conditions.
- The coating process has been adapted to cope with the limitation imposed by the size and movement constraint of used fuel canister.
  - These adaptation were made in terms of surface preparation,
  - Spray angle
  - Coating build-up rate
  - And coating thermal history.

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Thank you

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