Evaluation of Alternatives to Electrodeposited Cadmium for Threaded Fastener Applications (II)

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Agenda

Background
Program Goals
Coating Descriptions
Test Methods
Test Results
- Coating thickness/appearance
- Hydrogen pick up and cross-sections
- Resistance to vibration test results
- Calculation of friction coefficient: Torque-tension test
- Mechanical properties
- Tribological tests
- Salt spray test
- Stress-corrosion tests

Summary

Background

- Lockheed Martin Aeronautics (LM Aero) manufactures the F-16 Fighting Falcon in Fort Worth, Texas, USA
  - The world's most popular, most sought-after multirole fighter
  - Over 4400 delivered; over 110 different versions

Background (continued)

- Part of the F-16 manufacturing process involves removal of primer from the inlet surfaces to accommodate subsequent coatings
    - Cadmium dust is generated from the heads of cadmium-plated (Cd-plated) fasteners

Background (continued)

- LM Aero implemented additional PPE, shower facilities, and more frequent medical monitoring in compliance with the U.S. OSHA cadmium standard
- Cd-plated MS90353 blind bolts were replaced by IVD aluminum-coated blind bolts as partial solution
- Cd-plated threaded bolts also needed to be replaced
  - Primarily NAS 1580 and NAS 4452 fasteners
  - Several hundred per shipset
  - No plating alternatives available on standard

Program Goals

- Funding provided to LM Aero by U.S. Air Force to qualify and implement an alternative to cadmium plating on threaded fasteners
  - Identify candidate materials/technologies
  - Develop test plan
  - Solicit partnership from fastener manufacturer
  - Test representative fasteners plated/coated with candidates
  - Implement the best replacement based on test data, cost, availability

Program Goals (continued)

- Candidates selected based on performance potential, technology maturity, reasonable cost and throughput
  - Alternative substrates considered (e.g. SS, Ti) but cost, weight, and strength issues a concern
  - Secondary coating allowed to enhance lubricity
- Testing to evaluate various alternative coatings for corrosion protection, lubricity, compatibility with substrate
  - NAS 1580A3T12 selected as representative fastener
  - Plan to use NAS 1580 test results for cadmium on NAS 4452, with some possible additional testing

Coating Descriptions

- ***Cadmium***: baseline, QQ-P-416 type II chromate treatment
- ***AlumiPlate***: MIL-DTL-83488D High purity Al, Type II chromate.
    - An organic solvent based water-free electrolyte to electroplate high purity thin amorphous aluminum.
- ***Electrode-less Nickel***: AMS-C-26074, 0.0003”, no conversion coating,
    - a controlled infusion of P-Ni plating.
- ***Electrode-less Nickel-PTFE***: High Phosphorous, 0.0003” min, no conversion coating.
    - Deposits a durable, and dry lubricating coating that combines the PTFE (20-26%) in a strong, hard matrix of electroless Ni-P.
- ***Surface mineralization Zn-Ni:*** enable an environmentally benign cathodic conversion of a microscopically thin barrier of silicate.

Phase II Summary

	Salt-spray	Torque-tension	Run-on torque	Break-away torque	Push-in load	Stress-corrosion
EN	F	F	F	Pass	F	F
EN-PTFE	F	Ex	Pass	Pass	F	F
Cd	Base	Base	Base	Base	Base	Base
Zn-Ni	Pass	Pass	Pass	Pass	Pass	Pass
AlumiPlate	Ex	Pass	F	Pass	F	Ex

F: Fail; **Ex**: excellent

- It appears that no one coating offers the same broad range of properties as Cd plating.
- For the current investigation, Zn-Ni and Alumiplate came closest to the Cd characteristics overall.

Coating Summaries

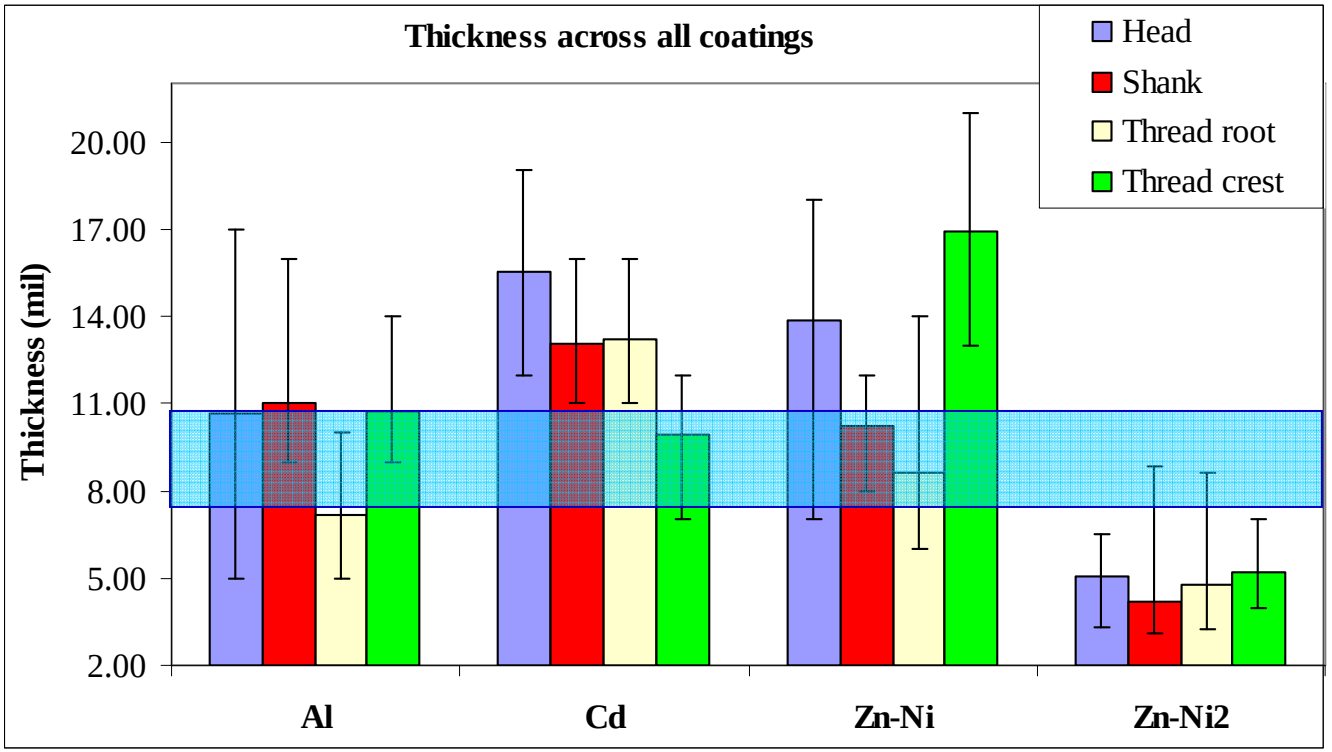
Coatings	Specification	Conversion coating	Lubrication	Coating approach
Cd	QQ-P-416 Type II Class 2	Chromate	Cetyl alcohol lube	Barrel
Zn-Ni	AMS 2417 Type II	Surface mineralization	Sharperize 0121	Barrel
Al	MIL-DTL-83488D Type II, Class 3	Hexavalent chromium	Dry film lube per MIL-PRF-46010	Rack
Zn-Ni2	AMS 2417 Type II	$Cr3^{+}$ Passivation	FINIGARD 111 top coat	Barrel

