ROWAN TECHNOLOGY GROUP
Linking Global Technologies with Markets

Replacing Chrome on Internal Diameters

Gorham Conference on Advanced Coating Systems for Gas Turbine Engines and Aircraft

March 1999

(Based on Technology Analysis for JSF)

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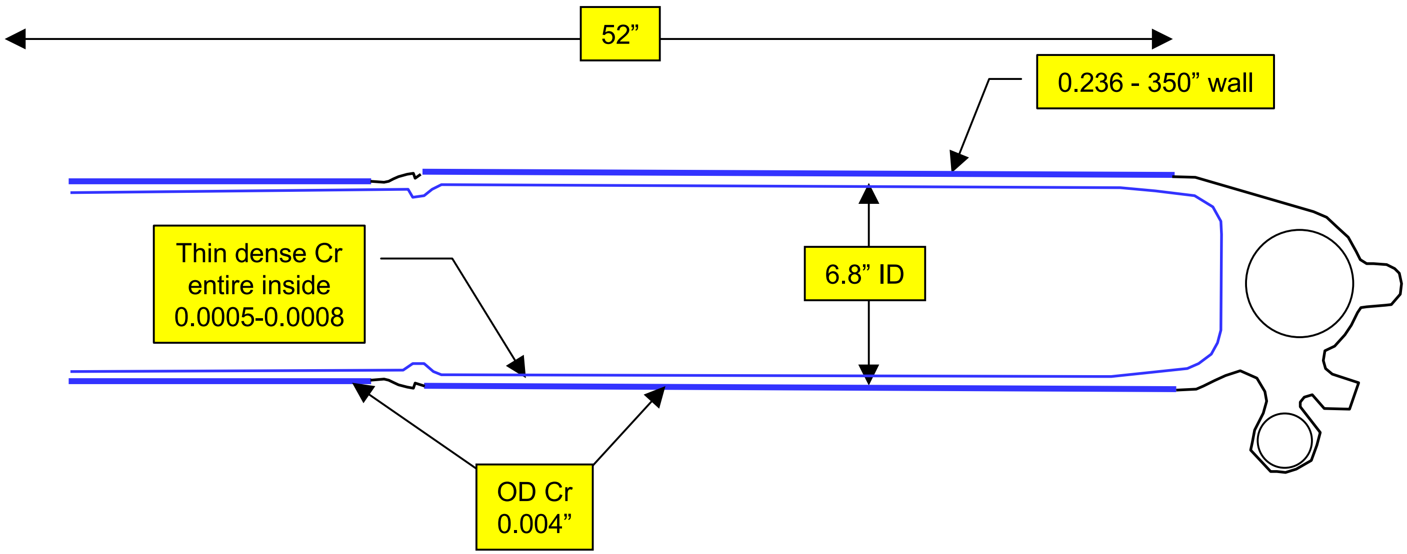
ID chrome replacement

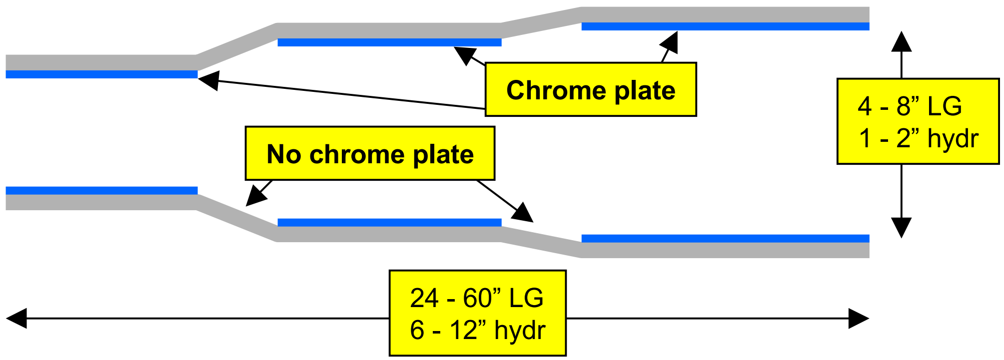
- Where do we use ID chrome and why?
- Requirements for ID chrome
- ID chrome alternatives discussion
- Best bets

Examples of ID chrome use



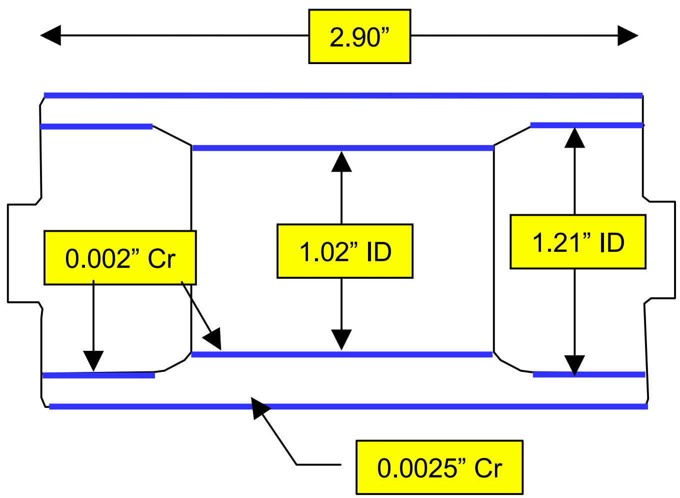
- **Landing gear actuator inner cylinder - 300M high strength steel**
  - **Note thin and thick coatings**
  - **Note large size**

