HCAT U.S. - CANADIAN HARD CHROME ALTERNATIVES TEAM

SERDP Strategic Environmental Research and Development Program

Thermal Spray Coatings for Internal Diameters

AeroMat 2002

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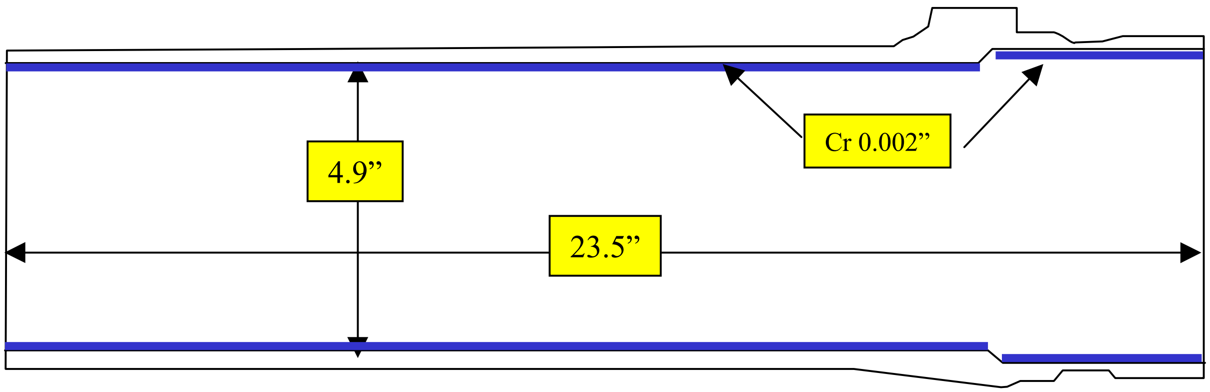
Where is ID chrome used?

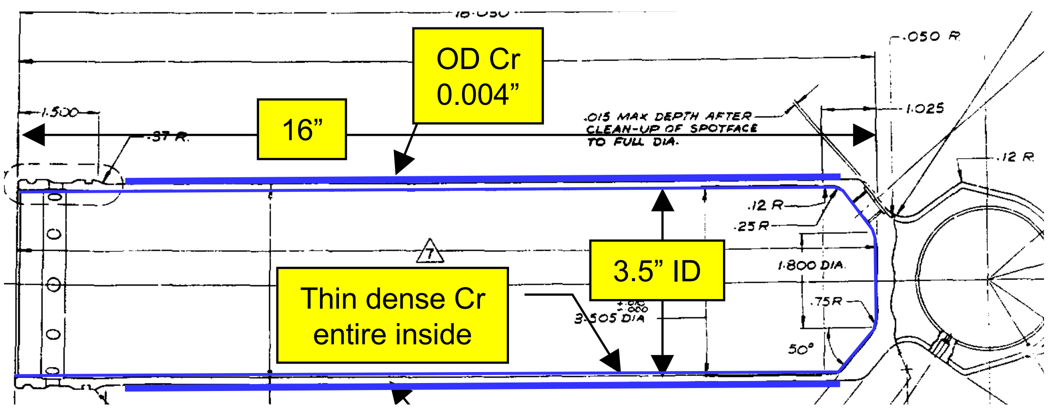
- OEM components
  - Not a lot of ID chrome by OEMs
    - mainly hydraulic cylinder IDs and lug bores and faces
    - some usage on pins to inhibit corrosion (because OD is already chromed for wear)
- Primary usage for MRO
  - Rebuild of worn inner surfaces of hydraulic outer cylinders
    - replates to 0.010” on radius

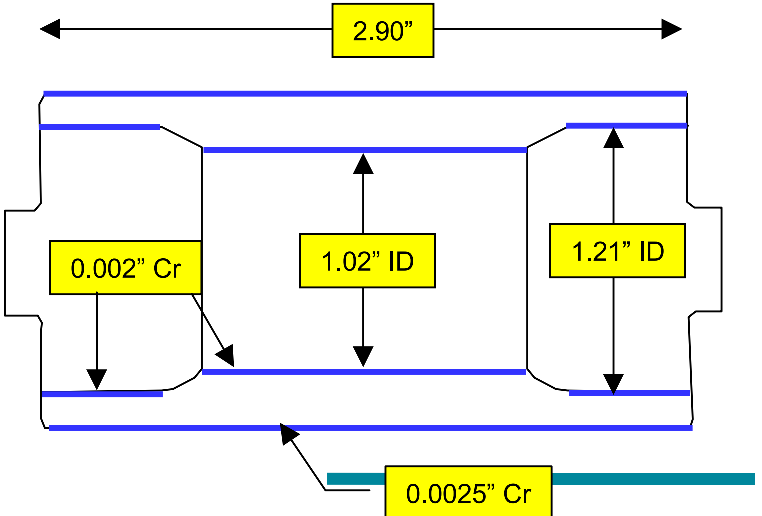
Technical background - components



F-18 MLG outer cylinder

LG actuator pin





LG actuator outer cylinder

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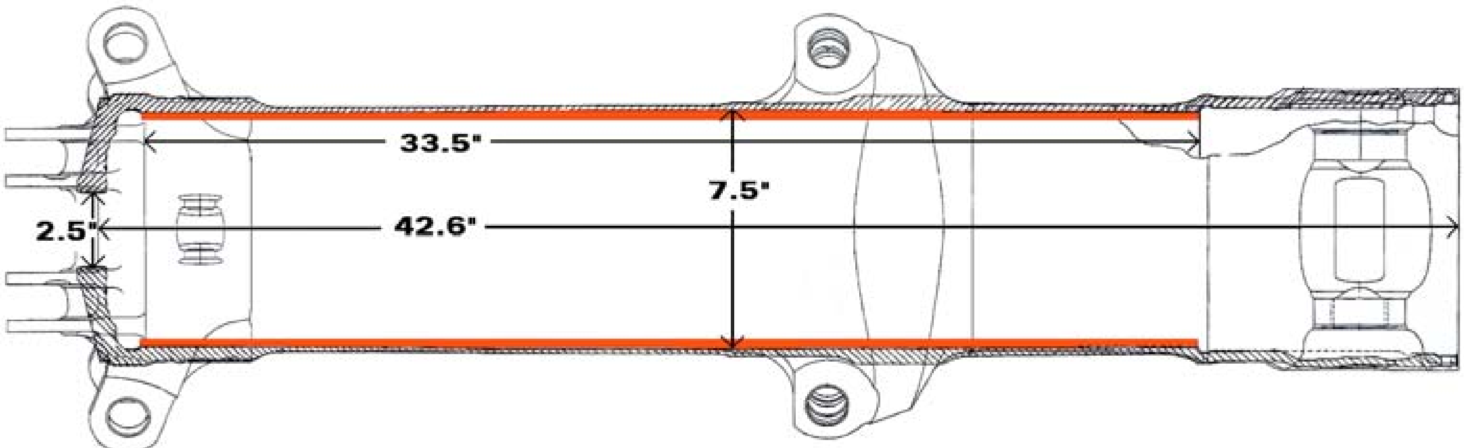
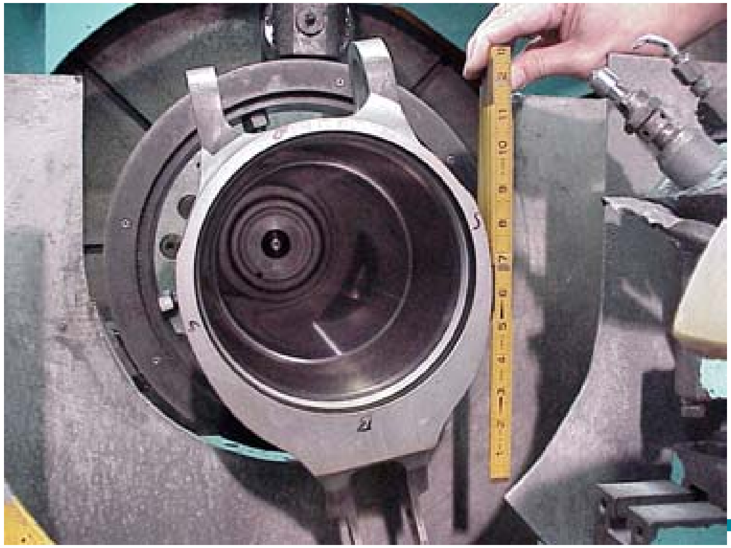
Example