Base coating target thickness (inch): 0.0003-0.00045

Test Methods: simulate the typical use of threaded fasteners

- General: Coating thickness, microstructure, Hydrogen pick up
- Corrosion Protection: Salt-spray (fog) & potential measurements
- Lubricity:
  - Torque-Tension test
  - Multi-cycle Run-on & Break-away
- Mechanical performances:
  - Tension, shear and fatigue
  - Stress-durability test
- Tribological properties
  - Resistance to insertion: Push–in test
  - Surface Roughness and Friction coefficient
- Resistance to Stress Corrosion Cracking
  - Stress corrosion testing per the NASM 1312-9 specification while measuring corrosion potential.
  - Stress corrosion testing via Al structure while measuring corrosion potential.

Coating thickness/appearance



- Coating is continuous, uniform in appearance, and free from contaminants and other apparent defects.
- Different coating thickness among all coatings.

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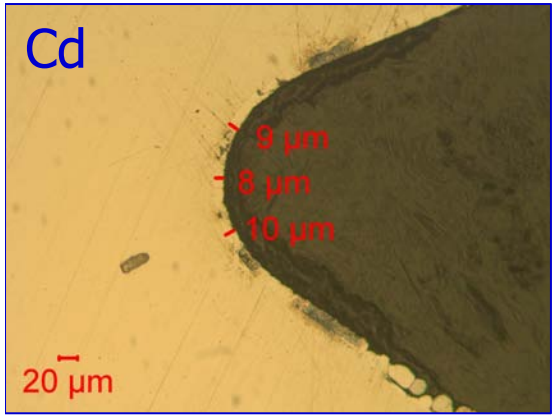
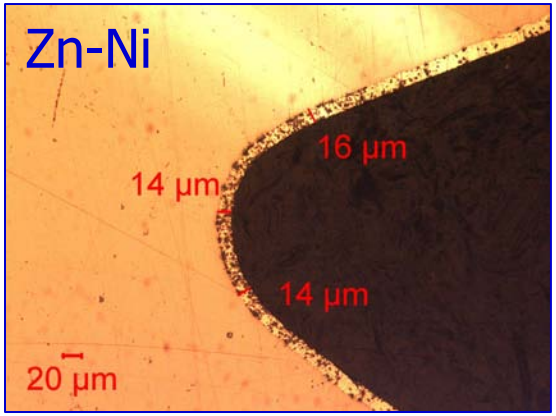
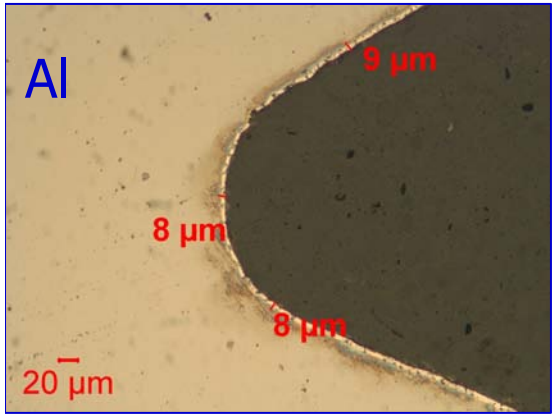
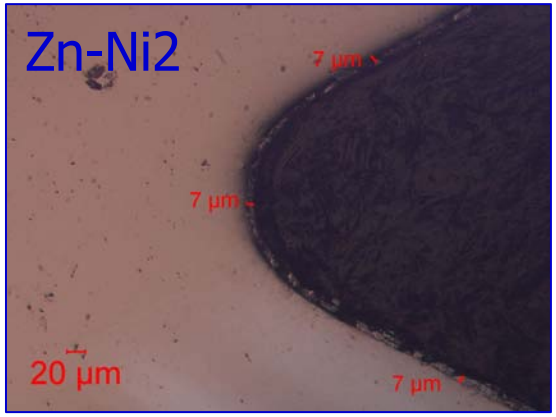
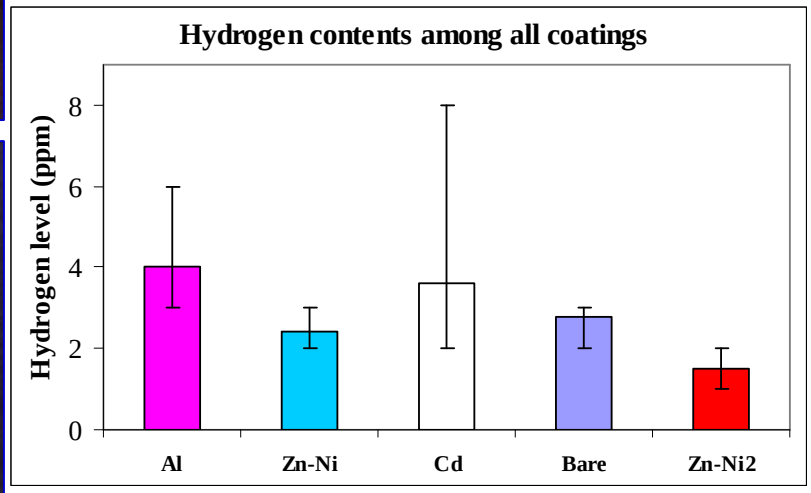
Hydrogen pick up and cross-sections











