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Tuskegee University College of
Engineering & Raytheon IDS

Test & Validation of Military Cylindrical Connector Materials for Use in the MENA Region

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Meeting Agenda

- Objective
- Preparation of Connectors
- Procedural Overview
- Overall Connector Performance
- Qualitative Observations
 - Salt Fog
 - Salt Fog & SO₂
 - Sand-Salt-Humidity/UV
- Salt Fog Test Data
- Salt Fog & SO₂ Test Data
- Sand-Salt-Humidity/UV Test Data
- SEM Data

Objective

- To evaluate cylindrical connector materials and finishes that are resistant to corrosion in the MENA (Mideast and Northern Africa) regions that have environments with corrosive sand, dust, salt laden atmosphere as well as high UV and humidity levels.

Connector Sample preparation

- Goal was to test 4 mated pairs of connectors for each material and finish. Aluminum, Stainless Steel and Composite connector body materials were tested with various finishes.
- The majority of military connectors were purchased from distributors, although many suppliers offered to provide connector samples at no cost.
- All connectors employed environmental seals in the mating face as well as in the wire sealing rear grommets.
- All connectors had plastic seal plugs installed into the wire grommet side to seal the internal connector inserts. No contacts were used.

Procedure Overview

- Connectors tested using standard methods
 - Neutral Salt Fog
 - SAE AIR5919A/ EIA-364-26C, 500 hrs min
 - Acidic Salt Fog & SO₂
 - ASTM G85:A4, 336 hrs min
 - Salt -Sand-Salt-Humidity/UV
 - Sand and Dust: MIL-STD-202, method 110, 28 hrs
 - UV: EIA-364-49 for UV, 500 hrs
- Additional Modified Testing
 - Tested Best Performing Connector finishes to Failure
 - Additional 750 hours of Salt Fog in increments of 250 hrs to 1250 hrs.
 - Additional 168 hours of SO₂ Salt Fog
 - Sand / Salt / Humidity /UV - mixed tests to mimic more realistic environmental conditions in MENA region
 - Tested Mis-matched connectors to determine compatibility with cadmium and nickel
- Data Parameters Captured Before and After Exposures
 - Conductivity
 - Resistance
 - Torque
 - Visual / Corrosion Observation

Overall Connector Performance Military & Commercial Standard

Mil/Com	Description				Salt Fog				Salt Fog & SO ₂		Sand-Salt-Humidity/UV
	Plug		Receptacle		Baseline	+250 H	+500 H	+750 H	Baseline	+168 H	
	Base	Coating	Base	Coating							
Mil	SS	Ni	SS	Ni	Green	Green	Green	Green	Green	Green	Green
Mil	SS	Passivated	SS	Passivated	Green	Green	Green	Green	Green	Green	Green
Mil	Al	Ni-PTFE	Al base	Ni-PTFE	Green	Yellow	Yellow	Yellow	Green	Green	Green
Mil	Composite	eNi	Composite	eNi	Green	Green	Green	Green	Yellow	Red	Green
Com	Al	Ni-2MILS	Al	Ni-2MILS	Green	Green	Green	Yellow	Green	Complete	Green
Mil	Al	Cd	Al	Cd	Green	Yellow	Red	Complete	Green	Yellow	Green
Com	Al	Cd	Al	Cd	Green	Green	Yellow	Yellow	Yellow	Yellow	Green
Com	Al	SnZn	Al	SnZn	Yellow	Red	Complete	Complete	NA	NA	NA
Com	Al	Cd	Al	Cd	Green	Yellow	Red	Complete	NA	NA	NA
Com	Al	Ni-PTFE	Al	ZnNi	Red	Complete	Complete	Complete	Red	Complete	NA
Com	Al	Ni-PTFE	Al	Ni-PTFE	Red	Complete	Complete	Complete	Red	Complete	Green
Mil	Al	Ni	Al	Ni	Red	Complete	Complete	Complete	Red	Complete	Green
Mil	Al	ZnNi	Al	ZnNi	Red	Complete	Complete	Complete	Yellow	Complete	Red

*Red: Torque failed (>3 connectors), Conductivity failed (>3 connectors), Corrosion observation (Moderate-Severe)

**Yellow: Torque passed or failed (1-2), Conductivity passed or failed (1-2), Corrosion observation (Light-Severe)

***Green: Torque passed (>3 connectors), Conductivity passed (>3 connectors), Corrosion observation (Light-Moderate)

NA - Not tested

Complete - Failed at the previous test interval

The best performers are in green; the worst performers are in red.

Overall Connector Performance (Continued)

Military & Commercial Standard Connectors

Mil/Com	Description				Salt Fog	Salt Fog/SO ₂	Salt Fog/SO ₂ /Add'l +136 hrs.
	Plug		Receptacle				
	Base	Coating	Base	Coating			
Com	Al	ZnNi	Al	Cd	Green	Yellow	Red
Com	Al	Cd	Al	ZnNi	NA	Green	Yellow
Com	Al	SnZn	Al	SnZn	Green	NA	NA
Com	Al	Cd	Al	Cd	Yellow	NA	NA
Mil	SS	Ni	Al	Ni	Green	Green	Red
Mil	Al	Ni	SS	NI	NA	Green	Red
Com	Al	Cd	Al	Ni-PTFE	Green	NA	NA

*Red: Torque failed (>3 connectors), Conductivity failed (>3 connectors), Corrosion observation (Moderate-Severe)
 **Yellow: Torque passed or failed (1-2), Conductivity passed or failed (1-2), Corrosion observation (Light-Severe)
 ***Green: Torque passed (>3 connectors), Conductivity passed (>3 connectors), Corrosion observation (Light-Moderate)

NA - Not tested
 Complete - Failed at the previous test interval

The best performers are in green; the worst performers are in red.

Overall Connector Performance (Taped) Military & Commercial Standard

- Comparison of Connector Performance: Red (worst)* < Yellow (average)** < Green (best)***

Mil/Com	Description		Salt Fog	Salt Fog: Tape	Salt Fog/SO ₂	Salt Fog/SO ₂ : Tape
	Plug	Receptacle				
Mil	Al base, Cd coating	Al base, Cd coating	Green	Green	NA	NA
Mil	Al base, ZnNi coating	Al base, ZnNi coating	Red	Green	NA	NA
Mil	Al base, Ni coating	Al base, Ni coating	Yellow	Green	Red	Green

*Red: Torque failed (>3 connectors), Conductivity failed (>3 connectors), Corrosion observation (Moderate-Severe)

**Yellow: Torque passed or failed (1-2), Conductivity passed or failed (1-2), Corrosion observation (Light-Severe)

***Green: Torque passed (>3 connectors), Conductivity passed (>3 connectors), Corrosion observation (Light-Moderate)

EPDM rubber tape and corrosion preventative compound spray beneath was used to protect finish in tape test.

NA - Not tested

Complete - Failed at the previous test interval

The best performers are in green; the worst performers are in red.

Salt Fog Test

Salt Fog Procedure

- Salt fog test conducted at Tuskegee University
 - AIR5919A/EIA-364-26C (Table 1A, sequence 1, Test Requirement)
 1. Mate/Unmate 50 times before
 2. Record Torque, Conductivity, and Resistance
 3. 452 hrs. mated, 48 hrs. unmated in salt spray chamber
 4. Mate/Unmate 450 times after
 5. Record Torque, Conductivity, and Resistance
- Salt Fog, additional 250 hour increments, conducted at Tuskegee University
 - Test connectors that passed conductivity
 1. Mate connectors; place in chamber
 2. 250 hrs. mated
 3. Mate/Unmate 450 times after
 4. Record Torque, Conductivity, and Resistance
 5. If connector passes Torque, Conductivity, and Resistance testing, repeat steps 1-5 again until failure

Testing to failure generates a better understanding of performance within the intended environment

Qualitative Observations: Salt Fog Results

Mil/ Com	Description				*Degree+	Comments (YES or No)				** Stage+	Conductivity		Torque	
	Plug		Receptacle			Discolor+	Flaking +	Pits+	Etching+		Pass	Fail	Pass	Fail
	Base	Coating	Base	Coating										
Mil	Al	Cd	Al	Cd	light	No	No	No	No	1	4	0	4	0
Com	Al	Cd	Al	Cd	light	No	No	No	No	1	3	0	3	0
Com	Al	Cd	Al	Cd	light	No	No	No	Yes	1	4	0	4	0
Mil	Composite	eNi	Composite	eNi	light	Yes	No	No	No	1	4	0	4	0
Mil	SS	Ni	SS	Ni	light	Yes	No	No	No	1	4	0	4	0
Mil	SS	Passivated	SS	Passivated	light	Yes	No	No	No	1	4	0	4	0
Mil	Al	Ni-PTFE	Al	Ni-PTFE	light	Yes	No	Yes	Yes	1	4	0	4	0
Com	Al	SnZn	Al	SnZn	light	Yes	No	Yes	Yes	1	2	0	2	0
Com	Al	Cd	Al	Ni-PTFE	light	Yes	No	Yes	Yes	2	2	0	2	0
Mil	Al	Ni	Al	Ni	light	Yes	Yes	Yes	Yes	1	4	0	4	0
Mil	SS	Ni	Al	Ni	light	Yes	No	Yes	Yes	2	2	0	2	0
Com	Al	Cd	Al	Cd	light	Yes	No	Yes	Yes	1	1	1	2	0
Com	Al	Ni-PTFE	Al	Ni-PTFE	light	No	Yes	Yes	No	1	1	2	1	2
Com	Al	ZnNi	Al	Cd	moderate	Yes	Yes	Yes	Yes	2	2	0	2	0
Com	Al	SnZn	Al	SnZn	moderate	Yes	No	Yes	Yes	2	3	0	1	2
Com	Al	Ni-PTFE	Al	ZnNi	moderate	No	No	Yes	No	2	1	2	1	2
Mil	Al	ZnNI	Al	ZnNI	moderate	No	Yes	Yes	No	3	1	3	3	1
Mil	Al	Ni	Al	Ni	severe	Yes	Yes	Yes	Yes	4	4	0	3	1

*Degree of Corrosion IAW: NAVAIR 01-1A-509-1 TM 1-1500-344-23-1 TO 1-1-689-1 Cleaning and Corrosion Control
 **Stage of Corrosion IAW: TB 43-0213, Technical Bulletin Corrosion Prevention and Control (CPC) for tactical Vehicles

*Overall qualitative assessment based on observing 2-4 connector sets.

Top performing post-Salt Fog testing is listed in table from best to worst.

Quantitative Results & Discussion: Salt Fog

Al base, Ni plated

Total Test Time: 548 hrs.



Initial



After 548 hrs

Seq 1: Salt Fog Test (500 hrs. Mated, 48 hrs. unmated) Test Start Date: Oct 6, 2015 & Test End Date: Oct 28, 2015												
Mil/Com	Torque engaged (Nm)		Torque disengaged (Nm)		Shell Conductivity (mV) (Testing: 1.5V)		Resistance (Ω)		Durability		Stage of Corrosion (1-4)	Degree of Corrosion
	Initial	After (Max 4.6)	Initial (Min 0.6)	After (Max 4.6)	Initial (Max 1.0)	After (Max 2)	Initial	After	Initial	After		
Mil	1.8	1.9	1	1.2	0.13	0.7	0.1	0.12	yes	yes	4	Severe
Mil	1.9	1.4	1.8	1.2	0.11	0.25	0.09	0.12	yes	yes	4	Severe
Mil	1.4	Seized	0.9	Seized	0.14	0.25	0.11	0.19	yes	NO	4	Severe
Mil	1.8	1.8	0.57	1.4	0.15	0.2	0.11	0.12	yes	yes	4	Severe

- **Observation:** One of four connectors failed torque; conductivity overall increased after salt fog exposure but connectors passed allowable max.
- **Root Cause:** SEM Analysis determined that the Ni plating corroded
- **Results:** This connector is not among the top performers, and did not continue testing in salt fog.

Connectors showed severe corrosion, yet seized connector still passed conductivity allowable max

Quantitative Results & Discussion: Salt Fog

Al base, ZnNi plated

Total Test Time: 548 hrs.