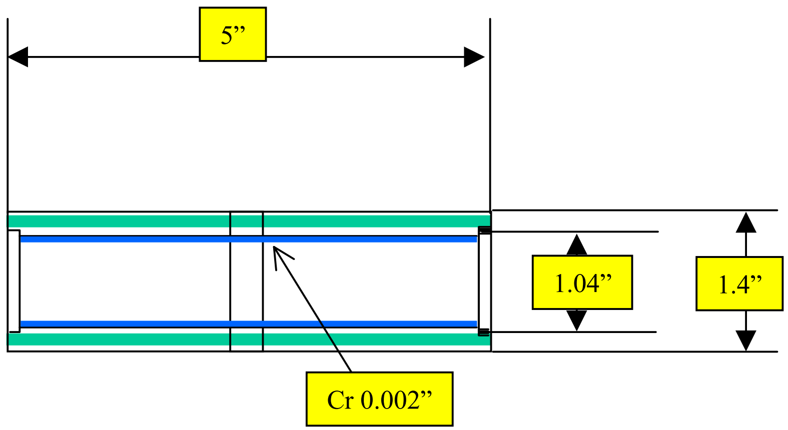
Examples of ID chrome use



- **Typical landing gear outer cylinder**
  - **Note internal shielding needed**

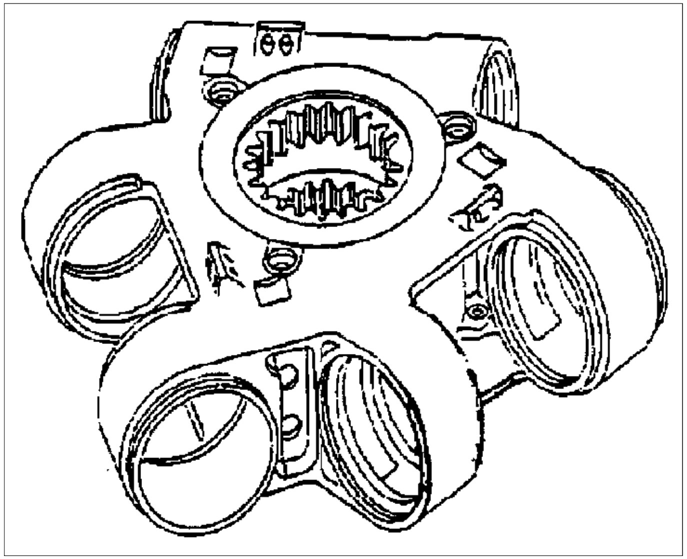
Examples of ID chrome use



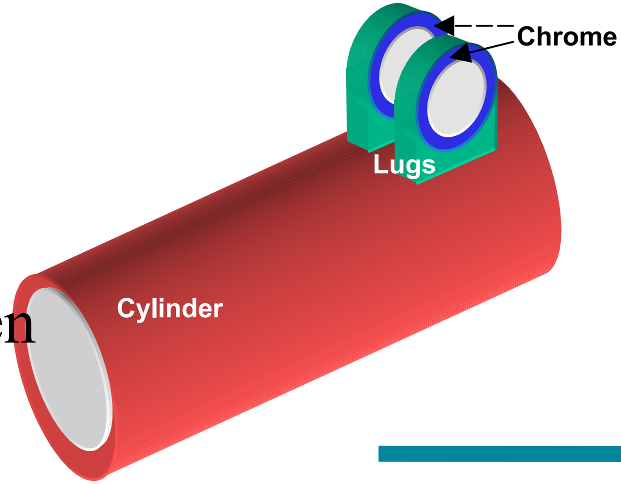


- Shock strut piston pin - Messier Dowty
  - Note depth, dia, shielding
- F-18 NLG torque arm pin - Boeing
  - Note depth, dia

Examples of ID chrome use



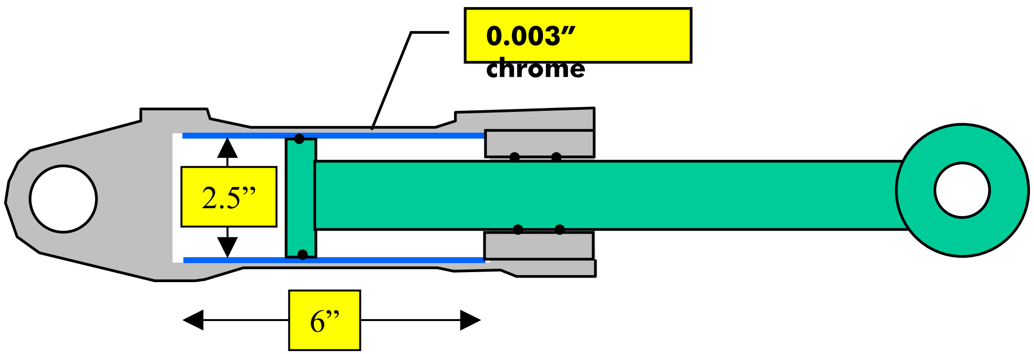
- **Helicopter rotor head - PH13-8Mo**
  - **Might just be done with standard gun, but note angles**



Landing gear lugs

Problem is flat faces between lugs

Examples of ID chrome use



- **Aileron servo - 4340 high strength steel**
  - **Note small ID, thin walls**

OD vs ID chrome

OD chrome

- Usually 0.003" OEM
- Exposure to outside - abrasion, corrosion
- Rebuild - 0.015"
- Easy to grind

ID chrome

- Often 0.0003" OEM thin dense chrome
  - often outside vendor
- Usually protected from outside - less rigorous corrosion/wear
- Rebuild 0.010"
  - spans wider thickness range
- Avoid grind if possible