• All hydrogen tests revealed zero or minimum hydrogen contents after coating

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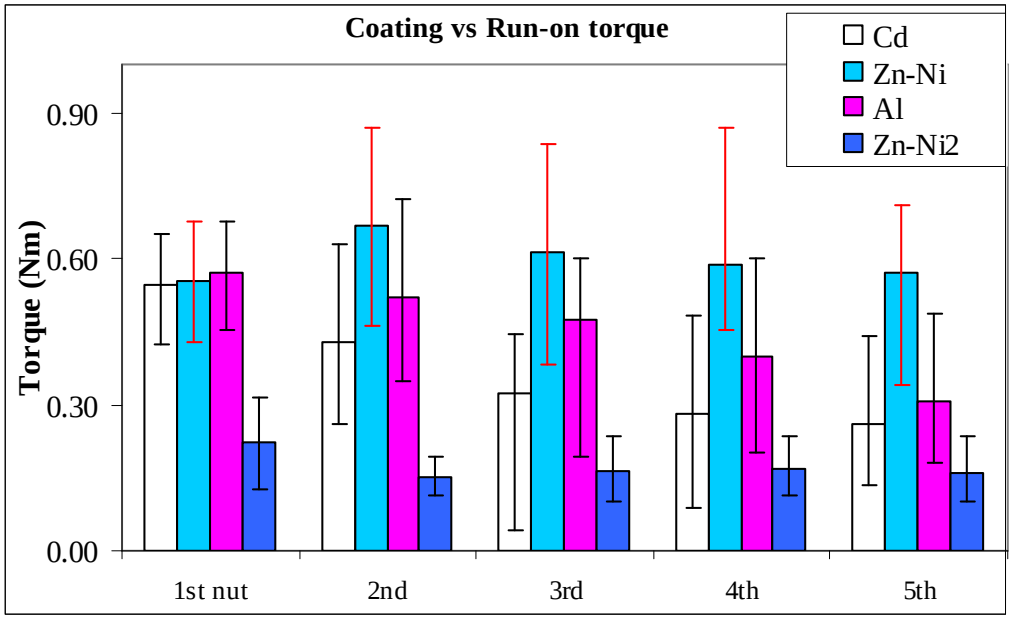
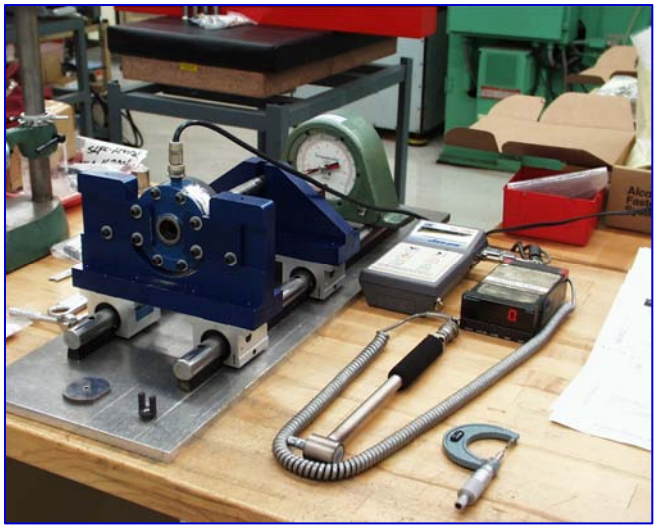
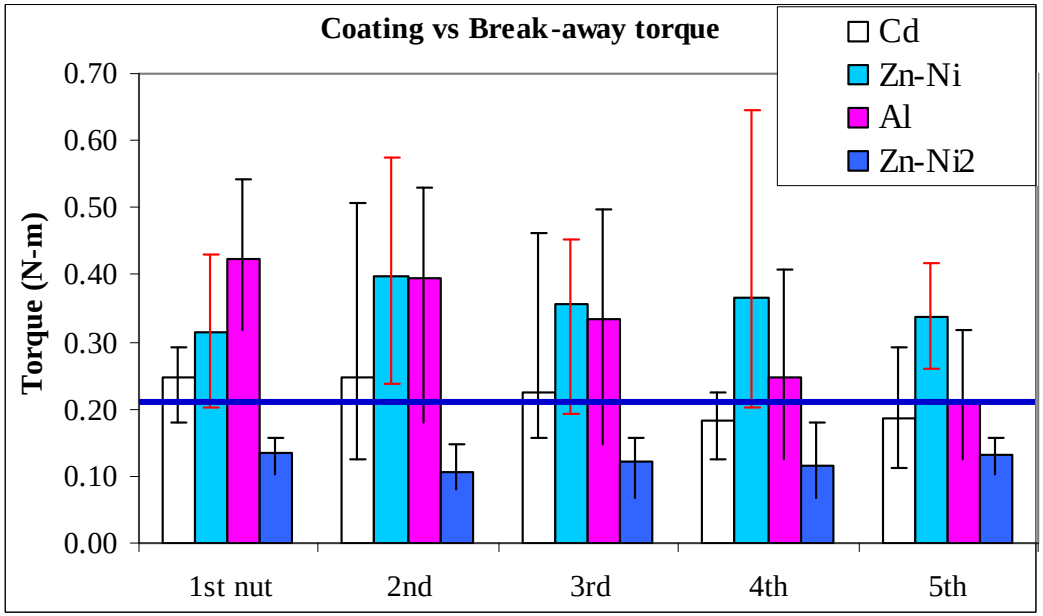
Resistance to vibration test results







Aerospace KFN541L-3F K-fast locking nuts were used for multi-cycle run-on and break-away testing.

All run-on torque values meet the requirements of 18 inch-pounds. The breakaway torque mirrors the run-on torque.

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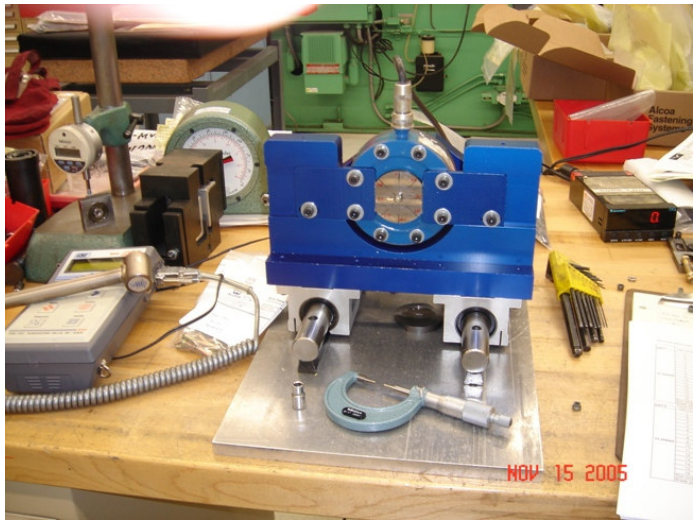
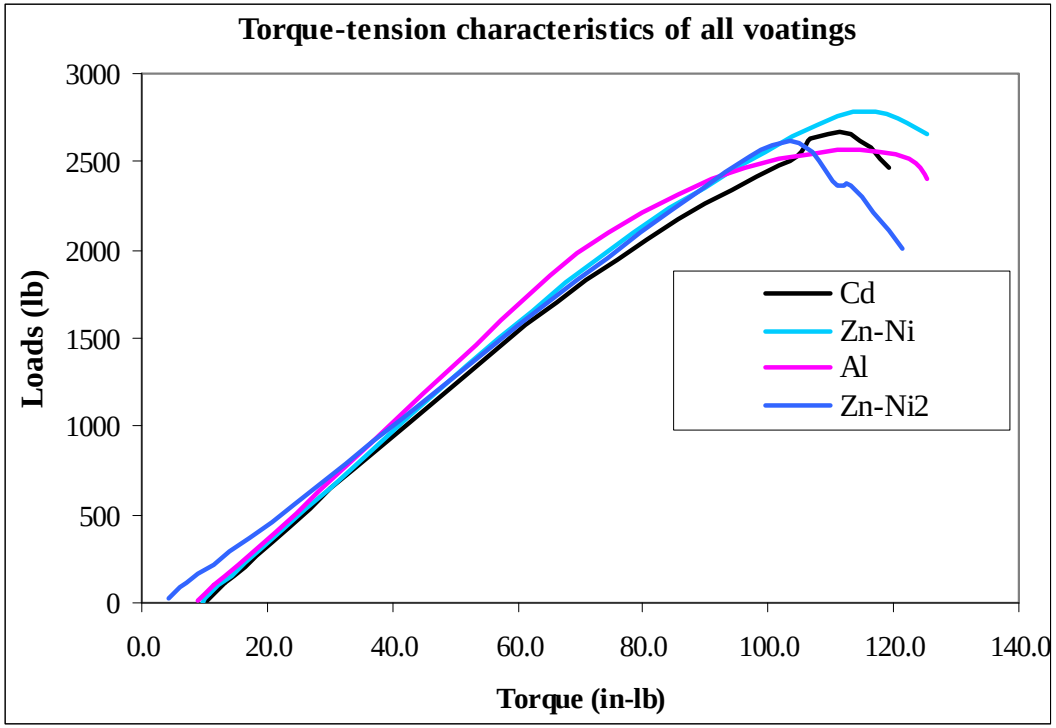
Calculation of friction coefficient:

