Electrodeposited Nano Co-P: Coating Development and Technology Insertion at NADEP-JAX

Integran Technologies Inc.

HCAT Meeting, New Orleans – January 24th, 2007

Report Documentation Page

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- Rowan Technologies – Keith Legg
- Integran Technologies
  - Francisco Gonzalez, Jon McCrea, Diana Facchini, Mike Uetz
- NADEP-JAX
  - Ruben Prato, John Devereaux, John Lamkin, Ernstine Lawson

Support for the Program

- SERDP and ESTCP Program Office
- JSF Office
- Technology Partnerships Canada

Collaborators

- Goodrich, Messier-Dowty, Pratt & Whitney Canada, Smiths Aerospace

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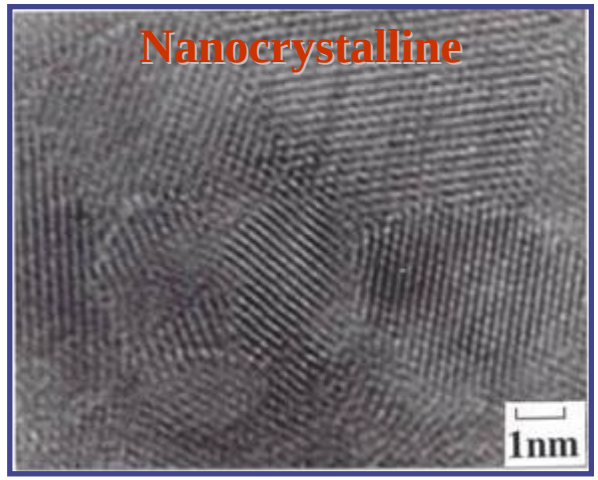
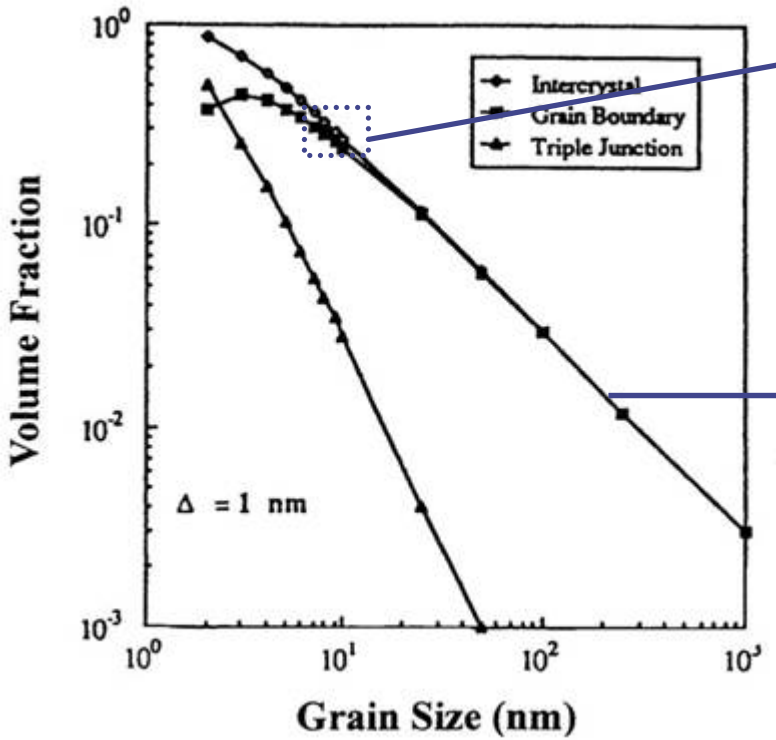
Overview

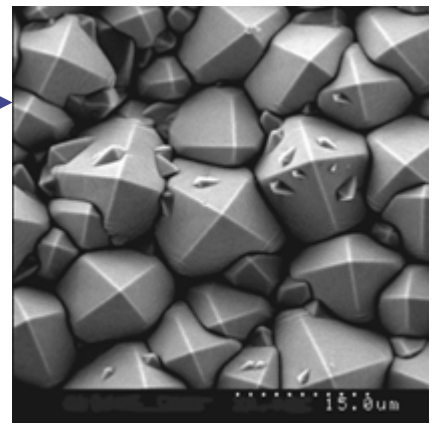
- **Nanocrystalline Materials**
- **History of the nCoP NLOS Cr-replacement Project**
- **Overview of nCoP Process and Properties**
- **Scale-up of Tank Process**
  - Installation at Integran
  - Installation at NADEP-JAX
  - Dem/Val Activities
- **Development of Selective Area (Brush) Plating**
- **Joint Test Protocol (JTP) – Sample Prep and Testing**
- **Thin Dense Chrome Development**
- **Application-specific Testing**
  - Smiths Aero
  - Messier Dowty
- **Summary**

Nanocrystalline Materials

A reduction in grain size below 100nm, significantly increases the intercrystalline content in the material, leading to many unique properties (high hardness/strength)







Need to understand the relationship between **Microstructure** and **Processing conditions**

History of Cr-Replacement Project

SERDP Project #PP-1152 – June 2000 to March 2003

Objectives: Develop an environmentally benign advanced nanocrystalline based coating technology that:

- Can be applied to non-line-of-sight surfaces
- Is compatible with conventional electroplating infrastructure
- Will produce coatings that meet or exceed the overall performance of hard chrome (hardness, wear, corrosion, fatigue)

Nano Co-P as EHC alternative was developed and demonstrated at the lab scale

ESTCP Project #PP-0411 – May 2003 to May 2006

Objectives:

- Scale up to industrial production & move to depot (Integran/NADEP-JAX)
- Develop nano Co-P selective plating as repair
- Develop nano Co-P based TDC alternative
- Define and Execute JTP

Cobalt alloy selection

- Good mechanical properties, High plating efficiency
- No constituents on EPA or AFMC lists of hazardous materials
- Longer term view

History of Cr-Replacement Project

Progression of TRL / Timeframe

Year **Project**

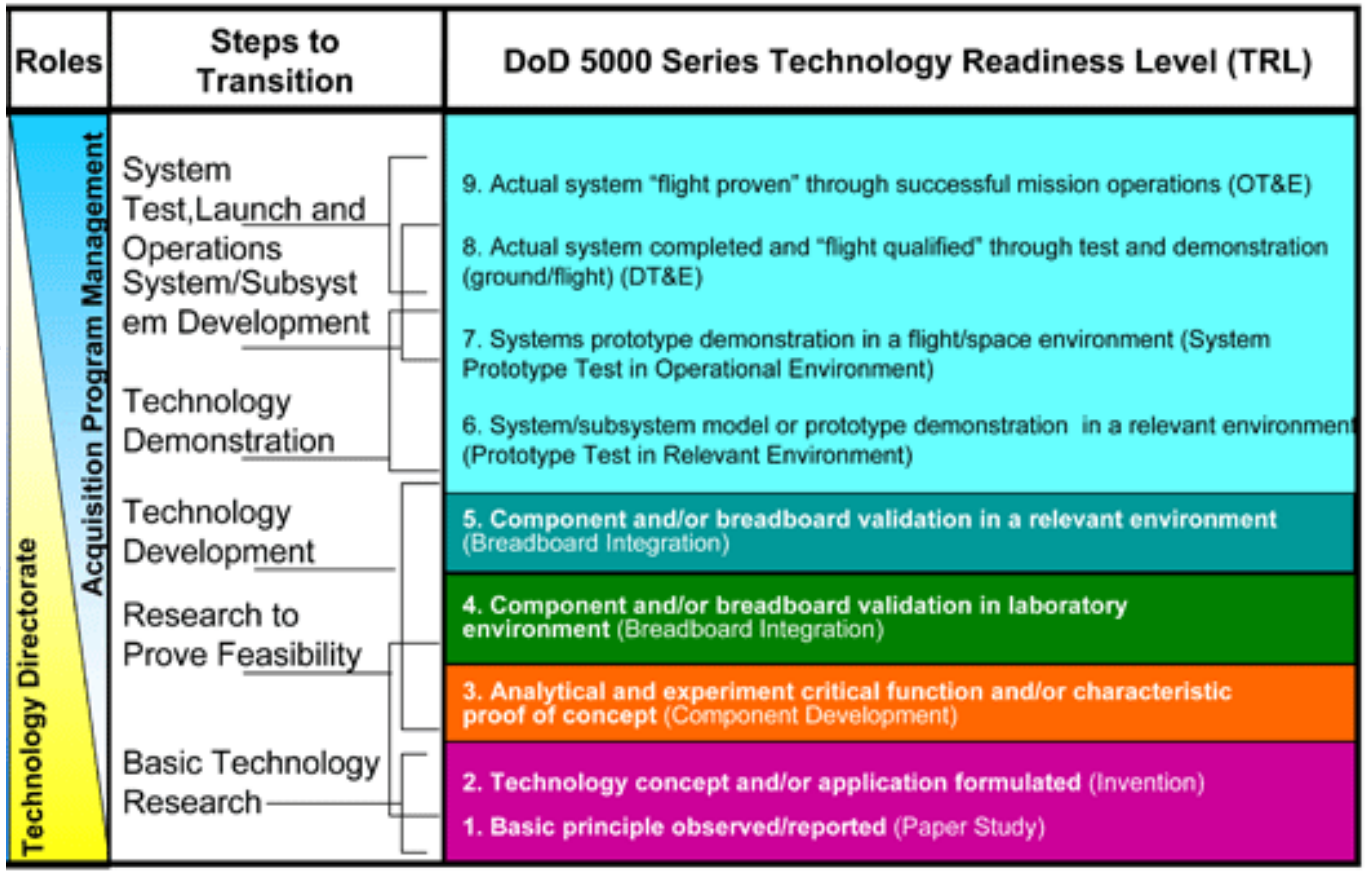
2006

ESTCP
PP-0411

2003

SERDP
PP-1152

2000



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Technology Description

Process

Simply an electrodeposition process

- Parameters modified to yield deposits with average grain sizes below 100nm using pulse plating

Plating Efficiency >90%

- High Deposition rates (2-8 mils/hr)
- 10x the plating rate of EHC at same power current density
- 1/10th the power consumption at the same plating rate

Consumable & nonconsumable anode

- Cobalt Pieces in Ti basket, Graphite

Phosphorus Content: 0 to 10wt%

- Controlled by solution chemistry and plating conditions

Technology Description

Solution Control and Maintenance

Similar to that required for nickel-plating solutions:

- **Filtration**
  - Control particles
- **pH monitoring**
  - Control deposit uniformity
- **Surface tension control**
- **Solution density monitoring**

Periodic maintenance procedures

- **Activated carbon treatment**
  - Organics
- **Dummying (low current density plating)**
  - Remove various metallic impurities

