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Cold spray bond coats structure and oxidation behavior

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Cold Spray bond coats:
Structure and oxidation behavior

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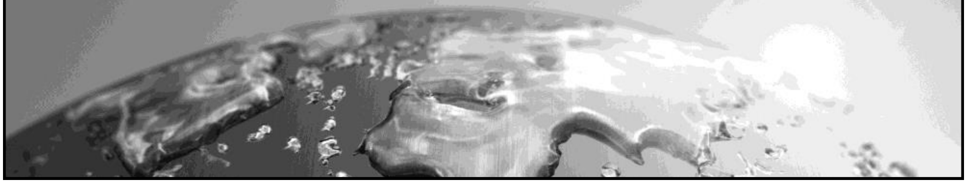
Thermal Barrier Coatings IV
23.06.2014



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Cold Spray in the Technology Space

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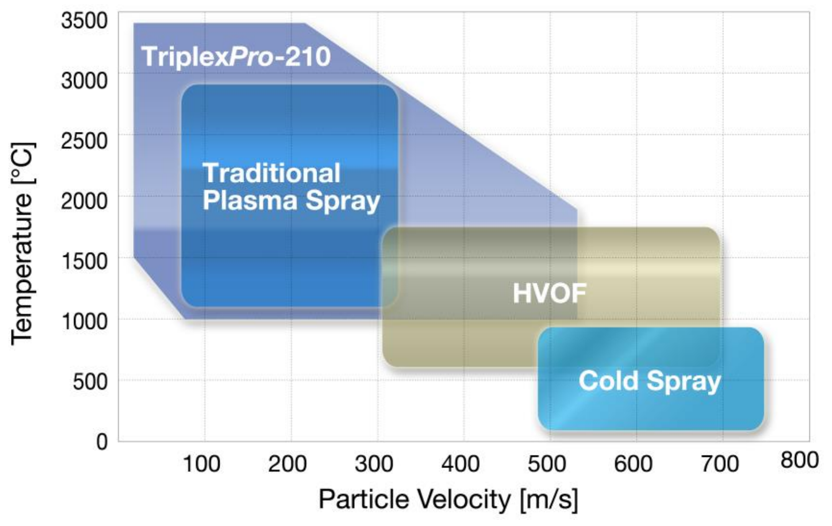

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The Principle of Cold Spray

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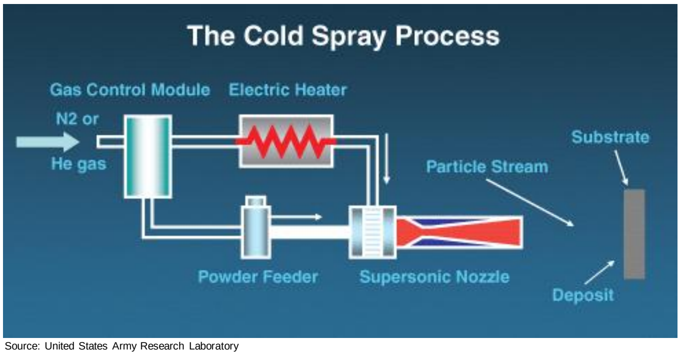

Source: United States Army Research Laboratory

- Powder particles are accelerated to supersonic velocities and impact in solid state onto a substrate
- Gas is heated for two reasons:
  - Increase of sonic speed → Increased speed of gas jet
  - Heating up particles → Increased ductility
- The particles are deformed due to the high kinetic energy and bond to the substrate

