Ogden Air Logistics Center

U.S. AIR FORCE

LHE Zn-Ni Corrosion Testing and Implications for Fasteners

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February 2022

Why Talk More LHE Zinc Nickel?

- Highlight Low Hydrogen Embrittling Zinc Nickel (LHE Zn-Ni) Performance Benefits
  - Improve corrosion performance of fastened systems
  - Improve fastener mechanical performance
  - Hasten the Substitution of LHE Zn-Ni for Cadmium
- Simplify LHE Zn-Ni Tank Plating Process
  - Present suggestions to make implementation easier and faster
- MIL-DTL-32648 LHE Zn-Ni for all corrosion tests and AF DWG 201427084 LHE Zn-Ni for all fastener tests -Class 2 Type II in all cases-
- MIL-STD-870 Cd for all corrosion tests and AMS-QQ-P-416 Cd for all fastener tests.

Outline

- LHE Zn-Ni Corrosion Testing
  - Class 3, Class 2, and Class 1 thickness
  - Wider thickness range testing (0.0001” up to 0.002”)
  - Fastener beach exposure corrosion Testing
    - Corrosion of simulated aircraft structures
- Implications for Systems with Fasteners
- Additional testing of LHE Zn-Ni
  - Fatigue
  - Adhesion
  - Mechanical Properties for Threads
- Specifications
- Conclusions and Recommendations

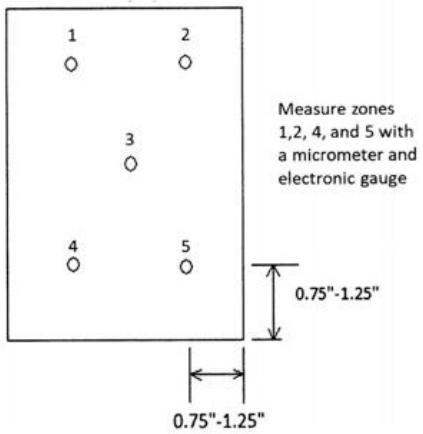
LHE Zn-Ni Corrosion Testing

- **Why do more LHE Zn-Ni Testing?**
  - **Hill AFB commitment to stop Cd plating by 2028**
  - **LHE Zn-Ni plating fixtures are challenging to design and to maintain**
    - **Class 1 (0.0005” - 0.0008”)**
    - **Class 2 (0.0003” - 0.0006”) -most common**
    - **Class 3 (0.0002” - 0.0005”)**
    - **Must plate the LHE Zn-Ni all at once**
- **Compared the corrosion performance of Class 1, Class 2, and Class 3 LHE Zn-Ni.**
  - **4” x 6” 4130 panels.**
  - **All with trivalent chromium conversion coating and baked 24 hours at 375 +/-25 °F.**

LHE Zn-Ni Corrosion Testing

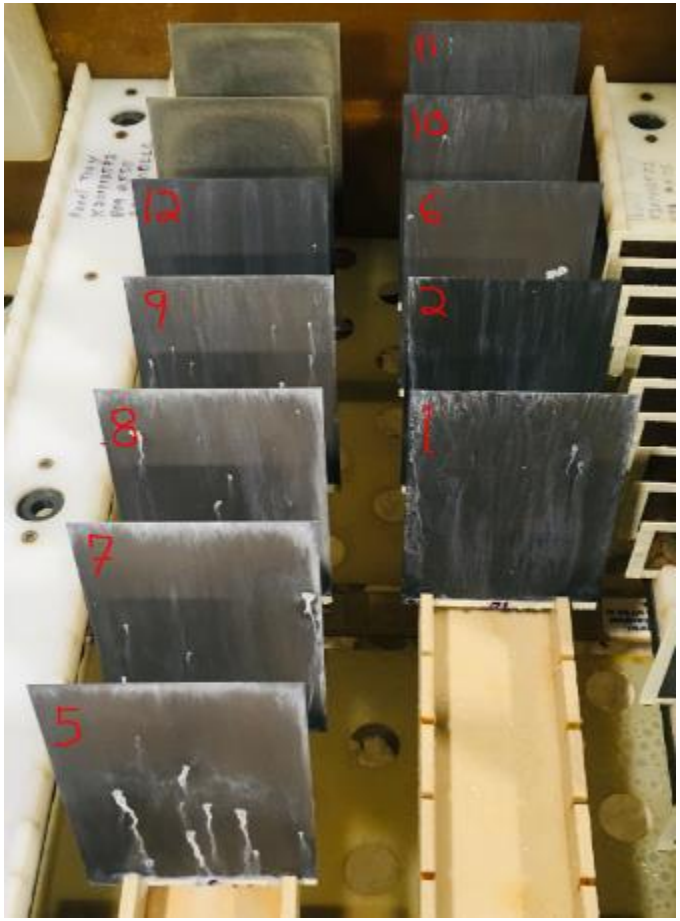
LHE Zn-Ni ASTM B117 Corrosion test results

Panel #	Average Thickness (mil)	Treatment	Time to Red Rust (hrs)
5	.58	Class 1 Type II	4704
6	.6	Class 1 Type II	5352
7	.38	Class 2 Type II	4704
8	.35	Class 2 Type II	5928
9	.33	Class 3 Type II	5928
10	.31	Class 3 Type II	5352