General ID coating requirements

- All of the same requirements as for OD chrome replacement

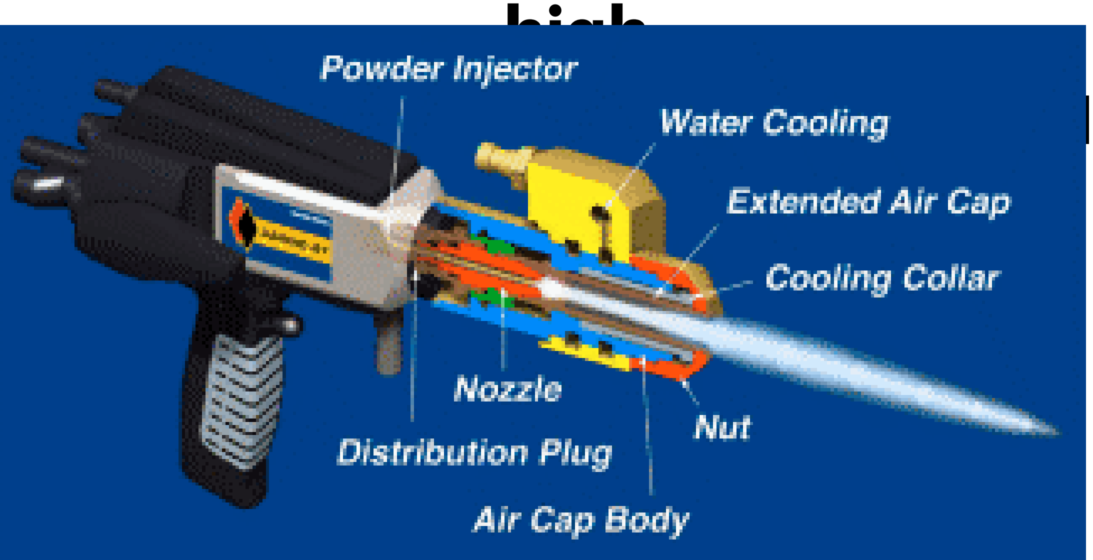
PLUS....

General ID coating requirements

- **Size** - blind or through; pins 1" IDx5"; actuators ≥1" IDx ≤24"; landing gear 3-15" IDx 60"
  - Heat and particle removal critical
- **Thickness** - 0.0003 - 0.020" as-deposited
  - Very broad range
- **Surface finish** - 16μ" Ra, 4μ" in some cases
  - Should not have to grind
- **Temperature** - <250C steel, <150C aluminum
- **Inspection**
  - How do QA, QC inside bore?

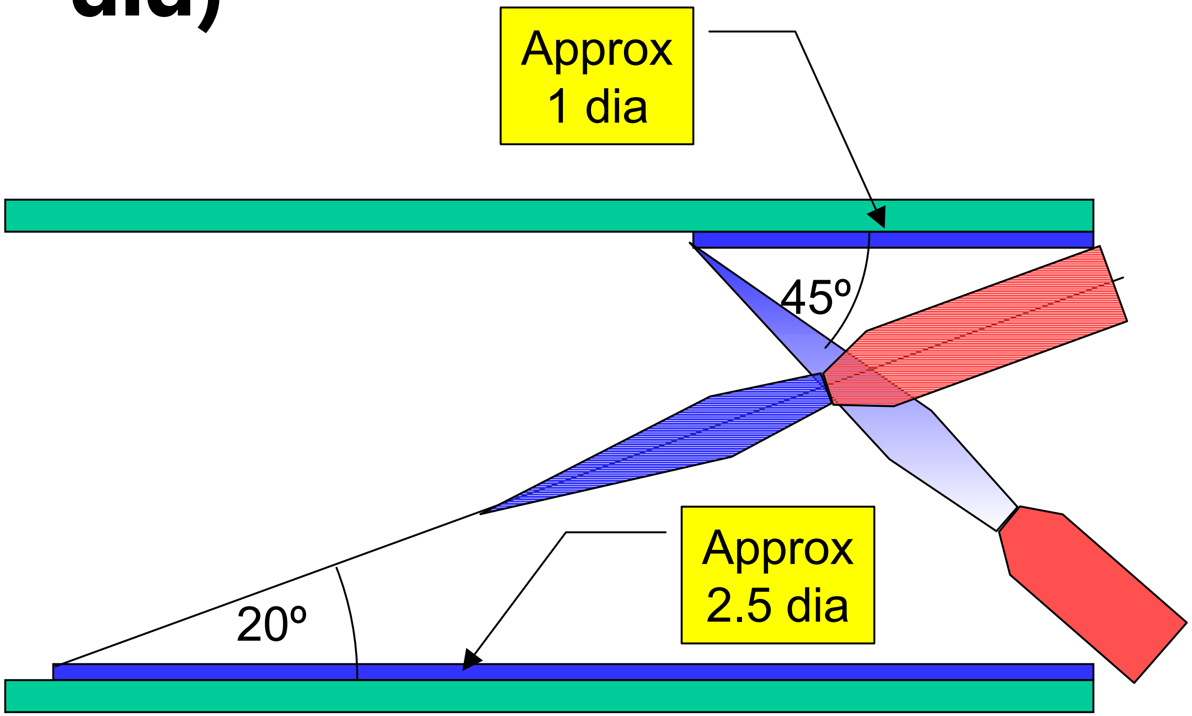
ID chrome alternatives

- Why not HVOF?
  - Minimum HVOF internal diameter 11"
    - Guns large
    - Power density in flame low, but total heat high
    - large ID