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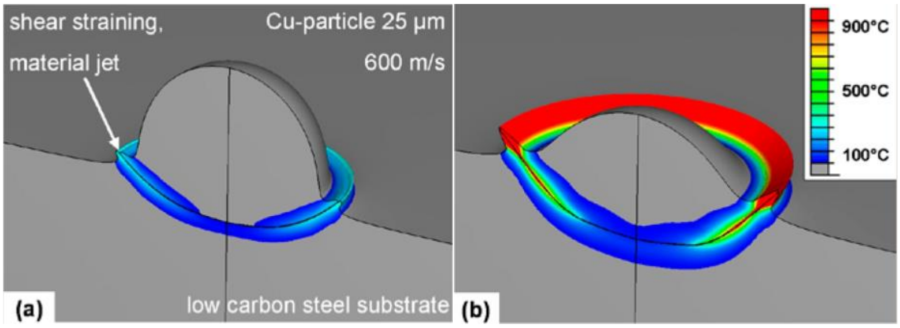
The Principle of Cold Spray



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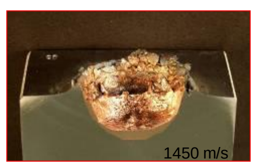
Bonding mechanism in cold spray

The powder particle has reached the minimum impact velocity (V_{crit}) which is needed to create a metallurgic bonding. This so called critical velocity depends on the material properties of the particle and the substrate.

Beyond the critical velocity the deformation and bonding quality of particles increase with increasing impact velocity,



If the impact velocity is too high more material is eroded than deposited. This limit is called erosion velocity V_{er}.

The ideal deposition condition: $V_{particle}$ is between V_{krit} and V_{er} = Window of Deposition

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Cold Spray Deposition

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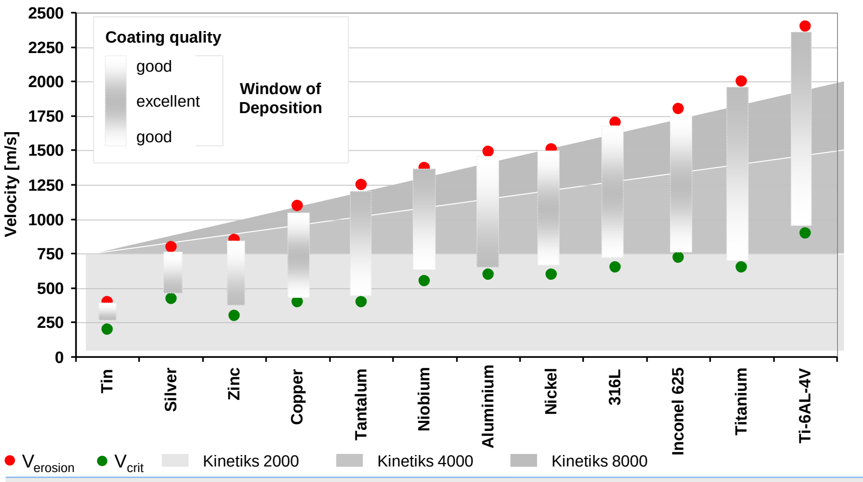
Window of Deposition for different materials (25µm) at an impact temperature of 20°C



For ideal coating: $V_{particle}$ is between V_{krit} and $V_{erosion}$ = Window of Deposition

Why using cold spray for MCrAlYs?

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Pros:

- Shadow masking sufficient – no bridging from masking tool onto component
- Low surface speeds: 100 – 500 mm/s ➔ application rates of more than 100 µm/pass possible
- Low heat input into substrates
- High target efficiency
- If N2 is used as process gas cold spray is cost competitive to HVOF
- Compressive Stress
- Good bonding

Cons:

- Low feed rates
- Sensitive to deviations from 90° spray angle
- High precicions required due to small track width and high application rate per pass
- Heavy spray gun, better to move the component

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Used Cold Spray Equipment

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- Kinetiks 8000 spray gun with 22 kW max. heating power
- Pre-heater with 30 kW max. heating power
- Nitrogen as process and carrier gas
- Max. operating pressure 40 bar
- D24 standard nozzle

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Untreated Feedstock Matierial