Initial



After 548 hrs

Seq 1: Salt Fog Test (500 hrs. Mated, 48 hrs. unmated)												
Test Start Date: Oct 6, 2015 & Test End Date: Oct 28, 2015												
Mil/Com	Torque engaged (Nm)		Torque disengaged (Nm)		Shell Conductivity (mV) (Testing: 1.5V)		Resistance (Ω)		Durability		Stage of Corrosion (1-4)	Degree of Corrosion
	Initial	After (Max 4.6)	Initial (Min 0.6)	After (Max 4.6)	Initial (Max 2.5)	After (Max 5.0)	Initial	After	Initial	After		
Mil	1.4	1.5	1.3	1.3	2.4	7.4	0.24	0.55	yes	NO	3	Moderate
Mil	1.3	1.8	1.9	1.5	1.7	22.5	0.23	0.46	yes	NO	3	Moderate
Mil	1.9	5.1	1.5	Seized	1.5	18.8	0.27	0.78	yes	NO	3	Moderate
Mil	1.8	1.8	1.3	1.5	1.2	2.2	0.28	0.6	yes	yes	3	Moderate

- **Observation:** Three of four connectors failed conductivity and one of the four failed torque.
- **Impact:** Majority of connectors failed conductivity.
- **Root Cause:** Signs of pitting on connectors that failed indicated ZnNi corrosion. Analyzed under SEM.
- **Results:** This set of connectors is not among top performers, but was tested further in salt fog.

Three connectors failed conductivity; no further testing required.

**Additional Salt Fog
Exposure to Failure
(798 or 750 Hours Tested)**

Qualitative Observations: Salt Fog

Total hrs. of Exposure: 798 or 750 Hours

Mil/ Com	Description				*Degree ⁺	Comments (YES or No)				** Stage ⁺	Conductivity		Torque	
	Plug		Receptacle			Discolor ⁺	Flaking ⁺	Pits ⁺	Etching ⁺		Pass	Fail	Pass	Fail
	Base	Coating	Base	Coating										
Mil	Composite	eNi	Composite	eNi	light	YES	NO	NO	NO	1	4	0	4	0
Mil	SS	Ni	SS	Ni	light	YES	NO	NO	YES	1	4	0	4	0
Mil	SS	Passivated	SS	Passivated	light	YES	NO	NO	YES	1	4	0	4	0
Com	Al	Cd	Al	Cd	light	YES	NO	NO	YES	1	4	0	4	0
Mil	Al	Cd	Al	Cd	light	NO	YES	NO	NO	1	3	1	4	0
Com	Al	Cd	Al	Cd	light	NO	NO	NO	YES	1	3	0	0	3
Com	Al	Ni 2MILS	Al	Ni 2MILS	moderate	YES	YES	YES	YES	1	4	0	4	0
Mil	Al	Ni-PTFE	Al	Ni-PTFE	moderate	YES	YES	YES	YES	1	3	1	4	0
Com	Al	SnZn	Al	SnZn	moderate	YES	NO	YES	Yes	2	2	1	0	3
Com	Al	Ni-PTFE	Al	Ni-PTFE	moderate	NO	YES	YES	NO	1	1	2	0	3
Com	Al	Ni-PTFE	Al	ZnNi	moderate	NO	NO	YES	NO	2	0	3	1	2
Mil	Al	ZnNi	Al	ZnNi	severe	NO	YES	YES	Yes	3	0	4	3	1

*IAW: NAVAIR 01-1A-509-1 TM 1-1500-344-23-1 TO 1-1-689-1 CLEANING AND CORROSION CONTROL

**IAW: TB 43-0213, TECHNICAL BULLETIN CORROSION PREVENTION AND CONTROL (CPC) FOR TACTICAL VEHICLES

+Overall qualitative assessment based on 3-4 quantity connector sets

Quantitative Results & Discussion:

Add'l Salt Fog – Al base, ZnNi

Total Test Time: 798 hrs.

At 548 hrs.

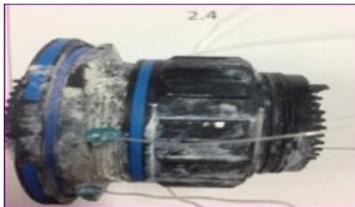
Moderate Degree of Corrosion



Seq 1: Salt Fog Test						
*Test Start Date: Oct 6, 2015 & Test End Date: Oct 28, 2015						
**Test Start Date: Dec 27, 2015 & Test End Date: Jan 6, 2016						
Mil/Com	Torque engaged (Nm)			Torque disengaged (Nm)		
	Initial	*After 548 hrs. (Max 4.6)	**After 798 hrs. (Max 4.6)	Initial (Min 0.6)	*After 548 hrs. (Max 4.6)	**After 798 hrs. (Max 4.6)
Mil	1.8	1.8	2.4	1.3	1.5	1.6

At 798 hrs.

Severe Degree of Corrosion



Seq 1: Salt Fog Test						
*Test Start Date: Oct 6, 2015 & Test End Date: Oct 28, 2015						
**Test Start Date: Dec 27, 2015 & Test End Date: Jan 6, 2016						
Mil/Com	Shell Conductivity (mV) (Testing: 1.5V)			Resistance (Ω)		
	Initial (Max 2.5)	*After 548 hrs. (Max 5.0)	**After 798 hrs. (Max 5.0)	Initial	*After 548 hrs.	**After 798 hrs.
Mil	1.2	2.2	25	0.28	0.6	0.8

- **Observation:** Torque and conductivity increase.
- **Impact:** One connector shows signs of flaking, etching, and pitting.
- **Root Cause:** ZnNi coating corroded.
- **Results:** This connector failed salt fog after 798 hours.

Previous connectors torque seized and conductivity failed; no further testing required.

Quantitative Results & Discussion:

Add'l Salt Fog – Al base, ZnNi mated to Al base, Ni-PTFE

Total Test Time: 750 hrs.

At 500 hrs.

Moderate Degree of Corrosion



Seq 1: Salt Fog Test						
*Test Start Date: Nov 3, 2015 & Test End Date: Nov 23, 2015						
**Test Start Date: Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
Mil/Com	Torque engaged (Nm)			Torque disengaged (Nm)		
	Initial	*After 500 hrs. (Max 2.7)	**After 750 hrs. (Max 2.7)	Initial (Min 0.3)	*After 500 hrs. (Max 2.7)	**After 750 hrs. (Max 2.7)
Com	0.35	0.7	0.6	0.32	0.8	0.7

At 750 hrs.

Moderate Degree of Corrosion



Seq 1: Salt Fog Test						
*Test Start Date: Nov 3, 2015 & Test End Date: Nov 23, 2015						
**Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
Mil/Com	Shell Conductivity (mV) (Testing: 1.5V)			Resistance (Ω)		
	Initial (Max 2.5)	*After 500 hrs. (Max 5.0)	**After 750 hrs. (Max 5.0)	Initial	*After 500 hrs.	**After 750 hrs.
Com	22.1	2.8	23.7	0.32	0.6	0.9

- **Observation:** Torque decreased slightly; conductivity exceeded allowable max.
- **Impact:** Connector showed pitting, loss of ball bearings and spring from spring finger, and clicking noise.
- **Root Cause:** ZnNi and Ni-PTFE coating corroded; spring finger corroded.
- **Results:** This is the last of this set of connectors; failed after 750 hours.

Torque seized for previous connectors; no further testing required.

**Additional Salt Fog
Exposure to Failure
(1048 or 1000 Hours Tested)**

Qualitative Observations: Salt Fog

Total hrs. of exposure: 1048 or 1000 Hours

Mil/ Com	Description				*Degree ⁺	Comments (YES or No)				**	Conductivity		Torque	
	Plug		Receptacle			Discolor ⁺	Flaking ⁺	Pits ⁺	Etching ⁺	Stage ⁺	Pass	Fail	Pass	Fail
	Base	Coating	Base	Coating										
Mil	Composite	eNi	Composite	eNi	light	YES	NO	NO	NO	1	4	0	4	0
Mil	SS	Ni	SS	Ni	light	YES	NO	NO	NO	1	4	0	4	0
Mil	SS	Passivated	SS	Passivated	light	YES	NO	NO	YES	1	4	0	4	0
Com	Al	Cd	Al	Cd	light	YES	NO	NO	YES	1	1	2	3	0
Com	Al	Cd	Al	Cd	light	YES	NO	YES	YES	1	4	0	2	2
Mil	Al	Cd	Al	Cd	light	YES	NO	NO	YES	1	1	2	2	1
Com	Al	SnZn	Al	SnZn	moderate	YES	NO	YES	YES	2	2	0	0	2
Mil	Al	Ni-PTFE	Al	Ni-PTFE	severe	YES	YES	YES	YES	4	3	0	3	0
Com	Al	Ni 2MILS	Al	Ni 2MILS	severe	YES	YES	YES	YES	4	4	0	4	0

*IAW: NAVAIR 01-1A-509-1 TM 1-1500-344-23-1 TO 1-1-689-1 CLEANING AND CORROSION CONTROL
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 +Overall qualitative assessment based on 2-4 quantity connector sets

Quantitative Comparison

Add'l Salt Fog – Al base, Ni-PTFE

Total Test Time: 1000 hrs.

Initial 750 Hour
Salt Fog



After 1000 Hour
Salt Fog



Connector (4.1) failed conductivity; no further testing required

Quantitative Results & Discussion: Add'l Salt Fog – Al base, Ni-PTFE Total Test Time: 1000 hrs.

At 750 hrs.

Moderate Degree of Corrosion



Seq 1: Salt Fog Test						
*Test Start Date: : Nov 3, 2015 & Test End Date: Nov 23, 2015						
**Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
***Test Start Date: April 7, 2016 & Test End Date: April 19, 2016						
Mil/Com	Torque engaged (Nm)			Torque disengaged (Nm)		
	*After 500 hrs. (Max 4.6)	**After 750hrs (Max 4.6)	***After 1000hrs (Max 4.6)	*After 500 hrs. (Max 4.6)	**After 750hrs (Max 4.6)	***After 1000 hrs. (Max 4.6)
Mil	1.3	0.8	1.9	1.2	0.7	1.4
Mil	1.7	0.9	1.4	0.8	0.5	1.2
Mil	1.2	1	1.1	1.1	0.8	1.1

At 1000 hrs.

Severe Degree of corrosion



Seq 1: Salt Fog Test						
*Test Start Date: : Nov 3, 2015 & Test End Date: Nov 23, 2015						
**Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
***Test Start Date: April 7, 2016 & Test End Date: April 19, 2016						
Mil/Com	Shell Conductivity (mV) (Testing: 1.5V)			Resistance (Ω)		
	*After 500 hrs. (Max 5.0)	*After 750 hrs. (Max 5.0)	**After 1000 hrs. (Max 5.0)	*After 500 hrs.	*After 750hrs	**After 1000 hrs.
Mil	0.58	0.82	1.3	0.1	0.2	0.2
Mil	1.1	2.2	0.8	0.6	0.2	0.2
Mil	1.6	0.96	1.3	0.6	0.2	0.2

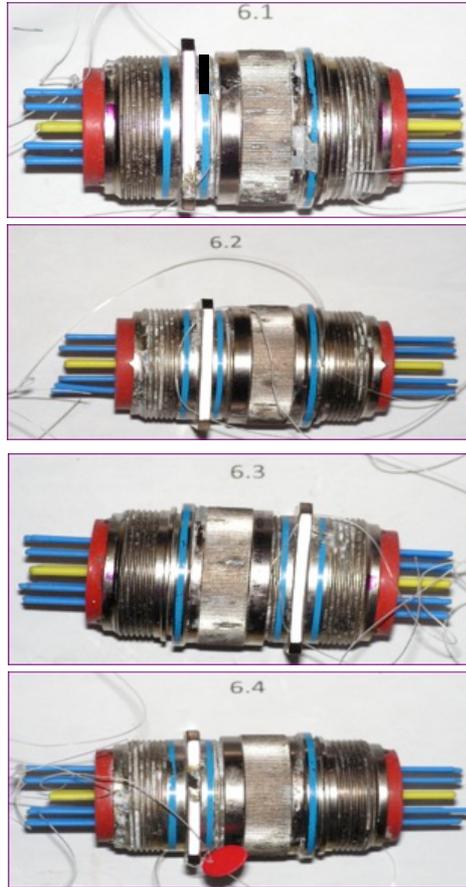
- **Observation:** Torque increased for all connectors; conductivity increased for two of three connectors.
- **Impact:** Connectors showed discoloration, etching, and pitting.
- **Root Cause:** Ni-PTFE is corroding.
- **Results:** All three connectors will be tested further among top performers.