Properties Summary

		Nanocrystalline Co-P	Hard Chrome
Hardness	*As-Deposited*	600-700 VHN	800-1200 VHN
	HT @ 250°C	700-800 VHN	-
			-
Ductility		2 – 7 % Elongation	<.1%
Thermal Stability		400°C	400°C
Wear	*Adhesive (Pin-on-disk)*	5-6 x 10^{-6} mm^3/Nm (Alumina Ball on Nano Co-P Disk)	9-11 x 10^{-6} mm^3/Nm (Alumina Ball on Cr Disk)
	Coefficient of Friction	0.5	0.7
	Abrasive (Taber)	18 mg / 1000 cycles (CS-17) 11 mg / 1000 cycles (CS-10)	3.2 mg / 1000 cycles (CS-17) 1.0 mg / 1000 cycles (CS-10)
Corrosion	Salt Spray	Protection Rating 7 @ 1000 hrs	Protection Rating 2 @ 1000 hrs

Scale up of Tank Process

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Industrial Scale Up at Integran Technologies

Integran Tank

- Dimensions (3'x5'x3') (~1300L)
- 1" Polypropylene
- Separate well to house pump and filter
- 3/4hp pump
- 1µm filter
- 60kw heaters (Ti) digitally controlled

Industrial Scale Up at Integran Technologies

Dem/Val Studies

- **Integran 1300 L Bath has been in operation for 26 months, >33,000 Amp-hrs, No major problems**
- **Process Verification**
  - Scaled-up process produces acceptable nanostructured coatings on small and large test coupons
  - Verified on large test pieces (4” ID, 1’ Length)
- **Operating Window Identification**
  - Optimal Bath chemistry and Pulse Conditions identified
  - Temperature, Current density and pH operating ranges identified
    - Based on hardness, grain size, composition, coating uniformity
- **Contaminant Study**
  - Completed a lab scale study of the effects of various metallic contaminants in the plating solution (Cr^{6+}, Cr^{3+}, Fe^{2+}, Fe^{3+}, Cu^{2+}, Ca^{2+}, Ni^{2+}, Na^{+}, F^{-} ,and SO_4^{2-})
- **Developed activation procedures for 4340, 4130, 300M, 15-5PH, Hy-Tuf, nCoP, Al**
- **Developed alkaline dip stripping solution: avg removal rate ~0.001”/hr**

Operating Manual and Process transferred to NADEP-JAX

Technology Transfer to NADEP-JAX

Milestone: Dem/Val Tank Setup at NADEP-JAX

- Dimensions
  - 47”x30”x48”
  - approx Vol. 290 gals
- Liner Type
  - Modified Vinyl based Terpolymer
  - 0.125” thick
- Ni Plated Copper Buss Bars
- In tank pump and filter
- ¾ hp pump
- 10 micron filter
- PVDF Steam Coil, new steam lines & regulator

290 gal Dem/Val plating tank

Technology Transfer to NADEP-JAX

Milestone: Chemistry Make-up at NADEP-JAX

- Operating Vol: 250 gals
- Proprietary Bath Chemistry
- Low pH
- High Temp
- Assisted by Integran

Building of new Nano Co-P Plating Bath

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Technology Transfer to NADEP-JAX

Milestone: Pulse Rectifier Installed at NADEP-JAX

- Integran's specifications
- Peak current 1500A
- Average current 500A
- Pulse timing (ton and toff)
  - 0-100ms, Δt=0.1ms
- Remote Control Micro Touch Controller
- First verified at Integran

Remote Controller

Pulse Rectifier

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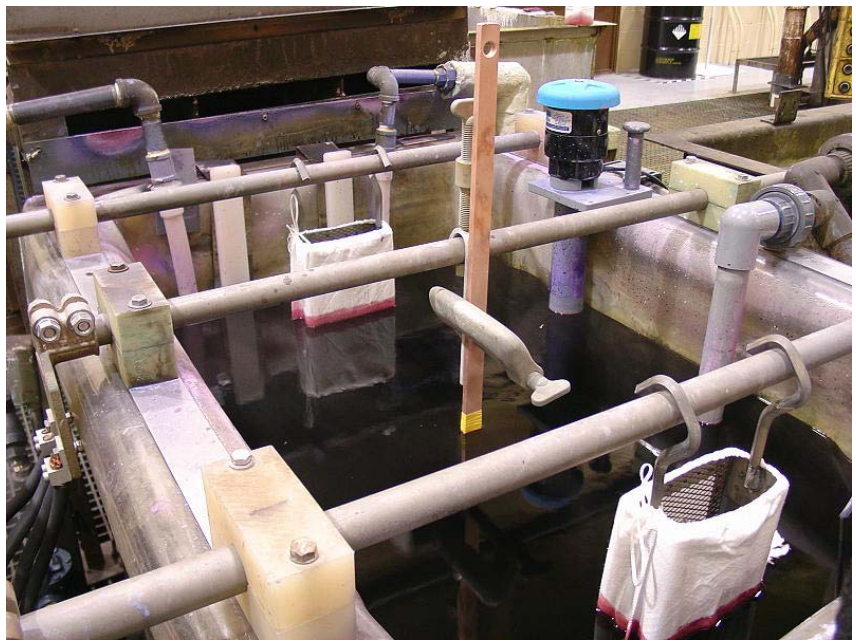
Technology Transfer to NADEP-JAX

Milestone: Initial Plating and Bath Optimization at NADEP-JAX

- 4130 Steel test coupons plated
- Initially dull, non-uniform deposits towards edges
  - Process parameters adjusted
- Subsequent deposits bright and uniform
- Plating rate: 5-6 mil/h



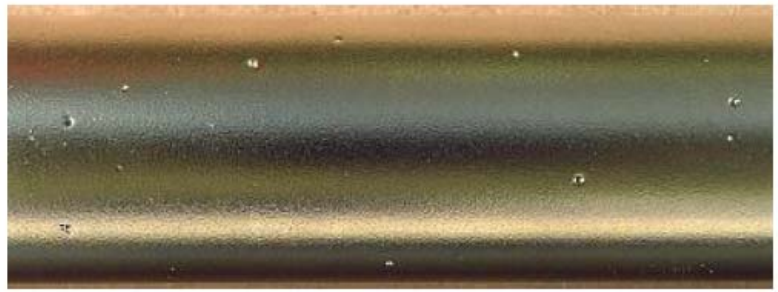
Dem/Val tank with Electrolyte and plating

First 4130 panel plated

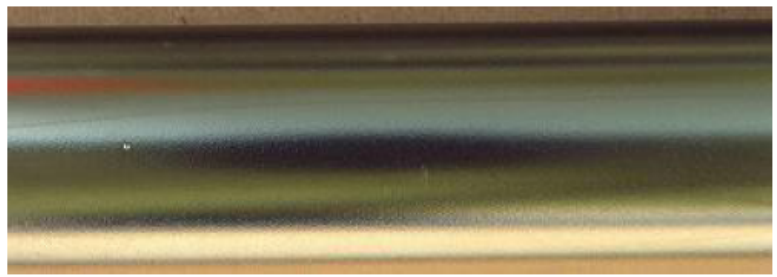
Technology Transfer to NADEP-JAX

Process Troubleshooting - Pitting

- Pitting of nano CoP observed at NADEP-JAX
  - All initially plated parts
  - Significant pitting present
- Caused by organic contamination
  - Leaching of newly installed liner from bath matrix and operating temperatures
- Carbon filtering significantly reduced pitting



Before carbon treatment

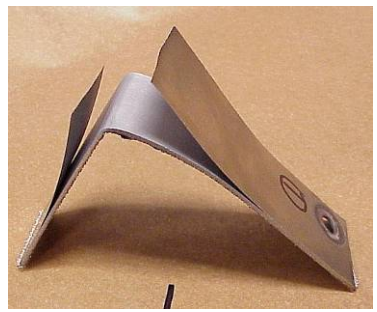


After carbon treatment

Technology Transfer to NADEP-JAX

Process Troubleshooting - Adhesion

- Adhesive failures of nano CoP observed at NADEP-JAX
  - 4130 flat coupons and IDs
  - Thought to be due to activation procedure
- Alternate activation procedure developed by Integran
  - Good adhesion demonstrated on 4130 flat coupons and IDs
  - Showed promise at NADEP-JAX
- Procedure to be implemented by NADEP-JAX
  - Activation tank setup in progress
  - Retrofit of existing nearby tank
  - Requires liner, buss bar & rectifier hook up