- **P3 Main Landing Gear outer cylinder**
- **Frequently ID chrome plated at JAX to rebuild worn ID**



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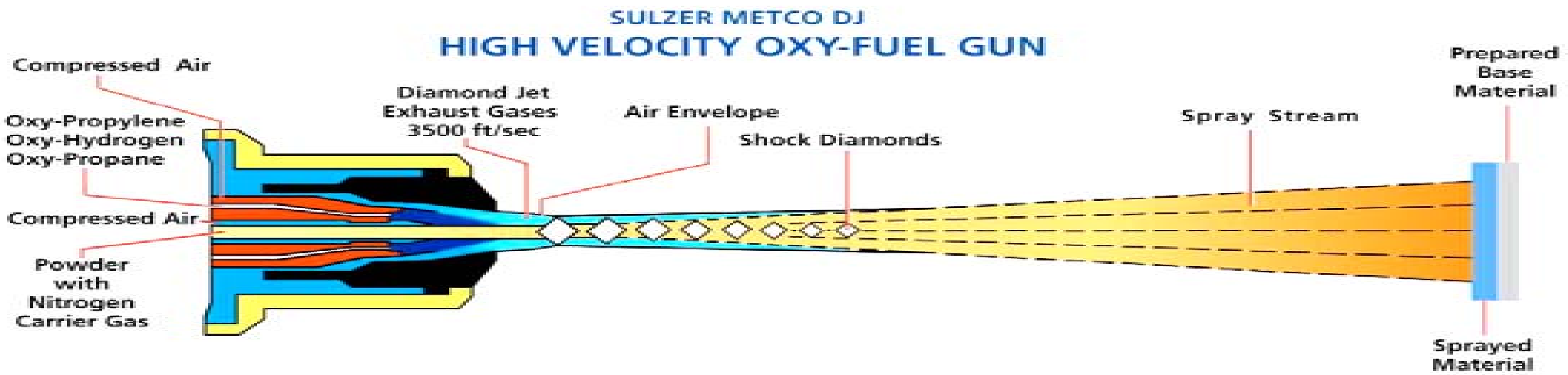
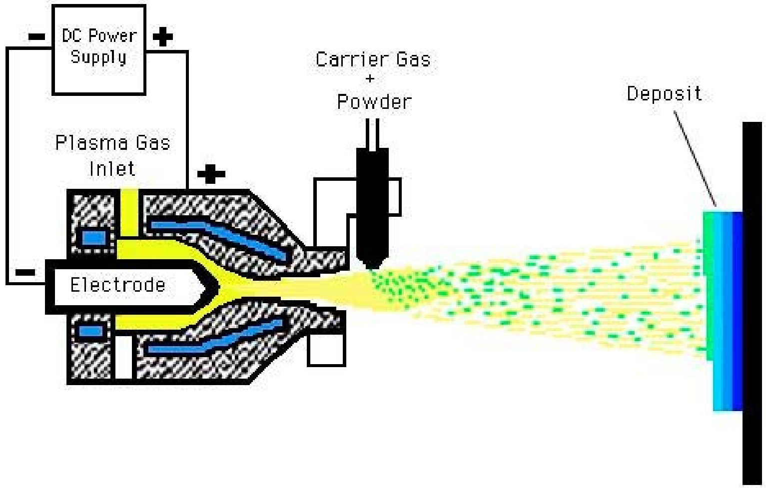
Why plasma spray not HVOF for IDs?

- HVOF is becoming accepted as the best alternative to OD chrome
  - But cannot coat IDs with HVOF
    - Requires minimum 11" ID to accommodate gun and stand-off
  - Logical and most cost-effective to use similar method for ID, done in same shop with similar equipment
- Therefore use plasma spray to get into smaller diameters and tighter locations

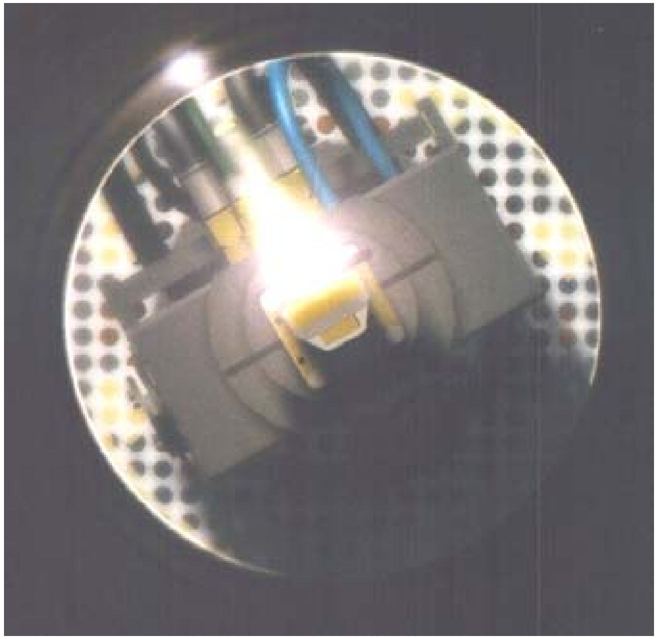
Difference between HVOF and plasma spray



- Plasma has
  - hotter heat source
  - lower particle velocity
  - shorter standoff
  - higher porosity coatings
  - lower adhesion strength



Technical approach



Sulzer Metco F210 ID gun

- Powder particles injected into plasma plume accelerate, heat, soften, splat onto surface
- Typical particle size - 50μm
- Typical coating thickness - 0.001" - 0.020"
- Hardness - 1,000 - 1,500 HV (EHC is 800 - 1,000 HV)
- Coating rate high - landing gear inner cylinder OD typically takes 20 min

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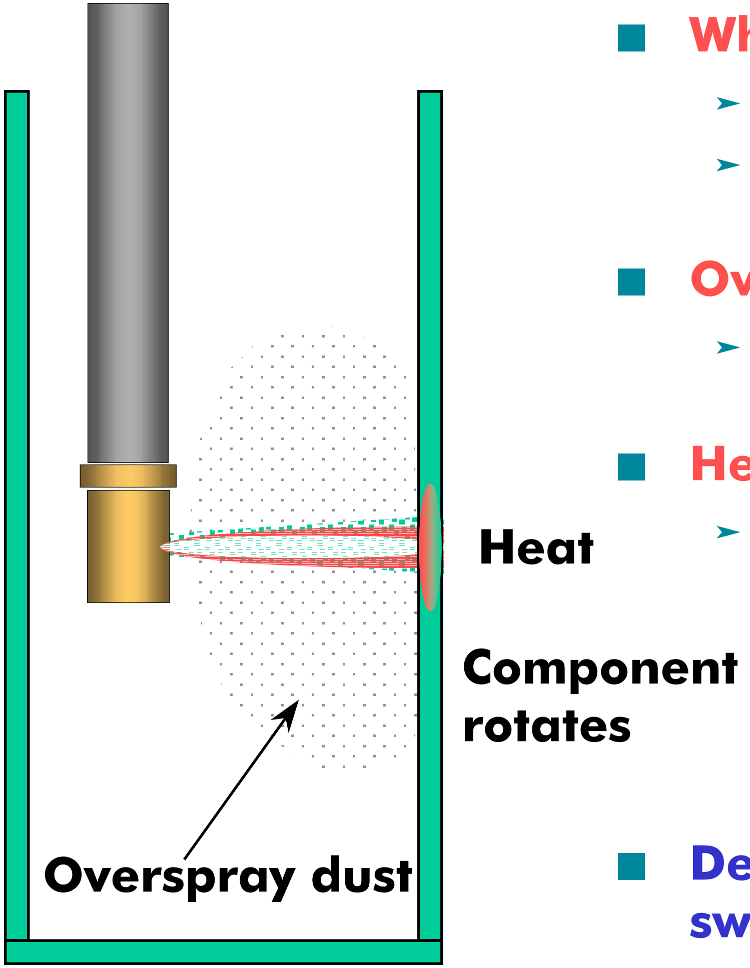
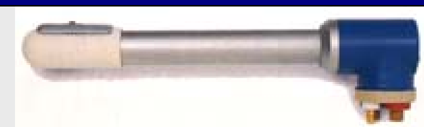
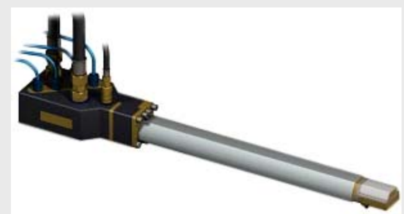
Critical issues