Quantitative Comparison

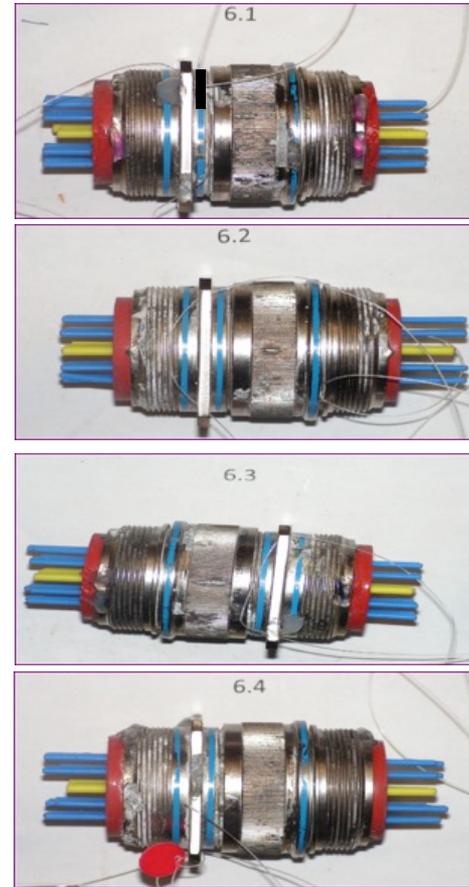
Add'l Salt Fog – Al base, Ni 2MILS

Total Test Time: 1000 hrs.

**Initial 750 Hour
Salt Fog**



**After 1000 Hour
Salt Fog**



Quantitative Results & Discussion:

Add'l Salt Fog – Al base, Ni 2MILS

Total Test Time: 1000 hrs.

At 750 hrs.

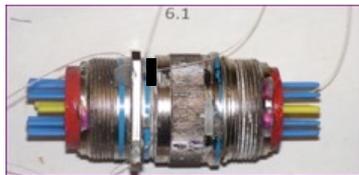
Moderate degree of corrosion



Seq 1: Salt Fog Test						
*Test Start Date: : Nov 3, 2015 & Test End Date: Nov 23, 2015						
**Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
***Test Start Date: April 7, 2016 & Test End Date: April 19, 2016						
Mil/Com	Torque engaged (Nm)			Torque disengaged (Nm)		
	*After 500 hrs. (Not Specified)	**After 750hrs (Not Specified)	***After 1000hrs (Not Specified)	*After 500 hrs. (Not Specified)	**After 750hrs (Not Specified)	***After 1000 hrs. (Not Specified)
Com	1.1	1.8	2.9	0.9	1.1	2.4
Com	1.3	1.7	3.3	1.1	1.3	2.4
Com	1.1	1.7	3.4	0.9	1.6	2.1
Com	1.2	1.6	2.5	0.8	1.2	2

At 1000 hrs.

Severe degree of corrosion



Seq 1: Salt Fog Test						
*Test Start Date: : Nov 3, 2015 & Test End Date: Nov 23, 2015						
**Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
***Test Start Date: April 7, 2016 & Test End Date: April 19, 2016						
Mil/Com	Shell Conductivity (mΩ) (Testing: 1.5V)			Resistance (Ω)		
	*After 500 hrs. (Not Specified)	**After 750 hrs. (Not Specified)	***After 1000 hrs. (Not Specified)	*After 500 hrs.	**After 750 hrs.	***After 1000 hrs.
Com	4.5	2.1	2.2	0.2	0.1	0.1
Com	4.2	1.4	0.9	0.3	0.1	0.1
Com	6.3	2.9	1.5	0.3	0.1	0.1
Com	4.7	1.9	1.2	0.1	0.1	0.1

- **Observation:** Torque increased for all connectors; conductivity decreased for three of four connectors.
- **Impact:** Connectors showed discoloration, etching, flaking, and pitting.
- **Root Cause:** Ni 2MILS coating is corroding.
- **Results:** This series will be tested further among top performers.

**Additional Salt Fog Exposure
to Failure
(1298 or 1250 Hours Tested)**

Qualitative Observations: Salt Fog

Total hrs. of Exposure: 1298 or 1250 Hours

Mil/ Com	Description				*Degree ⁺	Comments (Yes or NO)				**	Conductivity		Torque	
	Plug		Receptacle			Discolor ⁺	Flaking ⁺	Pits ⁺	Etching ⁺	Stage ⁺	Pass	Fail	Pass	Fail
	Base	Coating	Base	Coating										
Mil	Composite	eNi	Composite	eNi	light	Yes	NO	NO	NO	1	4	0	4	0
Mil	SS	Ni	SS	Ni	light	Yes	NO	NO	NO	1	4	0	4	0
Mil	SS	Passivated	SS	Passivated	light	Yes	NO	NO	Yes	1	4	0	4	0
Com	Al	Cd	Al	Cd	light	Yes	NO	Yes	Yes	1	1	0	1	0
Com	Al	Cd GTC	Al	Cd GTC	light	Yes	NO	Yes	Yes	1	3	0	3	0
Mil	Al	Cd	Al	Cd	light	NO	NO	NO	Yes	1	0	1	1	0
Com	Al	SnZn	Al	SnZn	moderate	Yes	NO	Yes	Yes	2	1	1	0	2
Mil	Al	Ni-PTFE	Al	Ni-PTFE	severe	Yes	Yes	Yes	Yes	4	3	0	3	0
Com	Al	Ni MGTC	Al	Ni MGTC	severe	Yes	Yes	Yes	Yes	4	4	0	3	1

*IAW: NAVAIR 01-1A-509-1 TM 1-1500-344-23-1 TO 1-1-689-1 CLEANING AND CORROSION CONTROL

**IAW: TB 43-0213, TECHNICAL BULLETIN CORROSION PREVENTION AND CONTROL (CPC) FOR TACTICAL VEHICLES

+Overall qualitative assessment based on 2-4 quantity connector sets

Quantitative Comparison

Add'l Salt Fog – Al base, Ni-PTFE

Total Test Time: 1250 hrs.

Initial 1000 Hour
Salt Fog



After 1250 Hour
Salt Fog

1 of 4 failed conductivity; 3 of 4 continued testing

Quantitative Comparison

Add'l Salt Fog – Al base, Ni-PTFE

Total Test Time: 1250 hrs.

At 1000 hrs.

Severe Degree of Corrosion



Seq 1: Salt Fog Test						
*Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
**Test Start Date: April 7, 2016 & Test End Date: April 19, 2016						
***Test Start Date: May 12, 2016 & Test End Date: May 22, 2016						
Label	Torque engaged (Nm)			Torque disengaged (Nm)		
	*After 750 hrs.	**After 1000 hrs.	***After 1250 hrs.	*After 750 hrs.	**After 1000 hrs.	***After 1250 hrs.
	(Max 4.6)	(Max 4.6)	(Max 4.6)	(Max 4.6)	(Max 4.6)	(Max 4.6)
4.2	0.8	1.9	1.8	0.7	1.4	1.4
4.3	0.9	1.4	1.4	0.5	1.2	2.3
4.4	1	1.1	1.8	0.8	1.1	1.1

At 1250 hrs.

Severe Degree of Corrosion



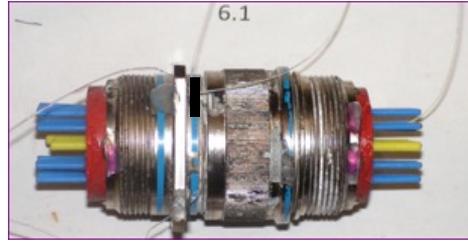
Seq 1: Salt Fog Test						
*Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
**Test Start Date: April 7, 2016 & Test End Date: April 19, 2016						
***Test Start Date: May 12, 2016 & Test End Date: May 22, 2016						
Label	Shell Conductivity (mV) (Testing: 1.5V)			Resistance (Ω)		
	*After 750 hrs.	**After 1000 hrs.	***After 1250 hrs.	*After 750 hrs.	**After 1000 hrs.	***After 1250 hrs.
	(Max 5.0)	(Max 5.0)	(Max 5.0)			
4.2	0.82	1.3	1.6	0.2	0.2	.3
4.3	2.2	0.8	1.1	0.2	0.2	.4
4.4	0.96	1.3	1.6	0.2	0.2	.3

- **Observation:** Torque engagement increased for one of three connectors; disengagement increased for one of three connectors; conductivity increased for all connectors.
- **Impact:** Connectors showed discoloration, etching, pitting, and flaking.
- **Root Cause:** Ni-PTFE coating is corroding on outer shell and inner thread.
- **Results:** Three of four connectors passed allowable conductivity.

Quantitative Comparison

Add'l Salt Fog – Al base, Ni 2MILS

Total Test Time: 1250 hrs.



**Initial 1000 Hour
Salt Fog**

**After 1250 Hour
Salt Fog**

Quantitative Comparison

Add'l Salt Fog – Ni 2MILS

Total Test Time: 1250hrs

At 1000 hrs.
Severe Degree of Corrosion



Seq 1: Salt Fog Test						
*Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
**Test Start Date: April 7, 2016 & Test End Date: April 19, 2016						
***Test Start Date: May 12, 2016 & Test End Date: May 22, 2016						
Mil/Com	Torque engaged (Nm)			Torque disengaged (Nm)		
	*After 750 hrs.	**After 1000 hrs.	***After 1250 hrs.	*After 750 hrs.	**After 1000 hrs.	***After 1250hrs
	(Not Specified)	(Not Specified)	(Not Specified)	(Not Specified)	(Not Specified)	(Not Specified)
Com	1.8	2.9	Seized	1.1	2.4	Seized
Com	1.7	3.3	3.6	1.3	2.4	2.3
Com	1.7	3.4	3.3	1.6	2.1	2.5
Com	1.6	2.5	3.6	1.2	2	1.6

At 1250 hrs.
Severe Degree of Corrosion



Seq 1: Salt Fog Test						
*Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
**Test Start Date: April 7, 2016 & Test End Date: April 19, 2016						
***Test Start Date: May 12, 2016 & Test End Date: May 22, 2016						
Mil/Com	Shell Conductivity (mV) (Testing: 1.5V)			Resistance (Ω)		
	*After 750 hrs.	**After 1000 hrs.	***After 1250 hrs.	*After 750 hrs.	**After 1000 hrs.	***After 12 50 hrs.
	(Not Specified)	(Not Specified)	(Not Specified)			
Com	2.1	2.2	Seized	0.1	0.1	.2
Com	1.4	0.9	20000	0.1	0.1	.3
Com	2.9	1.5	50000	0.1	0.1	.2
Com	1.9	1.2	30000	0.1	0.1	

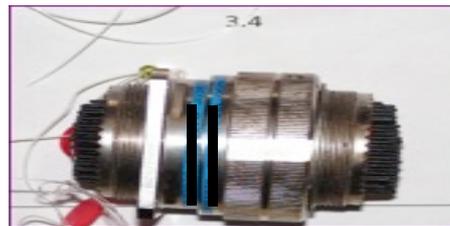
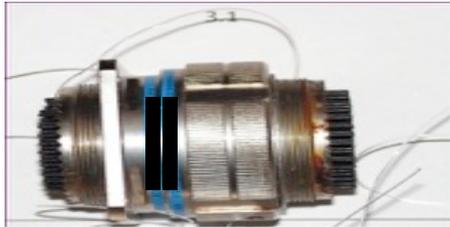
- **Observation:** Torque seized for one four connectors; conductivity increased for all connectors.
- **Impact:** Connectors showed signs of discoloration, etching, flaking, and pitting.
- **Root Cause:** Ni 2MILS coating is corroding
- **Results:** One of three connectors failed torque; the remaining three are among top performers after 1250 hours.

Overall Quantitative Comparison: Top Performers

Salt Fog & Add'l Salt Fog– SS base, Ni

Total Test Time: 1298 hrs.

**Initial 1048 Hour
Salt Fog**



**Post 1298 Hour
Salt Fog**



Quantitative Results & Discussion:

Add'l Salt Fog – SS base, Ni

Total Test Time: 1298 hrs.