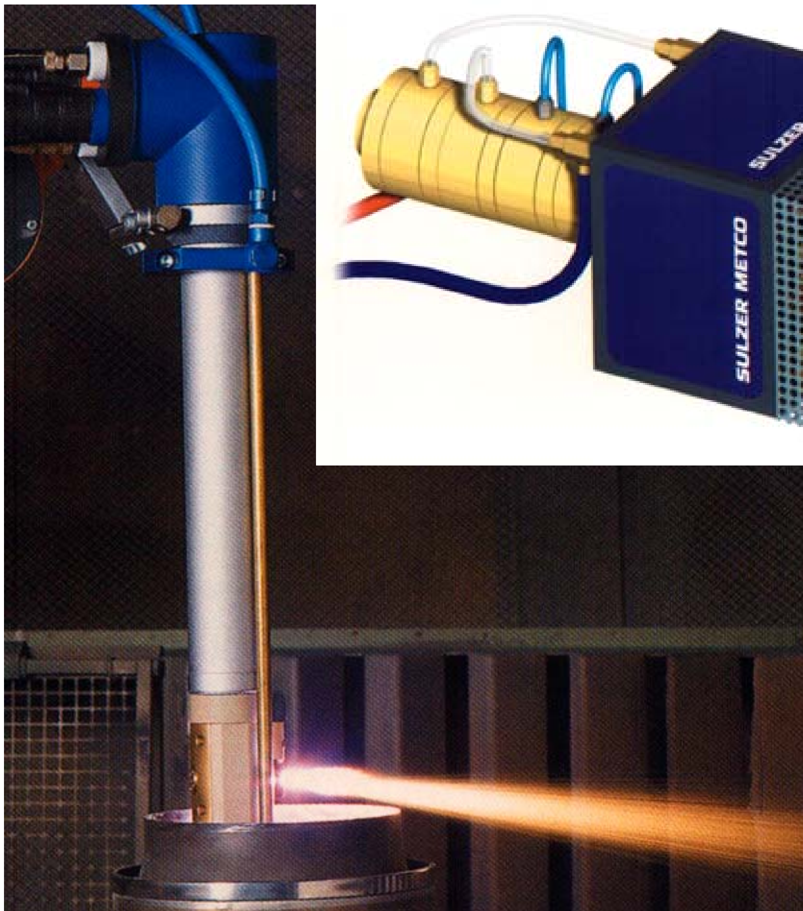


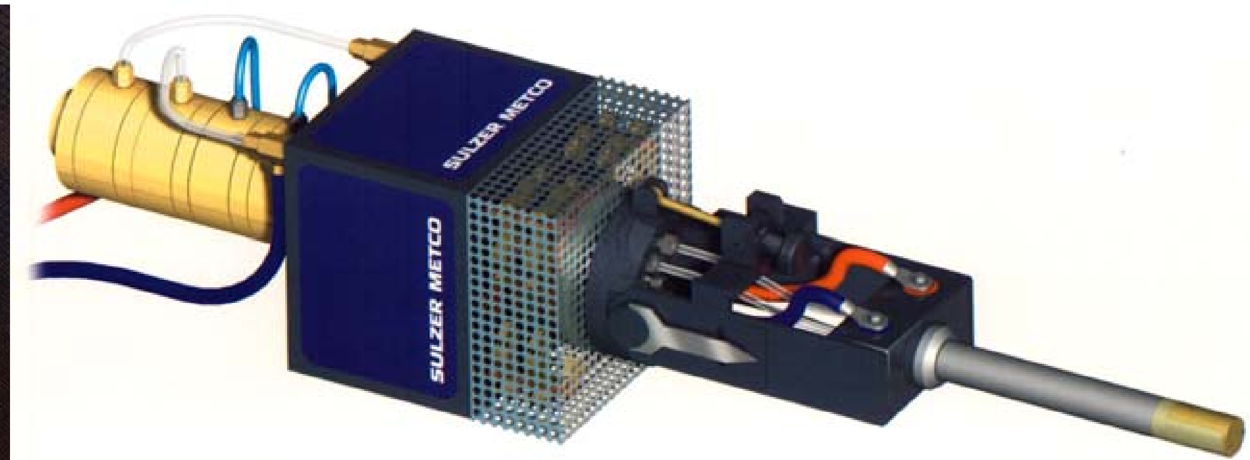
Where can HVOF be used?

- Depth ≤ diameter
- In some cases can go to 20° angle (2 dia)



Other thermal spray - plasma spray





- **ID plasma spray for diameters > 3″**
  - **Some guns to 1.5″, but more difficult**

Plasma spray for IDs

- ID>3" fairly easy, some guns >1.5"
  - Will easily fit most landing gear hydraulics
- Plasma coatings more porous than HVOF
  - Leakage in high pressure gas-over-fluid systems (e.g. landing gear)
- Heat removal
- Dust storms in blind holes

Other ID plasma spray issues

- Size - how small a diameter can we coat?
  - Higher plasma power density than HVOF
    - shorter stand-off (smaller ID)
- Can we replace thin dense Cr?
  - Surface finish
  - Thickness
- Smaller particles may solve problems
  - Lower porosity, less heat required, higher surface/volume ratio, shorter

ID plasma spray

Pros

- OEM and rebuild
- Good wear and fatigue performance
- Similar process and material to HVOF
  - easier approval
- No embrittlement

Applications: ID>3", rebuild

Cons

- Heat removal
- Overspray entrapment
- Porosity, roughness, minimum thickness
  - may be improved by small particles

Other ID methods - Electroless Ni-P, Ni-B

- Quite wide use - FAA, manufacturer specs
- Control and reproducibility difficult
- Composites difficult to maintain, keep uniform
- Heat treatment - up to 400C
  - Better hardness, wear
  - Worse corrosion, ductility
- Hydrogen embrittlement?

Other ID methods - Electroless Ni-P composites

- Include particles to change properties
  - Diamond, SiC, Cr_3C_2
  - Teflon
  - Combined SiC + PTFE (hydraulics)
- Wider range of properties available
- Difficult to ensure uniformity
- Problems holding in suspension
  - Especially O&R discontinuous use

Other ID methods - Electroless Ni-P, Ni-B

- Toxic 17 - Next against the wall after Cr
  - Problems with soluble Ni salts, dust
  - Southern Ca Air Quality Management District recommended adding Ni and Ni salts in general to Rule 1401 Feb 12, 1999 - New Source Review of Toxic Air Contaminants
    - Rule specifies maximum cancer risks, etc., making permitting more difficult
  - NAMF Ni Defense Fund

Electroless Ni

Pros

- OEM and rebuild
- Excellent uniformity in IDs, any aspect ratio
- Already approved for some applications
- Similar process and material to Cr plate

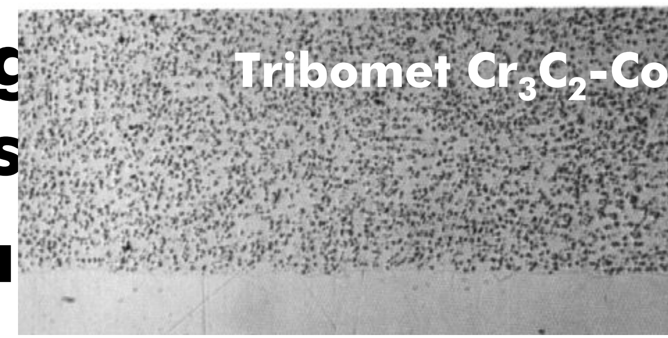
Applications: EN FAA ID repair;

