Cadmium Alternatives: Zinc-Nickel Electroplating & Repair of Aluminum Coatings

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Zinc-Nickel Performance Update

LHE Alkaline Zn-Ni Plating Development

- Project Goal
  - Develop an LHE (Low Hydrogen Embrittlement) Version of Alkaline Zn-Ni Plating for HSS Aircraft Parts
    - Look at Different Zn-Ni Formulas
    - Remove Brighteners and Other Additives to Create Low Embrittling Plating Process
- Based on Successful Test Results an LHE Alkaline Zn-Ni Formula was Selected for Further Development
  - Identified as IZ-C17 (contains 13 to 17% Ni)
  - Has Good Corrosion Performance
  - Passes Hydrogen Embrittlement and Re-Embrittlement Testing with ASTM F 519 Ty 1a.1 and 2a Test Specimens
    - Re-Embrittlement Test Specimens Exposed to Distilled Water and 3.5% Salt Water

IZ-C17 Zn-Ni Plating Tank

- 60 L Plating Tank Installed in Laboratory

IZ-C17 Zn-Ni Plating Process

IZ-C17 Zn-Ni Process

- Solvent Clean
- Grit Blast
- Water Rinse
- IZ-C17 Zn-Ni Plate
- Rinse
- Embrittlement Bake
- Rinse
- Chromate Conversion Coat
- Rinse

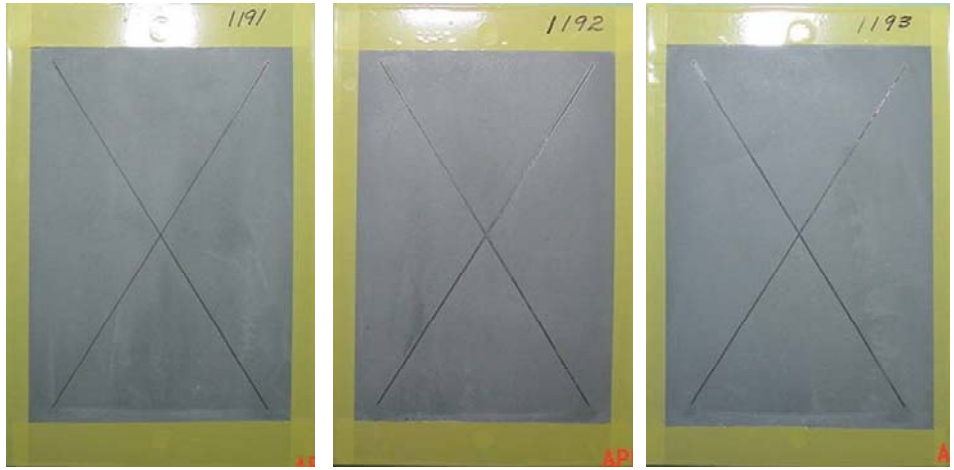
Zn-Ni Process is Easier and Less Hazardous Than Cadmium Plating

Cadmium Process

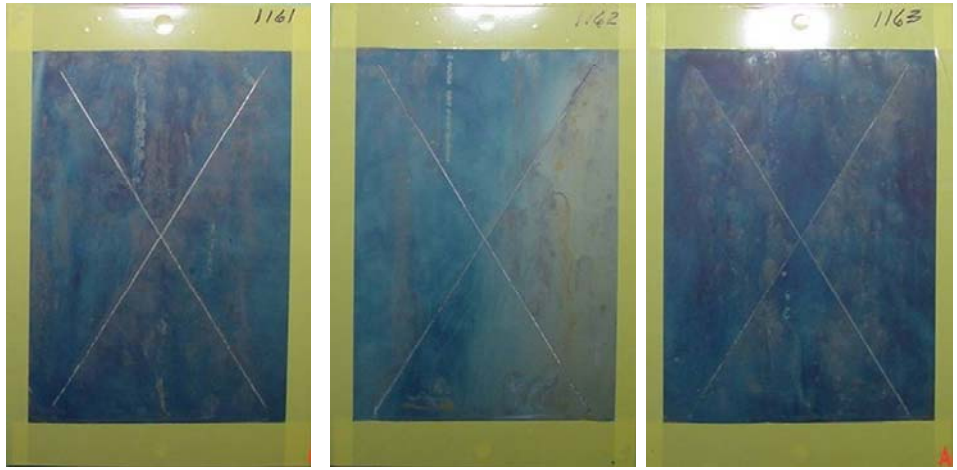
- Solvent Clean
- Grit Blast
- Water Rinse
- Cadmium Plate ($Cd + CN^-$)
- Rinse
- Chromic Acid Neutralize (Cr^{+6})
- Rinse
- Embrittlement Bake
- Nitric Acid Activate (HNO_3)
- Rinse
- Chromate Conversion Coat
- Rinse