Adhesion failures
Previously used activation

Good adhesion
Newly developed activation

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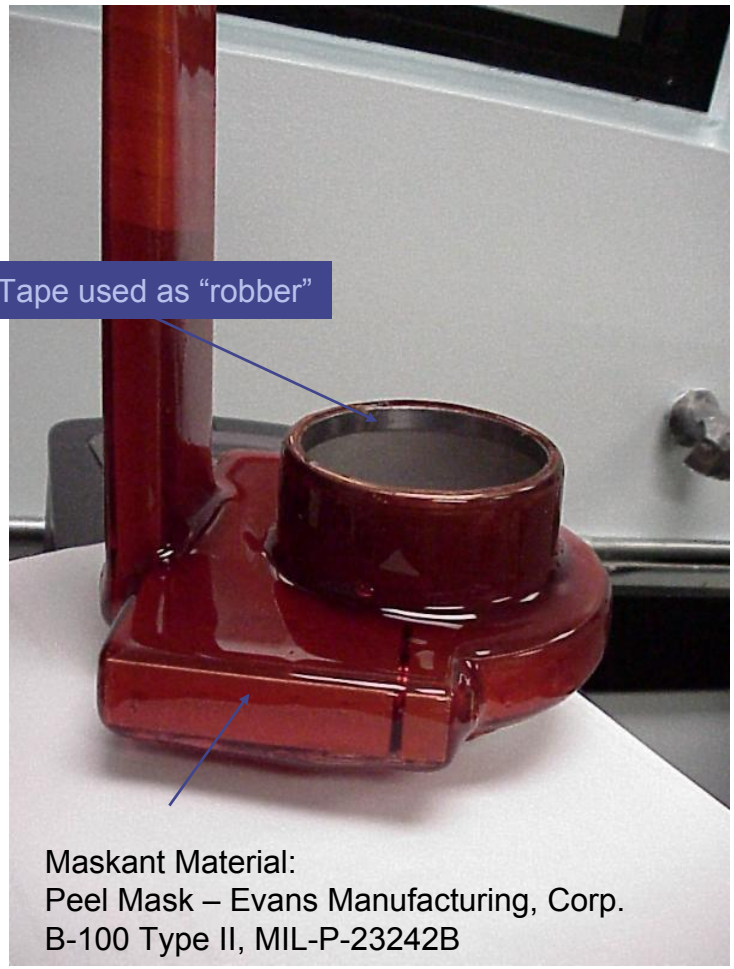
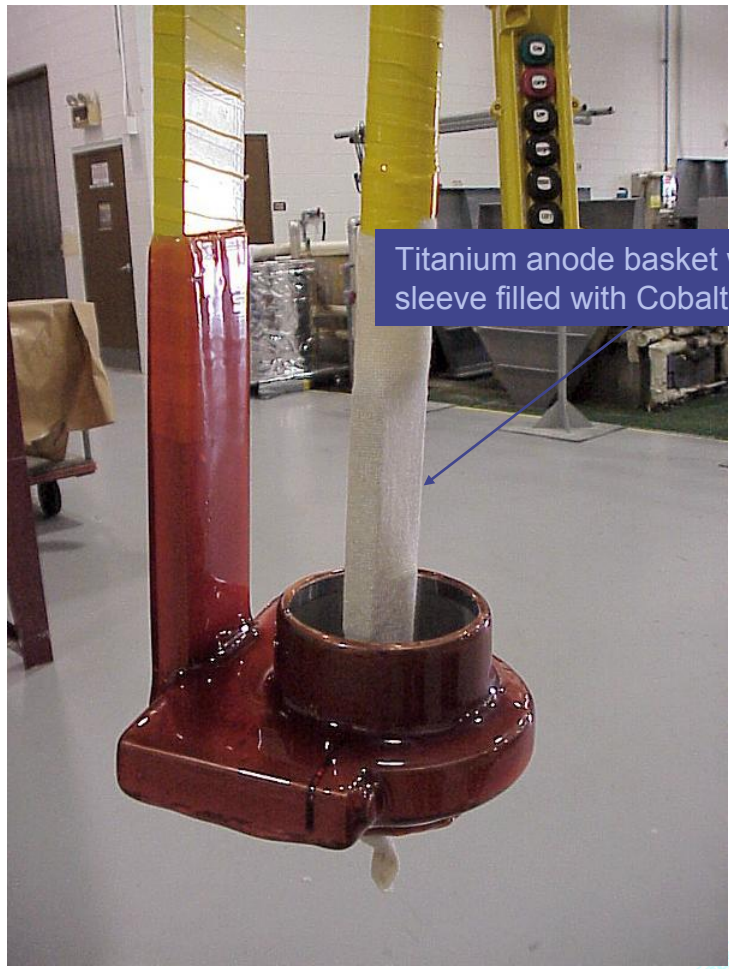
Component Plating Trials at NADEP-JAX

Demonstration with high temp maskant and titanium basket anode





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Section from a P-3 MLG Actuating Cylinder

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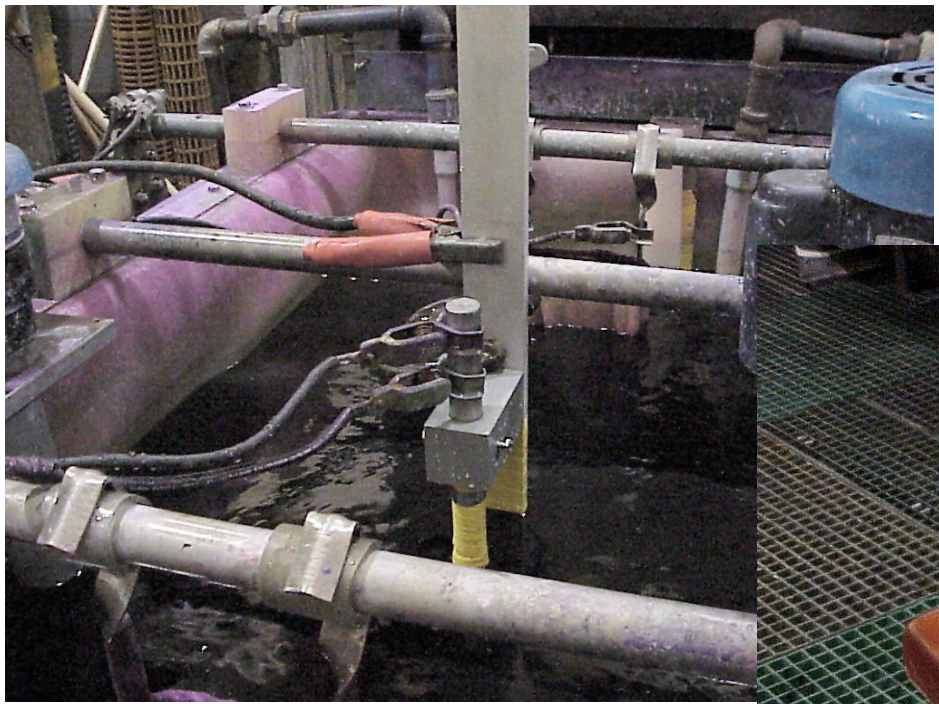
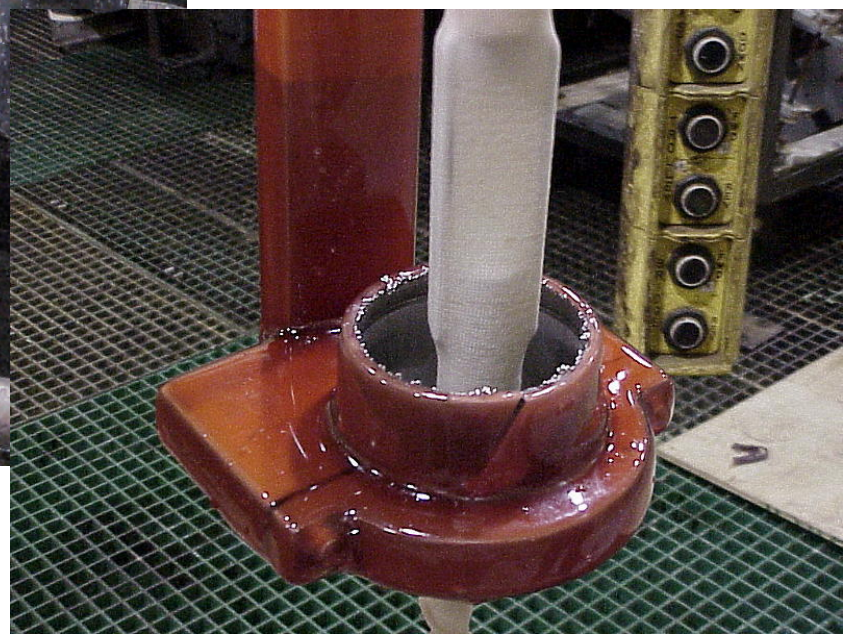
Component Plating Trials at NADEP-JAX