Cons

- Toxic 17
- Control difficult
- Thickness <0.002"

Other ID methods - Electroplating

- Co-based composites (e.g.Praxair Tribomet)
  - In use - primarily for eng
    Cr on some hydraulic IDs
  - Smooth finish (1-2μm Ra
  - 300-450HV
  - 750HV after 900C heat treat
  - Composites difficult



- Alloy plating? (e.g. Ni-W, Co-W-B)
  - Generally not easy to plate

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Electroplates

Pros

- OEM and rebuild
- Already approved for some applications
- Similar process to Cr plate

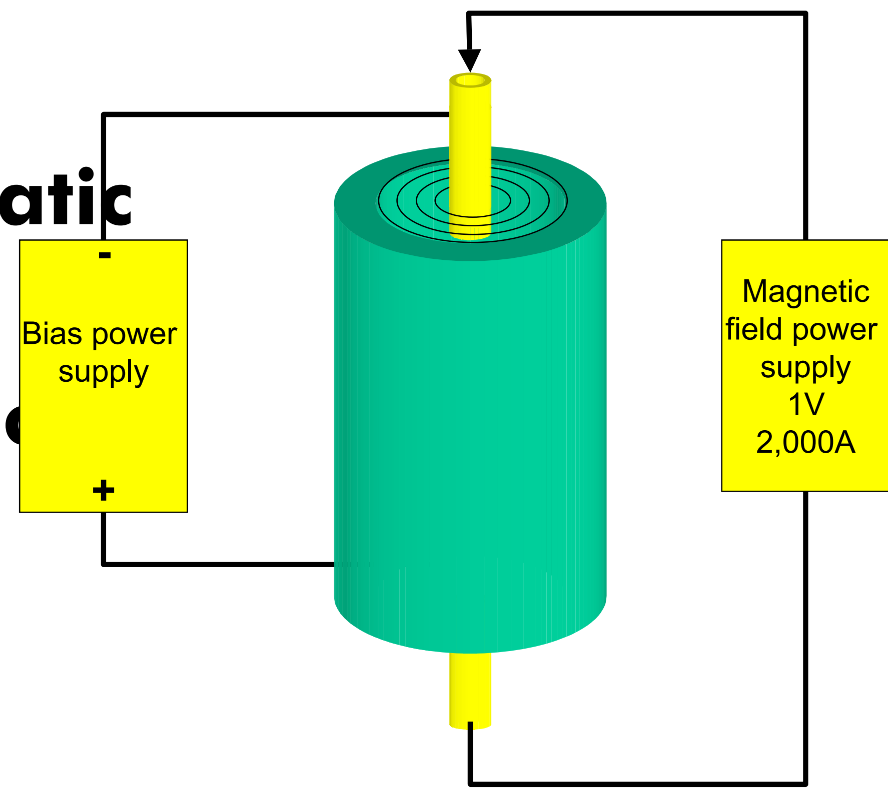
Applications:
Hydraulic IDs (Tribomet)

Cons

- Control of particles difficult, especially for O&R
- High temperature heat treat
  - May not be needed for Cr replacement

Other ID methods - linear magnetron PVD

- Open ended only
- Down to 1" ID
- Ion cleaning problematic
- TiN good for OEM
  - Typically microns thic
- Rebuild
  - Is it cost-effective?
  - Metals, alloys
- Surface Solutions only manufacturer



PVD

Pros

- Very good hardness, smoothness, adhesion

Applications: None yet, being tested for gun barrels (Ta)

Cons

- Vacuum complexities, costs
- High capital cost
- Not really suitable for rebuild
- Through holes only
- Slow deposition rate
- Ion cleaning essential but difficult

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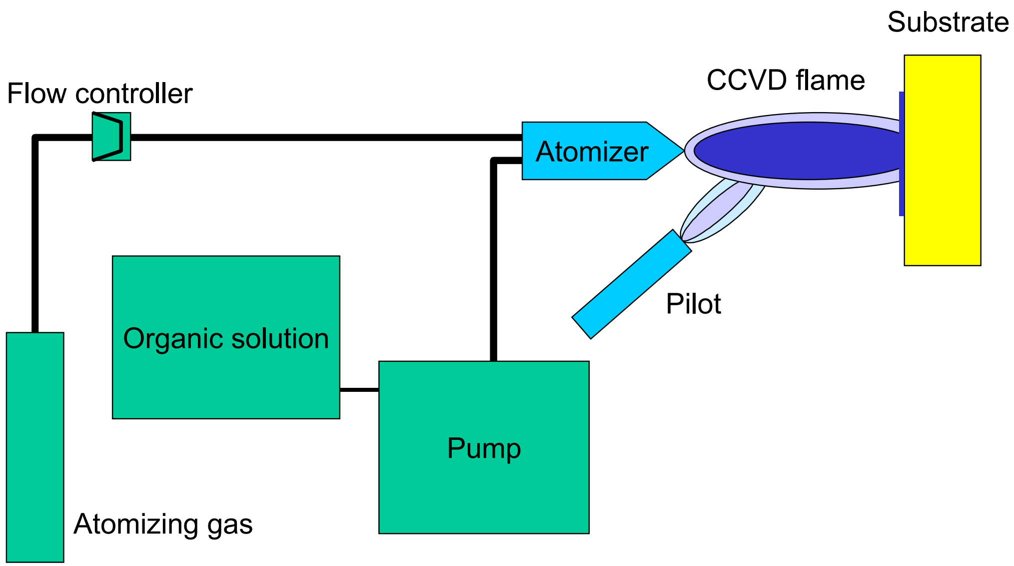
Other ID methods - CVD