IZ-C17 Zinc-Nickel Corrosion Tests

- LHE Cadmium Plating (Top) and IZ-C17 Zinc-Nickel Plating (Bottom)
  - Scribed ASTM B 117 Salt Spray Test after 1000 Hours Exposure
    - No Red Rust in Scribed Areas



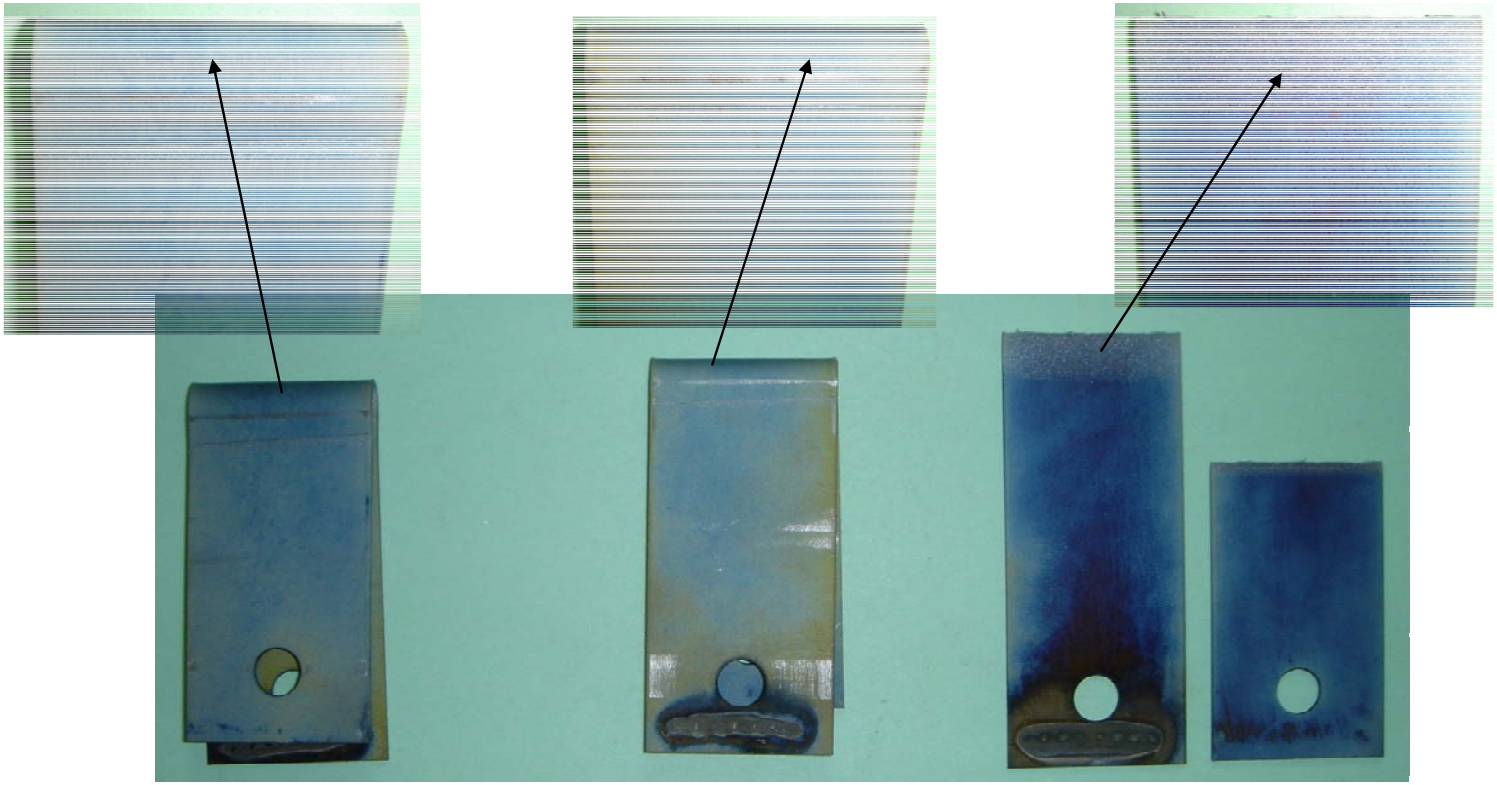
LHE Cadmium Plating – 1000 Hrs. ASTM B 117 Salt Spray Exposure