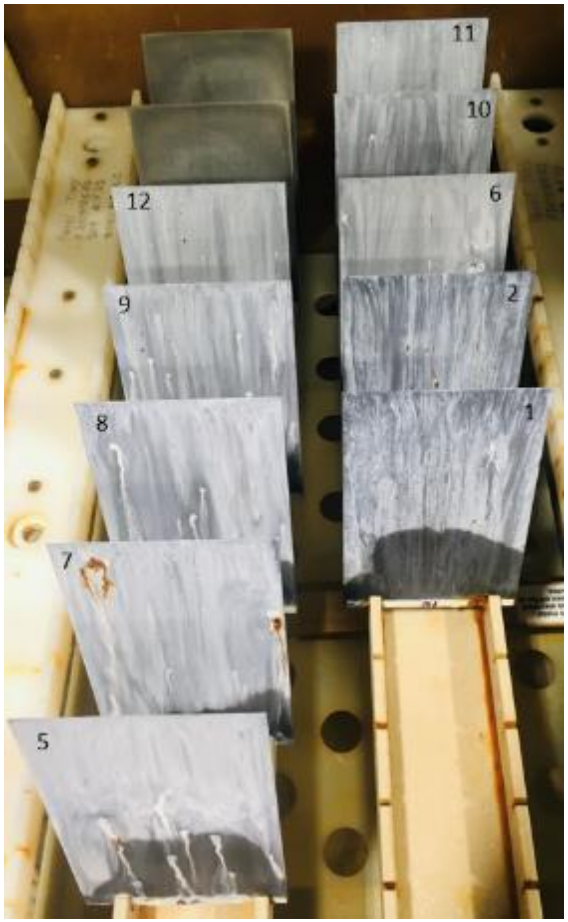


Pattern for thickness measurements

LHE Zn-Ni Corrosion Testing



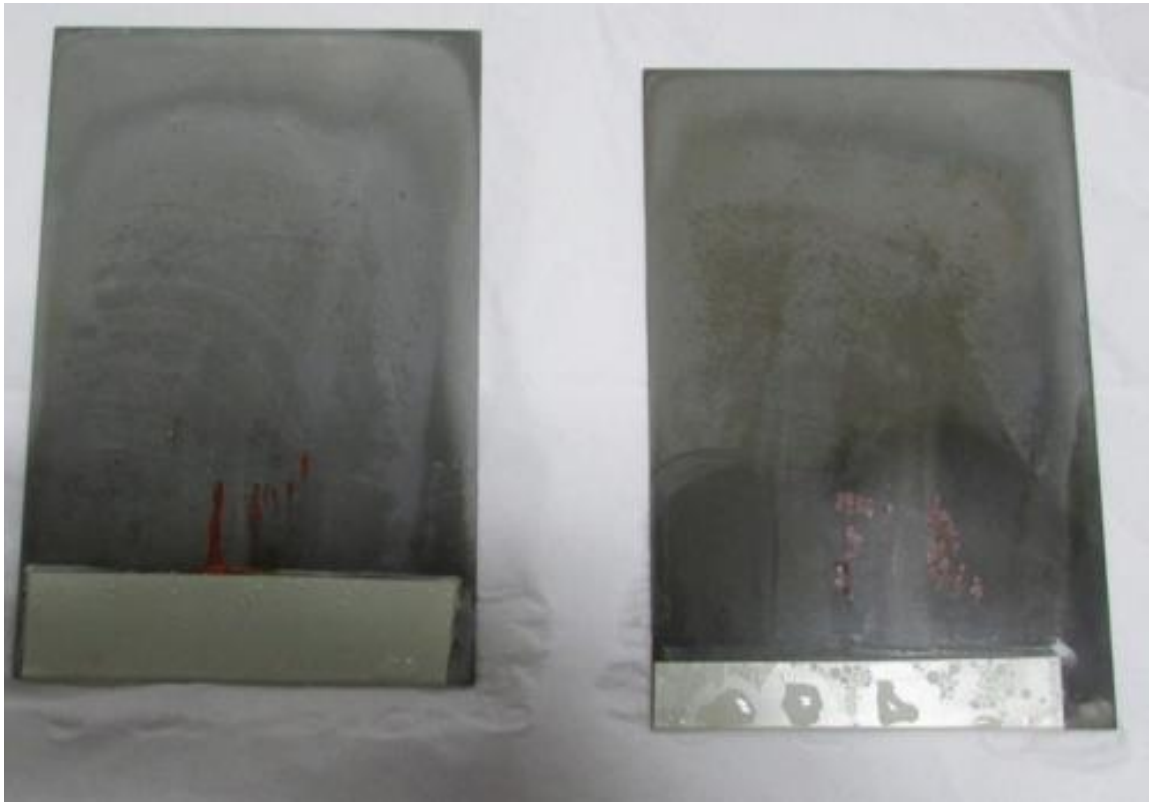
Zinc Nickel plated steel panels after 2,472 hours of ASTM B117 exposure



After 4,704 hours, first signs of red rust noted on panels 5, 7, 1, 2, and 12.

LHE Zn-Ni Corrosion Testing

- QQ-P-416 Class 3 Type II Cadmium (0.00035” and 0.0004” average thickness) at 1,125 hours salt spray.