- What is smallest ID we can coat?
  - Smallest gun, standoff, best particles
  - Will small/nano particles permit higher quality at smaller standoff?
- Overspray dust incorporation
  - Porosity - worse in blind holes
    - additional gas flow to remove particles
- Heat removal
  - Overheat component
    - additional gas flow to remove heat
    - minimize plasma power
      - reduces powder overheating
      - allows smaller particles
        - less porosity, smoother
- Design internal gas flow to cool and sweep out particles

Equipment and powders under test

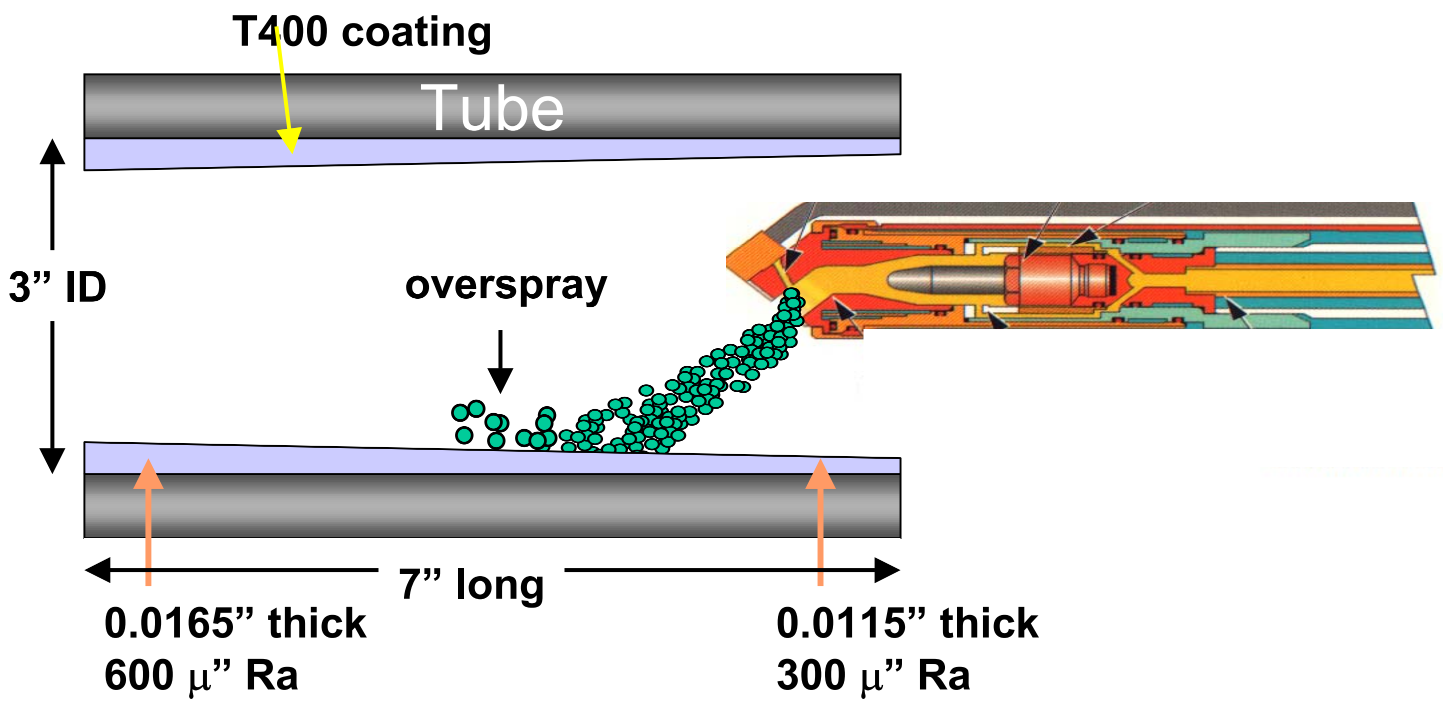
	Praxair-Indianapolis	Sulzer Metco	NRC
Equipment	 Praxair 2700 miniature gun 30kW, 1.5” ID	 Sulzer Metco F-100 20 kW 4” ID  Sulzer Metco F-210 12kW, 2.5” ID	All guns Characterize performance – velocity and temperature profiles Assistance to S-M and Prax  Sulzer Metco F300 9kW, 1.6” ID
Powder	Small particles T400, NiCrBSi alloys WC-NiCrBSi self-fluxing composite	Standard WC-12Co powders T400, self-fluxing composite?	All powders Optimize spray conditions Consider other materials
Issues	How best to remove overspray? Are small particles better? How small can we go with 2700?	Best conditions for large parts – landing gear outer cylinders How small can we go with F300?	Evaluate OSH issues, nanopowders Overspray removal, acoustic emission, microstructure

Sample holder for specimen spraying under ID conditions

Overspray removal

- The Sulzer Metco F210 gun uses several gas cooling jets that also serve to clear overspray from around the deposition region
- The Praxair 2700 gun has no additional gas jets as supplied
  - gas jet added

Spray with 2700 gun - effect of overspray incorporation if not blown away



- Tube rotates, spray head goes in and out
- Overspray incorporates into coating as go down tube

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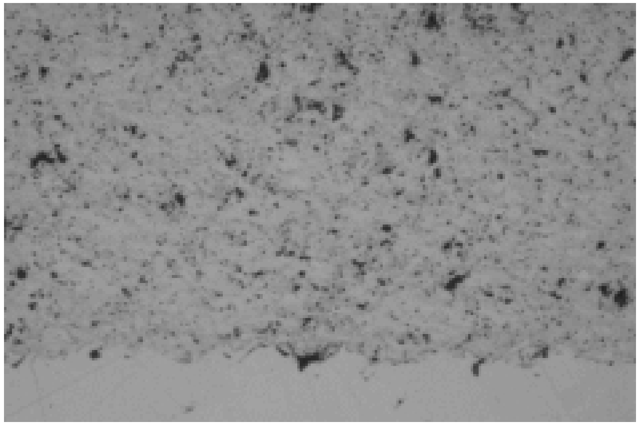
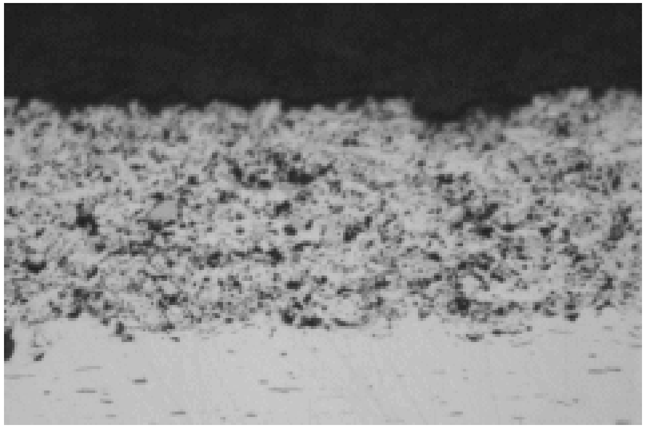
Effect of overspray incorporation - ID vs OD spray microstructure



WC-Co 38μm powder, 60° OD spray, 3% porosity



WC-Co 38μm powder, 60° ID spray, 9% porosity

- **ID spray has more porosity and is softer with the 2700 gun without overspray removal**