Demonstration on an ID section of a P-3 MLG Actuating Cylinder



nCo-P Plating on ID:
Section from P-3 MLG Actuating Cylinder

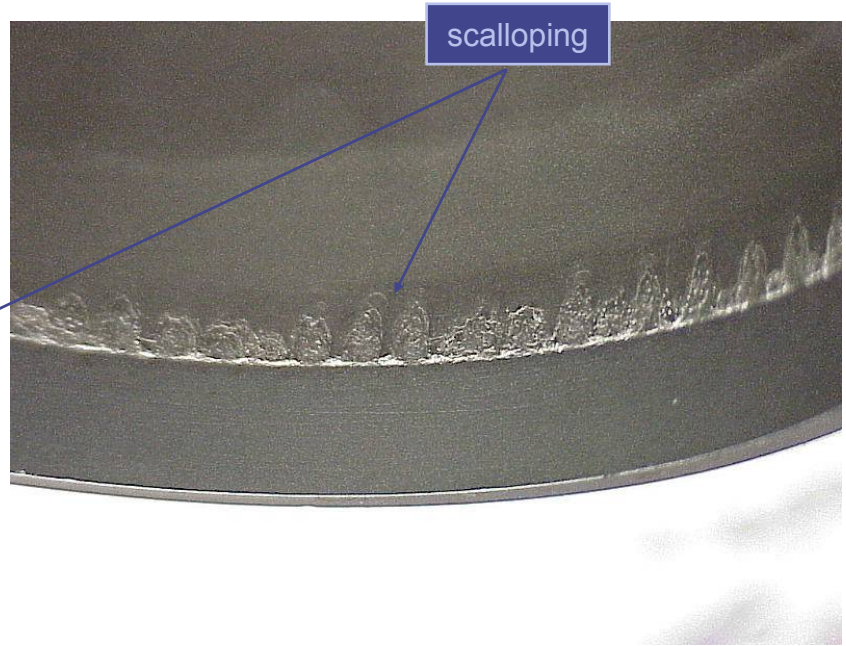
Plating Time: 4 hrs



Rack Assy after plating:
Section from P-3 MLG Actuating Cylinder

Component Plating Trials at NADEP-JAX

Demonstration on an ID section of a P-3 MLG Actuating Cylinder

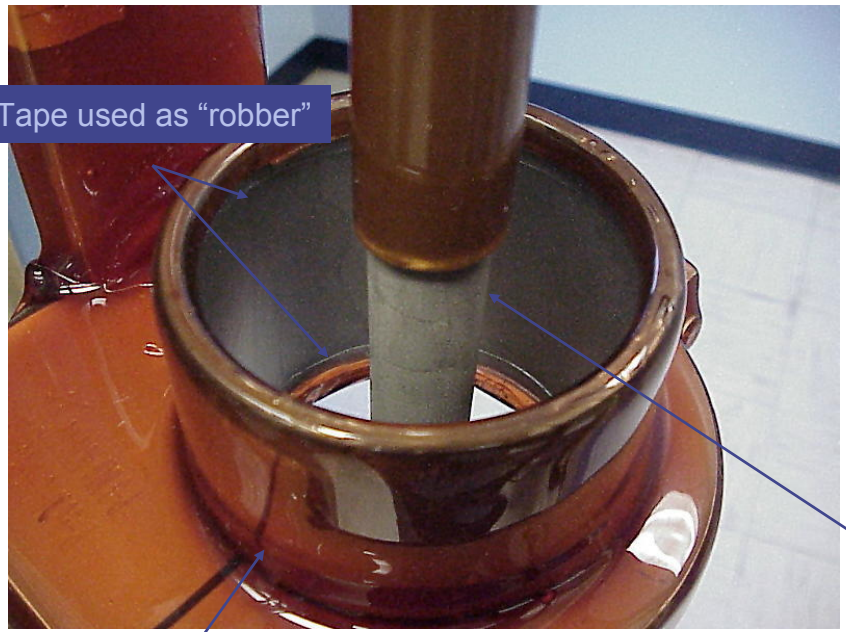


Part after de-masking:
Section from P-3 MLG Actuating Cylinder

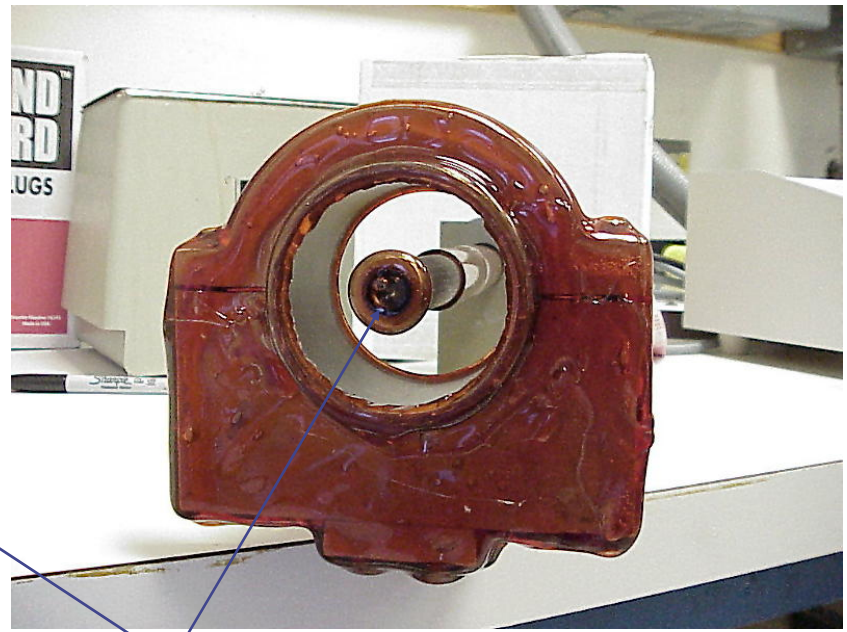
Appearance: Dull matt gray, few shallow pits
Coating Thickness: 10.0 mils /side
Deposition rate ~ 2.5 mil/hr

Component Plating Trials at NADEP-JAX

Demonstration with high temp maskant and Solid cobalt anode



Lead Tape used as “robber”



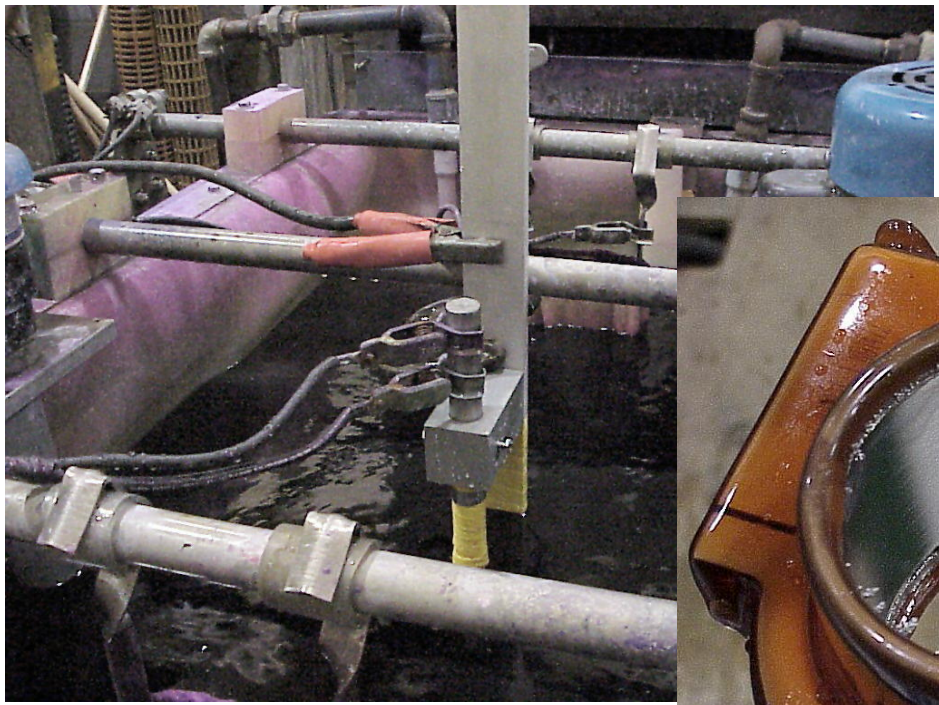
Maskant Material:
Peel Mask – Evans Manufacturing, Corp.
B-100 Type II, MIL-P-23242B

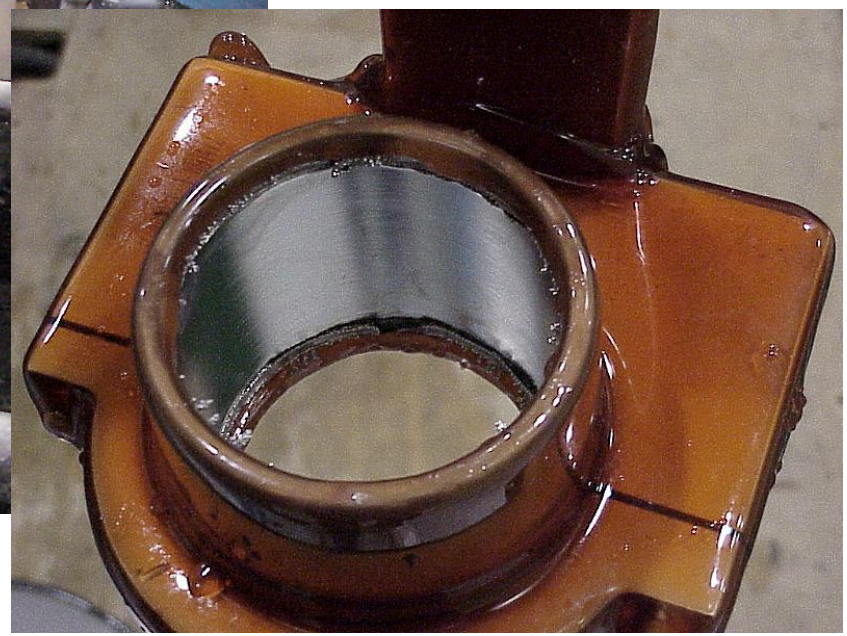
Cobalt Anode

Section from a P-3 MLG Actuating Cylinder

Component Plating Trials at NADEP-JAX

Demonstration on an ID section of a P-3 MLG Actuating Cylinder





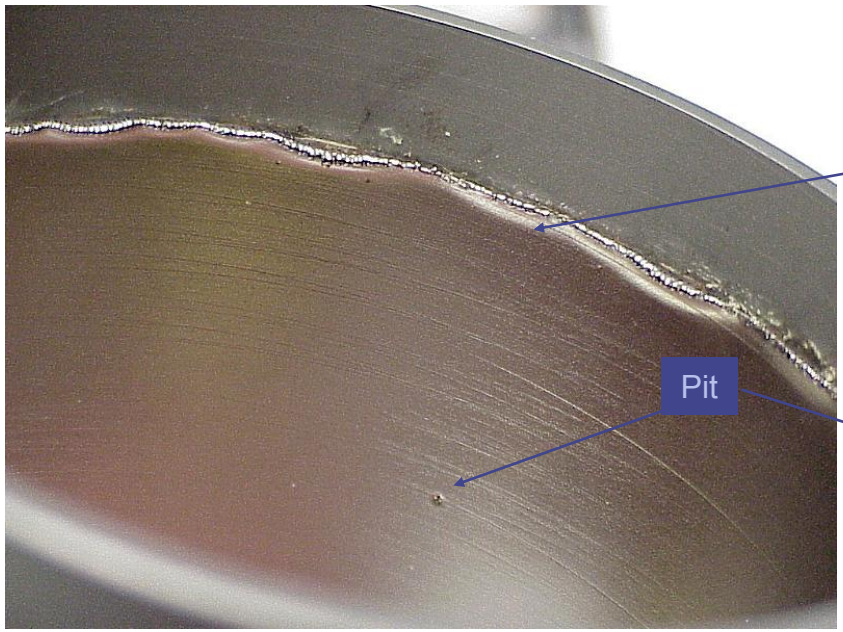
nCo-P Plating on ID:
Section from P-3 MLG Actuating Cylinder

Plating Time: 2 hrs

Rack Assy after plating:
Section from P-3 MLG Actuating Cylinder

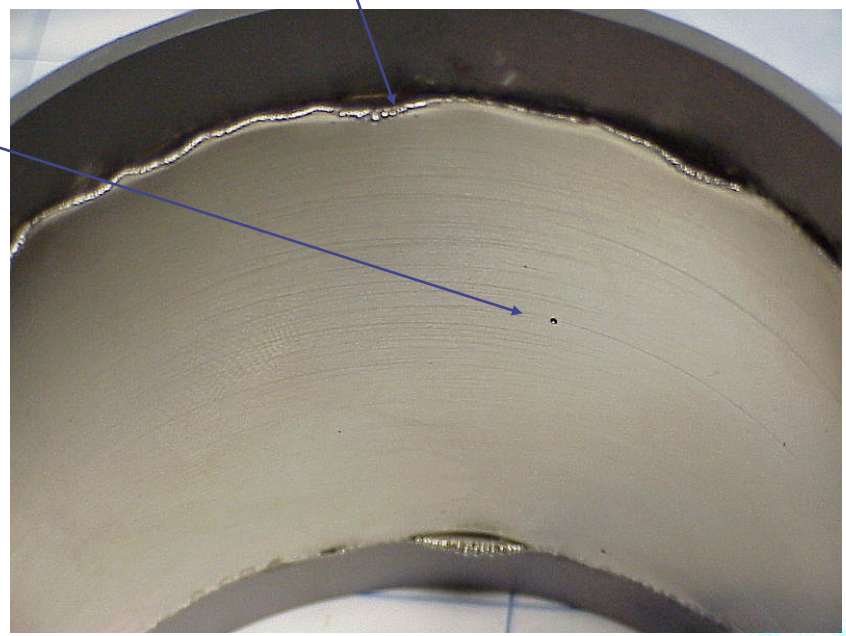
Component Plating Trials at NADEP-JAX

Demonstration on an ID section of a P-3 MLG Actuating Cylinder



Bridging of deposit over robber & maskant

Pit



Part after de-masking:
Section from P-3 MLG Actuating Cylinder

Appearance: Bright silver gray, 2 pits
Coating Thickness: 12.0 mils /side
Deposition rate ~ 6.0 mil/hr