- Combustion CVD?? Data not available
  - Best for oxides - brittle
  - Probably not for rebuild
  - Avoids toxic precursors, high te



Combustion CVD

Pros

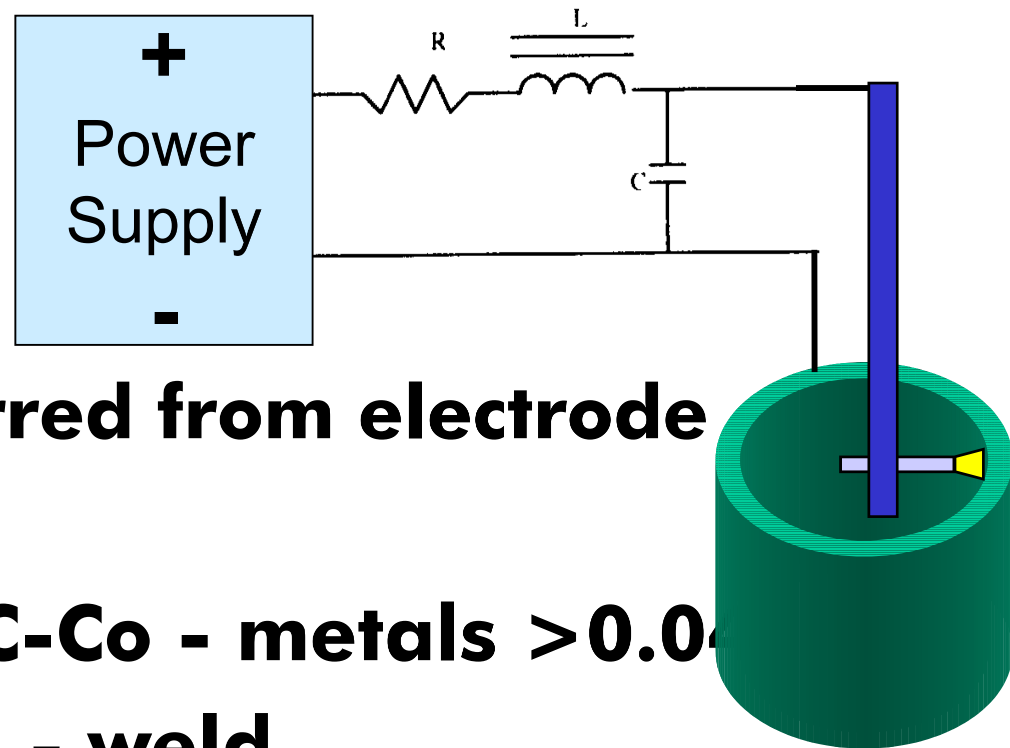
- Simple
- Low capital cost
- Avoids most CVD toxicity complications

Applications: None on IDs at present

Cons

- No data available, but lots of hype
- Primarily oxides (brittle and softer than most carbides)
- Early in development cycle

Other methods - Electrospark Deposition (ESD)



- Microarc welding
  - Material transferred from electrode
- Down to <0.5" ID
- 0.002" limit for WC-Co - metals >0.0
- Excellent adhesion - weld
- Small heat-affected diffusion zone
  - Fatigue effects?

Electrospark deposition

Pros

- OEM and rebuild
- Simple to use
- Very small IDs, large aspect ratios
- Low capital cost
- Excellent adhesion

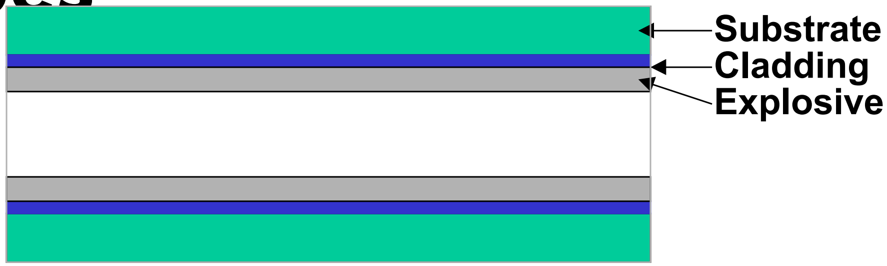
Applications: Under evaluation for aircraft; some nuclear tubes

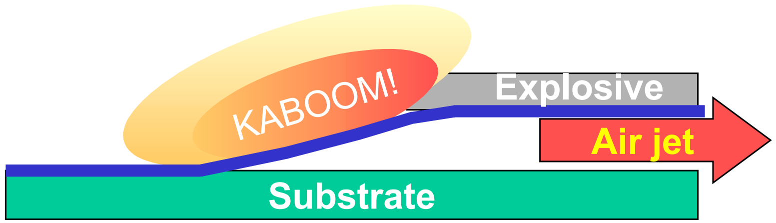
Cons

- Slow and expensive for large IDs ($5+/sq in)
- Heat-affected zone
  - uncertain fatigue
  - probable tensile stress
- CTE mismatch cracking may occur

Other methods - Explosive bonding

- Controlled explosion welds almost any 2 metals (e.g. Sigmabond)
  - Control to prevent wavy interface
- Good for simple shapes
- Unknown stresses
- Not for general use
- May be some specific applications





Explosive bonding

Pros

- Lots of fun!
- Very thick surface layers for repair
- High "deposition rate"

Applications: None yet; could use for repair of simple shapes

Cons

- Not for general use
  - possibility of "repair kits"
- Unknown effect on substrate (especially stress)
  - concern over crack propagation

Another ID alternative

- Don’t coat!
  - Use better underlying material
    - fine if problem is corrosion
    - cannot be done on expensive parts if wear is the problem, as no rebuild possible
    - there are now new steel design methods for rapid development, but approval is problem

Summary of ID alternatives

- Electroless Ni - very short term, but stopgap
- Co-based electroplates - short term
- Plasma spray - short term
- Electrospark - short term +
- Small particle/nanospray - intermed. term
- Linear magnetron PVD - intermed. term, limited use (probably no rebuild)
- Combustion CVD - long term, if at all