LHE Zinc-Nickel Plating – 1000 Hrs. ASTM B 117 Salt Spray Exposure

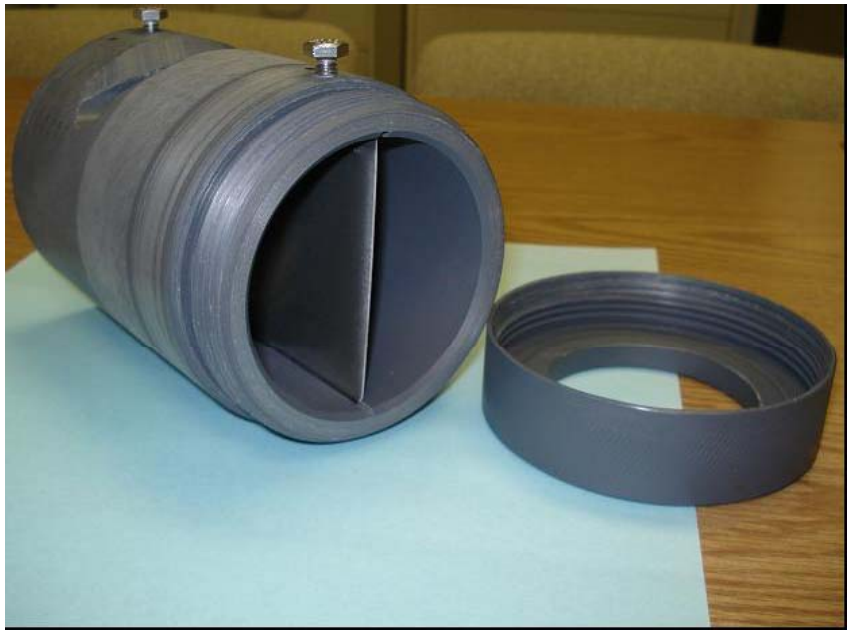
IZ-C17 Zn-Ni Adhesion and Thickness

- IZ-C17 Has Good Adhesion and Uniform Thickness



Sample # 3061	Sample # 3062	Sample # 3063
Thickness = 0.45 +/- 0.02	Thickness = 0.47 +/- 0.02	Thickness = 0.44 +/- 0.04
DAC Adhesion = Pass	DAC Adhesion = Pass	Mil Spec Adhesion = Pass