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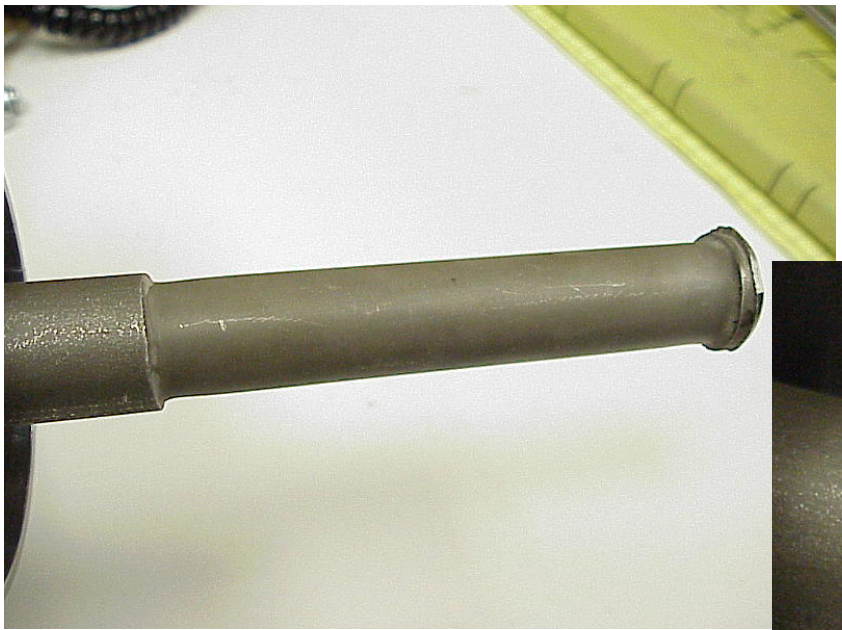
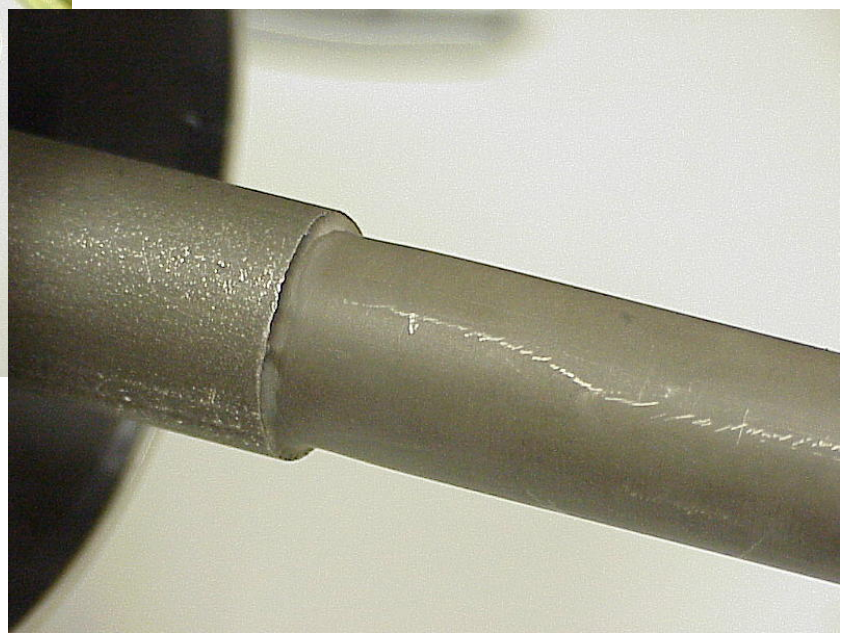
Component Plating Trials at NADEP-JAX

Demonstration on an ID section of a P-3 MLG Actuating Cylinder



Cobalt anode after 2 Hrs of plating ID Section from P-3 MLG Actuating Cylinder

Co Plated Anode Rod after Use



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Technology Transfer to NADEP-JAX

Setup Considerations for ID Component Plating

Masking

- Crucial step due to complex geometries
  - blind areas, pin holes, dissimilar metals, etc.
- Waxes used in Cr process not applicable due to high temp of solution
- Current "Peel Mask" maskant
  - small melting pot set up in the shop
  - not as forgiving as waxes with regards to trimming
  - degradation over time causing organic contamination
- Alternative masking method prefered - Platers Tape works, but difficult with complex geometries at JAX

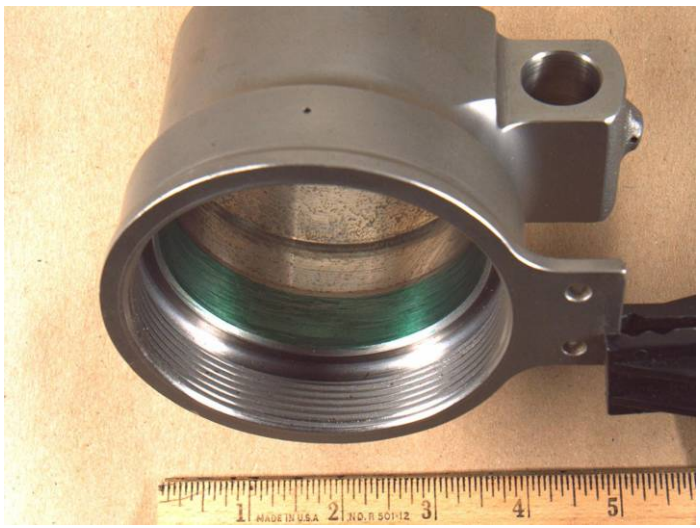
Anodes

- Cobalt rods
  - best performance
  - consumed very quickly
- Ti baskets with cobalt chips
  - proper anode:cathode area and adequate flow must be maintained for proper deposit characteristics

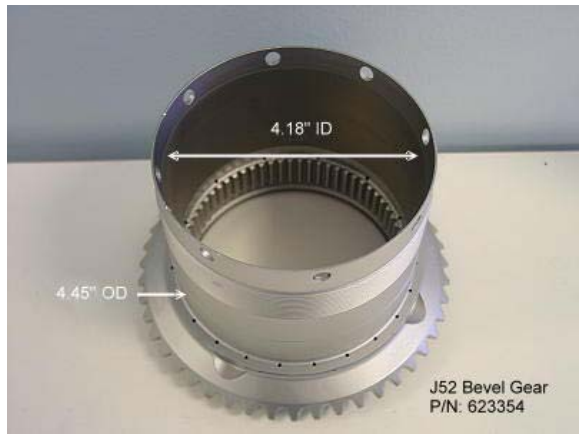
Rack Assembly of J52 Gear Spur

Technology Transfer to NADEP-JAX

Proposed Demo Parts to be Plated at NADEP-JAX



P-3 MLG Actuating Cylinder



J52 Bevel Gear

P3 MLG Cylinder Section, Axle Journal

Technology Partnerships Canada

Selective Area (Brush) Plating Development

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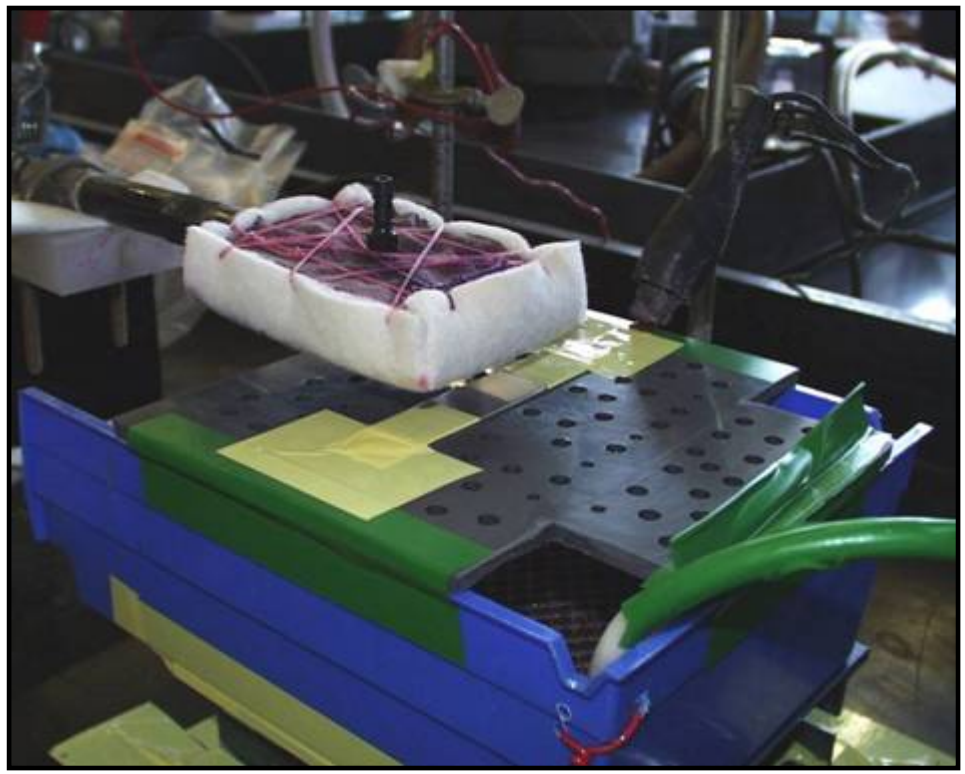
Selective Area (Brush) Plating Development

Overview

- Method to electrodeposit metal without tanks for localized coating
- Well characterized industrial process
- Moving anode – static cathode
- Can be easily field-implemented
- Can be applied manually, semiautomatic and automatic



Selective Area (Brush) Plating Development

Status

- Nano CoP brush plating procedure established
  - Optimized bath chemistry
    - Efficiency: > 90%
    - Deposition rate: 6mil/hr
    - High hardness: 600-700 VHN
    - Uniform composition
  - Good adhesion (ASTM B571)
  - Good tribological properties
  - Lower Coefficient of Friction
  - Adhesion on mild steel passes ASTM B571
- Process adapted for various geometries
  - cylindrical samples
  - large plates
  - thick deposits
- Samples being produced for JTP

Joint Test Protocol (JTP)
Sample Prep and Testing

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Joint Test Protocol (JTP)

JTP Summary*

- **Demonstrate adhesion on various substrates**
  - 4340, 15-5PH, Aermet 100, Al 7075 and Ti 10-2-3
- **Pre-Test Grinding Study**
- **Performance Testing (Tank plating)**
  - Corrosion (ASTM B117 & G85)
  - Rod-Seal Wear
  - Fluid Immersion
  - Hydrogen Embrittlement (ASTM F519)
  - Axial Fatigue (ASTM E466-96)

- **Performance Testing (Brush Plating)**
  - Axial Fatigue (ASTM E466-96)
  - Hydrogen Embrittlement (ASTM F519)
  - Corrosion (ASTM B117)

***Copy of JTP can be found on the HCAT website**

Pre-Test Grinding Study

Motivation

- Determine a set of reasonable (but not necessarily optimum) grinding conditions for nano CoP

Sample Preparation

- Piston Rods (1” diameter) coated with ~0.010” nano CoP at Integran
- Pre-Grinding study
  - 4 x 4130 (2 As-dep’d / 2 HT @ 191°C for 24h)
  - 2 x 15-5PH (As-dep’d)
- Final Grinding Study
  - 4340 HT to 260-280ksi
    - most susceptible or sensitive to grinding burns
    - 3 x As-dep’d
    - 3 x HT at 191°C for 24hrs
    - 3 x HT at 300°C for 1-3hrs