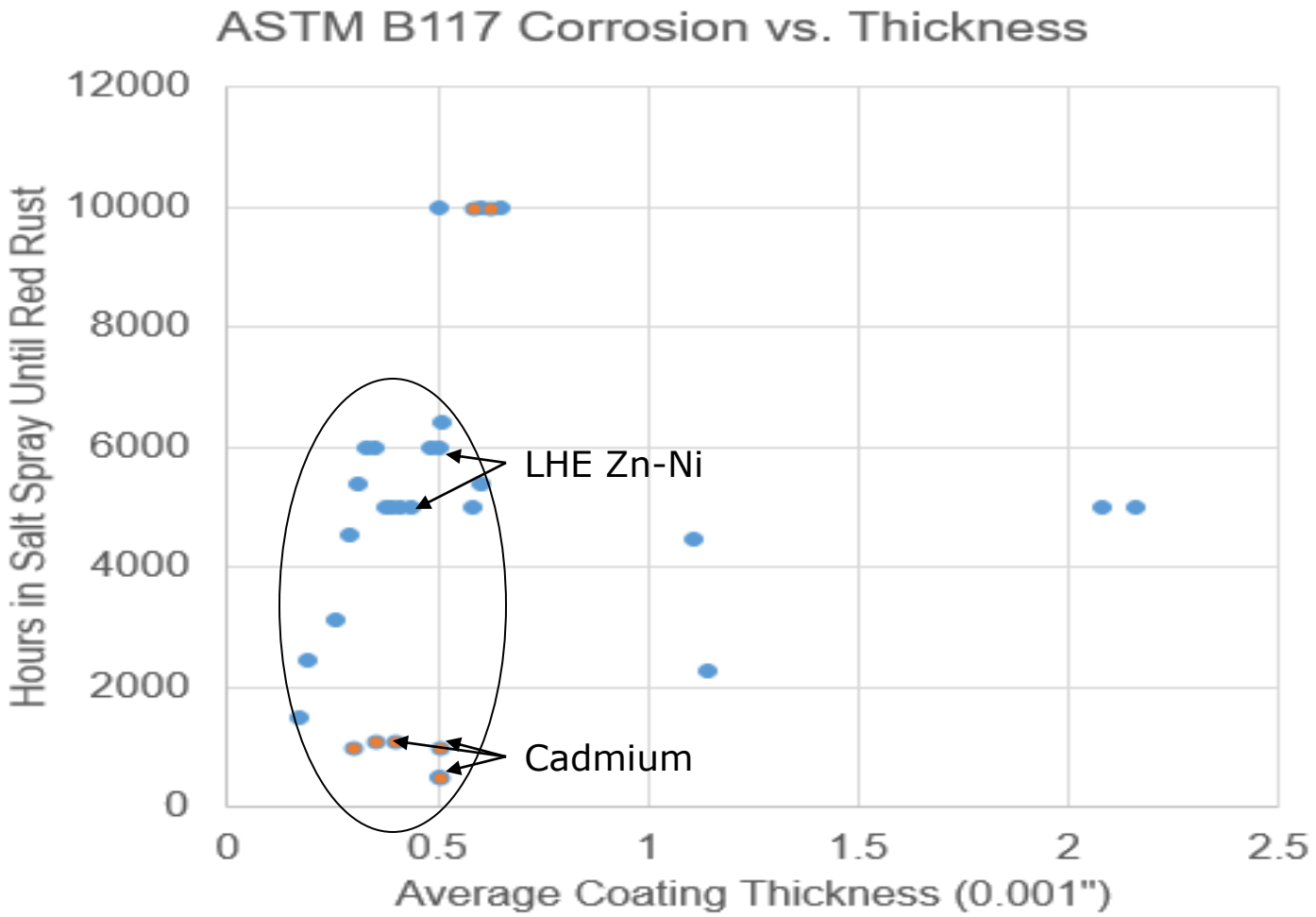


LHE Zn-Ni Corrosion Testing

- **0.0001” to 0.002” thickness range, ASTM B117 salt fog**

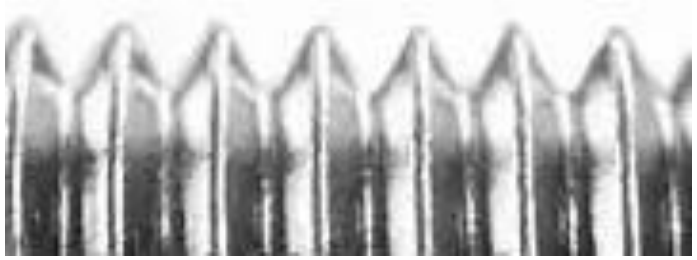
Specimen #	Center Thickness (mil)	Avg Thickness (mil)	Time to Red Rust (hours)
13	0.45	.5	6900
14	0.45	.48	6900
15	.2	.26	3128
16	.25	.29	4544
17	.1	.17	1496
18	.1	.19	2456
19	1.0	1.11	4472
20	1.05	1.14	2264
21	1.95	2.08	5000
22	1.95	2.16	5000

LHE Zn-Ni Corrosion Testing



LHE Zn-Ni Corrosion Testing

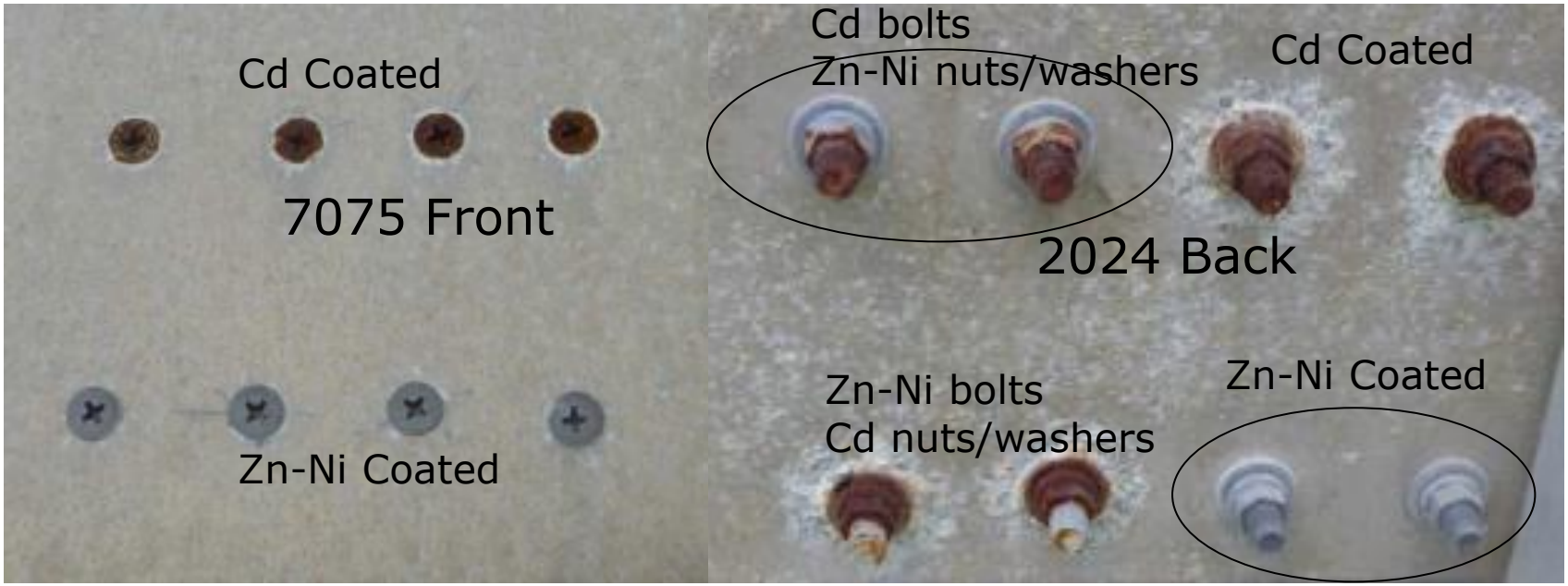
- Thin LHE Zn-Ni is much better than thin Cd
  - Fasteners frequently have very thin electroplated coatings in the roots of threads
- We should compare the relative performance of LHE Zn-Ni vs Cd for threaded fasteners!
- Testing has already been done (a lot of testing)
  - Beach exposure testing with simulated aircraft structures (metal plates secured by Cd or LHE Zn-Ni plated 4340 steel fasteners).
  - Compare ASTM B117 to beach corrosion.