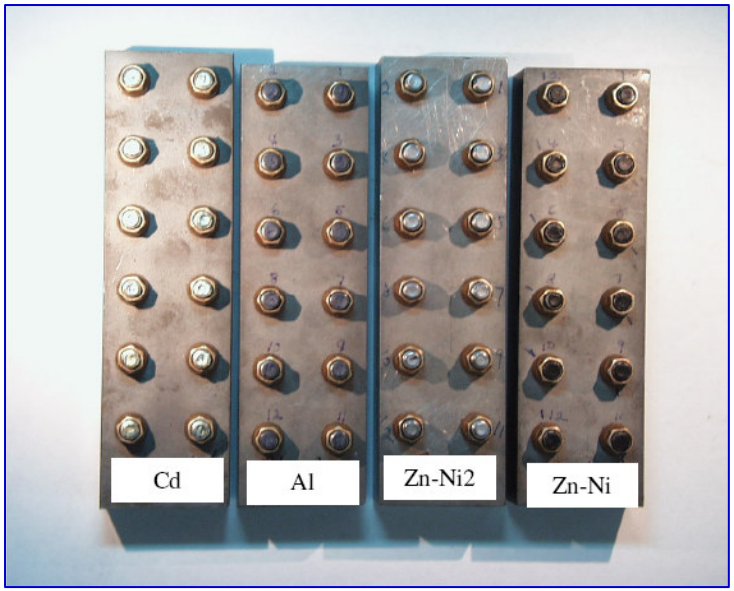
Torque-tension test

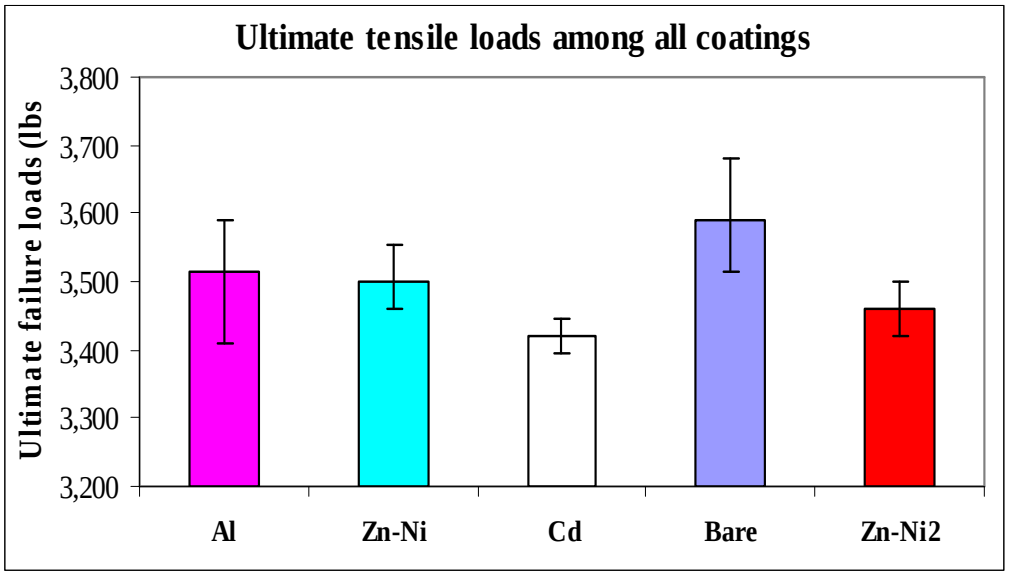




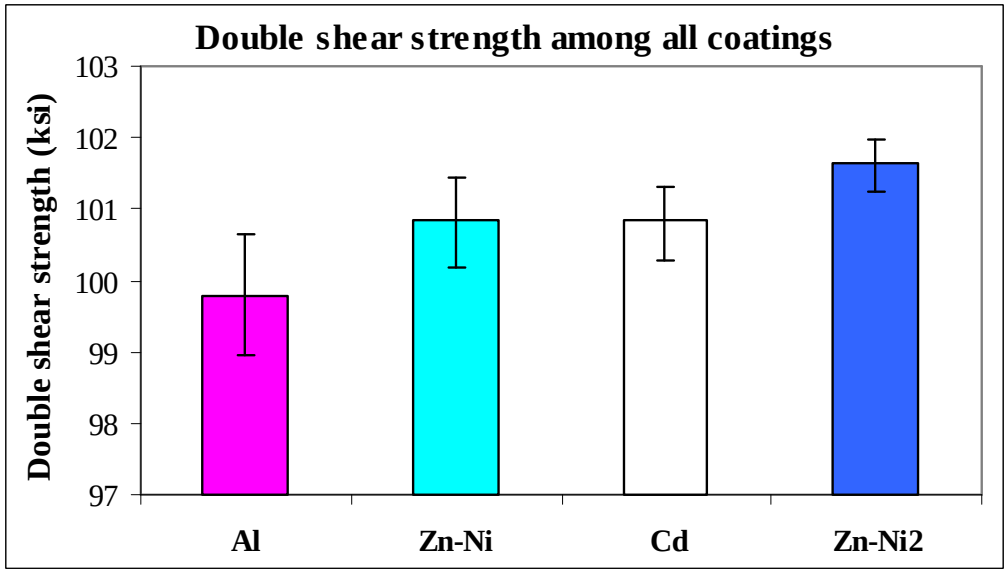
- It is desired that the candidate coatings mimic the torque-tension characteristics of bolts coated with cadmium.
- As expected, the secondary lubricants had a significant effect on torque-tension characteristics, making the alternative coatings similar in performance to Cd plating. Due to surface lubrication, all coatings have similar torque to achieve the required tension.