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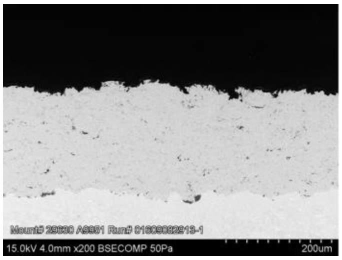
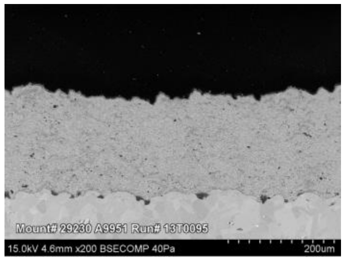
MCrAlY on IN718 or Hastelloy X – As-Sprayed Results

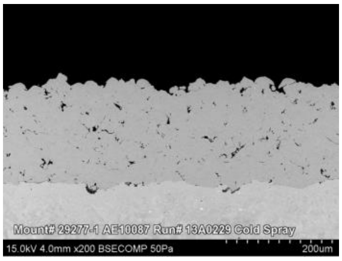
HVOF



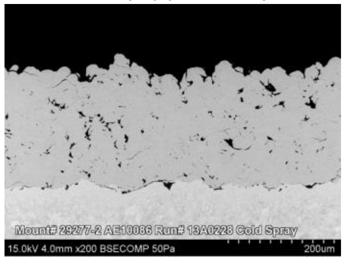
LPPS



Cold Spray (Fine Cut)



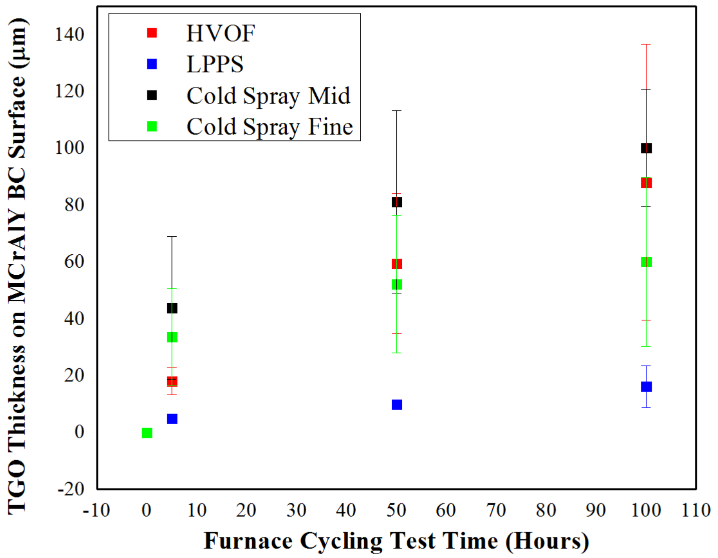
Cold Spray (Medium Cut)