At 1048 hrs.
Light Degree of Corrosion



Seq 1: Salt Fog Test						
*Test Start Date: Dec 27, 2015 & Test End Date: Jan 6, 2016						
**Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
***Test Start Date: April 7, 2016 & Test End Date: April 19, 2016						
Mil/Com	Torque engaged (Nm)			Torque disengaged (Nm)		
	*After 798 hrs. (Max 4.6)	**After 1048 hrs. (Max 4.6)	***After 1298 hrs. (Max 4.6)	*After 798 hrs. (Max 4.6)	**After 1048 hrs. (Max 4.6)	***After 1298 hrs. (Max 4.6)
Mil	1.8	1.3	2.2	1	1	1.3
Mil	1.6	1	1.9	1.1	0.8	1.3
Mil	1.9	1.3	2.6	1.1	0.9	1.4
Mil	1.9	1.2	1.8	1.2	0.7	1.1

At 1298 hrs.
Light Degree of Corrosion

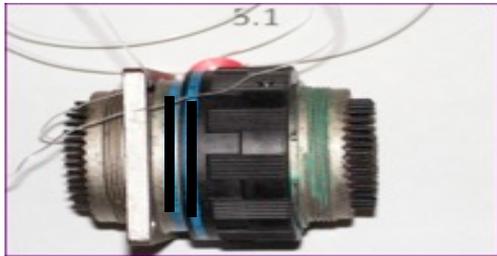


Seq 1: Salt Fog Test						
*Test Start Date: Dec 27, 2015 & Test End Date: Jan 6, 2016						
**Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
***Test Start Date: April 7, 2016 & Test End Date: April 19, 2016						
Mil/Com	Shell Conductivity (mV) (Testing: 1.5V)			Resistance (Ω)		
	*After 798 hrs. (Max 2.0)	*After 1048 hrs. (Max 2.0)	**After 1298 hrs. (Max 2.0)	*After 798 hrs.	*After 1048 hrs.	**After 1298 hrs.
Mil	0.8	1.7	0.9	0.1	0.1	0.1
Mil	0.6	0.74	0.6	0.1	0.1	0.1
Mil	0.6	0.9	0.7	0.1	0.09	0.1
Mil	0.54	0.61	0.5	0.1	0.1	0.1

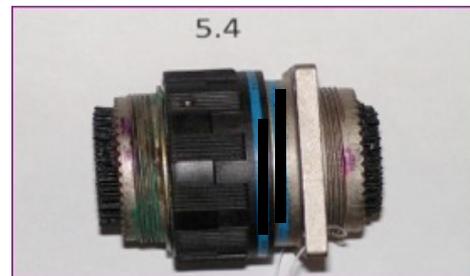
- **Observation:** Conductivity increased when torque engagement was low and conductivity was lower with higher engagement.
- **Impact:** Connectors showed minor discoloration.
- **Root Cause:** Ni coating still prevented severe corrosion and heavy discoloration after total 1298 hours of exposure to Salt Fog.
- **Results:** This set of connectors remains a top performer.

Overall Quantitative Comparison: Top Performers Salt Fog & Add'l Salt Fog – Composite base, eNi Total Test Time: 1298hrs

Initial 1048 Hour
Salt Fog



After 1298 Hour
Salt Fog



Quantitative Results & Discussion:

Add'l Fog – Composite base, eNi

Total Test Time: 1298 hrs.

At 1048 hrs.
Light Degree of Corrosion



Seq 1: Salt Fog Test						
*Test Start Date: Dec 27, 2015 & Test End Date: Jan 6, 2016						
**Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
***Test Start Date: April 7, 2016 & Test End Date: April 19, 2016						
Mil/Com	Torque engaged (Nm)			Torque disengaged (Nm)		
	*After 798 hrs.	**After 1048 hrs.	***After 1298 hrs.	*After 798 hrs.	**After 1048 hrs.	***After 1298 hrs.
	(Max 4.6)	(Max 4.6)	(Max 4.6)	(Max 4.6)	(Max 4.6)	(Max 4.6)
Mil	1	1.2	1.1	1.2	0.6	1.2
Mil	1.4	1.1	1.3	1.2	0.7	1.3
Mil	1.6	0.9	1.6	1.5	0.9	1.3
Mil	1.2	0.9	0.9	1.4	0.9	0.7

At 1298 hrs.
Light Degree of Corrosion

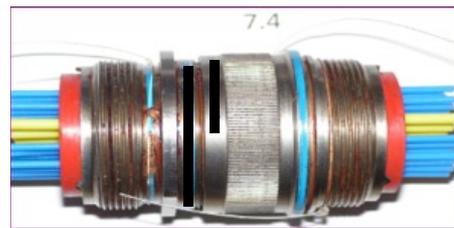
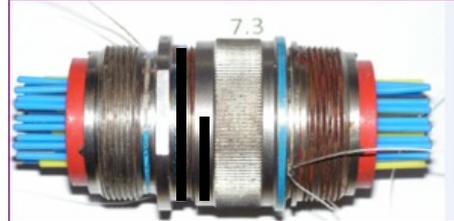
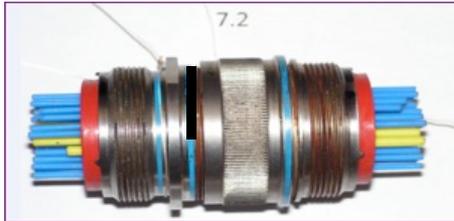
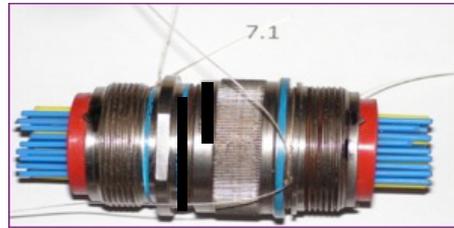
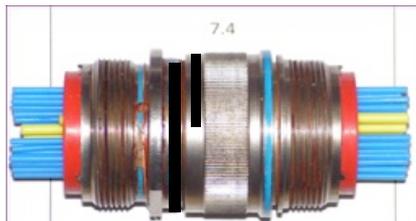
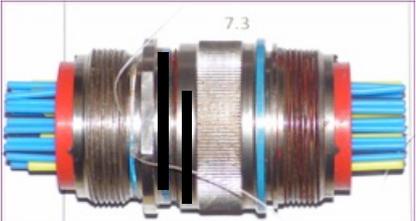
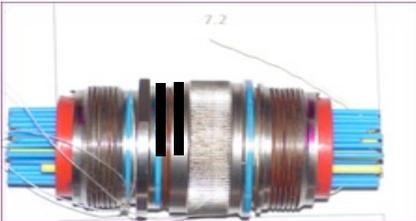
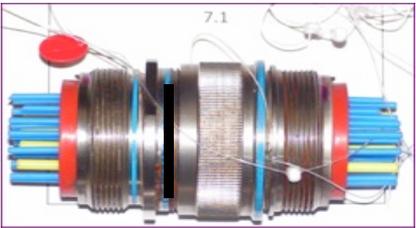


Seq 1: Salt Fog Test						
*Test Start Date: Dec 27, 2015 & Test End Date: Jan 6, 2016						
**Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
***Test Start Date: April 7, 2016 & Test End Date: April 19, 2016						
Mil/Com	Shell Conductivity (mV) (Testing: 1.5V)			Resistance (Ω)		
	*After 798 hrs.	*After 1048 hrs.	**After 1298 hrs.	*After 798 hrs.	*After 1048 hrs.	**After 1298 hrs.
	(Max 6.0)	(Max 6.0)	(Max 6.0)			
Mil	1.6	1.9	1.7	0.11	0.1	0.1
5.2/Mil	2	1.7	1.8	0.09	0.1	0.1
5.3/Mil	1.7	2	1.5	0.1	0.09	0.1
5.4/Mil	2.1	2.1	2	0.1	0.09	0.1

- **Observation:** Torque required for disengagement increased and conductivity stayed constant for all connectors.
- **Impact:** Connectors still showed minor discoloration.
- **Root Cause:** eNi coating still prevented severe corrosion and heavy discoloration after a total 1298 hours.
- **Results:** This set of connectors remains a top performer.

Overall Quantitative Comparison: Top Performers Salt Fog & Add'l Salt Fog – SS base, Passivated Total Test Time: 1298 hrs.

Initial 1048 Hour
Salt Fog



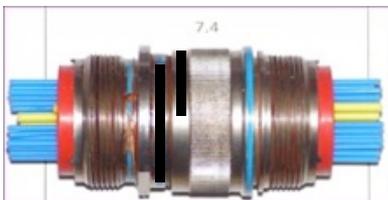
After 1298 Hour
Salt, Fog

Quantitative Results & Discussion:

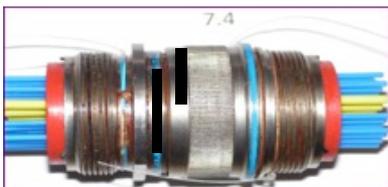
Add'l Salt Fog – SS base, Passivated

Total Test Time: 1298 hrs.

At 1048 hrs.
Light Degree of Corrosion



At 1298 hrs.
Light Degree of Corrosion



Seq 1: Salt Fog Test						
*Test Start Date: Dec 27, 2015 & Test End Date: Jan 6, 2016						
**Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
***Test Start Date: April 7, 2016 & Test End Date: April 19, 2016						
Mil/Com	Torque engaged (Nm)			Torque disengaged (Nm)		
	*After 798 hrs. (Max 4.6)	**After 1048 hrs. (Max 4.6)	***After 1298 hrs. (Max 4.6)	*After 798 hrs. (Max 4.6)	**After 1048 hrs. (Max 4.6)	***After 1298 hrs. (Max 4.6)
Mil	1.6	2.1	2.4	0.9	1	0.8
Mil	1.7	2	2.8	1.1	1.2	1.2
Mil	1.8	2.2	2.4	1.1	1.2	1.2
Mil	1.8	1.9	2.5	1	1.3	1.6

Seq 1: Salt Fog Test						
*Test Start Date: Dec 27, 2015 & Test End Date: Jan 6, 2016						
**Test Start Date: Feb 2, 2016 & Test End Date: Feb 12, 2016						
***Test Start Date: April 7, 2016 & Test End Date: April 19, 2016						
Mil/Com	Shell Conductivity (mΩ) (Testing: 1.5V)			Resistance (Ω)		
	*After 798 hrs. (Not Specified)	*After 1048 hrs. (Not Specified)	**After 1298 hrs. (Not Specified)	*After 798 hrs.	*After 1048 hrs.	**After 1298 hrs.
Mil	13.7	17.1	15.5	0.1	0.1	0.2
Mil	31	41	62.9	0.1	0.2	0.2
Mil	33	21.2	43.5	0.2	0.2	0.2
Mil	13	48.7	102	0.1	0.2	0.4

- **Observation:** Torque engagement increased for all connectors; disengagement increased for one of four connectors; conductivity increased for three of four connectors.
- **Impact:** Connectors showed discoloration and etching.
- **Root Cause:** Passivation prevented severe corrosion and severe discoloration after total 1298 hours.
- **Results:** This set of connectors remains a top performer.

Salt Fog & SO₂ Test

Salt Fog & SO₂ Procedure

- Salt fog and sulfur dioxide test (at Touchstone Labs)
 - ASTM G85:A4
 1. Mate/Unmate 50 times before
 2. Torque, Conductivity, and Resistance recorded before
 3. 336 hrs. mated
 4. Mate/Unmate 450 times after
 5. Torque, Conductivity, and Resistance recorded after
- Additional Salt fog and sulfur dioxide test (at Touchstone Labs)
 - Test connectors that passed conductivity
 1. Mate connectors; send to Touchstone
 2. 168 hrs. mated
 3. Mate/Unmate 450 times after
 4. Record Torque, Conductivity, and Resistance
 5. If connector passes Torque, Conductivity, and Resistance testing, Repeat steps 1-5 again until failure

Conditions more severe than salt fog; commensurate results obtained.