Mechanical properties Tension, shear, stress-durability tests





- All candidates tested met specification requirement.
- All fasteners passed 1000 hours at a tension of 70% of ultimate strength. In addition, no yielding or further elongation occurred during stress durability test.



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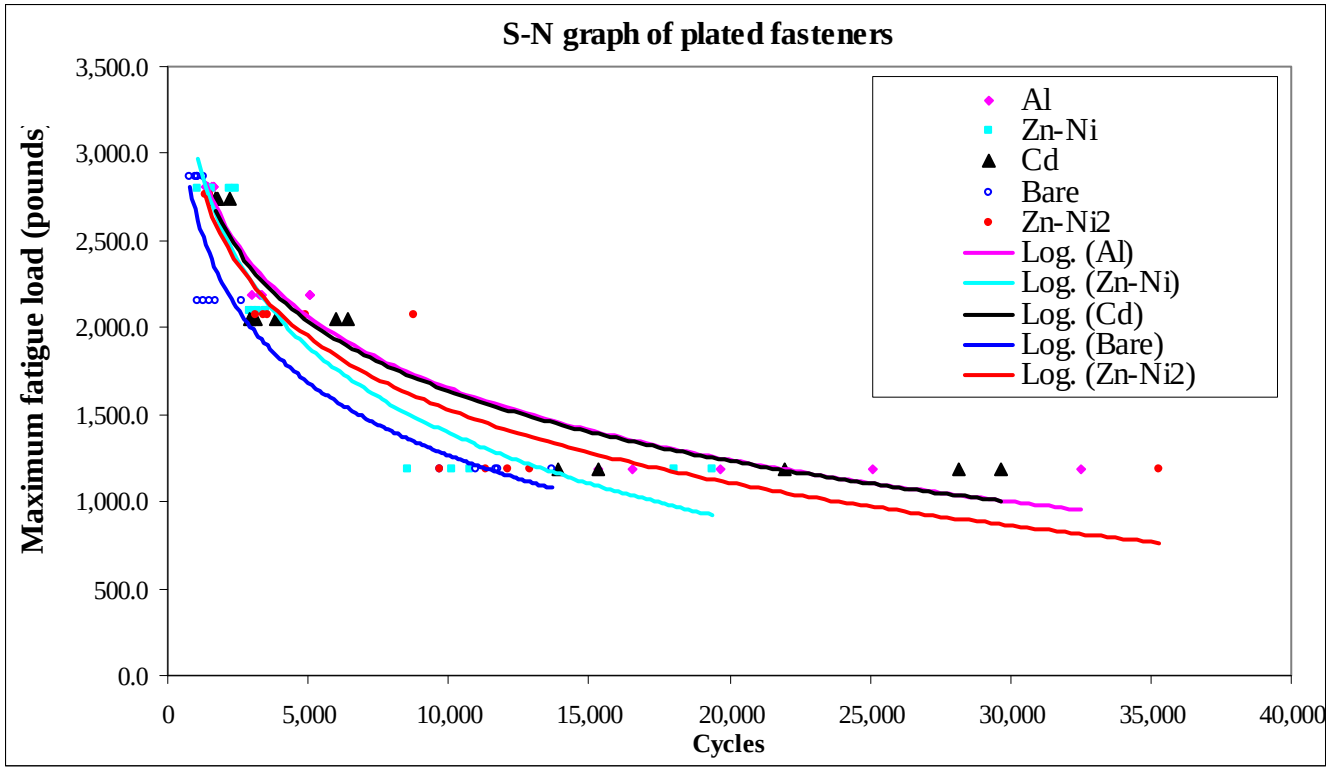
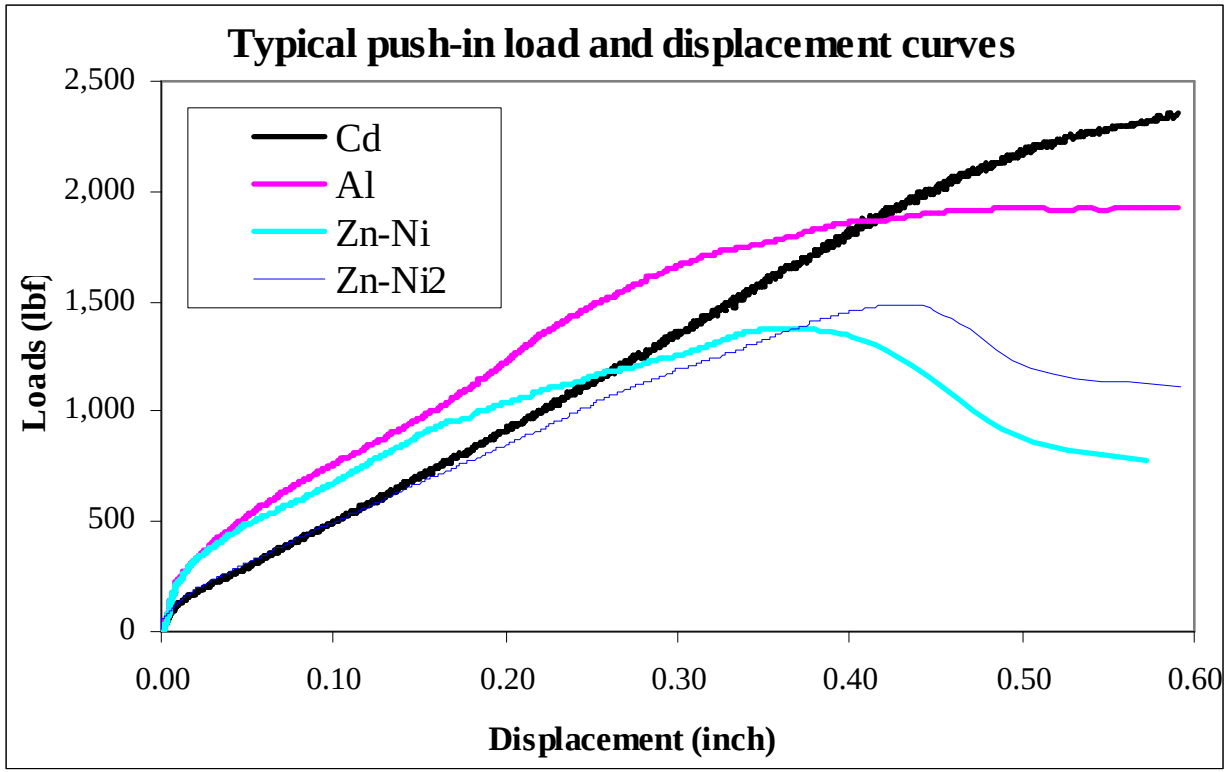
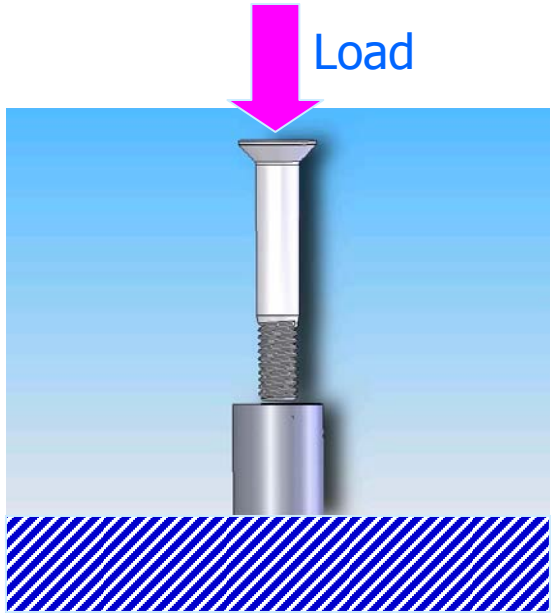
Mechanical properties fatigue