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Summary of ID alternatives

Technology	Principle	Company	Capabilities/Notes	Status OD	Status ID
Thermal spray					
HVOF	Powder + high temperature flame	e.g. Sulzer Metco, Praxair, TAFA	11" ID, WC-Co, alloys	Production	
Plasma spray	Powder + plasma	e.g. Sulzer Metco, Praxair	1.5" ID, WC-Co, alloys, metals	Production	Production/short
Small/ nanoparticle thermal spray	Small particles + plasma or flame	SUNYSB, ONR, U. Conn, NU. ONR (Larry Kabacoff), DARPA funding	Dense coatings, WC-Co, oxides. May make smaller guns possible	Research	Research/inter
Weld coating					
Electrospark (ESD)	Microarc weld	Advanced Surfaces and Processes, Batelle PNL	<0.5" ID, 120" long nanophase WC-Co, alloys. Smal diameter only	Development	Development/short
Explosive clad	Explosive bonding	Sigmabond Technologies	Metals, WC-Co	Research	
PVD/CVD					
Post-magnetron	Sputtering from high current rod	Surface Solutions, Praxair (ATP program), Army Benet Labs	Metals, alloys, nitrides; Ta (Army)	Development, research	Development/inter
CVD, MOCVD, plasma CVD	Deposition from gas	Various	Very small, long holes. High temperature/dangerous precursors	Production	
Combustion CVD	Precursors combined in flame	MicroCoating Corp	Compounds (oxides, etc). VOC solvents used	Research Development	Research/long
Plasma CVD	Precursors deposited by plasma	Metroline	Oxides, nitrides, metals	Production	Research/long
Hollow cathode evaporation	Small internal hollow cathode	U. Uppsala (Sweden)	Metals, nitrides. Low build-up	Research	
Laser deposition	Laser evaporation, alloying, and CVD	QQC Diamond	Diamond. No build-up	Research	
Laser Induced Surf. Improvement (LISI)	Laser alloying	Surface Treatment Technology, University of Tennessee	Alloys with surface material (not coating). No build-up	Research	
Plasma nitride	Nitriding at about 500C	e.g. Advanced Heat Treat	Surface treatment (no build-up, high temperature)	Production	
Wet plating					
Electroless Ni and Ni composites	Electroless Ni-P/B (+ SiC, Teflon, diamond, etc), Amplate	Various	Ni-P, Ni-B, and particle-filled alloys	Production	Production/iimmed
Brush plating	Ni electroplate	Various	Cr, Ni, other metals	Production	
Alloy plating	Electroplating of simple alloys	Various	Ni-W-B, Co-W	Production	Production/short
Co-composites, Tribomet®	Co alloy composite plate	Praxair	Co alloy, proprietary	Production	Production/short
Immediate (/immed)	Short term (/short)	Intermediate term (/inter)	Long term possibilities (/long)		

Pros and cons of alternatives

Electro and electroless plating

Pro

- Closest to drop-in
- Can do both ODs and Ids
- No heating

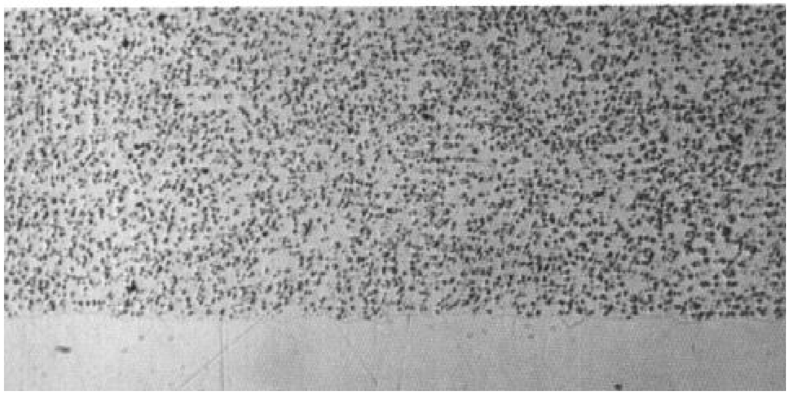
Applications: IDs of hydraulics, complex shapes

Con

- High wastewater volume
- Often Ni-based (EPA Toxic 17)
- Alloys and comp-osites difficult
- Hydrogen embrittle-ment common

Electroplating

- Most electroplates and electroless plates are Ni-based
- Some Co-based materials
  - e.g. Praxair Tribomet Cr_3C_2-Co
    - high heat treating temperature

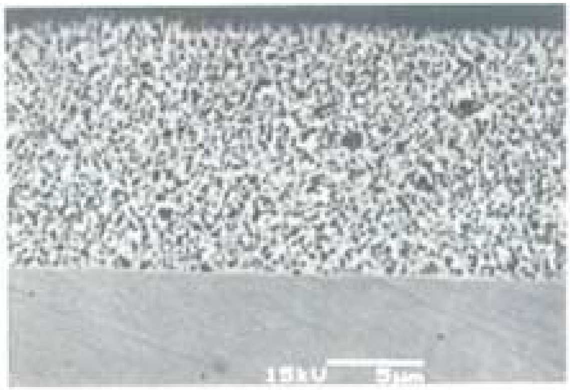


Electroplating - some problems

- Ni is an EPA toxic 17 material - potential for future stringent regulation
- Alloys
  - difficult control
  - proprietary technologies
- Composites
  - particles in suspension - holding them in suspension is difficult
  - proprietary technologies

Electroless plating

- Existing FAA specs - used on various aircraft parts
- Good uniformity and throwing power
  - Ni-P - commonest form, requires heat treat
  - Ni-B - more difficult to do, harder as-deposited
  - Composites
    - wide range of properties poss
    - difficult to control and hold in suspension



A cross section photomicrograph displays the dispersion of Teflon with electroless nickel at 3000X

Trivalent chrome

- Avoids Cr^{6+} emissions, but not stripping and grinding wastes
- Far more complex chemistry than hex
- Old methods were self-limiting
- New baths and pulse plating (e.g. NIST, Faraday Technology)
- Promising, but not yet commercial