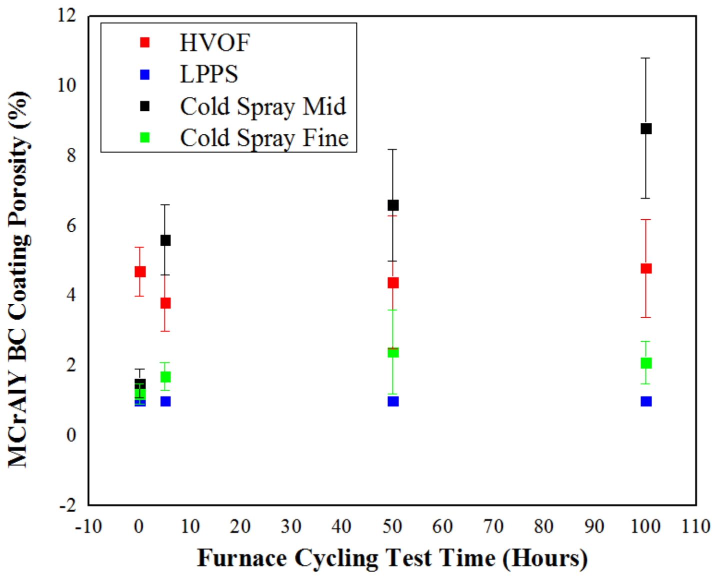
Heat Treat and FCT Parameters

- **Heat Treat Parameters:**
  - Heat up to 1080°C ± 15°C in vacuum of 0.3 Pa with ramp rates of:
    - Up to 260°C (no defined ramp rate)
    - 260 - 815°C (max. ramp rate of 15°C/min)
    - Above 815°C (max. ramp rate of 10°C/min)
  - 2-hour hold at 1080°C then gas-cooled to room temperature (cooling rate 1080°C to 538°C in 36 minutes - 15°C/min)
- **FCT Parameters – only bond coat:**
  - FCT temperature: 1000°C
  - Integral holding times of:
    - 5 hours
    - 50 hours
    - 100 hours

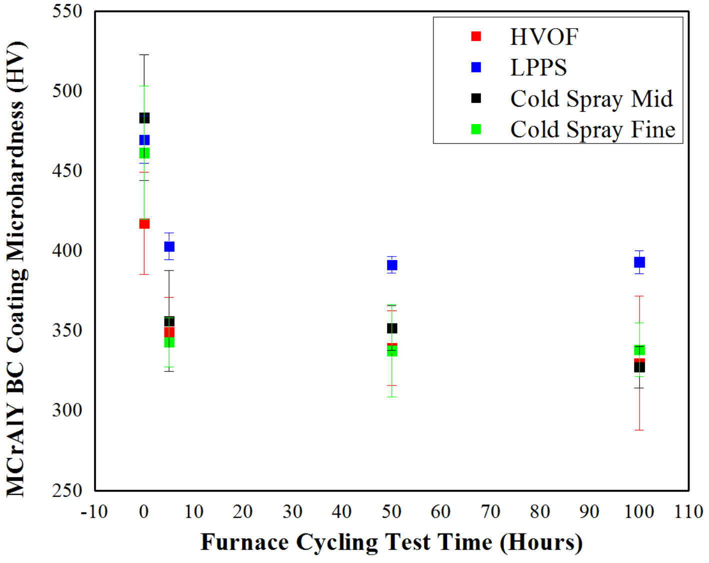
Oxidation Behavior of MCrAlY – TGO Thickness – AS/FCT



Coating Porosity – AS/FCT



MCrAlY Coating Microhardness – AS/FCT



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Pre-treated feedstock materials

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Coating systems and used processes

Process	System / Gun	Feedstock Powder Sprayed
Cold Spray	Sulzer Metco Kinetiks 8000	MCrAlY Bond coats (same composition as Amdry 995 series)
LPPS	Sulzer Metco F4-VB	MCrAlY Bond Coat (Amdry 9951)
APS	Sulzer Metco Triplex 210	Metco 204NS-G Top Coat

Spray System & Spray Parameters

Spray System	Kinetiks 8000	F4-VB	Triplex 210
Coating Type	Cold Spray	VPS	APS
Parameters			
Spray distance (*mm*)	60	275	150
Powder feed rate (*g/min*)	27	47	150
Primary Gas, Ar (*NLPM*)		50	50
Secondary Gas, H_2 (*NLPM*)		9	5
Inlet Gas (N_2) Pressure, (*bar*)	40		
Inlet Gas (N_2)Temperature (^0C)	950		
Powder Carrier Gas, N2 (*m3/h*)	6		
Powder Carrier Gas, Ar (*NLPM*)		1.9	7.5