Four 4130 and two 15-5PH rods used for pre-grinding study

Pre-Test Grinding Study

Results

- Rods ground to ~ 0.001” at NADEP-JAX
  - Followed Mil-Std-866 using standard Al2O3 abrasives
  - Rod was easily finished to a 2-3µin roughness
  - No problems, ground very similar to chrome
- Ground coating stripped at Integran
  - Using alkaline chemical dip solution
- Stripped parts subjected to Nital Etch at NADEP-JAX
  - No evidence of any grinding burns was present

Mil-Std-866 Acceptable for nCoP

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Corrosion

Sample Preparation

- Substrates
  - 4340
  - 15-5PH
  - 7075Al
- Nano CoP coating
  - 0.006”
  - 0.013”
- Post-plate grinding
  - final dimensions
    - 0.003”
    - 0.010”
  - Final surface finishes
    - 12-16 μ” Ra grind
    - <4 μ” Ra superfinish

4340	 0.006” nano CoP	 0.013” nano CoP
15-5PH	 0.006” nano CoP	 0.013” nano CoP
7075 Al	 0.006” nano CoP	 0.013” nano CoP

Corrosion

Testing details

- ASTM B117-9 salt fog
  - Solution: 5% NaCl
  - pH: 6.5-7.2
  - Temperature: of 35°C (95°F)
  - Test duration: 1000 h, inspect every 168 h
- ASTM G85, SO_2 salt fog
  - Solution: add SO_2
  - Test duration: 336 h, inspect at 100, 200 and 336 h
- Nano CoP to be compared to EHC of comparable thickness and surface finish (EHC samples prepared at NADEP-JAX)

Status

- Sample preparation complete
- Samples currently being ground

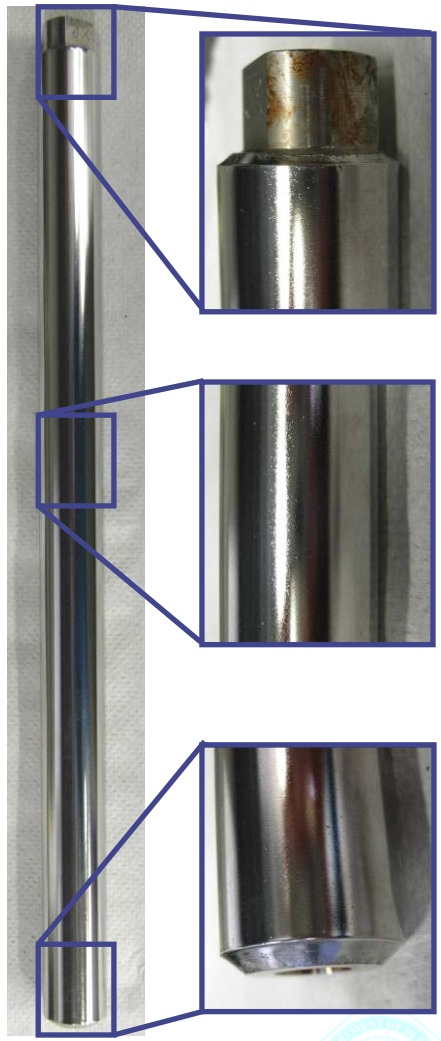
Rod-Seal Wear

Purpose

- Wear under simulated actuator service conditions
  - Compare performance of nano CoP to EHC
  - Determine optimum surface finishes on nano to minimize seal wear

Sample Preparation

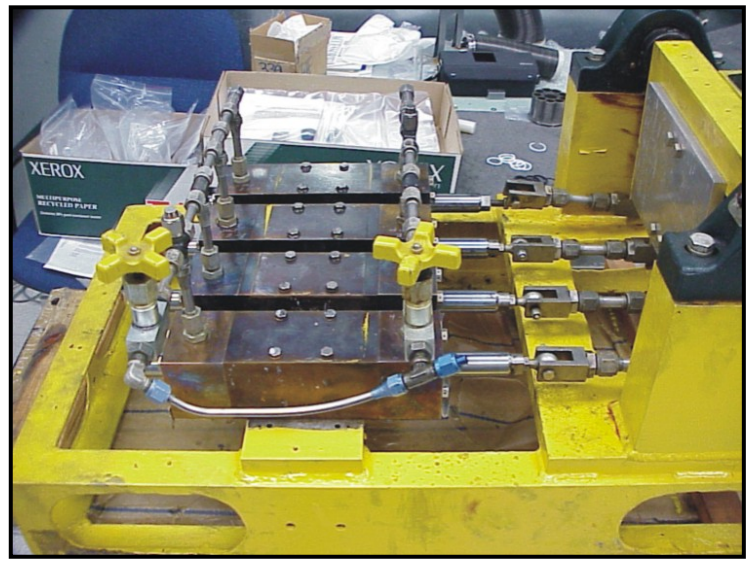
- Four hydraulic actuator rods
  - PH 13-8Mo, 16” long, 1” diameter
  - plated with 0.006-0.008” nano CoP
- Post-plating finishing
  - Rod #1: Hydrogen bake (375°F, 23h), ground to Ra 12-16 µinch
  - Rod #2: Hydrogen bake, ground to Ra 6-9 µinch
  - Rod #3: Hydrogen bake, superfinished to Ra < 4 µinch
  - Rod #4: Heat treat (300°C, 6 h), ground to Ra 6-9 µinch



Rod-Seal Wear

Testing details

- Hydraulic cylinder rod wear test
  - similar conditions to ID cylinder wear - wear against seals
  - master hydraulic piston drives four test rods
  - each rod passes through two blocks
- Two seal types to be tested per rod
  - standard MIL-P-83461 O-ring/Cap
  - Spring Energized PTFE
- Performance metrics
  - meet or exceed performance of hard chrome with a standard 12-15μ" Ra ground finish
- Testing to be conducted at NAVAIR Patuxent River



Rod-Seal Wear Test Apparatus Consisting of Four Rods Passing Through Blocks Containing Seals

Fluid Immersion

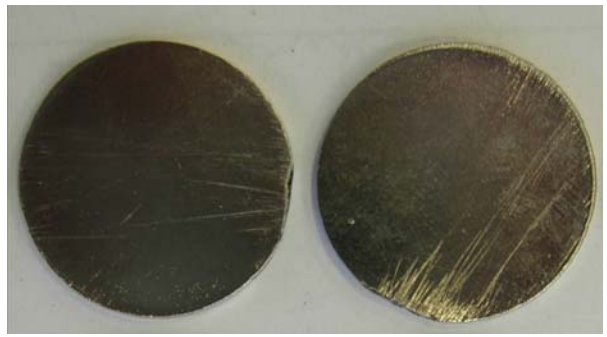
Sample Preparation

- 34 x 1” diameter 4340 discs
- Coated with 0.003” nano CoP

Testing Details

- Testing conducted at ARINC
- Coated discs submerged in various fluids
  - service conditions and overhaul fluids
- Specimens weighed before and after immersion
- Appearance of each specimen subsequent to immersion compared to that obtained prior to immersion

4340 discs
No coating



4340 discs
0.003” Nano CoP coating

Fluid Immersion

Preliminary Results – Visual Examination

- Visual examination of specimens after immersion
- Mass changes to be examined

No effect • fluorescent penetrant (for NDI) • MIL-C-87937 (aviation cleaner) • propylene glycol (de-icer) • Cee-Bee J-84A (heavy duty soak clean) • Cimstar 40 (grinding fluid)	**Discoloration** • Nital (grind burn etch) • Oakite 90 (alkaline cleaner) • Turco Vitro-Klene (Heavy duty soak clean)
Degradation • ammonium persulfate (grind burn etch) • Bleach • Turco scale Gon (descaling) • Sodium hydroxide (Cr strip) • 35% Nitric acid	**Not available** • Cd plating solution (inconclusive) • Hydraulic fluids (TBD)

Hydrogen Embrittlement (ASTM F519)

Sample preparation

- Type 1a2 bar (4340, long bar)
- plated with 0.003” or 0.020” nano CoP
- Hydrogen baked at 375°F for 24h or not baked

Testing details

- Constant load testing
  - Constant load 75% of Notch Tensile Strength (NTS)

Results

- Both baked and unbaked samples failed ASTM F519

Thick.	Stress (%NTS)	Hydrogen bake	Qty const load	Results #bars >200hrs
0.003”	75%	No	4	0/4
0.020”	75%	No	4	0/4
0.003”	75%	Yes	4*	2/4
0.020”	75%	Yes	4*	0/4

Hydrogen Embrittlement - Results

ESTCP JTP and Previous Results

Test	Coating Thickness	Plating Parameters	Bar Type	Heat Treatment	Result
SERDP	0.003”	A	1a.2	None	PASS
Goodrich	0.005”	B	1a.1	None 375F/12hrs	FAIL PASS
In-House	0.005”	A	1a.2	None 375F/12hrs	FAIL PASS
Ext Customer 1	0.004”	B	1a.1	375F/24hrs	PASS
Ext Customer 2	0.005”	A	1a.1	None 375F/24hrs	PASS PASS
ESTCP	**0.003”**	**B**	**1a.2**	**None / 375F/24hrs**	**FAIL**
ESTCP	**0.020”**	**B**	**1a.2**	**None / 375F/24hrs**	**FAIL**
ESTCP(RETEST)	0.003”	A	1a.2	375F/24hrs	**PASS**

Hydrogen Embrittlement Questions

Summary

- JTP HE results first instance of failure on thin coatings (< 0.005”) after baking, all previous tests passed with bake
- First tests of thick (0.020”) nano CoP coatings
- Type 1a.2 bars (long) are more sensitive than 1a.1 (short)
- While change in operating parameters did not have significant effect on coating properties (structure, composition, hardness) it did have large effect on HE

Questions:

- Did change in operating parameters:
  - Somehow change deposit characteristics to let Hydrogen escape during bakeout?
  - Prevent hydrogen from getting in?
  - Does the fully dense coating prevent hydrogen from escaping?
  - How does nCoP compare to Ni / other dense non-chrome electroplated coatings?