- The testing has a stress ratio of 0.1 and frequency of 30 Hz. Fatigue test loads were specified as 45%, 60% and 80% of the UTS.
- The fatigue life of Al-coated fasteners was comparable to the Cd, indicating no apparent fatigue penalty associated with this coating. However, both Zn-Ni and Zn-Ni2 candidates exhibited a lower fatigue life relative to Cd.

Tribological properties: Push-in tests





The desired maximum installation force is less than 8896 (N) or 2000 lbs.

• Fastener was pushed into interference aluminum hole at constant rate of 4000 lbf/min. Thus the required load and load-displacement curves can be measured.

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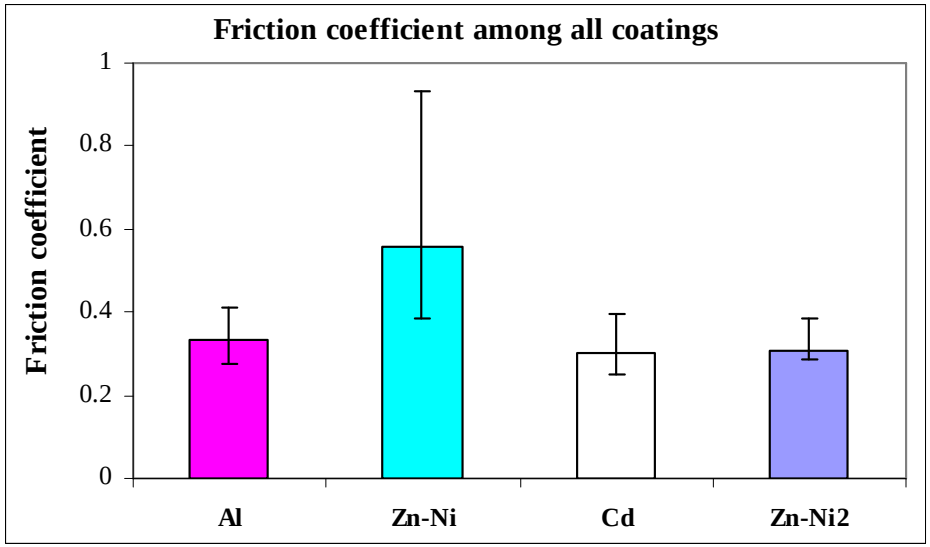
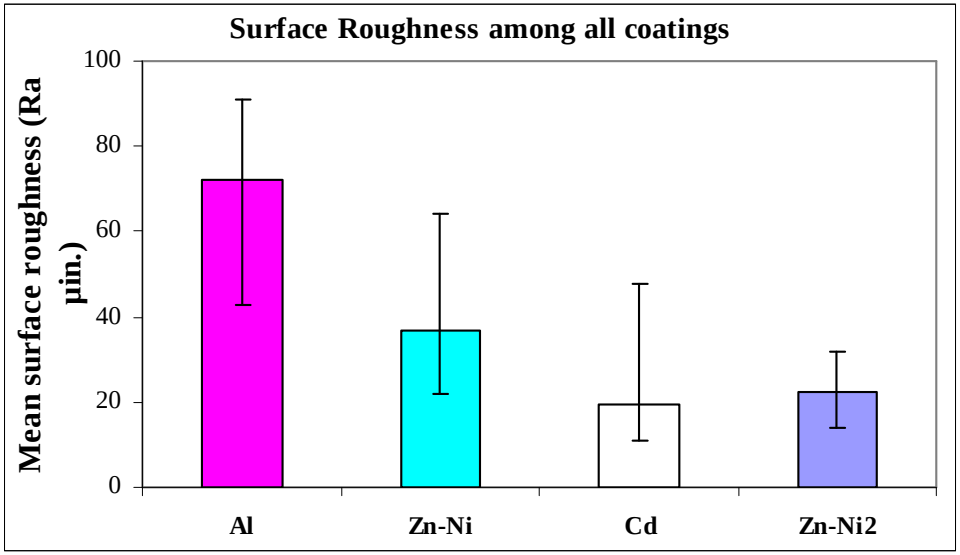
Tribological properties: Roughness & friction





- The Al and Zn-Ni2 coatings have a coefficient of friction comparable to Cd plating while Zn-Ni coating had significantly higher coefficient.

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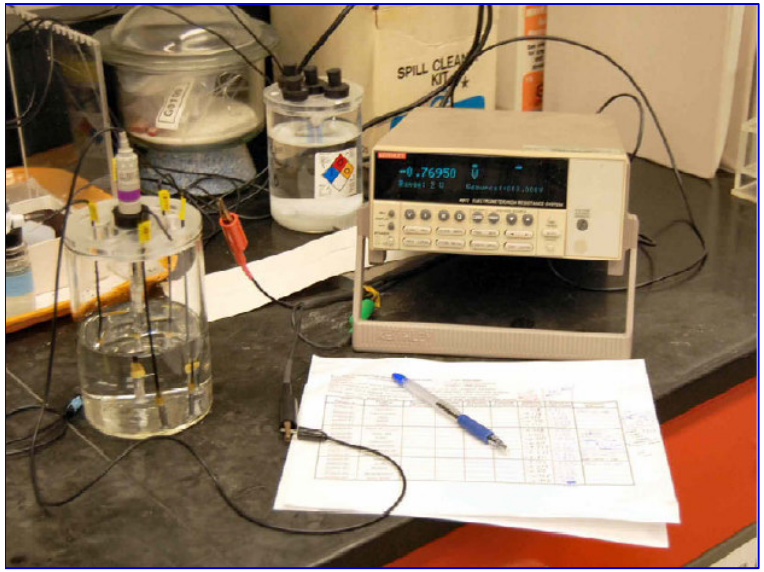
1000 hours Salt spray tests



Corrosion potential measurement for salt spray

• All of the coated fasteners looked very good. While some showed mild staining and discoloration, none of them exhibited any evidence of a "structural" corrosion behavior, e.g., in the form of pits or cracks.