LHE Zn-Ni Corrosion Testing

- **After 2.5 years of exposure, LHE Zn-Ni appears to surpass Cd performance in all of the galvanic sheet stackups and the Simulated Aircraft Structures (SAS), with Cd coating failure before LHE Zn-Ni in every case.**
  - **2024 Al, 7075 Al, 4130 Steel, Ti-6Al-4V**

LHE Zn-Ni Corrosion Testing



- 2.5 years beach exposure in North Carolina 7075 Al on front, 2024 on back
- Fasteners are 4340 steel 160 ksi

LHE Zn-Ni Corrosion Testing

Front (2024 Aluminum)
1.5 years

Back (Ti-6Al-4V))
1 year

2024 Aluminum and Ti-6Al-4V

What if this structure needed maintenance?

LHE Zn-Ni Corrosion Testing

7075 Aluminum after 1000 hours ASTM B117

Area under fasteners is conversion coated

Implications for Systems With Fasteners

- Much corrosion on outer mold lines originates at fasteners (Photos: F-15s Kadena AFB painted with Chrome-free primer 02-GN-093)
  - Kadena F-15's receive paint/touch up at 3 years
  - Would LHE Zn-Ni plated fasteners reduce corrosion?

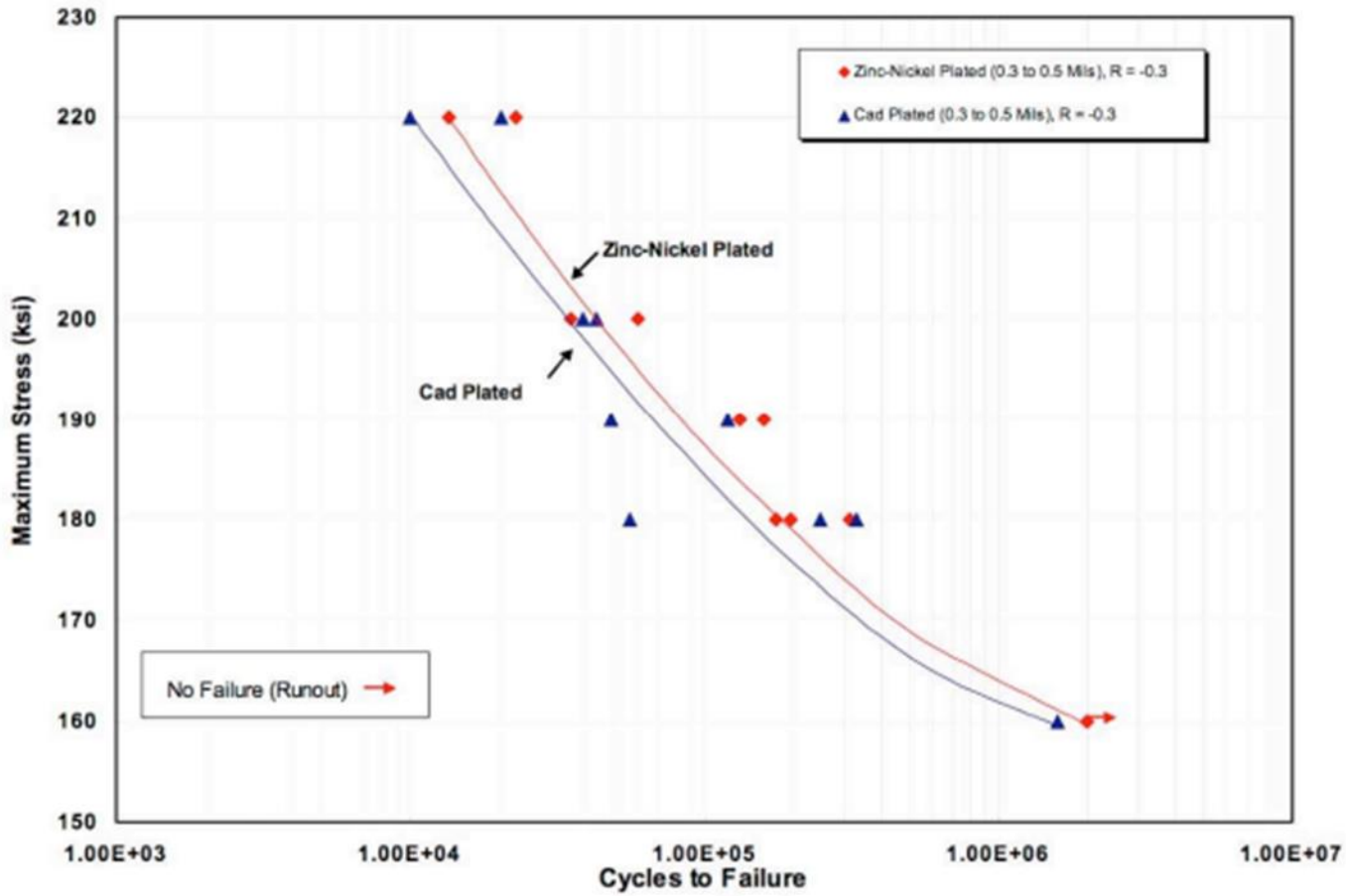



Corrosion Test Recap

- **LHE Zn-Ni is clearly better for steel fasteners, especially in aluminum-aluminum structures.**
  - **Performs much better than cadmium when it is thin**
    - **Hypothesis: More voluminous zinc oxide corrosion products fills gaps and voids in the coating to create a barrier**
- **Need more than just corrosion testing in order to make the change.**
  - **This has been done, excerpts to follow**
    - **Fatigue**
    - **Adhesion**
    - **Torque Tension and Run-on/Breakaway**