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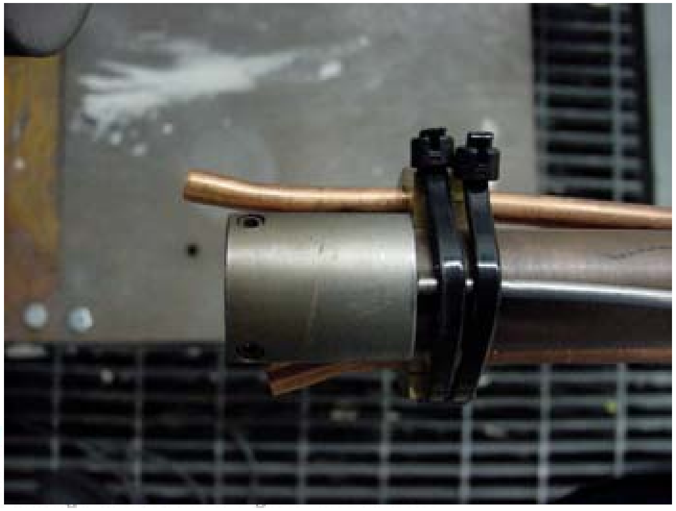
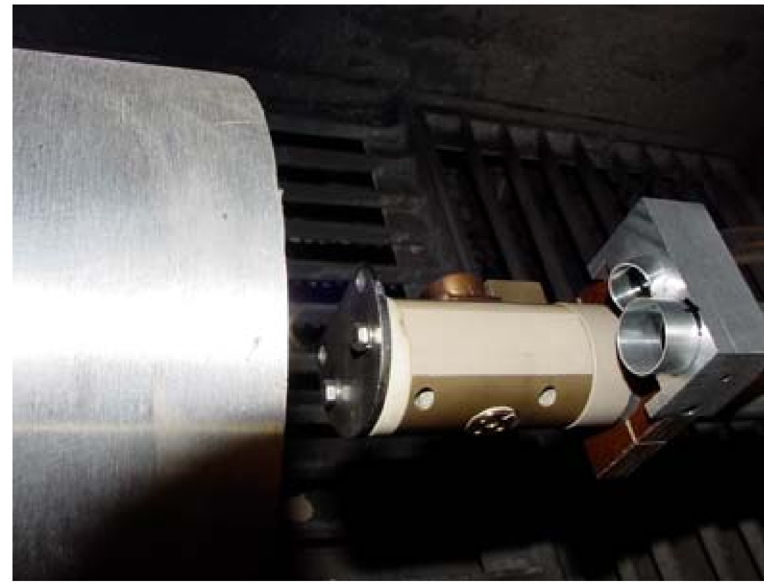
Solution under test

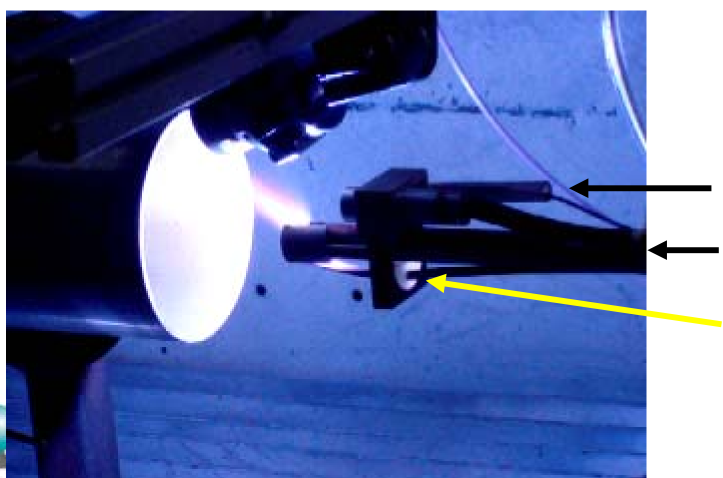


- Tube blows gas jet (Ar or air) to remove overspray from the area about to be sprayed
- However
  - How much gas should be used?
  - Where should the gas jet aim?

Overspray Monitoring Equipment

An optical sensor has been built at NRC to monitor the amount of overspray (dust in the air) in a volume near the spray jet inside a cylindrical tube while spraying. Uses existing, relatively large, optical hardware on the F-100 gun in a 6" diameter tube





optical system

gun

air jet

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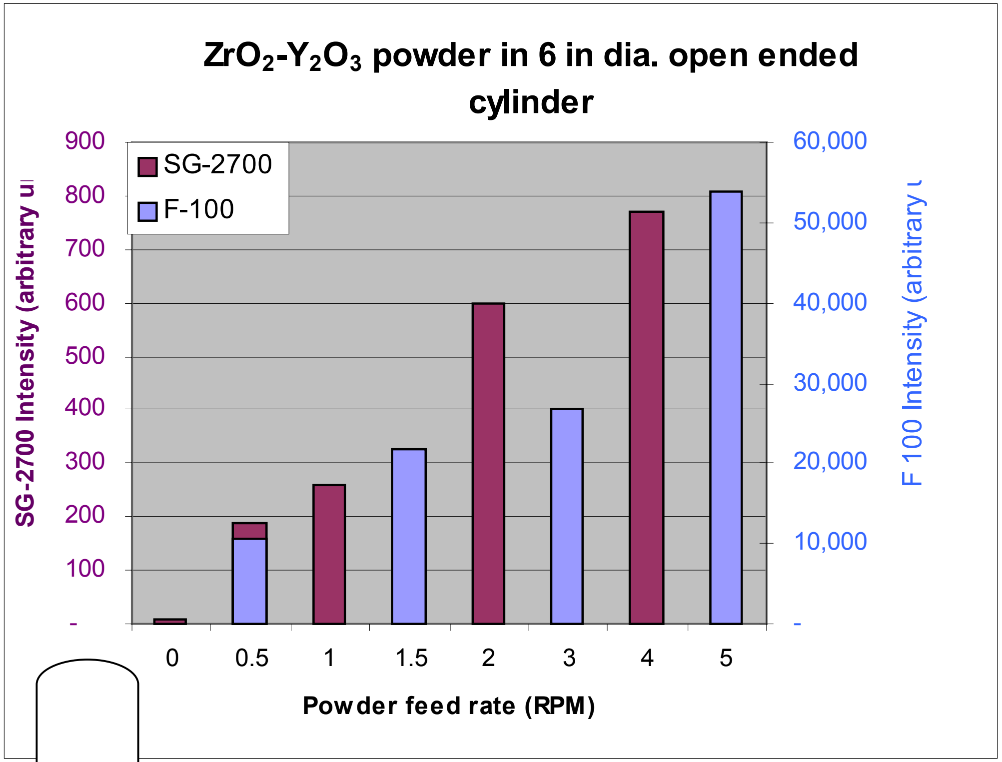
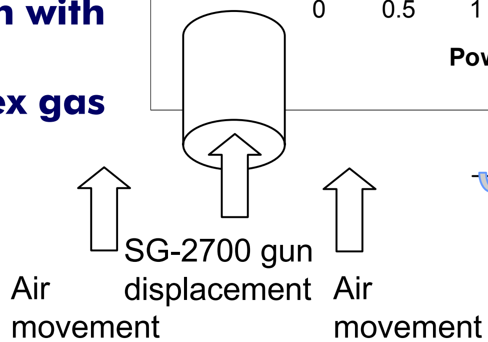
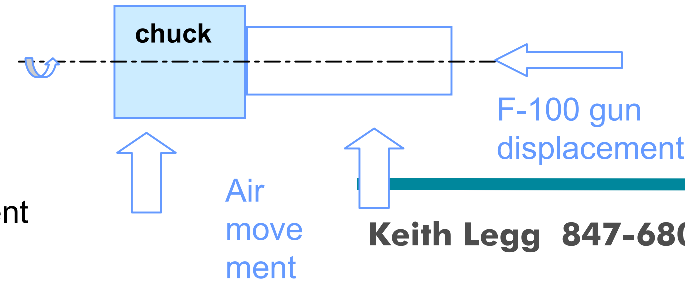
Monitoring of Overspray

- **Preliminary tests to assess viability of the sensor concept.**
  - **Show sensitivity to spray conditions (gun, powder) and powder feed rate (amount of powder being fed into volume)**
- **Two orientations**
  - **Left axis: SG 2700 gun with added air jet and parallel vortex gas flow**
  - **Right axis: F100 gun with no air jet and perpendicular vortex gas flow (std for OD)**