Thermal sprays

Pro

- Many different materials available
- Higher performance
- Good build-up
- No hydrogen embrittlement
- No fatigue debit

Applications: hydraulic rods, landing gear

Con

- Can overheat some alloys
- ID coating difficult
- Fine powder overspray

Vacuum coatings - CVD and PVD

Pro

- Many materials - hard nitrides, carbides, etc.
- Clean
- Well-defined
- (CCVD too early to tell, but mostly oxide)

Applications: small actuators, bearing surfaces, engine

Con

- Complexity
- Low build-up
- High temperature
- Dangerous precursors (CVD)
- Extreme surface cleanliness (PVD)
- Mostly small items

Heat treatments - nitriding, carburizing

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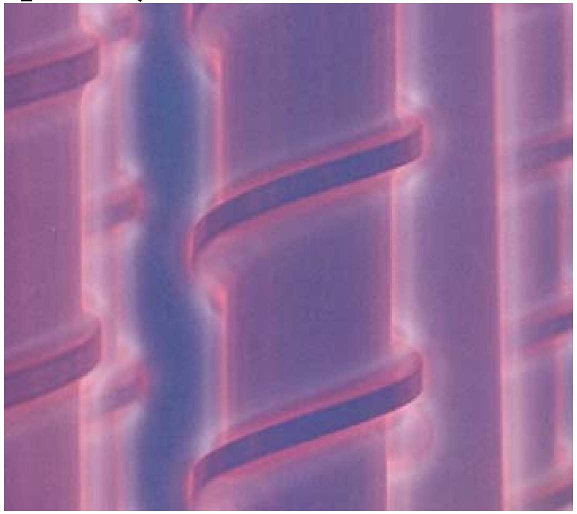
Pro

- Well-defined
- Commercially available
- Large items
- No interface

Applications: hydraulic rods (nitrocarburizing) large gears, pistons

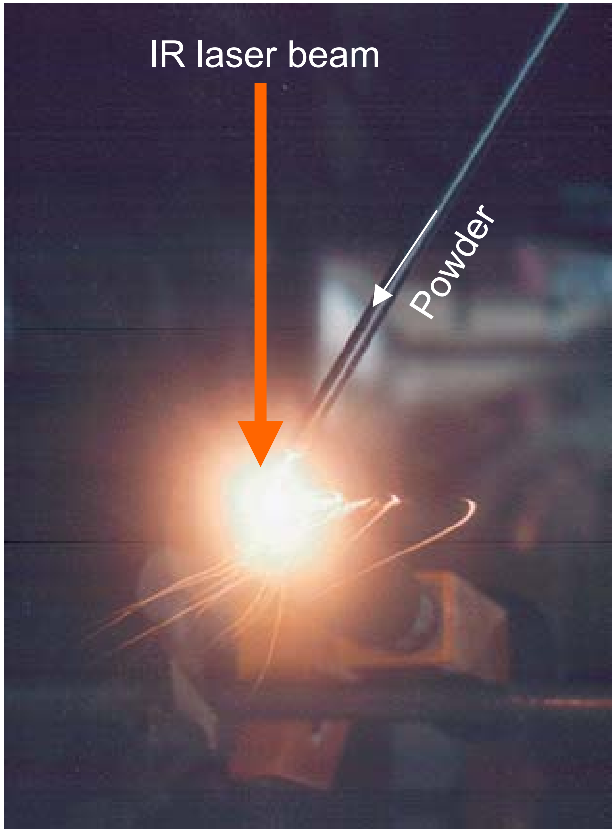
Con

- No build-up
- High temperature (warpage, loss of temper)

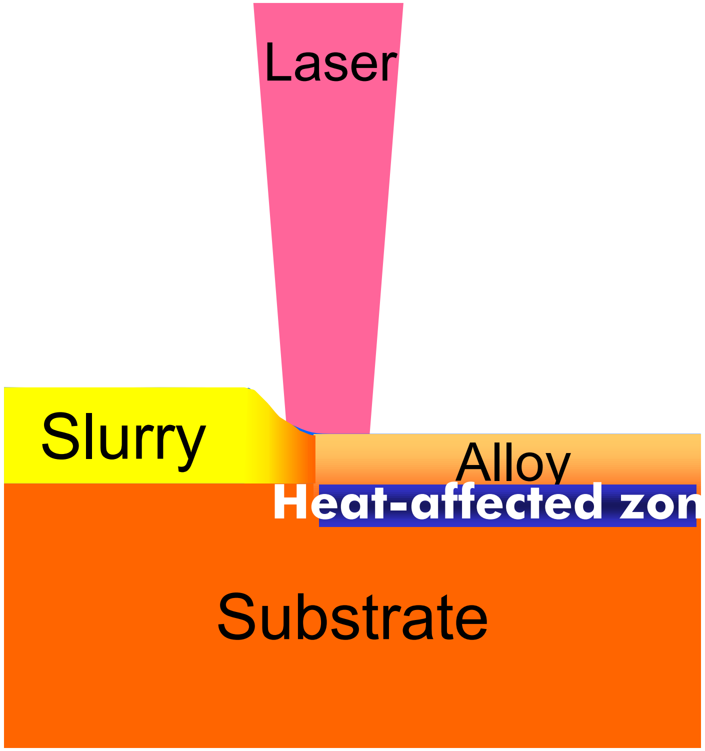


Laser methods

Laser cladding



LISI



Laser methods - LISI, cladding

Pro

- Clean
- Well-controlled power input
- Surface heating only
- Open-air

Applications: turbine blade tips

Con

- Surface heat-affected zone (esp. cladding)
- No build-up - LISI
- Difficult to control - cladding

Ion implantation

Pro

- Low temperature
- No interface
- Can improve hard chrome wear life

Applications: no commercial uses in aerospace

Con

- Complex, expensive equipment
- Small case depth
- No build-up
- Difficult for IDs