Fatigue

300M Steel, 280-300 ksi

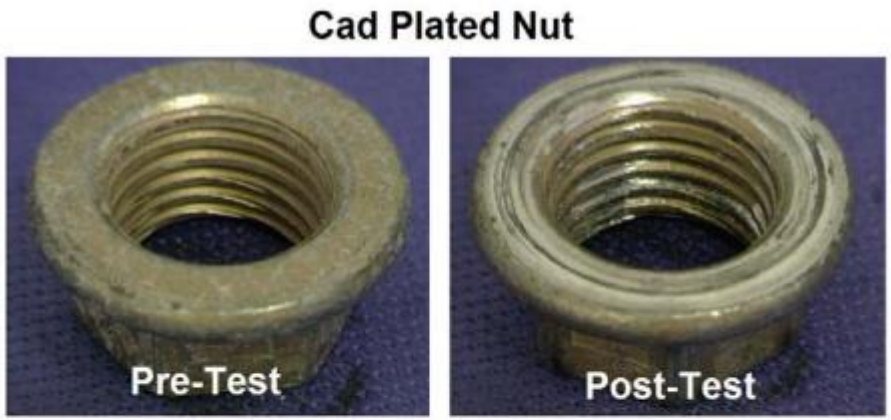


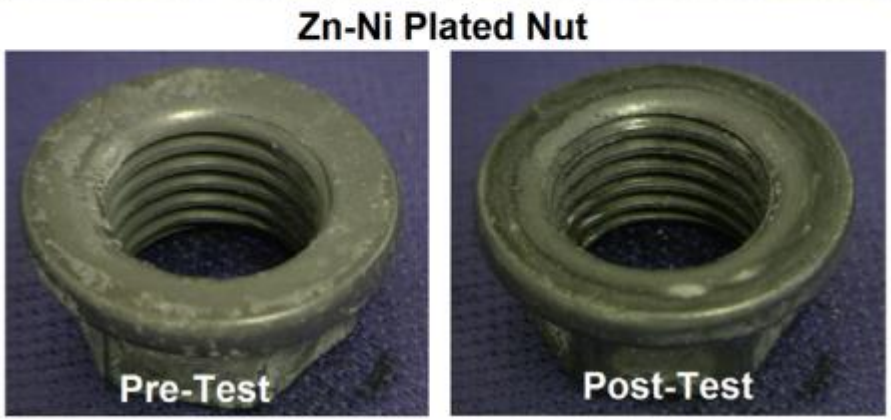
Adhesion

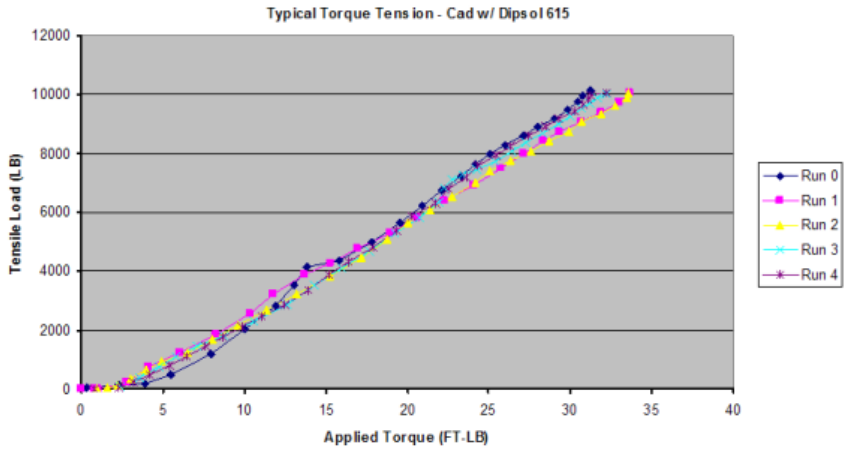
- 1” by 4” bend test (used in plating world)
  - LHE Zn-Ni fails this test at thicknesses > 0.0008”
  - LHE Zn-Ni is not flexible, plastic deformation of substrate causes the coating to lose adhesion.
- Bond Plug Testing (used to test high velocity oxy fuel applied tungsten carbide cobalt coatings)
  - 0.0007” to 0.0027” thickness range
  - All 8 LHE Zn-Ni plated specimens had adhesion above 10,000 psi (the epoxy adhesive failed between 10,700 and 13,000 psi)
    - Cadmium loses cohesion at thicknesses above 0.001”
    - Any areas of thick cadmium will roll off with light mechanical contact

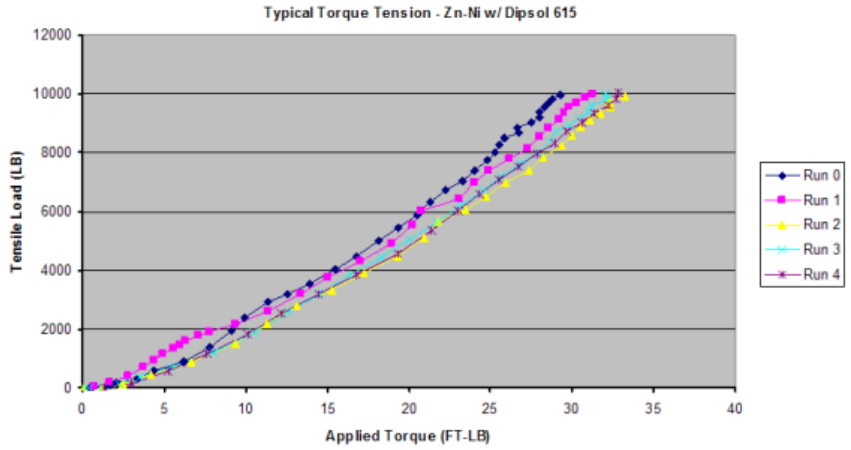
Properties for Fasteners

- Torque-tension









Properties for Fasteners

- **Run-on and Breakaway Torque**
  - **“Overall, the Zn-Ni plated fasteners showed better results in terms of maximum run-on and minimum breakaway torque.”**
  - **In all cases, both the Cd and Zn-Ni plated bolt/nut pairs satisfied the maximum installation and breakaway torque defined in NASM25027.**

Properties for Fasteners

- **Conclusions from torque-tension and run-on/breakaway testing:**
  - **In general, we found the average locking/breakaway torque results for non-lubricated and lubricated Cd and LHE Zn-Ni plated fasteners to be statistically within allowable limits.**
  - **Established fastener torque values would not need to be changed for LHE Zn-Ni.**
  - **After multiple cycles, Cd plated nuts showed minor to moderate wear/galling. This could also be felt through the torque wrench. LHE Zn-Ni plated nuts showed minimal to no signs of wear.**
- **Performance varies depending upon lubricant.**