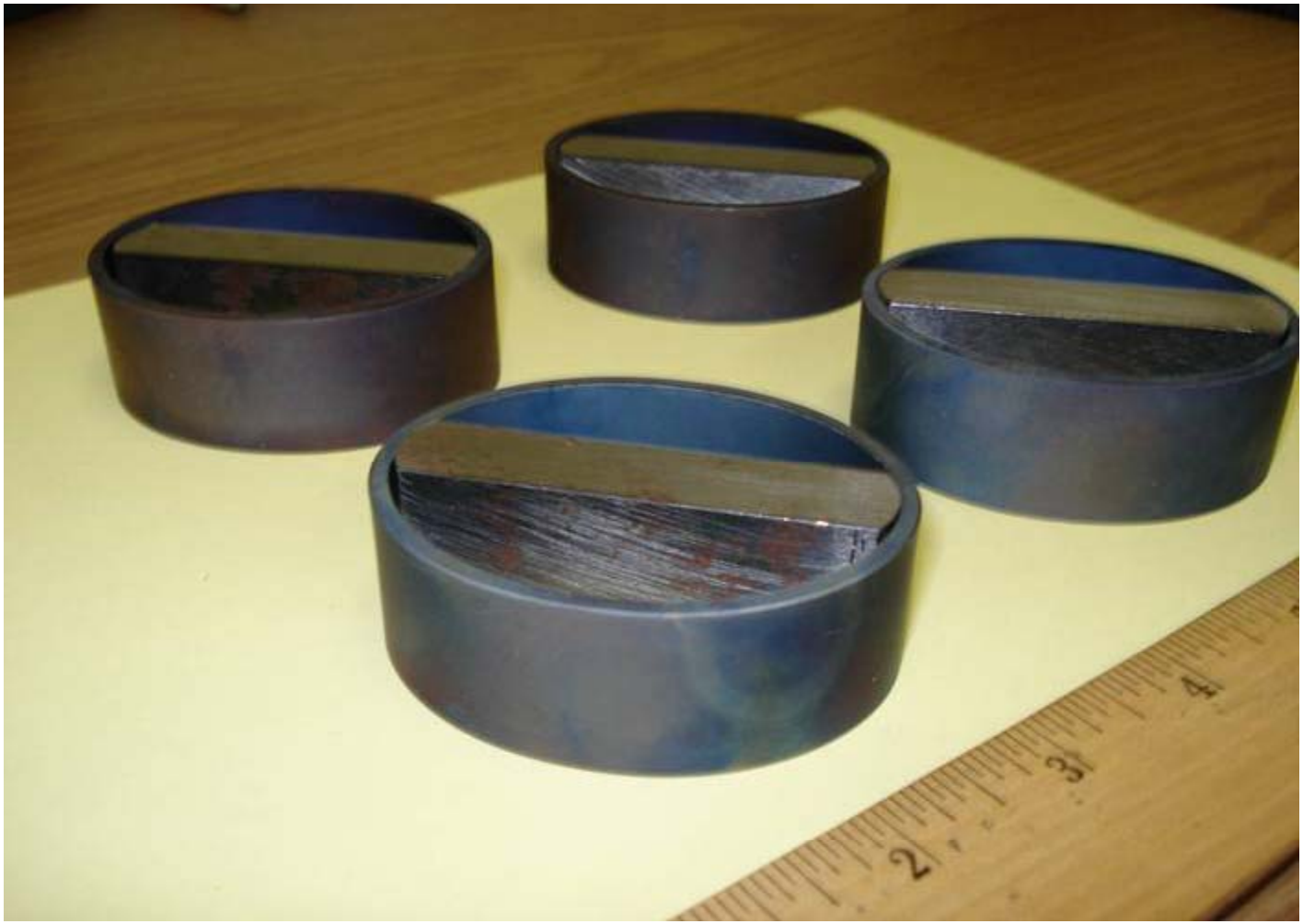
JCAT Throwing Power Test



Hull Cell Test Panel Inserted
In Plastic Tube

Tube with Hull Cell Test Panel
Placed in Zn-Ni Plating Bath

IZ-C17 Type 2a HE Testing



IZ-C17 Fatigue Test Specimens

2007 Testing of IZ-C17 Zn-Ni Plating

- Numerous Qualification Tests with IZ-C17 LHE Zn-Ni Plating Completed in 2007 – Report Issued to Air Force
  - Hydrogen Embrittlement (1a.1, 1a.2, 2a)
  - Adhesion and Metallurgy
  - Corrosion Testing (Salt Spray and Galvanic)
  - Fluid Immersion (ASTM F 483)
  - Lubricity (Fasteners)
  - Strippability
    - Ammonium Nitrate (pH 10)
    - Dilute Hydrochloric Acid
  - Throwing Power (JCAT Method)
  - Fatigue

Zinc-Nickel vs. Cadmium Score Sheet

Properties	LHE Cadmium	IZ-C17 LHE Zinc-Nickel
Corrosion - Salt Spray	1000 hours	+ 1000 hours
Hydrogen Embrittlement (1a.1)	Pass	Pass
Hydrogen Re-Embrittlement - Water	Marginal	Pass
Hydrogen Re-Embrittlement - Salt Water	Fail	Pass
Throwing Power	Poor	Good
Fatigue	Good	Good
Lubricity	Good	Needs Lubricant
Electrical Properties	Good	TBD
Fluid Immersion	Good	Good
Strippability	Good	Good*

* Dilute HCl Solution - Strips Zn-Ni in 10 seconds and is Non-Embrittling

Evaluation of IZ-C17+

- Dipsol has Improved the LHE Zinc-Nickel Plating Bath with Better Stability and Longer Plating Bath Life
  - IZ-C17+
- IZ-C17+ is Similar to IZ-C17 But Contains Better Stabilizers and Bath Life Extenders
- Preliminary Tests Have Shown that IZ-C17+ is Equivalent in Performance to IZ-C17
  - Tests Performed with Tri-Chrome Conversion Coating
- SBIR Project to to Implement LHE Zn-Ni Plating at Air Force ALC
  - Boeing Partnered with ES3
  - IZ-C17 or IZ-C17+ Will Be Used for This Application

IZ-C17+ Zn-Ni Plating Process

IZ-C17+ Zn-Ni Process

- Solvent Clean
- Grit Blast
- Water Rinse
- IZ-C17+ Zn-Ni Plate
- Rinse
- TriCr Conversion Coat
- Rinse
- Embrittlement Bake

TriCr CC on Zinc-Nickel Is Not Affected by the 375ºF Baking Temperature

IZ-C17 Zn-Ni Process

- Solvent Clean
- Grit Blast
- Water Rinse
- IZ-C17 Zn-Ni Plate
- Rinse
- Embrittlement Bake
- Rinse
- Chromate Conversion Coat
- Rinse

IZ-C17+ with TriCr CC Process is Easier and Less Hazardous Than IZ-C17 with HexCr CC