Qualitative Observations: Salt Fog & SO₂

Mil/ Com	Description				*Degree ⁺	Comments (YES or No)				**	Conductivity		Torque	
	Plug		Receptacle			Discolor ⁺	Flaking ⁺	Pits ⁺	Etching ⁺	Stage ⁺	Pass	Fail	Pass	Fail
	Base	Coating	Base	Coating										
Mil	SS	Passivated	SS	Passivated	light	Yes	NO	NO	NO	1	4	0	4	0
Mil	SS	Ni	SS	Ni	Light	Yes	NO	Yes	NO	1	4	0	4	0
Mil	Al	Cd	Al	Cd	moderate	NO	NO	NO	NO	2	4	0	4	0
Mil	SS	Ni	Al	Ni	moderate	Yes	Yes	No	Yes	2	2	0	2	0
Mil	Al	Ni	SS	Ni	moderate	Yes	No	Yes	Yes	2	2	0	2	0
Mil	Al	Ni-PTFE	Al	Ni-PTFE	moderate	Yes	Yes	Yes	Yes	2	4	0	4	0
Com	Al	Cd	Al	Cd	moderate	Yes	Yes	NO	Yes	2	4	0	3	1
Com	Al	Ni-PTFE	Al	Ni-PTFE	moderate	No	Yes	Yes	Yes	2	1	1	1	1
Mil	Composite	eNi	Composite	eNi	moderate	Yes	NO	NO	Yes	2	2	2	4	0
Com	Al	Ni-PTFE	Al	ZnNi	moderate	Yes	Yes	Yes	No	2	0	2	0	2
Com	Al	Cd	Al	ZnNi	severe	Yes	Yes	NO	Yes	4	4	0	4	0
Mil	Al	ZnNi	Al	ZnNi	severe	Yes	Yes	Yes	NO	4	4	0	4	0
Mil	Al	Ni	Al	Ni	severe	Yes	Yes	Yes	Yes	4	4	0	4	0
Com	Al	ZnNi	Al	Cd	severe	Yes	Yes	NO	Yes	4	2	1	3	0
Mil	Al	Ni	Al	Ni	severe	Yes	Yes	NO	NO	4	4	0	0	4

*Degree of Corrosion IAW: NAVAIR 01-1A-509-1 TM 1-1500-344-23-1 TO 1-1-689-1 Cleaning and Corrosion Control

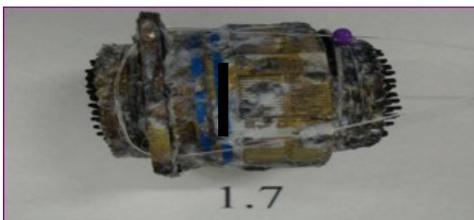
*Overall qualitative assessment based on observing 2-4 connector sets.

**Stage of Corrosion IAW: TB 43-0213, Technical Bulletin Corrosion Prevention and Control (CPC) for tactical Vehicles

Top performing post-Salt Fog & SO₂ Testing: SS/Ni and SS/Passivated

Quantitative Comparison Salt Fog & SO₂ - Al base, Ni Total Test Time: 336 hrs.

Initial

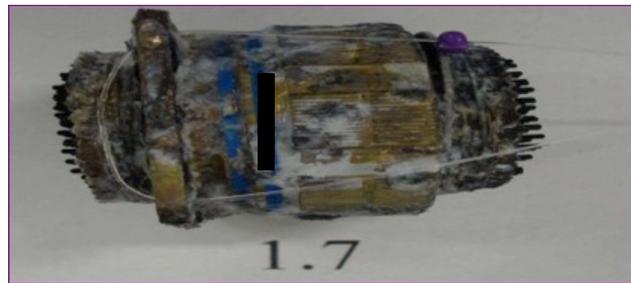


After 336 Hour
Salt Fog & SO₂

Quantitative Results & Discussion: Salt Fog and SO₂ – Al base, Ni Total Test Time: 336 hrs.



Initial



After 336 hrs.

Seq 2: SO ₂ Test (336 hrs.) (Test Start Date: Oct 20, 2015 & Test End Date: Nov 5, 2015)												
Mil/Com	Torque engaged (Nm)		Torque disengaged (Nm)		Shell Conductivity (mV) (Testing: 1.5V)		Resistance (Ω)		Durability		Stage of Corrosion (1-4)	Degree of Corrosion
	Initial	After (Max 4.6)	Initial (Min 0.6)	After (Max 4.6)	Initial (Max 1.0)	After (Max 2.0)	Initial	After	Initial	After		
Mil	1.3	Seized	1.2	Seized	0.22	1.4	0.15	0.1	yes	NO	4	Severe
Mil	1.2	Seized	0.98	Seized	0.39	0.05	0.25	0.17	yes	NO	4	Severe
Mil	1.2	Seized	0.89	Seized	0.28	0.12	0.19	0.13	yes	NO	4	Severe
Mil	1.3	Seized	1.2	Seized	0.18	0.05	0.33	0.22	yes	NO	4	Severe

- **Observation:** After 336 hrs. exposure, connectors seized; they failed to engage and disengage.
- **Impact:** Connectors showed signs of discoloration and flaking.
- **Root Cause:** Base metal and coating are corroded, leading to coupling nut seizing.
- **Results:** Poor connector based on engage and disengage, but acceptable based on conductivity.

Torque seized for connectors; severe corrosion; still passed conductivity allowable max.

Quantitative Comparison

Salt Fog & SO₂ - Al base, Cd mated to Al base, ZnNi

Total Test Time: 336 hrs.

Initial



After 336 Hour
Salt Fog & SO₂

Quantitative Results & Discussion:

Salt Fog & SO₂ – Al base, Cd mated to Al base, ZnNi

Total Test Time: 336 hrs.



Initial



After 336 hrs.

Seq 2: SO ₂ Test (336 hrs.) (Test Start Date: Oct 20, 2015 & Test End Date: Nov 5, 2015)												
Mil/Com	Torque engaged (Nm)		Torque disengaged (Nm)		Shell Conductivity (mV) (Testing: 1.5V)		Resistance (Ω)		Durability		Stage of Corrosion (1-4)	Degree of Corrosion
	Initial	After (Max 4.6)	Initial (Min 0.6)	After (Max 4.6)	Initial (Max 2.5)	After (Max 5.0)	Initial	After	Initial	After		
Com	1.8	2.1	1.2	1.2	0.25	5.2	0.1	0.3	yes	NO	4	Severe
Com	1.7	1.5	1.3	1.1	0.4	1.1	0.1	0.5	yes	yes	4	Severe
Com	1.6	1.1	1	0.7	0.3	0.7	0.1	0.5	yes	yes	4	Severe

- **Observation:** Torque decreased for two of three connectors and conductivity increased for two of three connectors.
- **Impact:** Connectors showed discoloration, flaking, and etching.
- **Root Cause:** ZnNi coating is corroded; Cd coating corroded slightly.
- **Results:** Two of the three connectors will be further tested among top performers.

Connectors severely corroded; two of three passed conductivity allowable max.

**Additional Salt Fog & SO₂
Testing
(Total 504 hours of Exposure)**

Qualitative Observations: Salt Fog & SO₂

Total hrs. of Exposure : 504 hours

Mil/ Com	Description				*Degree ⁺	Comments (YES or No)				** Stage ⁺	Conductivity		Torque	
	Plug		Receptacle			Discolor ⁺	Flaking ⁺	Pits ⁺	Etching ⁺		Pass	Fail	Pass	Fail
	Base	Coating	Base	Coating										
Mil	SS	Passivated	SS	Passivated	light	Yes	NO	NO	NO	1	4	0	4	0
Mil	SS	Ni	SS	Ni	moderate	Yes	NO	NO	Yes	1	4	0	4	0
Mil	Al	Ni-PTFE	Al	Ni-PTFE	moderate	Yes	Yes	Yes	Yes	2	4	0	4	0
Mil	Al	Cd	Al	Cd	moderate	Yes	NO	Yes	Yes	2	4	0	3	1
Mil	Composite	eNi	Composite	eNi	moderate	Yes	Yes	NO	Yes	2	2	0	1	1
Mil	SS	Ni	Al	Ni	moderate	Yes	Yes	No	Yes	2	1	0	0	1
Com	Al	Cd	Al	Cd	moderate	Yes	Yes	NO	Yes	2	4	0	3	1
Mil	Al	Ni	SS	Ni	moderate	Yes	Yes	Yes	Yes	2	2	0	0	2
Com	Al	ZnNi	Al	Cd	severe	Yes	Yes	NO	Yes	4	1	1	1	1
Com	Al	Cd	Al	ZnNi	severe	Yes	Yes	NO	Yes	4	3	1	3	1
Mil	Al	ZnNi	Al	ZnNi	severe	Yes	Yes	Yes	NO	4	0	3	3	0
Mil	Al	Ni	Al	Ni	severe	Yes	Yes	Yes	Yes	4	4	0	0	4

*IAW: NAVAIR 01-1A-509-1 TM 1-1500-344-23-1 TO 1-1-689-1 CLEANING AND CORROSION CONTROL

**IAW: TB 43-0213, TECHNICAL BULLETIN CORROSION PREVENTION AND CONTROL (CPC) FOR TACTICAL VEHICLES

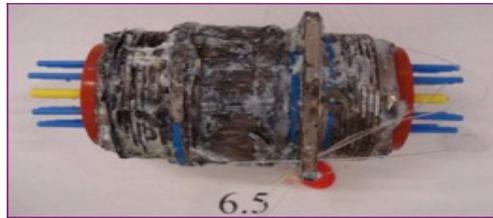
+Overall qualitative assessment based on 3-4 quantity connector sets

Top performer post-Salt Fog & SO₂ Testing: SS/Passivated

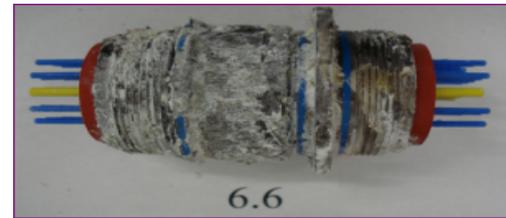
Quantitative Comparison

Add'l Salt Fog & SO₂ - Al base, Ni 2MILS

Total Test Time: 504 hrs.



After 336 Hour
Salt Fog & SO₂



After 504 Hour
Salt Fog & SO₂



Quantitative Results & Discussion:

Add'l Salt Fog & SO₂ – Al base, Ni 2MILS

Total Test Time: 504 hrs.

At 336 hrs.
Severe Degree of Corrosion



Seq 2: Salt Fog & SO ₂						
*Test Start Date: Oct 20, 2015 & Test End Date: Nov 5, 2015						
**Test Start Date: May 19, 2016 & Test End Date: June 2, 2016						
Mil/Com	Torque engaged (Nm)			Torque disengaged (Nm)		
	Initial	*After 336 hrs. (Max 4.6)	**After 504 hrs. (Max 4.6)	Initial (Min 0.6)	*After 336 hrs. (Max 4.6)	**After 504 hrs. (Max 4.6)
Com	1.8	1.22	Seized	1.3	1.1	Seized
Com	1.2	1.2	Seized	1	0.86	Seized
Com	1.2	1.35	Seized	1.1	1.1	Seized
Com	1.8	1.4	Seized	1.1	1	Seized

At 504 hrs.
Severe Degree of Corrosion



Seq 2: Salt Fog & SO ₂						
*Test Start Date: Oct 20, 2015 & Test End Date: Nov 5, 2015						
**Test Start Date: May 19, 2016 & Test End Date: June 2, 2016						
Mil/Com	Shell Conductivity (mΩ) (Testing: 1.5V)			Resistance (Ω)		
	Initial (Max 1.0)	*After 336 hrs. (Max 2.0)	**After 504 hrs. (Max 2.0)	Initial	*After 336 hrs.	**After 504 hrs.
Com	0.35	0.65	0.8	0.07	0.09	0.1
Com	0.3	0.5	0.6	0.1	0.07	0.1
Com	0.24	0.7	0.6	0.1	0.09	0.1
Com	0.45	0.55	0.54	0.1	0.09	0.1

- **Observation:** Torque failed to unmate; conductivity increased for two of four connectors.
- **Impact:** Connectors showed discoloration, etching, flaking, and pitting.
- **Root Cause:** Ni MGTC coating is corroding.
- **Results:** : This set connectors made it among top performers after 504 hours.

Quantitative Comparison

Add'l Salt Fog & SO₂ - Al base, ZnNi

Total Test Time: 504 hrs.



After 336 Hour
Salt Fog & SO₂



After 504 Hour
Salt Fog & SO₂



Quantitative Results & Discussion:

Add'l Salt Fog & SO₂ – Al base, ZnNi

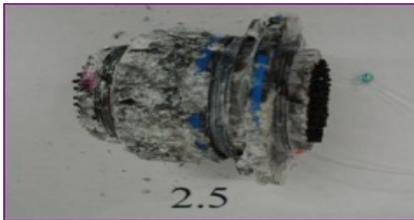
Total Test Time: 504 hrs.