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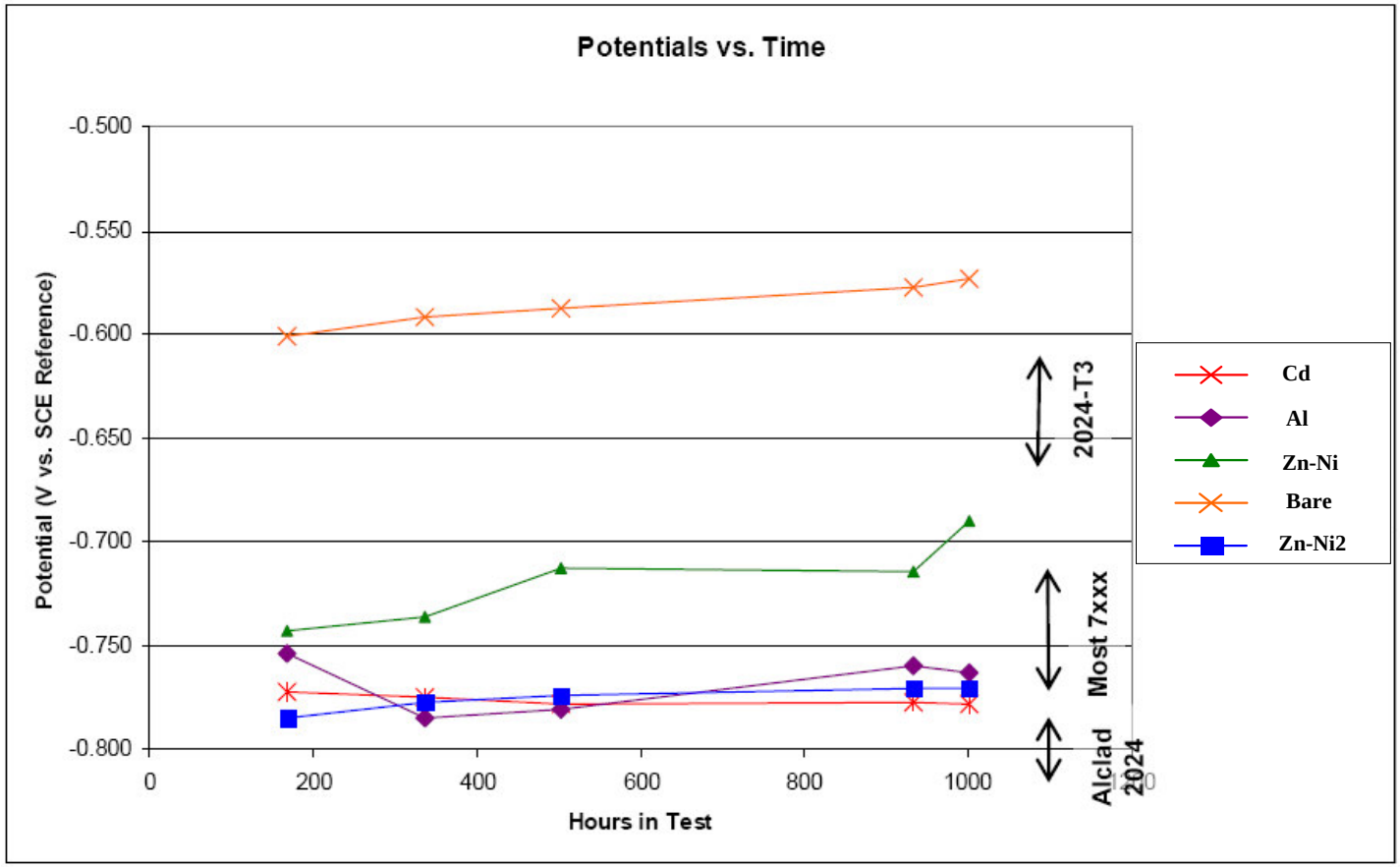
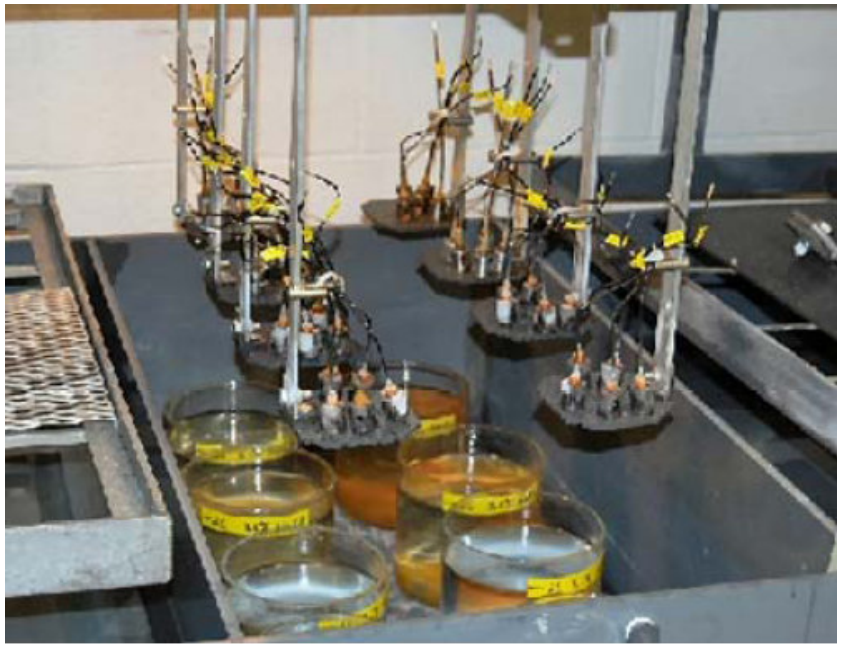
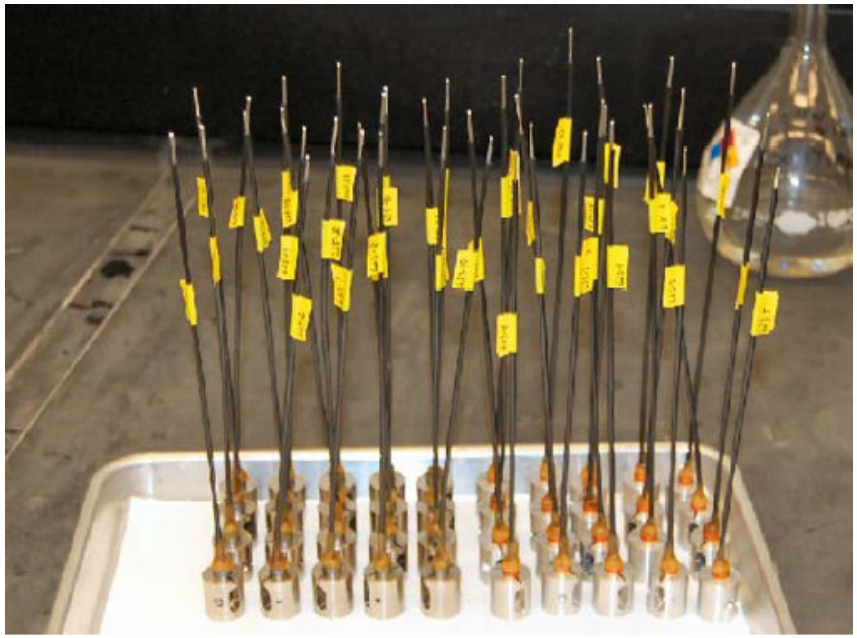
Corrosion potential measurements