2008 Tasks to Implement Zn-Ni

- Issue DPS for LHE Zn-Ni Plating
- Set-Up Larger Tank (200 to 400 Gallon) for Production Process Control Testing
- Continue to Evaluate Tri-Chrome Conversion Coating on Zn-Ni
- Develop an Accelerated Hydrogen Embrittlement Test
- Perform Hydrogen Re-Embrittlement Tests with Maintenance Fluids (Cleaners and Paint Strippers)
- Perform Additional Fatigue Tests
- Evaluate Performance of Aircraft Paint Systems on Zn-Ni
- Develop Touch-Up Brush Plating to Repair Zn-Ni
- Evaluate Electrical Bonding and Grounding Performance
- Identify Lubricant System for Zn-Ni Plated Fasteners

Repair of Aluminum Coatings Update

Current IVD Al Repair Methods

- IVD Aluminum Repair Methods on HS Steel Alloys
  - Condition 1: Bare IVD Al on Steel
    - Touch-Up with Brush Cd Plating
  - Condition 2: Painted IVD on Steel
    - Remove rust and scratches
    - Apply two coats epoxy primer
    - Apply one coat sprayable or brushable sealant
    - Apply two coats polyurethane top coat
- IVD Al Repairs Shall Not Exceed 5% of Total Part Area or 0.5 in^2 per Individual Area
  - Repairs That Exceed Limits
    - IVD Al Shall Be Stripped and Reapplied

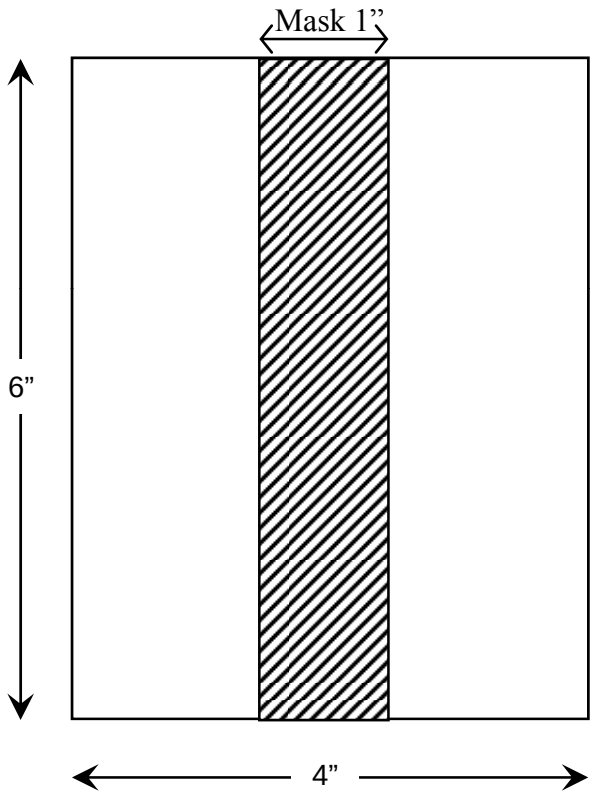
Alternative Al Coatings and Repairs

- IVD Aluminum Coating Alternatives Being Developed or Implemented for High Strength Steel
  - Sputter Aluminum
  - Electroplated Aluminum – Alumiplate
  - APCVD Aluminum
- An Environment Friendly Repair Method is Needed for These Environment Friendly Coating Processes
  - Sn-Zn Brush Plating
  - Zn-Ni Brush Plating
  - SermeTel 249/273
  - Cold Spray Aluminum

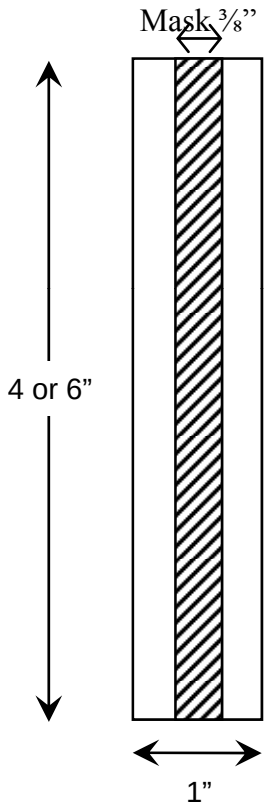
Brush Plating

- Potential Candidates Considered
  - LDC 5030 Sn-Zn and SIFCO 4018 Zn-Ni
- LDC 5030 Sn-Zn Selected Because of No-Bake Hydrogen Embrittlement Performance
- Aluminum Surface Preparation for Brush Plate
  - Bare Aluminum – Poor Adhesion
  - Zincate Brush Treat – Inconsistent Results
  - Nickel Strike – Good Adhesion
- Corrosion and Adhesion Tests Performed with Brush Sn-Zn and Cadmium Applied to Damaged IVD Aluminum Steel Test Panels