Note: *Target coating thickness in all cases is <200 µm*

Feedstock Microstructures

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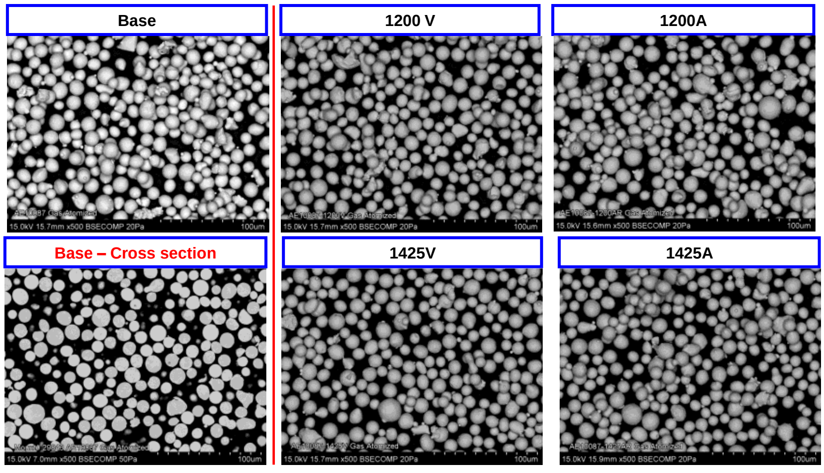
Co-32Ni-21Cr-8Al-0.5Y – Amdry 995 series

- Fine cut: -22+5 µm (Base, FAC,1200V, 1200A, 1425V, 1425A)



Feedstock Particle Size Distribution

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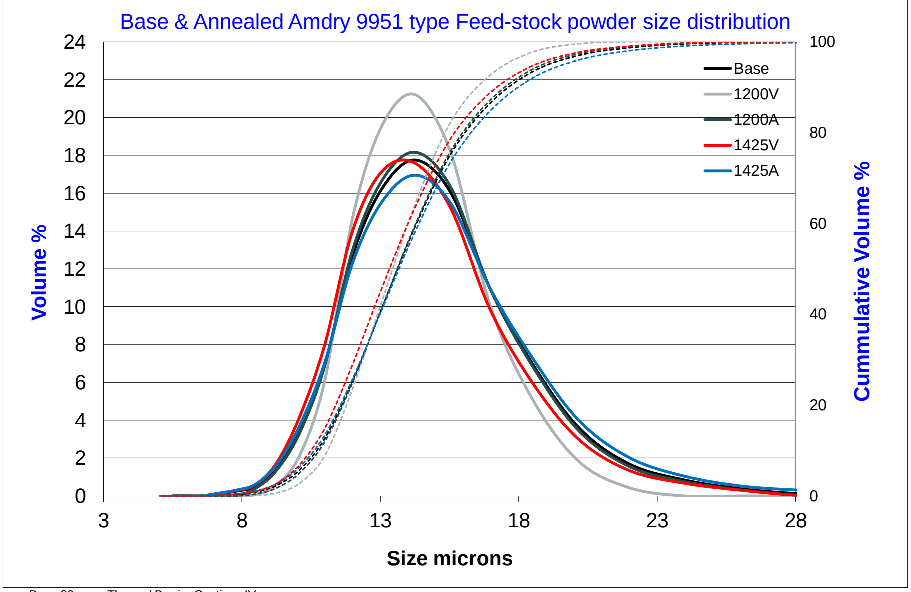

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Chemical Composition of Cold Spray Feedstock Materials

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	Feedstock Chemistry (Weight %)					
Element (A9951 TYPE)	BASE	FAC	1200V	1200A	1425V	1425A
Cobalt (Co)	Bal	same as base	Bal	Bal	Bal	Bal
Nickel (Ni)	31.62		31.45	31.66	31.40	31.30
Chromium (Cr)	20.52		20.42	20.59	20.40	20.38
Aluminum (Al)	7.86		7.81	7.88	7.80	7.76
Yttrium (Y)	0.43		0.41	0.44	0.46	0.45
Carbon (C)	0.01		0.01	0.01	0.01	0.01
Sulfur (S)	<0.010		<0.010	<0.010	<0.010	<0.010
Oxygen (O_2)	0.048		0.059	0.053	0.060	0.057
Nitrogen (N_2)	0.005		0.006	0.006	0.006	0.006

FAC: Base powder with fluidizing agent added (less than 0.2%wt.)