Specifications for LHE Zn-Ni on fasteners

- Zinc Nickel Formulations are often Proprietary!
- AF DWG 201427084 (12-18% nickel, ES3 process)
  - Barrel plating of fasteners, -used to produce beach corrosion test specimens discussed here.
- MIL-DTL-32648 (Air Force, 12-15% nickel) (2020)
  - Used to produce corrosion specimens
- MIL-PRF-32660 (Navy, 12-15% nickel) (2020)
- AMS2461 (SAE, 12-16% nickel) (2020)
- MIL-PRF-32647 (Zinc Nickel for Fasteners) (2020)
  - 12% to 17% nickel; Selectable K factor
- BAC5680 (Boeing, proprietary)

Conclusions and Recommendations

- For fastener applications, LHE Zn-Ni is not a compromise or a substitute, it is an upgrade
  - I think it can improve the performance of all fastener systems including hexavalent chromium free.
- Recommend replacing cadmium coated fasteners with LHE Zn-Ni coated fasteners ASAP.
- Need to update NAS fastener specifications!
- Recommend allowing a wider range of LHE Zn-Ni coating thicknesses to simplify processing of larger complex components (not for fasteners).
  - Recommend 0.0002” to 0.0012” thickness range for all surfaces that will be subsequently painted and for surfaces that are not dimensionally critical.

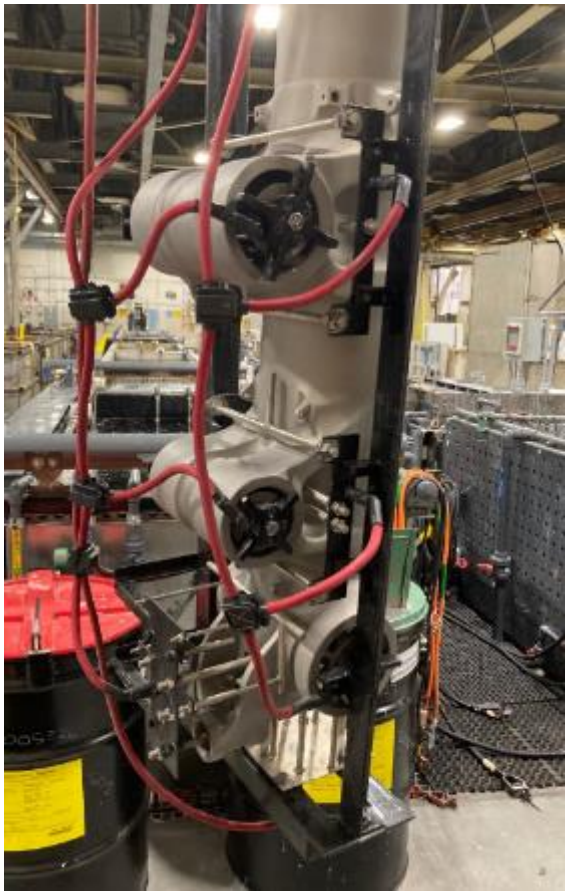
Thanks

- Thanks to Eric Berrett and the electroplating team at Hill AFB
- Thanks to Shane Shupe and the Hill AFB Chemistry Lab for time and space in Salt Fog Chambers
- Thanks to Dave Frederick and the 417th SCMS, ES3, and AFRL for the enormous amount of Zinc Nickel testing and evaluation they have done for the past 15 years (Fatigue, Beach Corrosion, Torque Tension, etc.)
  - What I have presented here is just the "tip of the iceberg" of all the work they have done.

Questions?

BACKUP SLIDES

- **Fixturing for B-1 Truck beam and outer cylinder.**



BACKUP SLIDES

- 0.0001” to 0.002” thickness range, ASTM B117 salt fog
- LHE Zn-Ni per MIL-DTL-32648

0 HOURS 336 HOURS

BACKUP SLIDES

- Zinc Nickel Class 3 lasted as long as Class 1 in ASTM B117 salt fog (5,000 hours for both 0.0003" and 0.0006" thick Zinc Nickel plated panels)
  - Is performance not a function of thickness for Zn-Ni?
  - Class 3 Cadmium lasts 1000-1200 hours in salt spray.
  - Class 3 Zinc Nickel lasts 4X longer than Class 3 cadmium
  - All testing done in the same salt spray chamber