Follow up Studies Being Conducted to Address these Questions

Axial Fatigue

Sample Preparation

- Peened fatigue smooth bars
  - 4340, 15-5PH or 7075 Al
- Coated with nano CoP
  - 0.006”, 0.013” or 0.018” as-deposited
  - 0.003”, 0.010” or 0.015” ground, Ra of 12-16 uinch

4340 fatigue bar coated with Nano CoP (as-dep’d)

15-5PH fatigue bar with Nano CoP (as-dep’d)

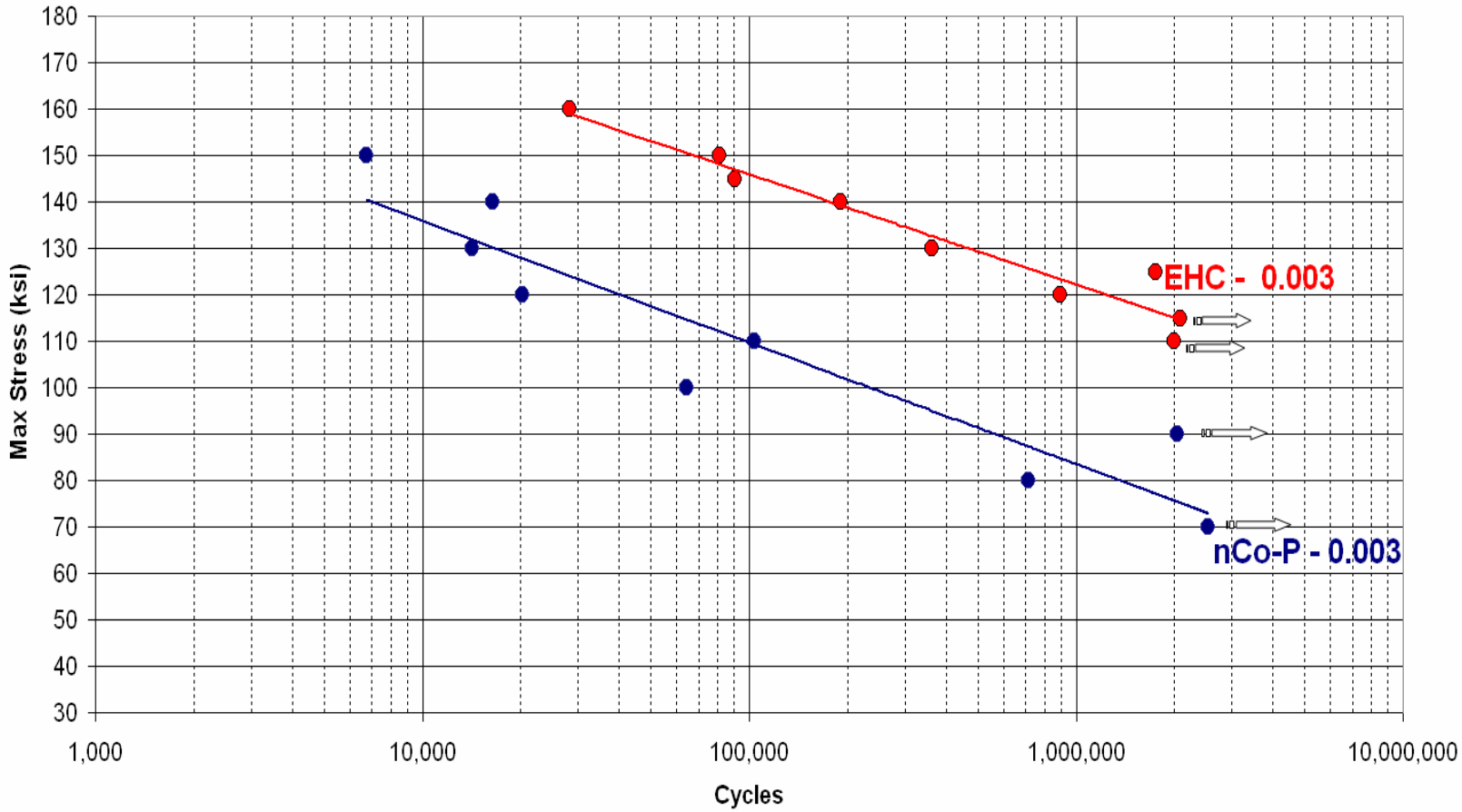
Testing Details

- Load-controlled constant amplitude axial fatigue testing (ASTM E466-96)
- Loads spread between high and low loads
  - High load – 85% of Fty (yield)
  - Low load – uncoated specimen fatigue life is approximately 10^6 cycles (runout)
  - maximum four points per load
- R ratio: R = -1
- Compare S-N curve to EHC coated samples of similar thickness

Axial Fatigue

Results – 4340 Substrate

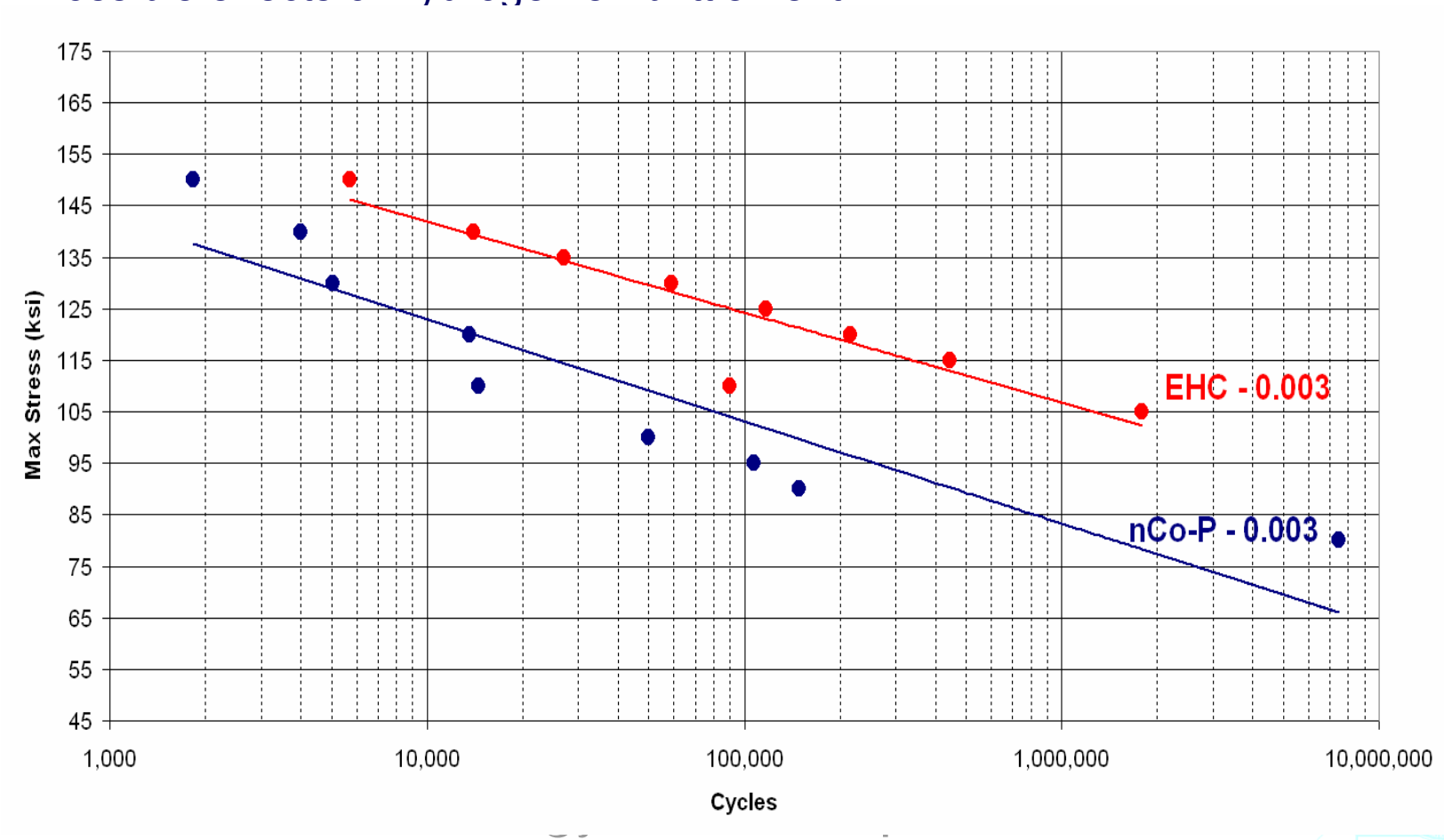
- Nano CoP shows fatigue debit compared to EHC at 0.003” and 0.010”
- Possible effects of hydrogen embrittlement?



Axial Fatigue

Results – 15-5PH Substrate

- Nano CoP shows fatigue debit compared to EHC at 0.003” and 0.010”
- Possible effects of hydrogen embrittlement?



Brush Plating Performance Testing

Testing to date - Hydrogen Embrittlement

Sample Preparation

- 8 Type 1a1 notched tensile bars (short bars)
  - brush plated with 0.003” nano CoP
  - 4 bars hydrogen baked at 375°F for 24h
  - 4 bars not baked

Testing Details

- 75% of Notch Tensile Strength (NTS)

Results

- Hydrogen baked - **PASS**
  - 1 of 4 fractured < 200h
  - Remaining bars step-loaded to >95% NTS
- Not hydrogen baked – **PASS**
  - 1 of 4 fractured < 200h
  - Remaining bars step-loaded to >95% NTS

No hydrogen bake

Hydrogen bake

Brush Plating Performance Testing

On-going Sample Preparation

- Corrosion
  - 4”x6” peened 4340 and 15-5PH test panels
  - 0.003” and 0.010” nano CoP
- Hydrogen Embrittlement
  - Type 1a1 notched bars (short bars)
  - 0.010” nano CoP
  - With and without hydrogen bake at 375°F for 24h
- Axial Fatigue
  - Peened 4340 and 15-5PH smooth bars
  - 0.010” nano CoP (0.013” as-deposited)

Thin Dense Chrome (TDC) Development

Technology Partnerships Canada

HCAT Meeting – Jan 24th, 2007 – New Orleans

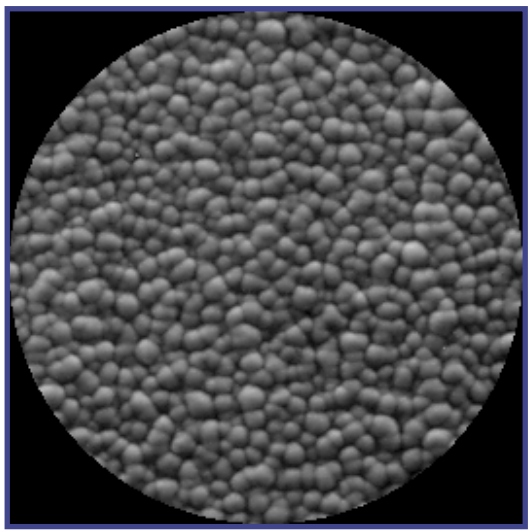
TDC Alternative Development

Investigated Range of CoP Alloys (0-12wt%P) and tested for:

Thickness Uniformity, Surface Finish, Morphology, Adhesion, Ductility, Corrosion, Hardness, Sliding and Abrasive Wear Testing