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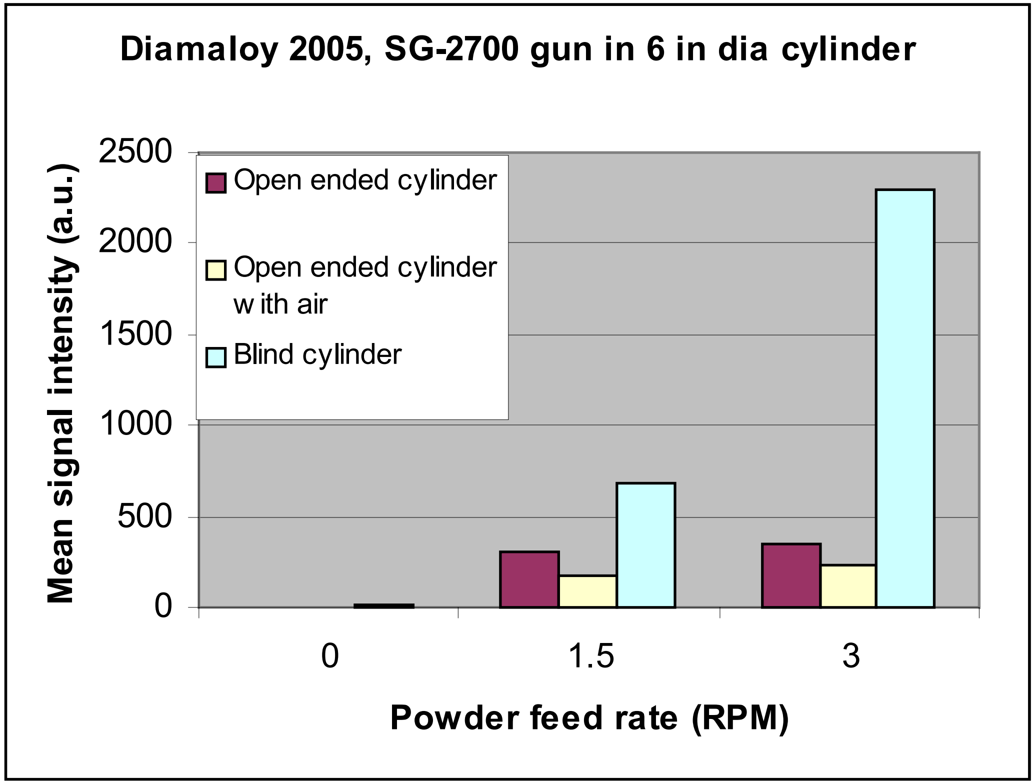
Monitoring of Overspray WC-17Co powder

- **The signal is sensitive to**
  - cylinder geometry
  - powder feed rate
  - presence of auxiliary air jets
- **Even for powder producing a low level of overspray the technique seems to be applicable**



Blind hole 10x open hole

Developments to be made in overspray monitoring

- Miniaturize the sensor head to apply the technique in a 3" ID
- Conduct tests to calibrate the signal
- Determine best approaches to overspray minimization
- Establish the best configuration for overspray removal system for the 2700 gun

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ID limits

- Despite claims on ID guns of coating down to 1.5" standoff for good quality is 1.5" - 2"
  - Means that, including gun diameter, practical minimum coating diameter is 2.5" - 3"
  - Therefore plasma spray is good for
    - landing gear outer cylinders (typically >6" ID)
    - utility actuators (typically >2.5")
  - Limited application for
    - flight surface actuators
    - dampers
    - lugs
  - Not for
    - landing gear and hydraulic pin IDs
    - position sensor IDs on inner cylinders

Small particles and nanoagglomerates

- Extensive searching by NRC has found no truly commercial WC-Co nano-powder on market
  - Only lab-scale quantities available, some companies no longer supply it (or even in business)
- Published data show highly variable results, none particularly exciting
  - Properties generally worse than standard material
    - WC tends to dissolve into matrix, forming alloy
- Sulzer Metco data shows similar results
- Nanopowder removed from consideration
- Powder in range 20-40μm works well
  - Small powder harder to feed

Coating quality

- Major initial concern over porosity
  - High porosity will permit leakage, especially in gas-over-fluid landing gear systems
  - Would like to avoid use of sealers
- Hardness not as important since most ID coatings see fairly benign wear environment
  - HVOF testing has shown importance of fracture strength
- All test coatings have been done in 3” ID tube