Repair Test Specimens



Corrosion Test Specimen



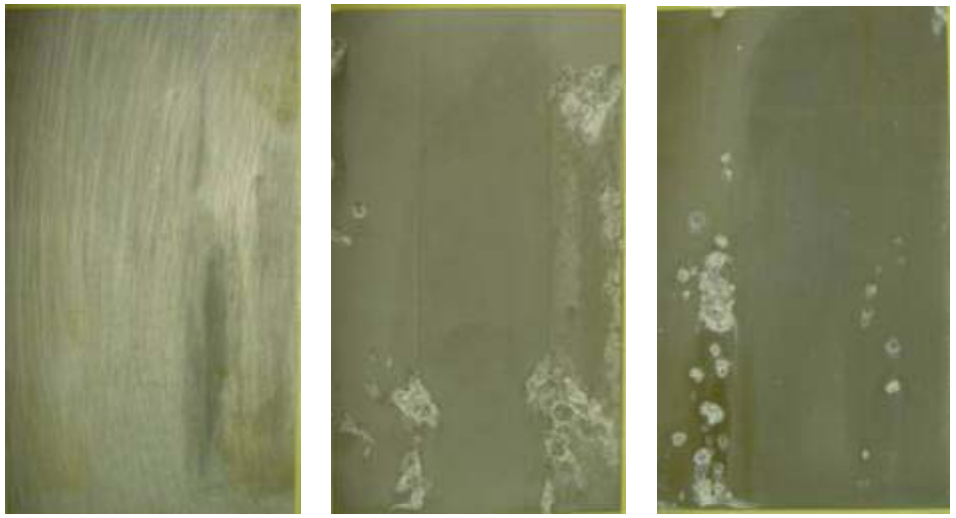
Adhesion Test Specimen

4130 Steel with IVD Aluminum Applied

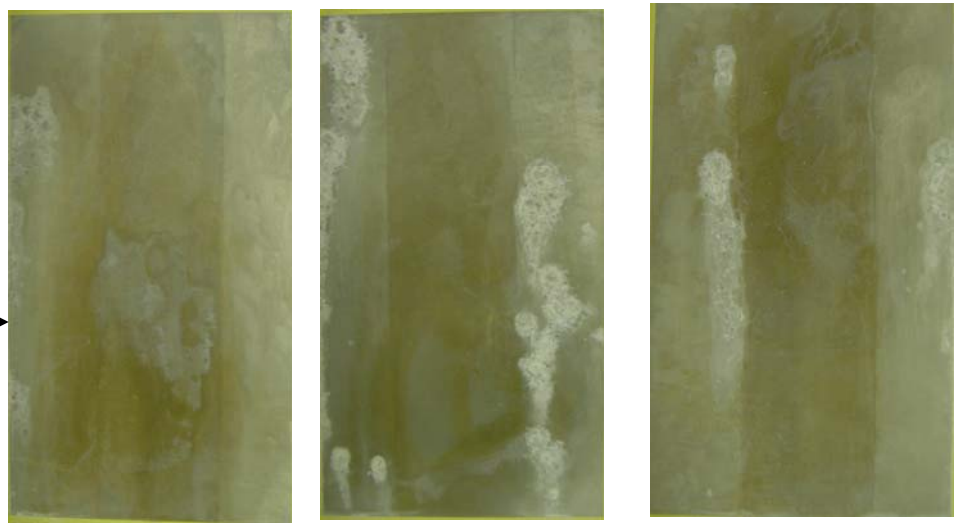
Brush Tin-Zinc on IVD Al

ASTM B 117 1000 Hours

Brush Cd Repair on IVD Al

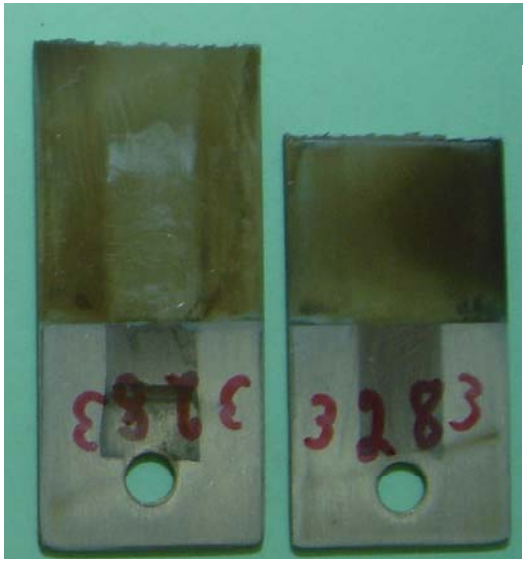


Brush Tin-Zinc Repair on IVD Al



Brush Plating Properties

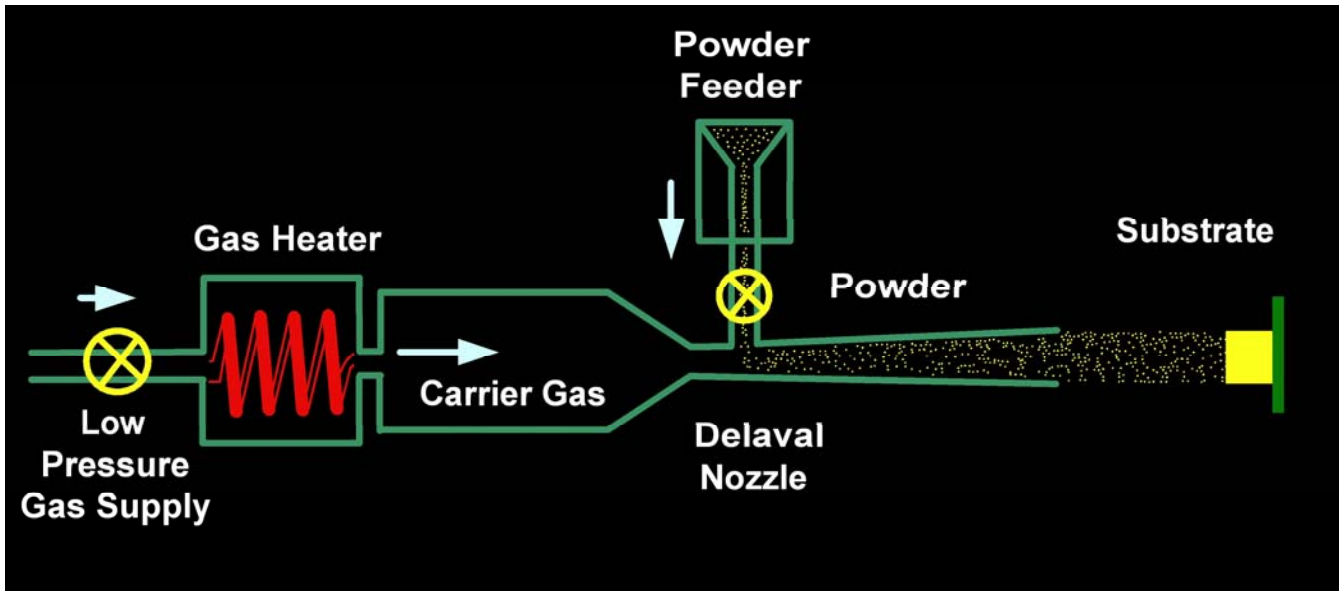
- Adhesion of LDC 5030 Brush Sn-Zn on IVD Aluminum is Good with the Nickel Strike
- Fatigue Test Results for Brush Sn-Zn are Similar to Brush Cd Plate



SermeTel 249/273

- Repair Specimens Prepared for JG-PP JTP Phase I
  - SermeTel 249/273 Applied to Bare Steel for Hydrogen Embrittlement and Adhesion Testing in Phase I