At 336 hrs.
Severe Degree of Corrosion



Seq 2: Salt Fog & SO ₂						
*Test Start Date: Oct 20, 2015 & Test End Date: Nov 5, 2015						
**Test Start Date: May 19, 2016 & Test End Date: June 2, 2016						
Mil/Com	Torque engaged (Nm)			Torque disengaged (Nm)		
	Initial	*After 336 hrs. (Max 4.6)	**After 504 hrs. (Max 4.6)	Initial (Min 0.6)	*After 336 hrs. (Max 4.6)	**After 504 hrs. (Max 4.6)
2.5/Mil	1.8	2.1	2.6	1.3	1.1	2.4
2.7/Mil	1.2	1.8	2.8	1.2	1.4	3.1
2.8/Mil	1.8	2.2	2.6	1.7	1.6	3.2

At 504 hrs.
Severe Degree of Corrosion



Seq 2: Salt Fog & SO ₂						
*Test Start Date: Oct 20, 2015 & Test End Date: Nov 5, 2015						
**Test Start Date: May 19, 2016 & Test End Date: June 2, 2016						
Mil/Com	Shell Conductivity (mV) (Testing: 1.5V)			Resistance (Ω)		
	Initial (Max 2.5)	*After 336 hrs. (Max 5.0)	**After 504 hrs. (Max 5.0)	Initial	*After 336 hrs.	**After 504 hrs.
Mil	2.4	2.3	330	0.2	0.1	0.2
Mil	0.6	1.1	320	0.2	0.1	0.2
Mil	1.8	1.5	6.1	0.2	0.1	0.2

- **Observation:** Torque increased and conductivity failed allowable max.
- **Impact:** Connectors showed discoloration, etching, pitting, and flaking.
- **Root Cause:** ZnNi coating is corroding.
- **Results:** This set of connectors failed conductivity after 504 hrs..

Overall Quantitative Comparison: Top Performers

Salt Fog/SO₂ & Add'l – SS base, Passivated

Total Test Time: 504 hrs.

After 336 Hour
Salt Fog & SO₂



After 504 Hour
Salt Fog & SO₂



Quantitative Results & Discussion:

Add'l Salt Fog & SO₂ – SS base, Passivated

Total Test Time: 504 hrs.

At 336 hrs.

Light Degree of Corrosion



Seq 2: Salt Fog & SO ₂						
*Test Start Date: Oct 20, 2015 & Test End Date: Nov 5, 2015						
**Test Start Date: May 19, 2016 & Test End Date: June 2, 2016						
Mil/Com	Torque engaged (Nm)			Torque disengaged (Nm)		
	Initial	*After 336 hrs. (Max 4.6)	**After 504 hrs. (Max 4.6)	Initial (Min 0.6)	*After 336 hrs. (Max 4.6)	**After 504 hrs. (Max 4.6)
7.5/Mil	2.8	1.5	2.6	1.7	0.27	2.2
7.6/Mil	2.5	1.4	2.6	1.6	1.1	2.1
7.7/Mil	2.2	1.7	2.6	2.2	1.2	2.2
7.8/Mil	2.9	1.8	2.6	1.7	0.8	2.2

At 504 hrs.

Light Degree of Corrosion



Seq 2: Salt Fog & SO ₂						
*Test Start Date: Oct 20, 2015 & Test End Date: Nov 5, 2015						
**Test Start Date: May 19, 2016 & Test End Date: June 2, 2016						
Mil/Com	Shell Conductivity (mΩ) (Testing: 1.5V)			Resistance (Ω)		
	Initial (Not Specified)	*After 336 hrs. (Not Specified)	**After 504 hrs. (Not Specified)	Initial	*After 336 hrs.	**After 504 hrs.
Mil	25.3	8.8	10200	0.3	0.2	0.1
Mil	16.5	8.1	34500	0.35	0.44	0.2
Mil	4.5	6.4	87500	0.32	0.13	0.2
Mil	3.3	8	71000	0.2	0.3	0.6

- **Observation:** Torque increased; conductivity increased.
- **Impact:** Connectors only showed signs of discoloration and etching.
- **Root Cause:** Passivation prevented severe corrosion.
- **Results:** : This set of connectors made it among top performers after 504 hours.

Overall Quantitative Comparison: Top Performers

Salt Fog/SO₂ & Add'l – SS base, Ni

Total Test Time: 504 hrs.

After 336 Hour
Salt Fog & SO₂



After 504 Hour
Salt Fog & SO₂

Quantitative Results & Discussion: Add'l Salt Fog & SO₂ – SS base, Ni Total Test Time: 504 hrs.

At 336 hrs.

Moderate Degree of Corrosion



Seq 2: Salt Fog & SO ₂						
*Test Start Date: Oct 20, 2015 & Test End Date: Nov 5, 2015						
**Test Start Date: May 19, 2016 & Test End Date: June 2, 2016						
Mil/Com	Torque engaged (Nm)			Torque disengaged (Nm)		
	Initial	*After 336 hrs.	**After 504 hrs.	Initial	*After 336 hrs.	**After 504 hrs.
		(Max 4.6)	(Max 4.6)	(Min 0.6)	(Max 4.6)	(Max 4.6)
Mil	1.7	1.4	1.4	1	0.8	1.2
Mil	1.8	1.4	1.4	1.2	1.1	1.2
Mil	2.3	1.4	1.8	1.7	1.2	1.8
Mil	1.6	1.2	1.2	1	1.1	1.2

At 504 hrs.

Moderate Degree of Corrosion



Seq 2: Salt Fog & SO ₂						
*Test Start Date: Oct 20, 2015 & Test End Date: Nov 5, 2015						
**Test Start Date: May 19, 2016 & Test End Date: June 2, 2016						
Mil/Com	Shell Conductivity (mV) (Testing: 1.5V)			Resistance (Ω)		
	Initial	*After 336 hrs.	**After 504 hrs.	Initial	*After 336 hrs.	**After 504 hrs.
	(Max 1.0)	(Max 2.0)	(Max 2.0)			
Mil	0.58	0.88	0.94	0.12	0.28	0.2
Mil	0.58	0.58	0.55	0.11	0.36	0.2
Mil	0.69	0.64	0.66	0.11	0.4	0.2
Mil	0.63	0.48	0.64	0.1	0.37	0.3

- **Observation:** Torque engagement for one of four connectors increased, disengagement increased and conductivity for two of four connectors slightly increased.
- **Impact:** Connectors only show discoloration.
- **Root Cause:** Ni coating prevented severe corrosion.
- **Results:** : This set connectors made it among top performers after 504 hours.

Sand-Salt-Humidity/UV Test

Detail on the Non-Standard Sand-Salt-Humidity/UV Procedure

General Procedure

1. Mate/Unmate 50 x
2. Inspect, Record Torque, Conductivity, and Resistance
3. 28 hrs. mated in sand/salt chamber
4. Conductivity and Resistance recorded after sand/salt test
5. 500 hours mated in QUV
6. Mate/Unmate 450 times after
7. Inspect, Record Torque, Conductivity, and Resistance

■ Sand / Salt Details

- Method: MIL-STD-202, method 110
- Sand: Ground silica, technical grade, Min-U-Sil 5 (98.3% silica; median particle size = 1.7 microns)
- Salt (NaCl): Morton/5 microns
- Sand + NaCl: Mixture based on information on soil in MENA environment
 - Maximum of 1.082% chloride ion in soil; calculates to 2.97 g NaCl per 100 g sand

UV Testing details

Method: EIA-364-49 for UV
Lamp type: UVA-340 (365-295 nm)
Irradiance: 0.68 W/m² at 340 nm
Temperature: 50⁰ C
Humidity: 100%

Qualitative Observations: Sand-Salt-Humidity/UV

Mil/Com	Description				*Degree ⁺	Comments (Yes or NO)				**Stage ⁺	Conductivity		Torque	
	Plug		Receptacle			Discolor ⁺	Flaking ⁺	Pits ⁺	Etching ⁺		Pass	Fail	Pass	Fail
	Base	Coating	Base	Coating										
Com	Al	Ni-PTFE	Al	Ni-PTFE	light	NO	NO	NO	NO	1	4	0	4	0
Com	Al	Ni 2MILS	Al	Ni 2MILS	light	NO	NO	NO	NO	1	4	0	4	0
Mil	Al	Ni-PTFE	Al	Ni-PTFE	light	NO	NO	NO	NO	1	4	0	4	0
Mil	Al	Cd	Al	Cd	light	NO	NO	NO	NO	1	4	0	4	0
Mil	Composite	eNi	Composite	eNi	light	Yes	NO	NO	NO	1	4	0	4	0
Mil	SS	Ni	SS	Ni	light	Yes	NO	NO	NO	1	4	0	4	0
Mil	SS	Passivated	SS	Passivated	light	Yes	NO	NO	NO	1	4	0	4	0
Com	Al	Cd	Al	Cd	light	Yes	NO	NO	NO	1	4	0	4	0
Mil	Al	Ni	Al	Ni	light	NO	Yes	NO	Yes	1	4	0	4	0
Mil	Al	ZnNi	Al	ZnNi	light	Yes	NO	NO	NO	2	1	3	4	0

*IAW: NAVAIR 01-1A-509-1 TM 1-1500-344-23-1 TO 1-1-689-1 CLEANING AND CORROSION CONTROL

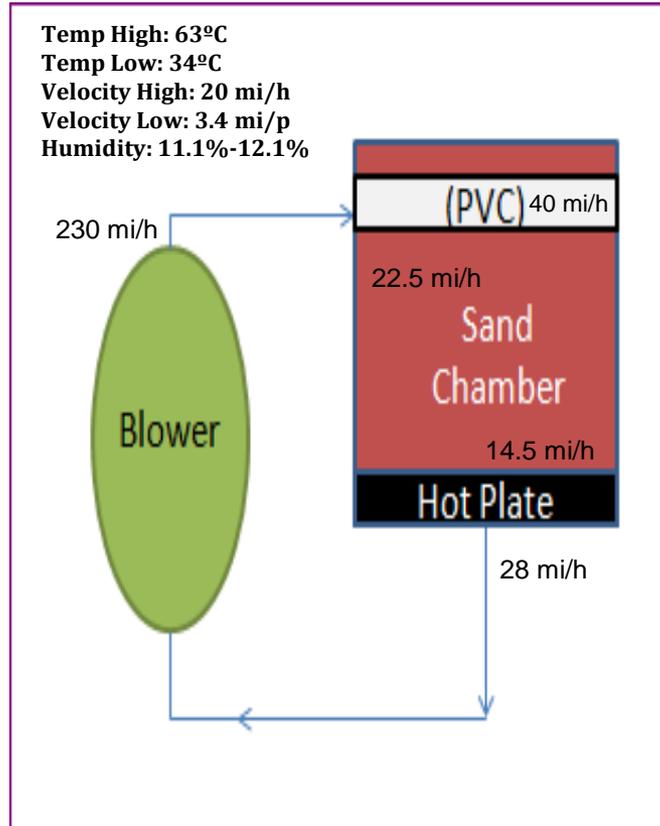
**IAW: TB 43-0213, TECHNICAL BULLETIN CORROSION PREVENTION AND CONTROL (CPC) FOR TACTICAL VEHICLES

*Overall qualitative assessment based on 2-4 quantity connector sets

Worse performer post-Sand-Salt-Humidity/UV & Testing: Al/ZnNi

Sand-Salt-Humidity Test Equipment

Chamber A set-up



Tuskegee Sand Chamber designed to mimic the MENA environment

Connectors Post-Sand-Salt-Humidity Testing

- Connectors in Chamber A after sand-salt-humidity test and before brushing (cleaning), conductivity measurements, and UV testing



Connectors appear to have endured a sand storm similar to that observed in the MENA region

Quantitative Comparison

Sand-Salt-Humidity/UV – Al base, ZnNi

Total Test Time: 528 hrs.

Initial



After 528 Hour
Sand-Salt-Humidity/UV

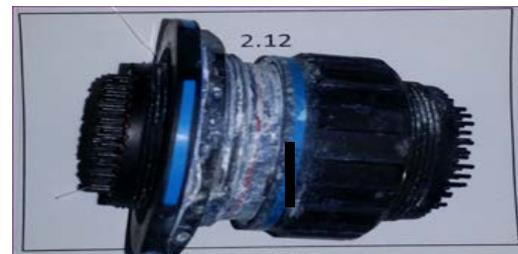
Quantitative Results & Discussion:

Sand-Salt-Humidity/UV – Al base, ZnNi

Total Test Time: 28 hrs. Sand-Salt-Humidity & 500 hrs. UV



Initial



After 528 hrs.