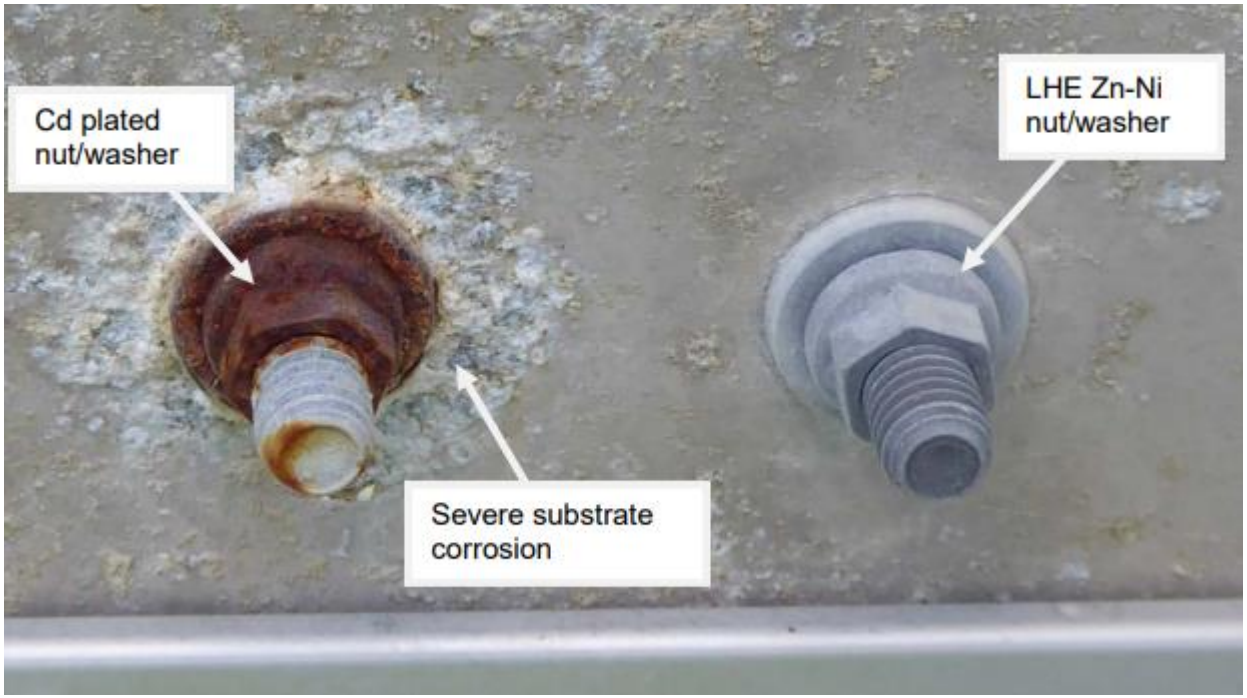
Backup Slides

- **After repeated cycles, the cadmium smears and starts to expose bare steel and fare worse**

<u>After 15 installation and removal cycles:</u>
Upon visual comparison of the Cd and LHE Zn-Ni plated nuts after test completion, the LHE Zn-Ni plated nuts typically showed no evidence of plating lost while the Cd plated nuts ranged from minor wear to galling on the threaded areas

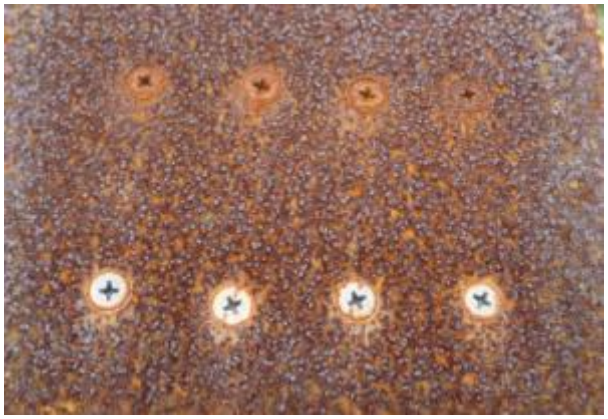
Based upon installation test results in this program, the ES3 LHE Zn-Ni plating is suitable as a Cd replacement for threaded aircraft fasteners/components.

BACKUP SLIDES



- 2.5 years beach exposure in North Carolina 7075 Al on front, 2024 Aluminum on back

BACKUP SLIDES



Front (4130 Steel)
6 months

4130 Steel and 2024 Al

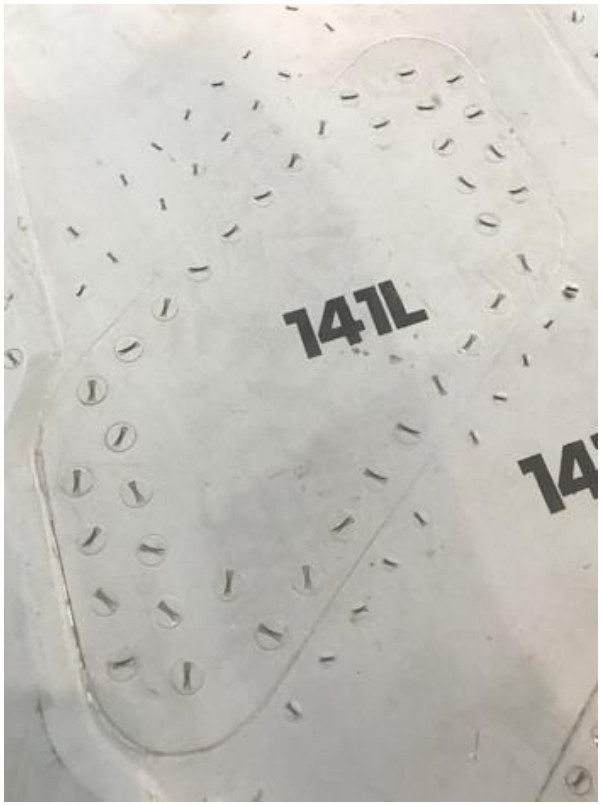
Back (2024 Al)
1 year

Back (2024 Al)
2 years

Backup Slides

The fasteners installed into the 4130 steel SAS also appear to show LHE alkaline Zn-Ni is superior in corrosion resistance to Cd in this environment. On SAS 4 through 8 (4130 steel), the LHE alkaline Zn-Ni plated fasteners have consistently resisted corrosion better than the Cd plated fasteners. This is quite evident on SAS 6, where a row of LHE alkaline Zn-Ni plated nuts were installed directly beside a row of Cd plated nuts. The Cd plating has completely failed after one (1) year of exposure, while the LHE alkaline Zn-Ni coating shows little red corrosion