Feedstock Phase Composition (XRD)

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Phase	structure	VOL%				
		BASE	1200V	1200A	1425V	1425A
NI-Co	Cubic		85.9	84.9	77	77.2
$Ni_{0.65}Cr_{0.3}Al_{0.05}$	Cubic					
$Ni_{0.65}Cr_{0.3}Al_{0.12}$	Cubic	91.7				
$Co_{0.8}3Al_{0.17}$	Cubic					
$Ni_{0.4}Al_{0.6}$	Cubic	8.3				
$Ni_{0.67}Cr_{0.66}Al_{0.67}$	Cubic		9,5	10.5	22.5	22.8
NIAl	Cubic	<0.5				
$Cr_{0.38}Co_{0.62}$	Hexagonal		4.6	4.6	0.5	<0.5

NOTE: 120 minutes @ 1200V, 1200A, 1425V & 1425A, Cooled to room temperature

Feedstock nano-hardness

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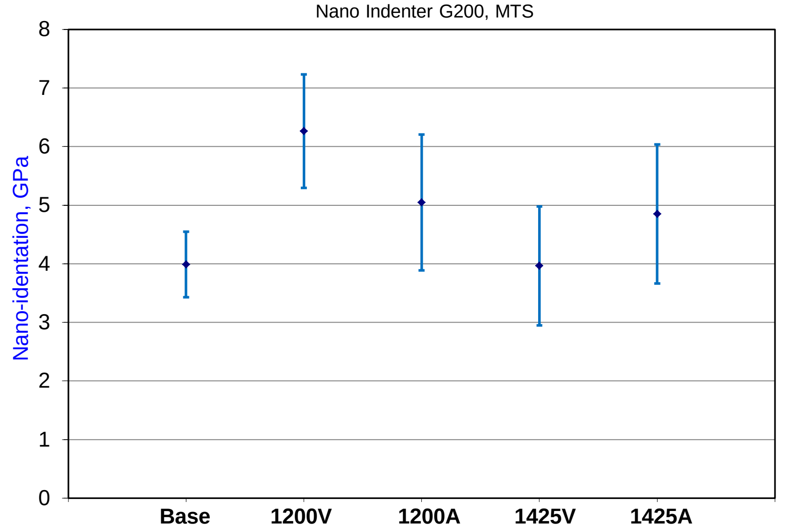
Type of Feed stock vs. nano-indentation

(mean, ± std. deviation, hardness values at max load)

Nano Indenter G200, MTS



Cold Spray Bond Coat – as sprayed
Base & FAC feedstock

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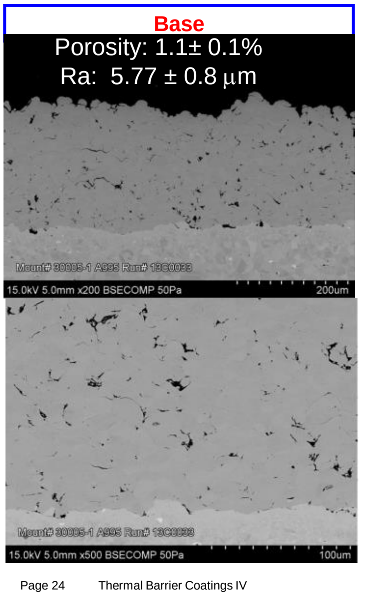