Seq 3: Sand & UV Test														
Sand Test Duration: 28 hrs. & UV Test Duration: 500 hrs.														
Test Start Date: Dec 15 2015 Test End Date: Jan 6, 2016														
Label Mil/Com	Torque engaged (Nm)		Torque disengaged (Nm)		Shell Conductivity (mV) (Testing: 1.5V)			Resistance (Ω)			Durability		Stage of Corrosio n (1-4)	Degree of Corrosio n
	Initial	After (Max 4.6)	Initial (Min 0.6)	After (Max 4.6)	Initial (Min 2.5)	After Sand (Max 5.0)	After UV (Max 5.0)	Initial	After Sand	After UV	Initial	After		
Mil	1.8	1.4	1.2	1.2	1.4	3.7	13.8	0.23	0.17	0.5	yes	NO	1	Light
Mil	1.3	1.6	0.9	1.6	2.9	5.8	27.7	0.18	0.13	0.1	yes	NO	1	Light
Mil	1.8	2.1	1.6	1.5	0.58	1.3	3.5	0.32	0.19	1.1	yes	yes	1	Light
Mil	1.3	2.9	1	1.9	2	5.4	12.2	0.17	0.15	0.1	yes	NO	1	Light

- **Observation:** Torque engagement increased for three of four connectors; disengagement increased for two of four connectors; initial conductivity for one of four connectors failed; after sand and UV conductivity increased for all connectors.
- **Impact:** Connectors showed discoloration.
- **Root Cause:** ZnNi coating is corroding due to sand and salt.
- **Results:** One of four connectors will be tested further.

SEM Analysis Data

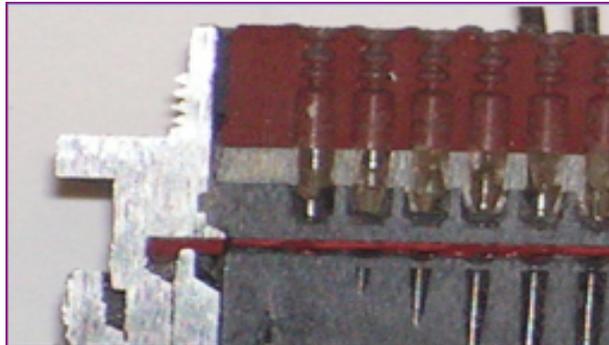
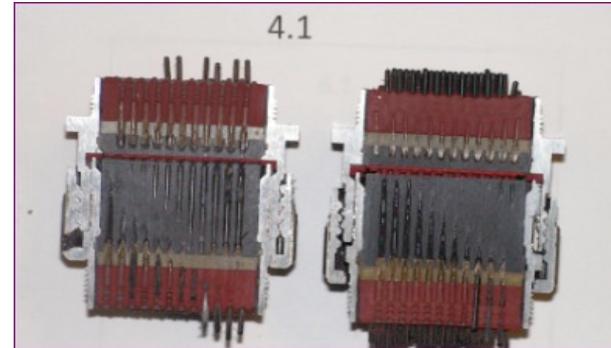
SEM Analysis Data

Slide #	62-66	67-72	73-76	77-79	80-82
Mil/Com	Mil	Com	Mil	Mil	Mil
Condition	Salt Fog	Salt Fog	Sand, Salt/UV	Salt Fog	Salt Fog
Description	Al base, Ni-PTFE	Al base, Ni-PTFE	Al base, ZnNi	Al base, ZnNi	Al base, Ni

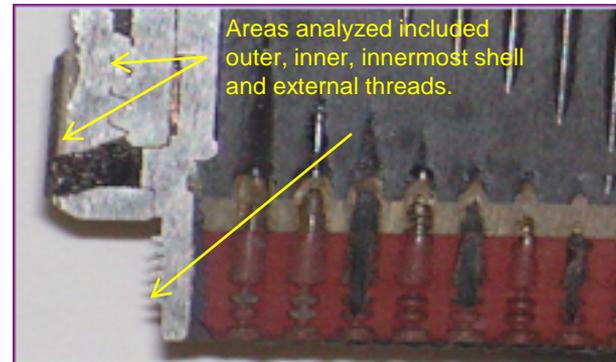
Connector Post 750 Hrs Salt Fog Mil grade-Al base, Ni-PTFE



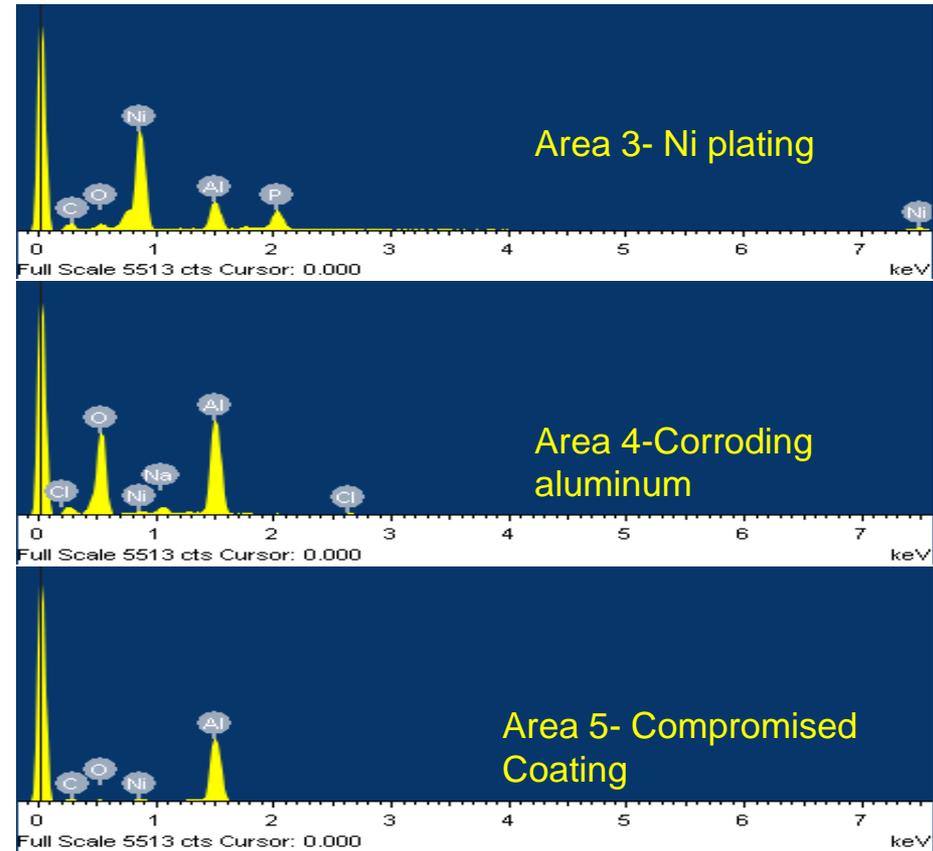
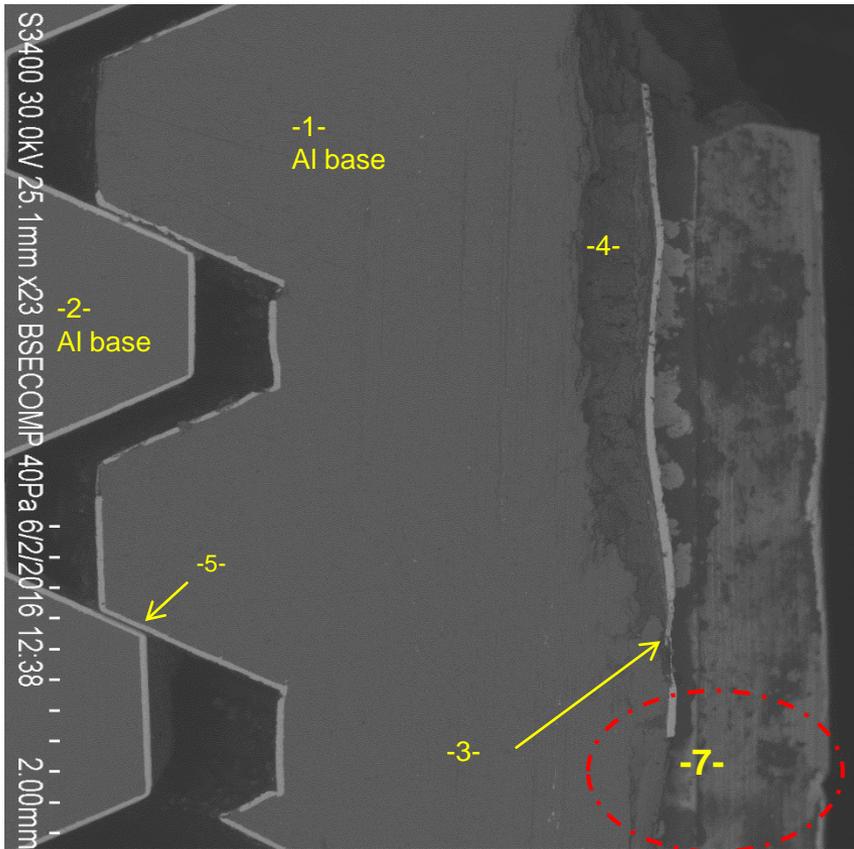
Ni-PTFE
plated
sample



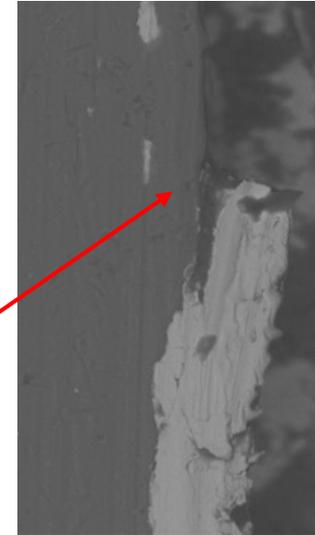
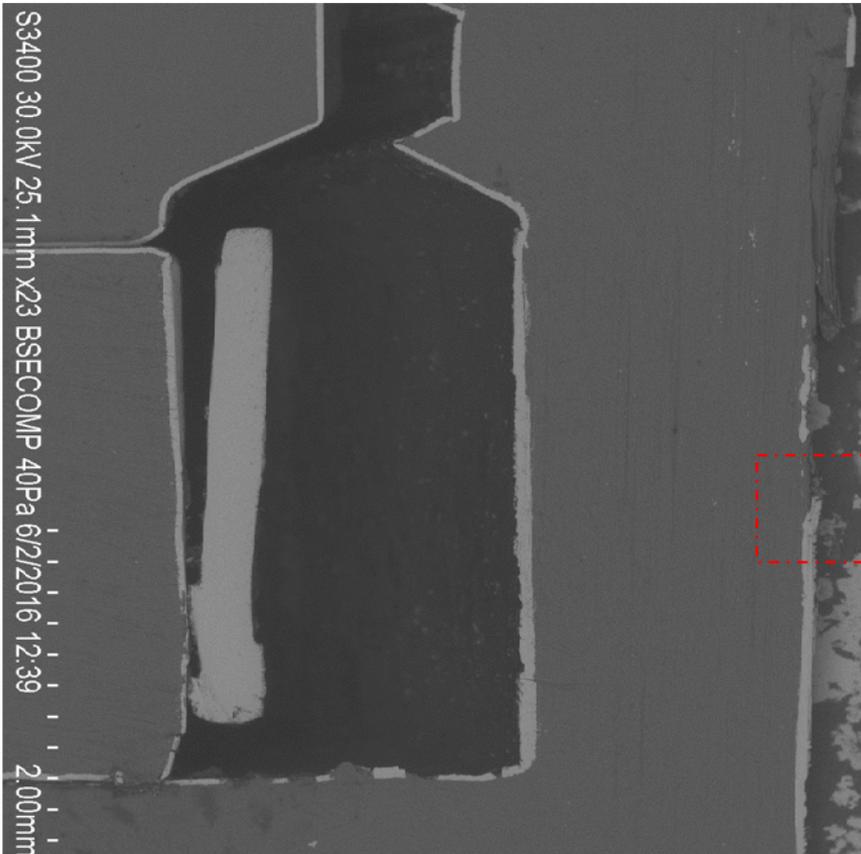
Ni-PTFE
plated
sample



Mil grade-Al base, Ni-PTFE

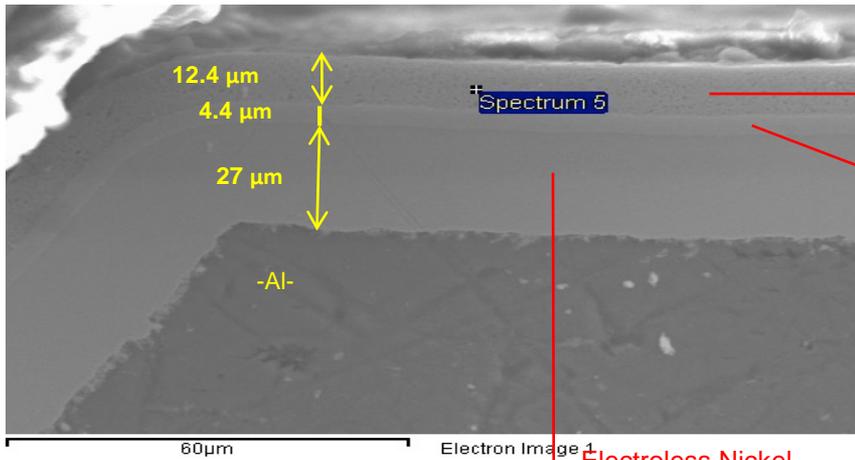


Area 7 - Mil grade- Al base, Ni-PTFE

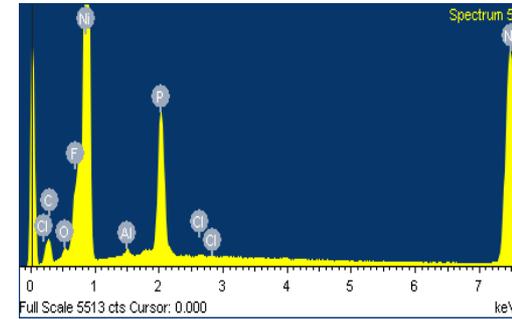


- Evidence of compromised Ni PTFE coating.