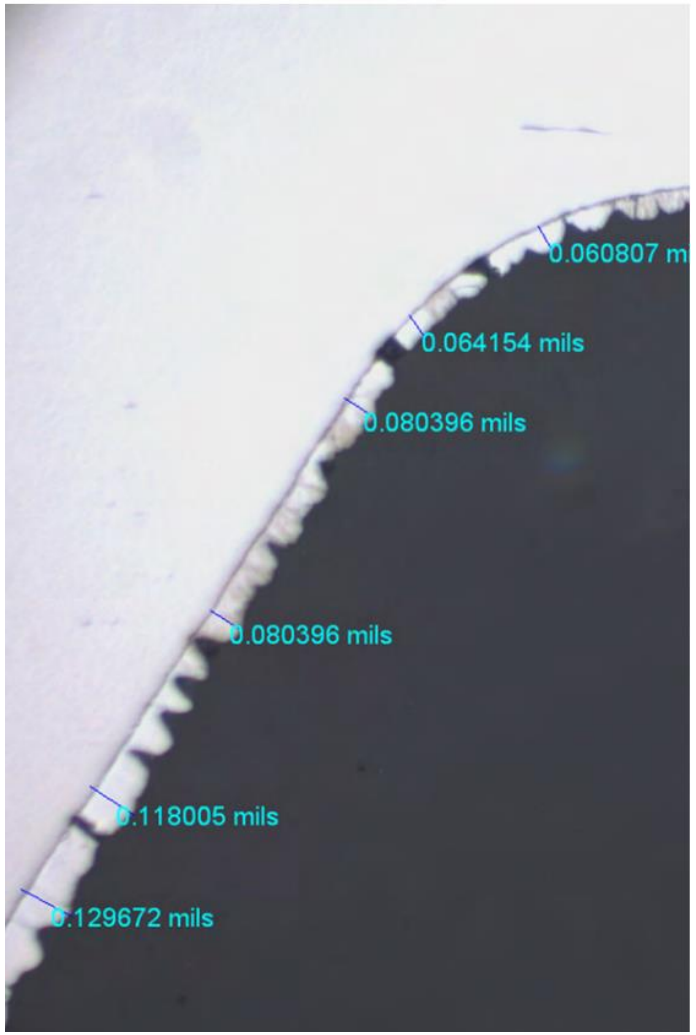
Backup Slides



- **F-15 JASDF, Kadena AFB (chromated primers)**

BACKUP SLIDES

- **Rhetorical Question:**
  - **How does LHE zinc nickel perform so well when it is thin??**
  - **Looks terrible in cross sectional analysis**
  - **Photo of an F-519 Type 1a.1 specimen at the notch to verify coverage.**
- **Mark Robison:**
  - ***"Oxidized zinc may rapidly fill the gaps and porosity"***



BACKUP SLIDES

4 Test Fixture Fabrication

To test the corrosion resistance of LHE alkaline Zn-Ni plated fasteners against Cd, six galvanic sheet stackups and eight simulated aircraft structures were fabricated from various aerospace materials. The fasteners chosen are standard aerospace fasteners manufactured from 4340 alloy steel (160 KSI) and Cd plated in accordance with QQ-P-416 Class II, Type 2 specification. (See Table 1 for types used).

	Designation
Bolt	NAS6203-3
Screw	NAS517-3-3
Washer	AN960-10
Hex Nut	AN315-3R
Lock Nut	MS21043-3

Table 1 Long Term Exposure Test Fasteners

Since unplated fasteners were not available, a portion of the Cd plated fasteners were stripped to bare metal using an Ammonium Nitrate solution and re-plated for the test with LHE alkaline Zn-Ni in accordance with draft USAF Drawing 201427084. (See Figure 3)

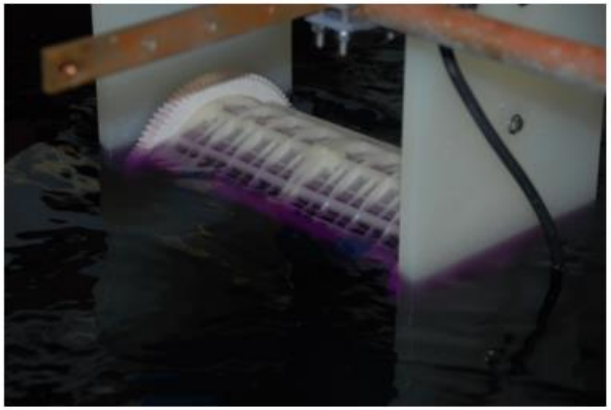


Figure 3 Barrel Plating Fasteners with LHE alkaline Zn-Ni

BACKUP SLIDES

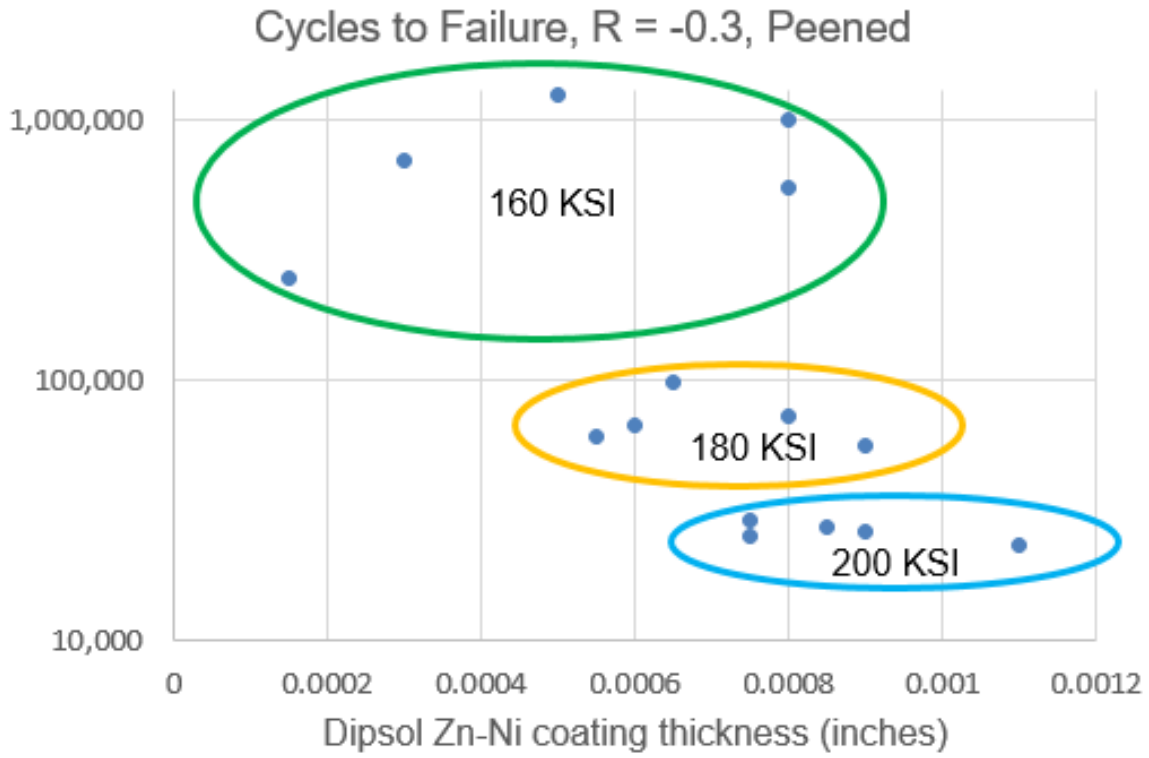


Figure 12: Fatigue data for 300M steel at 160 ksi, 180 ksi, and 200 ksi and various LHE Zn-Ni coating thicknesses