    - Failed Adhesion but Passed HE Tests
- Additional Type 1a.1, 1x4 and 4x6 Samples Prepared and Shipped to CTC for Phase II Testing
  - No Results to Report

Cold Spray Aluminum

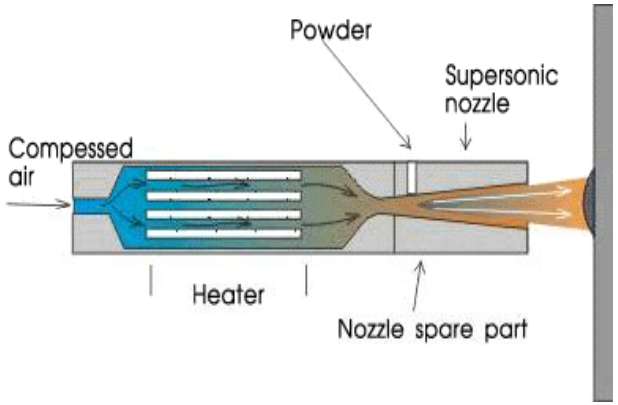


- Cold Spray – Particles Impacting on Substrate Do Not Melt
- Process Adaptable to Wide Variety of Operating Conditions (Supply Gases, Gas Temperature, Powders, Feeder Designs, Nozzle Designs, Manual or Robotic Application)

Cold Spray Aluminum

- Need Robust and Easy to Operate Portable Cold Spray Equipment For Repair of Aluminum Coatings
- Equipment and Processes Available from Several Different Companies
  - Dymet
  - Centerline
  - K-Tech
  - ARL
  - Innovati
  - Delphi
  - ASB
    - CGT
  - Etc.