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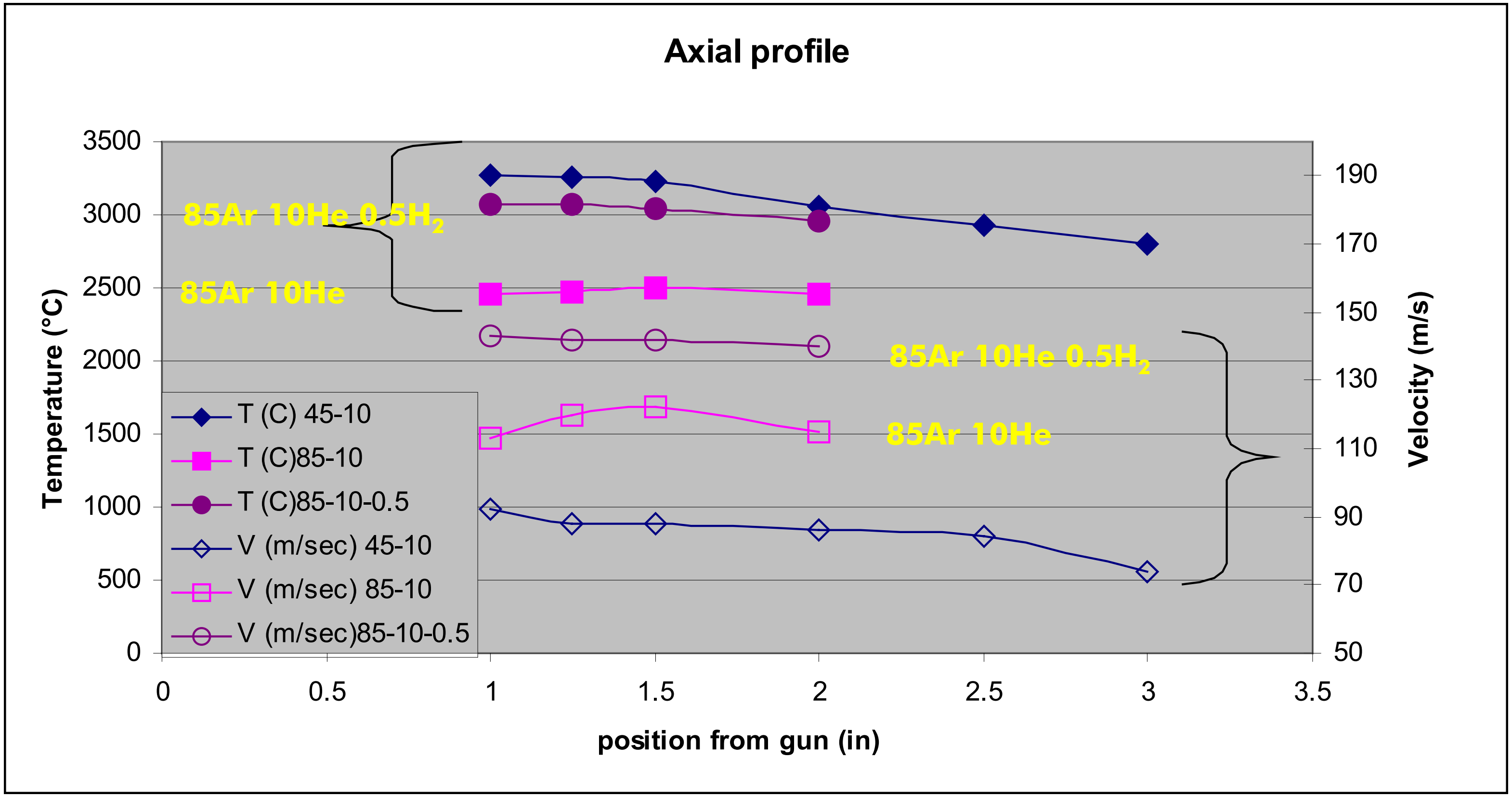
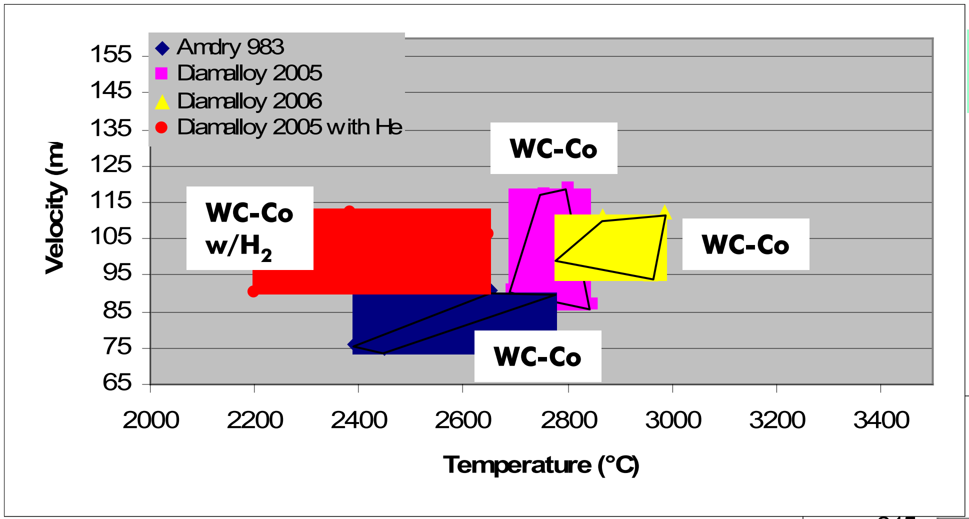
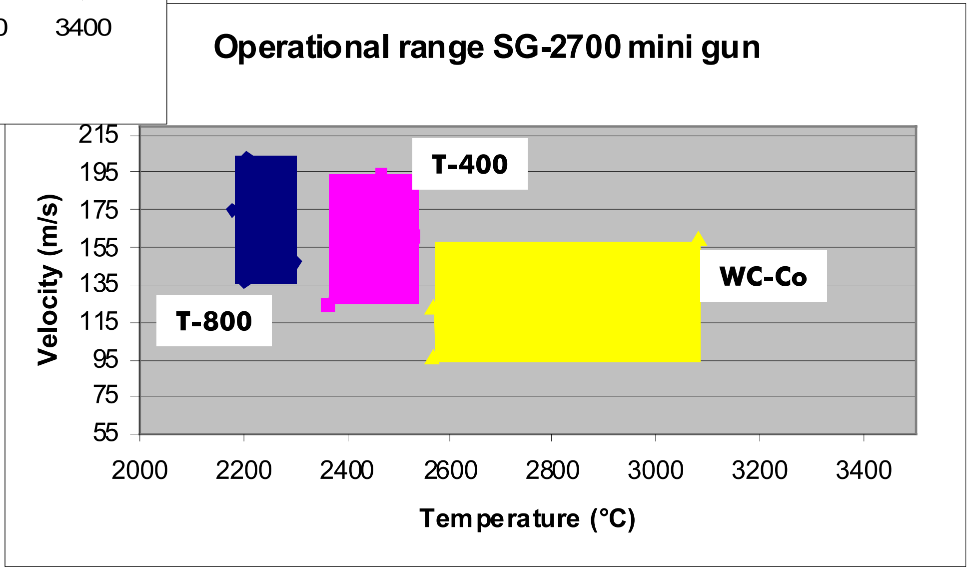
Effect of adding hydrogen