(Benchmark comparison made against TDC (AMS 2438A)

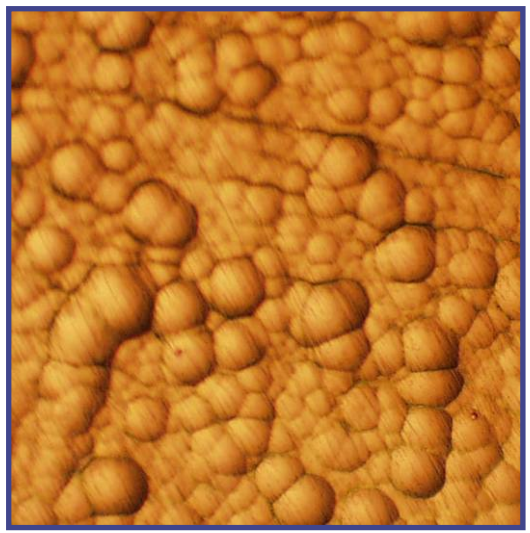
Surface morphology is **nodular** (similar to that of Thin Dense Chrome)



Thin Dense Chrome

Hardness

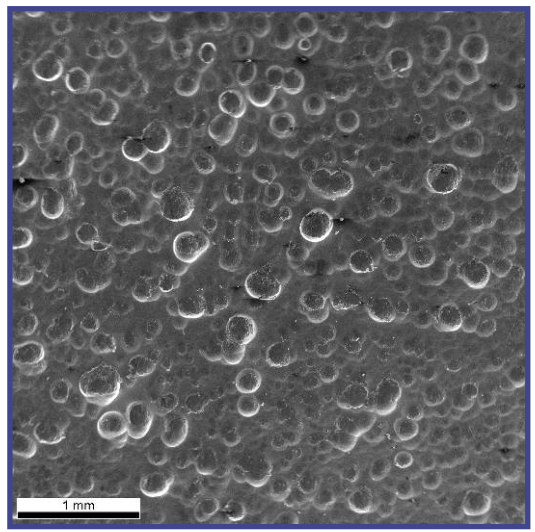
>900VHN



Co 2-3wt% P

Hardness

~600-650VHN As-Dep



Co 11wt% P

Hardness

~700VHN As-Dep

TDC Alternative Summary

Two Classes of Coatings Recommended

	Class 1 nCoP 2-3wt%P HT 191°C – 24hrs	Class 2 nCoP 11-12wt%P HT 300°C – 6hrs
Application Types	When corrosion resistance is required and the substrates cannot be HT to 250°C	When corrosion resistance is not required and the substrates can be HT above 250°C
Thickness Uniformity	Need proper masking/shielding to achieve required thickness	
Surface Finish	Surface roughness unaltered after coating to 0.0005”	
Adhesion	Pass	Pass
Ductility	4-5%	~1%
Corrosion Salt Spray	Pass	Fail
Hardness	650 VHN	1100 VHN
Wear (Sliding)	Good	Good
Wear (Abrasive)	Good ~18mg/1000cycles	Very Good ~7.7mg/1000cycles

Application-Specific Testing

Technology Partnerships Canada

HCAT Meeting – Jan 24th, 2007 – New Orleans

TDC Alternative Dem/Val

Motivation

- Part of Dem/Val to qualify nano CoP as TDC alternative

Objectives

- Demonstrate nano CoP for use as TDC alternative in actuator cylinder

Methods

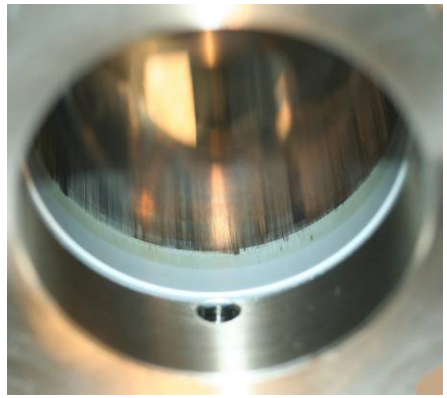
- Actuator cylinder IDs coated with 0.0003" nano CoP
- Endurance testing and evaluation at Smiths Aerospace
  - Compared to Armoloy NTDC in a side by side rig test

Technology Partnerships Canada

TDC Alternative Dem/Val

Preliminary results

- **Endurance testing and evaluation**
  - Nano Co-P showed similar behaviour and performance to Armoloy NTDC
  - Considered equivalent in this application
- **Future Work**
  - More extensive testing of nano CoP required for this application
  - Commercial details
    - Local suppliers of this process?
    - Would like more information of production quantity processing costs from a more dedicated, production facility



TDC-coated actuator
Post-test

nano CoP-coated actuator
Post-test

Endurance Testing

Motivation

- TDC alternative for NLOS applications in landing gear manufacturing

Objectives

- Demonstrate adhesion on base metal substrates
- Design and fabricate plating anodes for plating 1” ID cylinders
- Assess performance of nano CoP coatings in utility actuator application

Methods

- Nano CoP (0.0005”) applied to
  - OD surface of actuator piston rods
  - ID surface of actuator cylinders
- Endurance testing at Messier Dowty
  - 20,000 cycles
  - simulates a scheduled commercial overhaul inspection

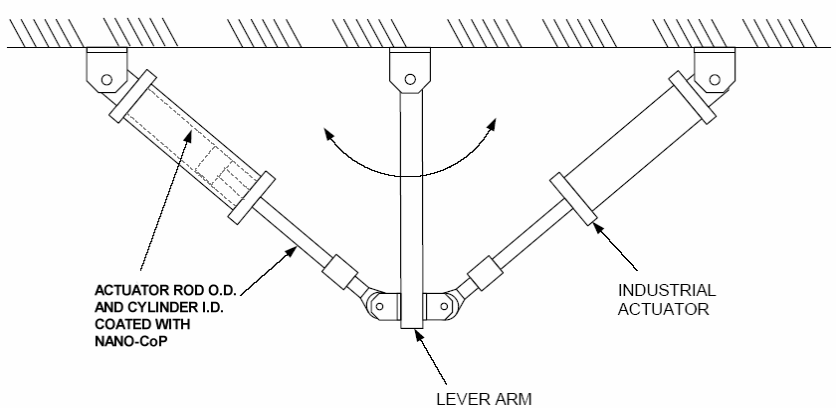


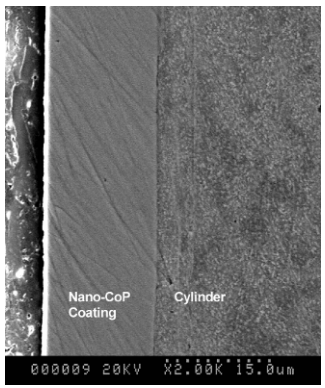
FIGURE 1 – ILLUSTRATION OF TEST SETUP

Endurance Testing

Performance Testing and Results

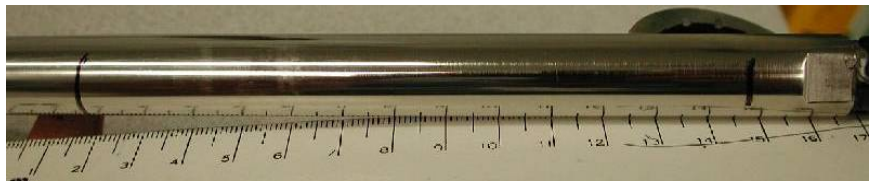
nano CoP coating

- conformed to substrate surface
- no change in surface roughness (Ra = 0.06)

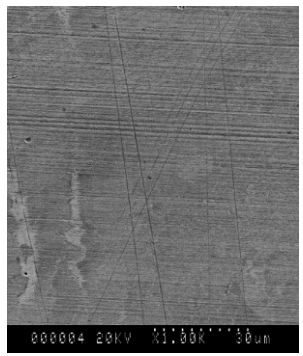


- 1 of 3 cylinders showed delamination during sectioning
  - caused by activation procedure
  - corrective actions implemented

Endurance testing



- Minor wear/scoring (discoloration)
  - localized areas of piston and cylinder
  - sub-micron depth scoring (negligible wear)



- Acceptable leakage performance
  - <1 drop of hydraulic fluid in 25 cycles

- tests successful in meeting performance goals
- coating under consideration for the A 380 nose landing gear design team

Summary

- **Industrial scale-up of nCoP process successful to date**
- **NADEP-JAX Dem/Val**
  - Tank installation complete
  - Technology transfer underway
  - Some growing pains incurred (i.e. issues with Pitting/Adhesion/Anode Set-up)
  - Issues have been addressed Dem/Val process continues
- **JTP Testing**
  - Sample preparation and testing well underway
  - Initial hydrogen embrittlement issues seem to be resolved
  - Additional studies being performed to get to root of HE Problem
  - Fatigue testing to be repeated
- **TDC Alternative Development**
  - Preliminary testing compete
  - Application-specific testing ongoing
- **Application-specific testing**
  - Actuator rig testing reveals good results against polymeric/rubber seals

The End

THANK YOU FOR LISTENING!

History of Cobalt Use

Cobalt is widely used in industry for years:

- **Pigments**
  - Cobalt coloring of ceramics has been known for well over 2,000 years in Persia and Egypt
- **Metallurgical**
  - Superalloys, Hastalloy, Stellite, Thermal Spray Alloys, Co-WC
- **Electronics**
  - Samarium cobalt hard magnets
  - Magnetic particle recording
  - Perpendicular recording with Co-Cr
- **Catalysts**
- **Medicine**
  - Co-Cr alloys in prosthetics
  - Cobalt 60 used in food and medical sterilisation
- **Agriculture**
  - Animal feed to increase vitamin B12 in meat
- **Plating**

Cobalt Health Concerns?

Cobalt in small amounts is essential to many living organisms, including humans

- Cobalt is a central component of the vitamin cobalamin, or vitamin B-12.
- Having 0.13 to 0.30 mg/kg of cobalt in soils markedly improves the health of grazing animals.

Health Studies

- Co(II) added to a brand of beer in the 1960, increased rate of cardiomyopathy (later attributed to poor diet combined with Co ingestion
- Diamond polishers exposed to Co, WC, etc metal dust developed chromic fibrotic lung disease, however workers exposed to cobalt in strictly Co-refining showed no evidence of lung fibrosis
- No human case studies have indicated Co alone to be potential carcinogen

American Cancer Society Has Four Categories of Carcinogens:

1. "Known to Be Human Carcinogens“
- Cadmium and cadmium compounds
- Chromium [VI] compounds
- Nickel compounds

2. "Probably Carcinogenic to Humans"

3. “Reasonably Anticipated to Be Human Carcinogens"
- Cobalt Sulfate

No chemicals used in Nano CoP Process on the ACS list of Carcinogens