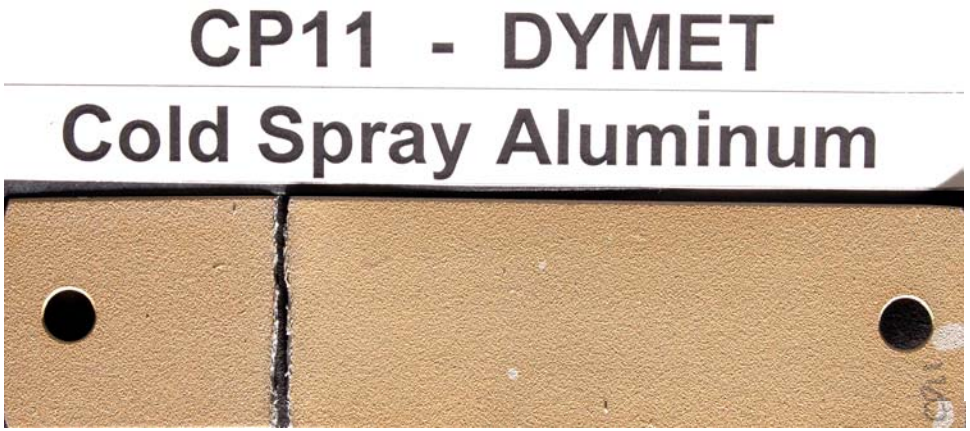
Dymet



- Steel Test Samples Sent to Obinsk Center for Powder Spray (OCPS) for Application of Cold Spray Al with Dymet Equipment
- Coating Appearance was Acceptable But System Did Not Seem to be Operator Friendly

Dymet Results

- Test Results for Steel Samples Received from OCPS with Dymet Cold Spray Al Coatings
  - Good Adhesion
  - Good Corrosion Performance (1000 Hr B 117 Scribed – No Rust)
  - Process is Non-Embrittling to HS Steel
  - Thickness 1.5 to 2 mil



Passed Bend to Break Adhesion Tests

Centerline SST

- Centerline SST Unit is Improved Version of Dymet Equipment

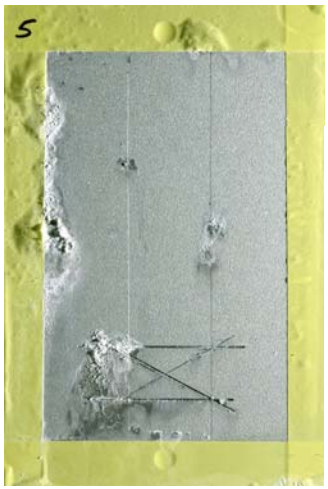
SST Results for Cold Sprayed Al

- Adhesion Testing Carried Out on Steel and IVD Aluminum
  - Passed Tape Adhesion Test
  - Passed Glass Bead Burnish Adhesion Test at 60 psig
    - This is the Adhesion Test Used for IVD Al
  - Some Flaking on Bend-to-Break Test
- Corrosion Test Results Carried Out on Damaged IVD Aluminum Steel Panels
  - Exceeded MIL-DTL-83488 Requirement

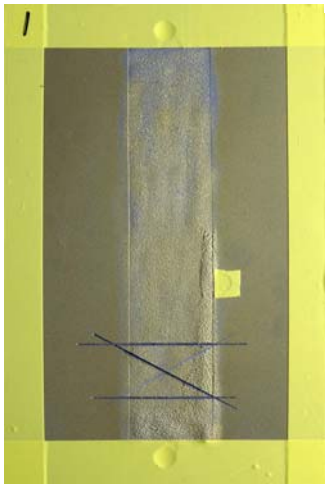
Corrosion Test of SST Cold Spray Al

ASTM B 117 1008 Hours

Cold Sprayed Al
Applied Robotically



Cold Sprayed Al
Applied Manually



0 Hours

1008 Hours

Cold Spray Test Plans

- Purchase Centerline SST Portable Unit
  - Develop Process to Repair Damaged Aluminum Coatings
    - Thickness
    - Adhesion
    - Corrosion
    - Fatigue
    - Hydrogen Embrittlement
- Continue to Work with Other Cold Spray Vendors and Laboratories to Repair
  - Damaged Alclad Aircraft Skins
  - Damaged Aluminum Aircraft Parts

Questions?