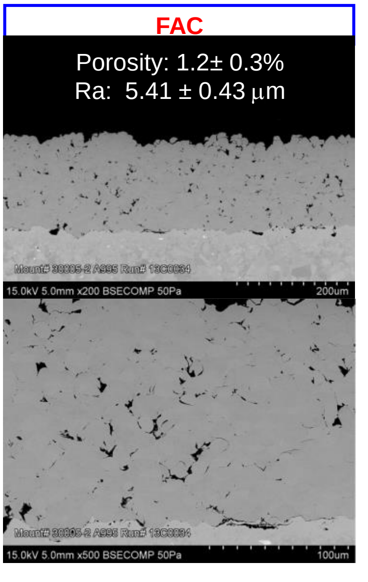

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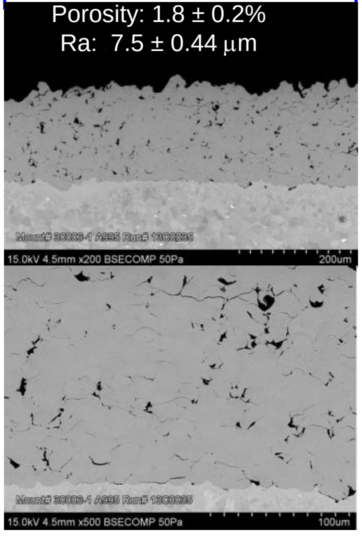
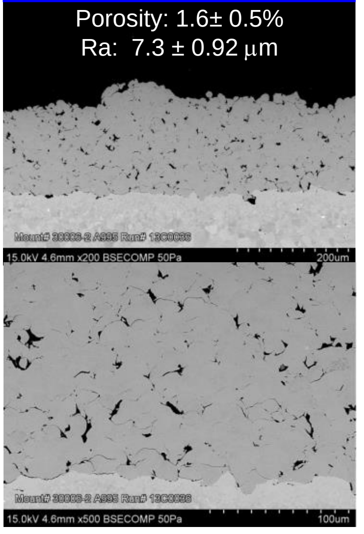
Cold Spray Bond Coat – as-sprayed
1200V & 1200A feedstock

1200V

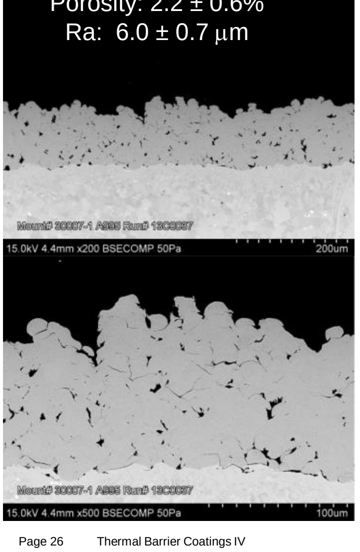


1200A

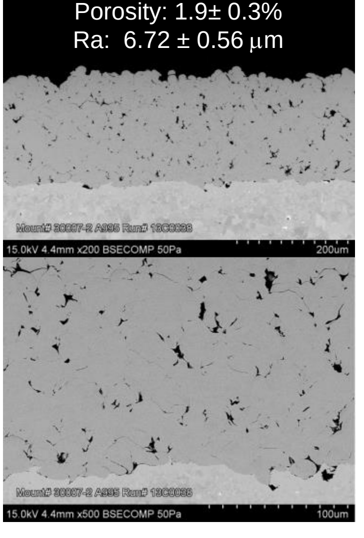


Cold Spray Bond Coat – as sprayed
1425V & 1425A feedstock

1425V



1425A



Bond Coat Properties – as-sprayed Summary

Kinetiks 8000, 40 bar, 950 ⁰C
Substrate: IN 718 plates

Feedstock	DE	Roughness R_a (µm)	Bond Strength (Mpa)	Porosity (%)	oxide (%)	Macro-Hard (HR-15N)	Micro-Hardness (0.3kgf)
BASE	46	5.8	60.78	1.1	2.6	82.1	466
FAC	**67**	5.4	71.83	1.2	2.7	82.1	458.9
1200V	44	7.5	76.13	1.8	4.6	82.3	535
1200A	54	7.3	53.40	1.6	4.8	82.7	534.3
1425V	60	6.0	76.28	2.2	3.9	81.8	486.5
1425A	59	6.7	69.62	1.9	3.8	83.5	529.1