Typical operating ranges



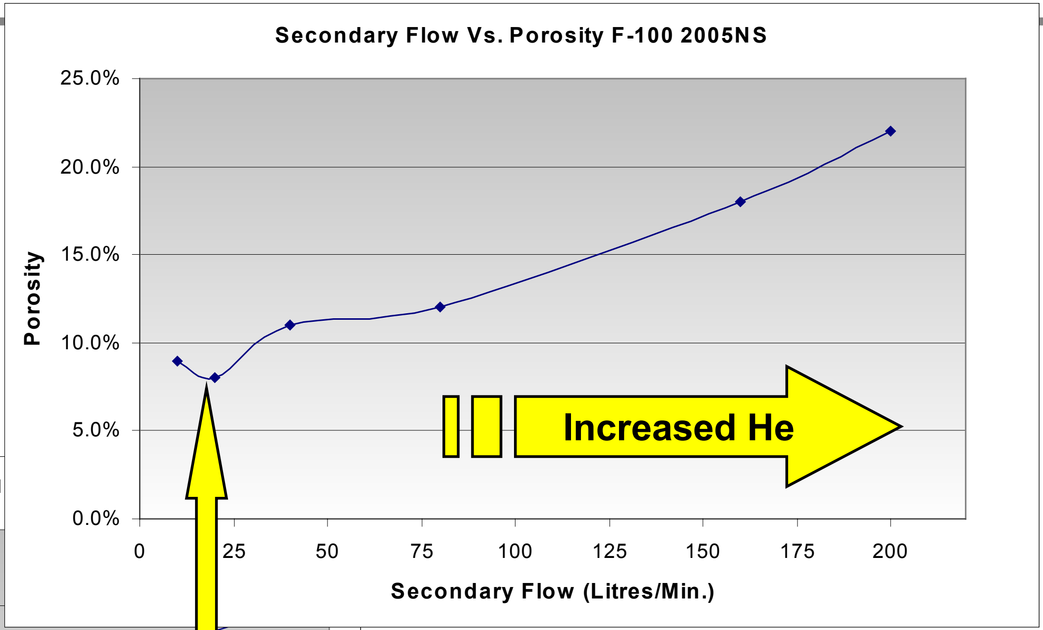
Sulzer Metco F100 gun

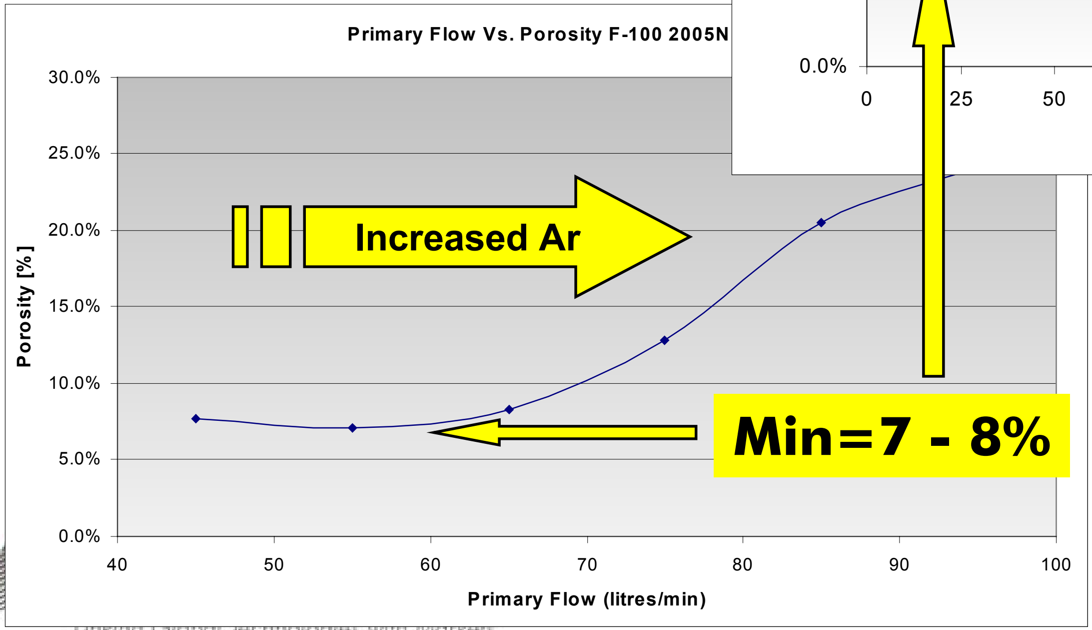


Praxair 2700 mini-gun

Initial data - effect of Ar and He flow - F-100 gun

Optimum operating ranges found for Ar, He, H_2



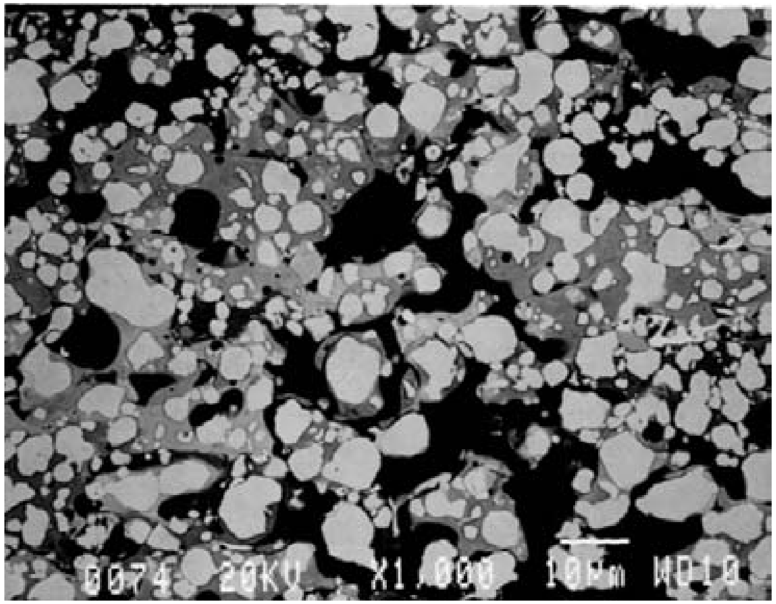


No matter what you do with the most common powders, you cannot get porosity below 7-10%

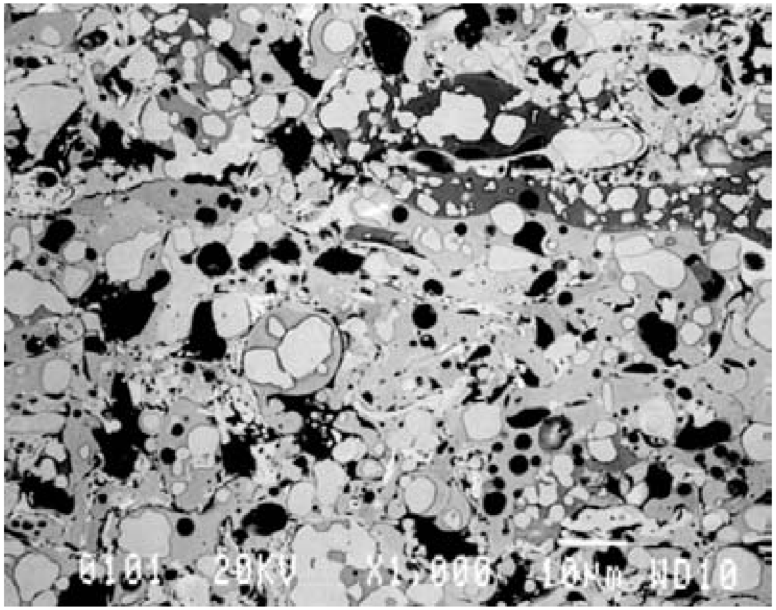
WOULD REQUIRE SEALERS

CAN WE GET IT BETTER?

Typical WC-Co microstructures F-100 gun



19.9% porosity
Ar(85) He(10) condition



8.3% porosity
Ar(85) He(10) H_2 (0.5) condition

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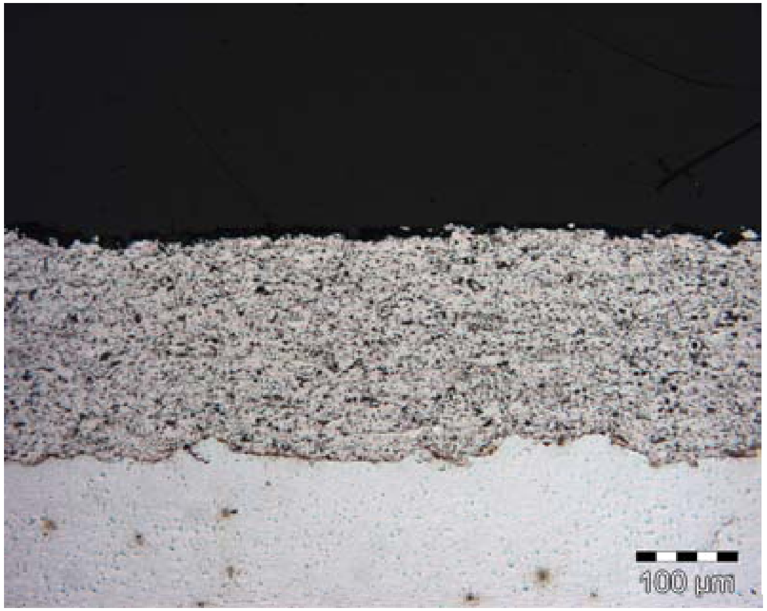
WC-Co optimization (Sulzer Metco)

Powder Number	Chemical Composition	Particle size range	Manufacturing method
D 2006	WC-17Co	-30 +5.5 μm	Spray died and sintered
D 2005NS	WC-17Co	-53 +11 μm	Spray died and sintered
M 73F	WC-17Co	-53 +11 μm	Spray died and sintered
SM 5843	WC 10Co 4Cr	-45 +11 μm	Sintered and crushed
SM 5847	WC 10Co 4Cr	-53 +11 μm	Agglomerated/Sintered
D 2002	(WC 12Co) 33Ni 9Cr 3.5Fe 2Si 2B 0.5C self-fluxing	-45 +11 μm	Blend
SM 5803	WC 12Co 25(Ni base super alloy)	-45 +11 μm	Blend
M 439NS	(WC 12Co) 33Ni 9Cr 3.5Fe 2Si 2B 0.5C	-63 +15 μm	Blend
M 439NS-2	(WC 12Co) 33Ni 9Cr 3.5Fe 2Si 2B 0.5C	-90 +15 μm	Blend
D 2003	W_2C/WC 12Co	-45 +5.5 μm	Fused
SM 5810	WC 12Co	-63 +11 μm	Spherical Composite
A 9830	WC 17Co	-53 +20 μm	Spherical, Agglomerated and densified
D 5848	WC 10Co 4Cr	-45 +11 μm	Spray dried and Sintered
D 5826	WC 17Co	-45 +11 μm	Spray dried and Sintered

ID coating alternative materials

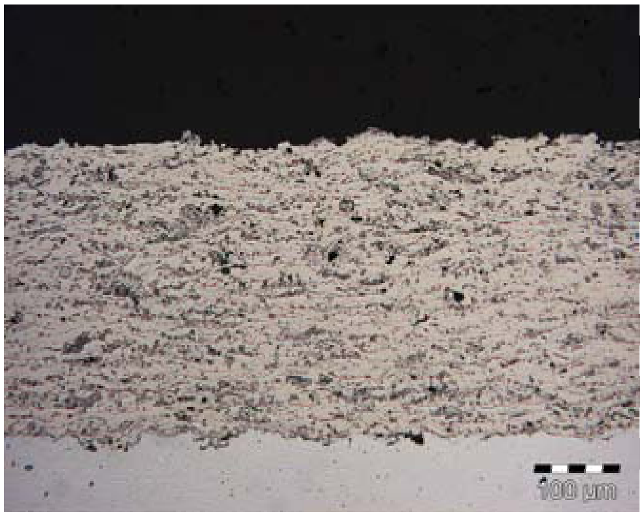
- We have settled on a list of materials as a result of ID spraying experience
- WC-12Co (fused powder)
  - WC-Co now used on production landing gear and hydraulics
  - Much better wear resistance than Cr
  - Fairly easy to spray
  - Fused powder for low porosity coatings
  - Fracture strength may be an issue
- T-400
  - Widely used in GTEs
  - On hydraulic rods - not as wear-resistant as WC-Co, but better than Cr (Green, Tweed tests)
  - Lubricious - can use on both outer cylinder ID and piston head OD
- WC-50(NiCrFeBSiC) self-fluxing
  - Very low porosity
  - Intermediate hardness