- With the exception of Zn-Ni, the coating systems all exhibit essentially an identical corrosion potential. The reason for the difference on the Zn-Ni may be related to the surface silicate layer due to surface mineralization.
- All coating materials will serve well in their role as sacrificial coatings, geared to protect the steel

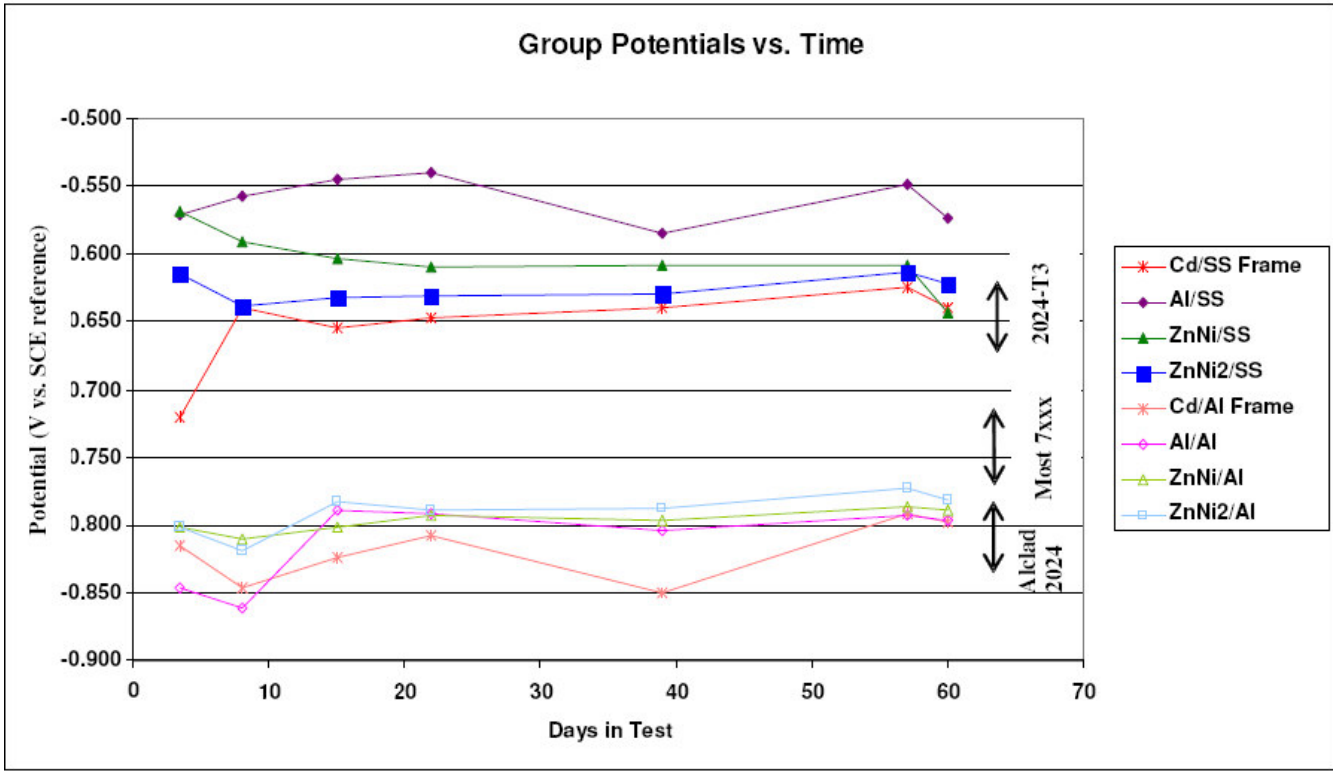
Stress-corrosion tests





- Fasteners were installed onto NASM1312 defined fixture. The applied loads were 1300 and 1500 pounds for aluminum alloy 7075-T6 and stainless steel 303, respectively, due to limited offset torques. In all cases, no evidence of SCC was observed.
- The total running time is 1000 hours.

Stress-corrosion tests



- Any galvanic impact of the fastener/air-frame couple should be similar to what is presently seen for Cd-plated fasteners.
- The corrosion potential of each fastener was periodically measured and were very consistent.

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Summary

Test Description	Zn-Ni	Zn-Ni2	Al
Appearance	=	=	=
Mass	+	+	+
Coating thickness	=	--	--
Microstructure	=	=	=
Hydrogen level	+	+	=
Torque tension	=	=	=
Multi-cycle run-on torque	+	+	+
Multi-cycle breakaway torque	+	--	=
Tensile strength	+	+	+
Double shear strength	=	+	--
Fatigue	--	--	=
Sustained tensile load	=	=	=
Roughness	--	=	--
Friction	--	=	=
Push-in test	+	+	=
Salt fog test	=	=	=
Salt fog corrosion potential	*	=	=
Stress corrosion test (Stainless steel fixture)	=	=	=
Stress corrosion potential (Stainless steel fixture)	=	=	=

Plus (+): better
equivalent (=): similar
minus (-): worse

Star (*):
interpretation needed

• For the current investigation, all candidates came closest to the Cd characteristics overall.

Next Action

- Re-evaluate Zn-Ni, Zn-Ni2 and AlumiPlate made by AFS.
  - Repeat mechanical tests plus tensile, shear and fatigue tests.
  - Repeat corrosion test.
  - Testing for both NAS1580 and NAS4452 fasteners.
- Schedule to finish testing by September 2008, implementation by March 2009