Effect of Inlet Gas Temperature

Kinetik 8000, N_2 40 bar					
Powder	Temp. (°C)	Roughness R_a (µm)	Porosity (%)	Oxide (%)	Micro hardness (HV0.3 kgf)
BASE (-22+5 µm)	800	9.6	2.6	2.8	430 ± 44
	900	7.9	1.3	1.6	454 ± 38
	950	7.0	1.1	2.6	466 ± 32
	1000	5.1	0.9	< 1.0	480 ± 57

Coating Properties – Effect of Inlet Gas Temperature

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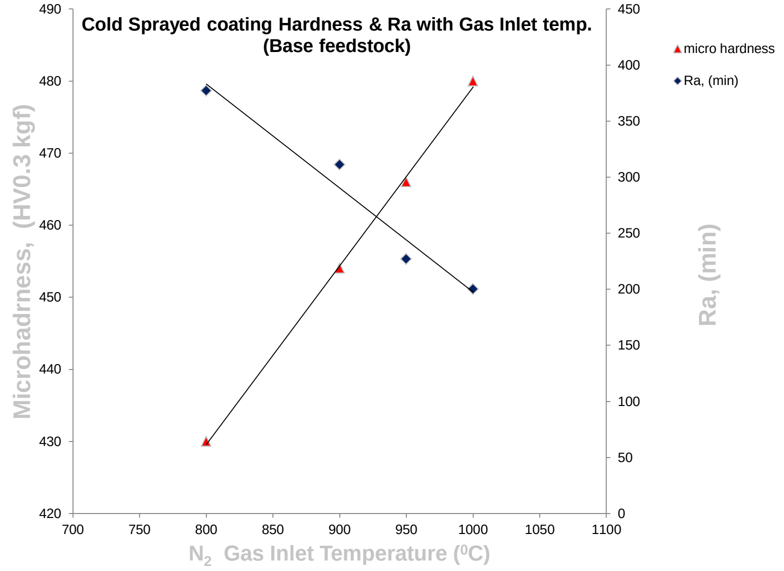

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Coating Properties – Kinetik 8000

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Kinetik 8000, N_2 40 bar

Powder	Temp. (°C)	Size (µm)	R_a (µm)	Porosity (%)	Oxide (%)	Micro hardness (HV0.3 kgf)
Coarse	800	-45+22	14.2	3.6	1.2	405 ± 54
	900		11.6	2.2	0.9	464 ± 42
	1000		12	3.7	1.9	437 ± 58
Mid	800	-38+11	11.7	2.5	1.2	446 ± 48
	900		10.7	2.4	1.5	443 ± 54
	1000		9.9	1.4	1.4	446 ± 54
Fine	800	-22+5	9.6	2.6	2.8	430 ± 44
	900		7.9	1.3	1.6	454 ± 38
	1000		5.1	0.9	< 1.0	480 ± 57

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Coating Properties – Furnace Cycle Testing

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TEST CONDITIONS

Equipment	CM 12" Furnace
Heat Time (min)	10
Dwell Time (min)	40
Forced air cool time (min)	10
Dwell Temp (^{0}C)	1135

Coating Properties – Furnace Cycle Testing

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Bond Coat (MCrAlY)	TOP Coat	#Samples	Average cycles to failure
Base	Metco 204NS-G	4	375
FAC		4	320
1200V		4	406
1200A		4	355
1425V		4	385
1425A		4	410
Amdry 9951 (VPS)		6	415

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Conclusion

Cold spray produces dense MCrAlY coatings with low oxide content

The cold spray process offers unique advantages like no fine dust in the overspray, high application rate and deposition efficiency

Coating properties depend strongly on the feedstock material

Fluidizing agent improved handling of the material but not the coating

Further reduction of porosity required – Annealing did not have the expected effect

Influence of substrate temperature, trajectory parameters, spray distance, addition of helium to the process gas still under investigation

Thank you.