WC-12Co (Diamalloy 2003)

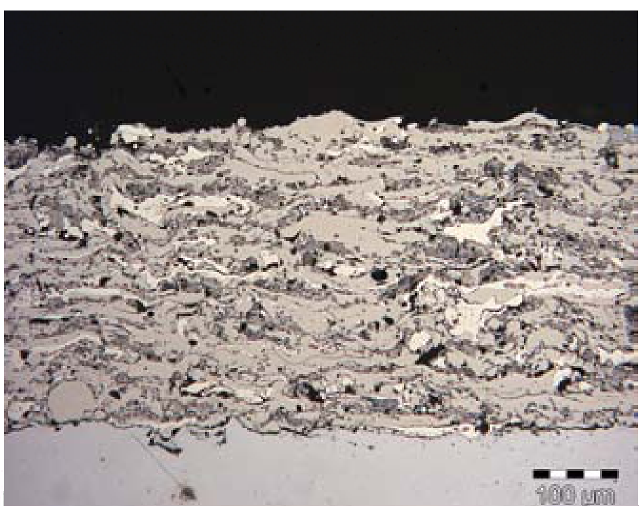


- Porosity: 2.1%
- Macro hardness: 85.8 HR15N
- Micro hardness: 833 HV 0.3
- Microcracks
  - EHC also microcracked
- No delamination
- Probably acceptable

Diamalloy 2002 self-fluxing

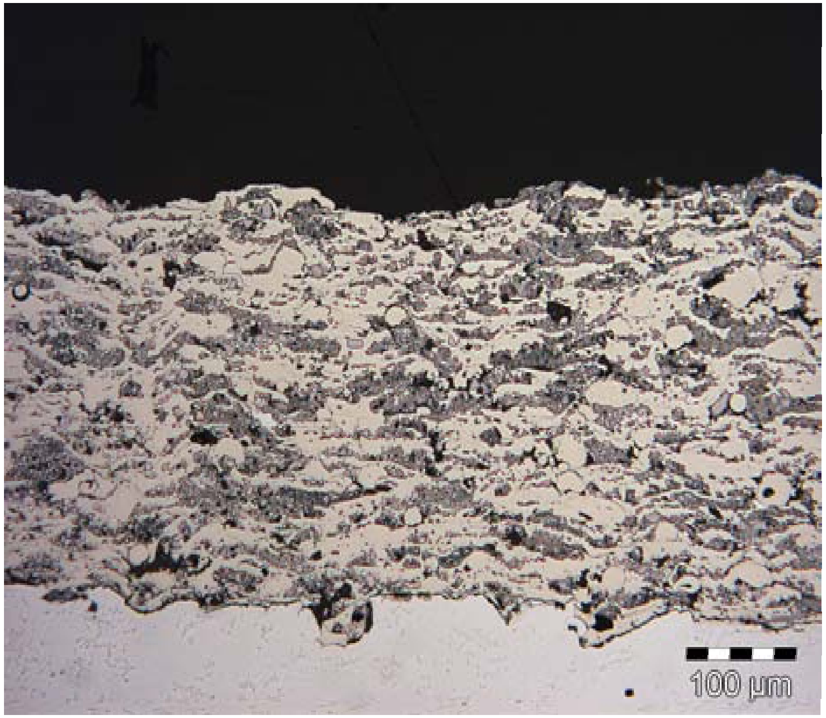


- Microstructure sprayed on 3″ ID
- Porosity: <1%
- Macro hardness: 83.9 HR15N
- Micro hardness: 609HV 0.3
- No cracks, no delamination
- Better porosity



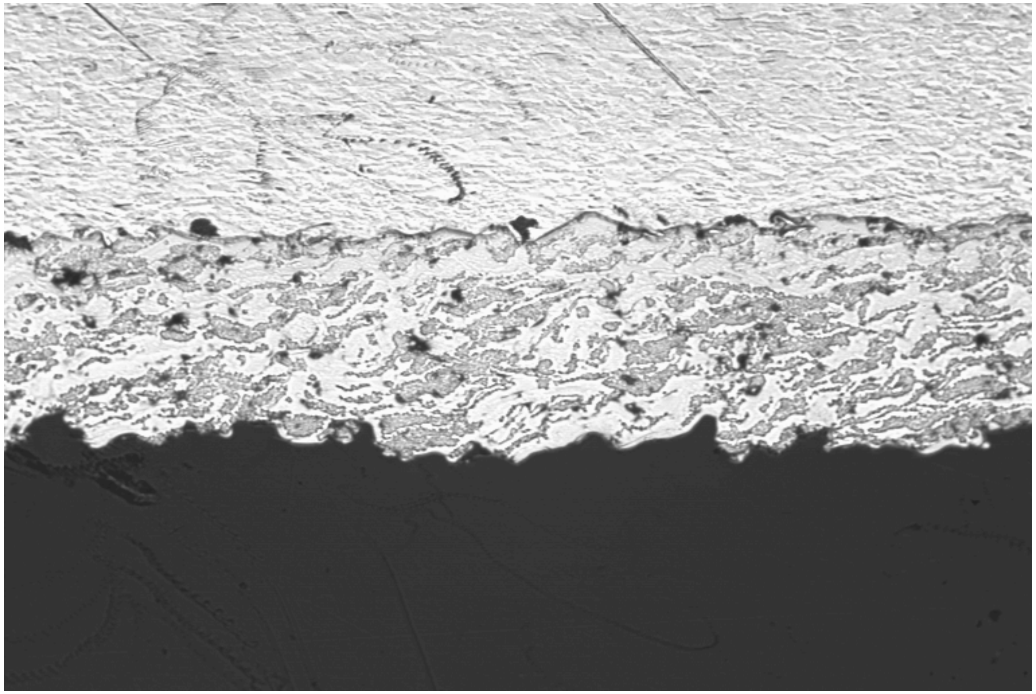
- Microstructure sprayed on 3″ ID
- Porosity: 2.3%
- Macro hardness: 81.9 HR15N
- Micro hardness: 707 HV 0.3
- No cracks, no delamination
- Better hardness

Diamalloy 439 self-fluxing



- Microstructure sprayed on 3" ID
- Porosity: 1.8%
- Macro hardness: 77.2 HR15N
- Micro hardness: 528 HV 0.3
- No cracks
- Partial delamination
- Unacceptable

TAFA 1334F self-fluxing material



- Hardness 770HV
- Low porosity
- Good adhesion
- Note: ID Plasma WC hardness
  - 500 - 800 HV
  - vs 1,000 - 1,200 HV for HVOF
  - Not as wear-resistant but not a serious issue

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Tribaloy 400 with Praxair 2700 gun (no overspray removal)

Parameter	Value
Surface speed	2400 in/min
Feed rate	18 gm/min
Standoff	2”
Torch head	30° to normal
Results	
Metallography	Homogeneous with dispersed porosity
Hardness	415 HV 300 gm
Almen residual stress	+0.003” tensile
Average bond strength	8,200 psi
Surface roughness	300 μ” Ra entrance end 600 μ” Ra exit end

Current status

- Good microstructural quality coatings demonstrated on 3" IDs with good spray rate
- SM-F100, SM-F210, Praxair 2700 guns characterized for process envelope
- T400, WC-Co fully optimized
  - ready for testing
- Self-fluxing material almost optimized
- "Fumespector" laser dust density measurement system developed and tested
- Test coupons about to be sprayed and tested for
  - metallography, adhesion
  - corrosion, erosion, wear, fatigue

Conclusions

- So far plasma spray appears to be a good way to coat IDs > 2.5″ or 3″
  - Method is fast (can spray large area in short time)
  - Can produce quite hard, low porosity material
  - We can control the overspray with proper gas jet design
- Heat removal still to be determined
  - Hardness tests on ID-coated specimens
- Performance to be measured in next 6 months
  - Corrosion, wear, fatigue