Area 5 - Mil grade- Al base, Ni-PTFE

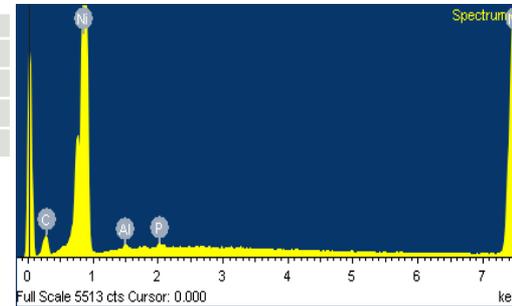


Element	Weight%
C	13.43
O	1.06
F	8.95
Al	0.53
P	10.98
Cl	0.19
Ni	64.86



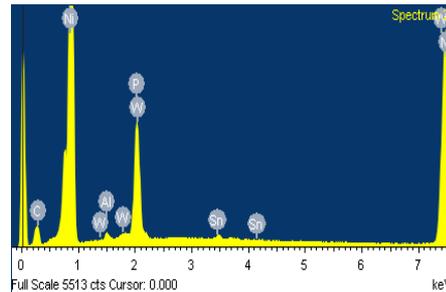
Electrolytic Nickel

Element	Weight%
C	11.59
Al	0.55
P	0.41
Ni	87.45

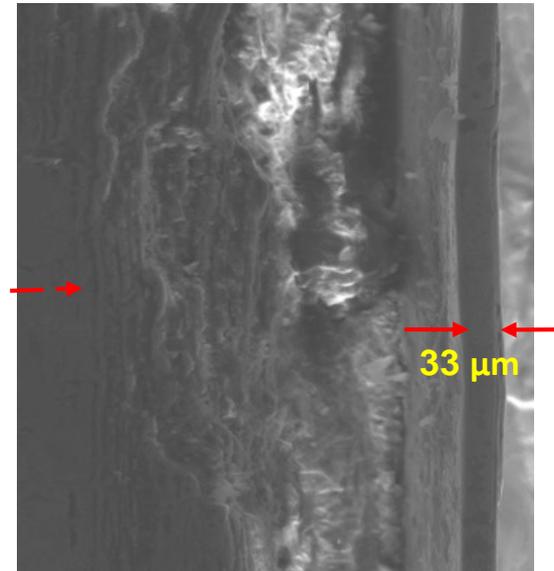
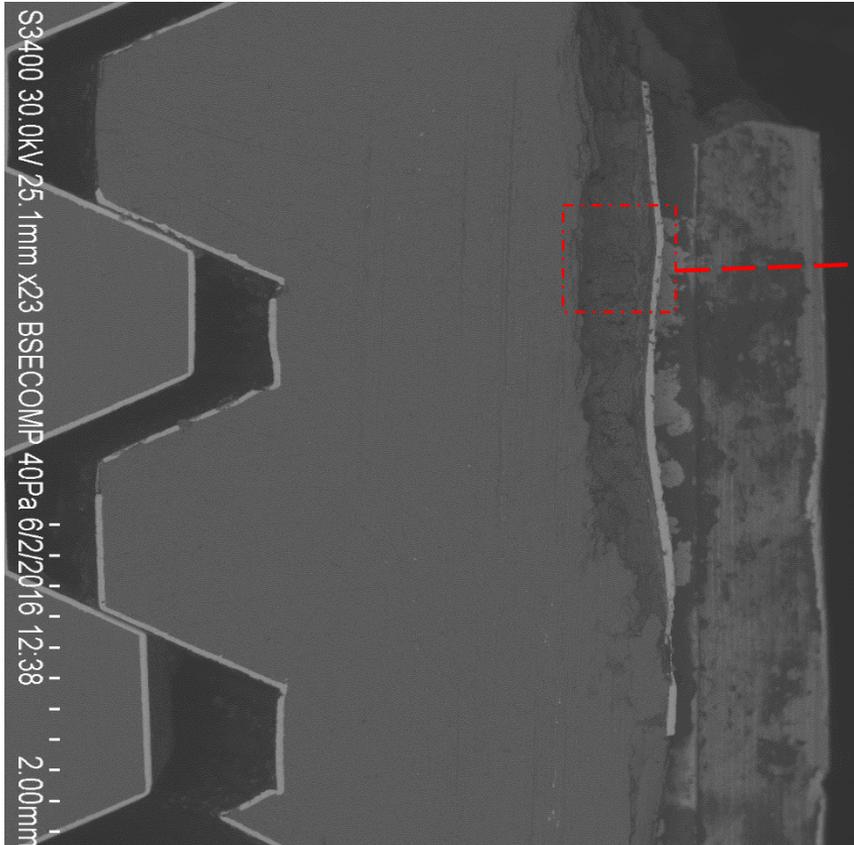


Electroless Nickel

Element	Weight%
C	13.23
Al	0.66
P	10.35
Ni	73.67
Sn	0.98
W	1.12



Area 4 - Mil grade-Al base, Ni-PTFE

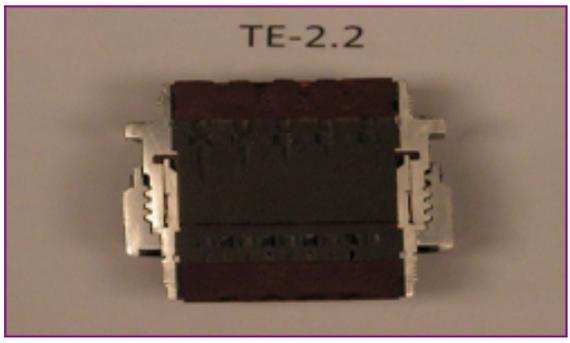


- Evidence of corrosion exits under the coating that remains.

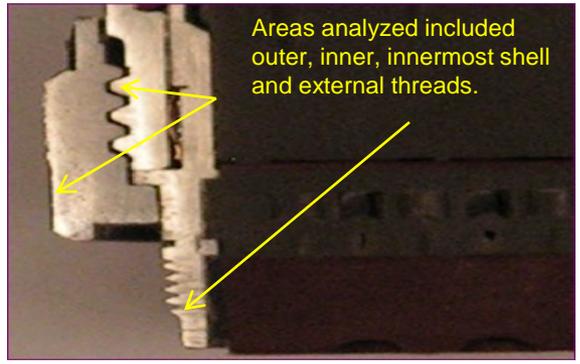
Connector Post 500 Hours Salt Fog Com grade- Al base, Ni-PTFE



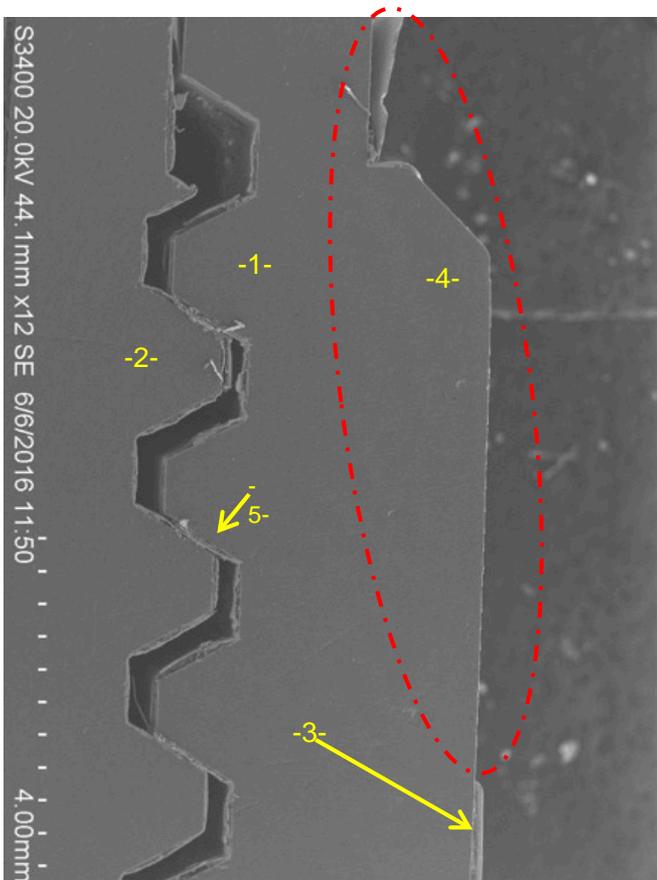
Ni-PTFE
plated
sample



Ni-PTFE
plated
sample



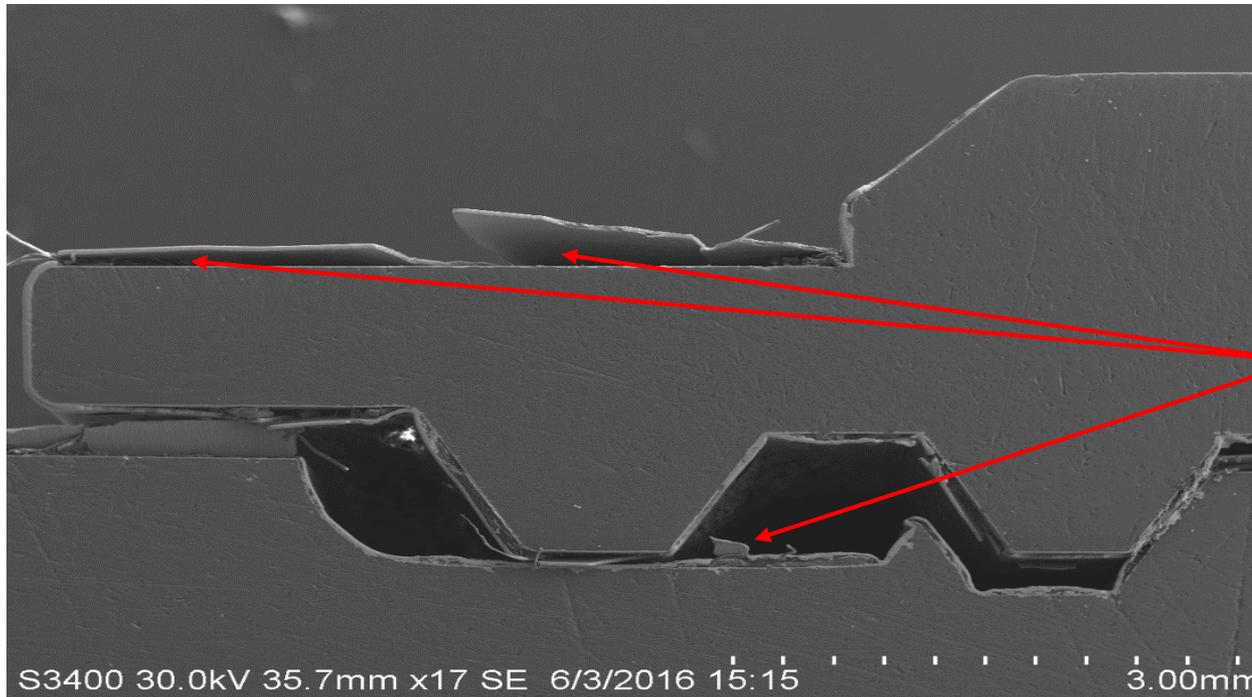
Com grade-Al base, Ni-PTFE



- Coating being disbonded in Area 3.
- Completely compromised coating in Area 4.
- Mating teeth with compromised coating on each side in Area 5

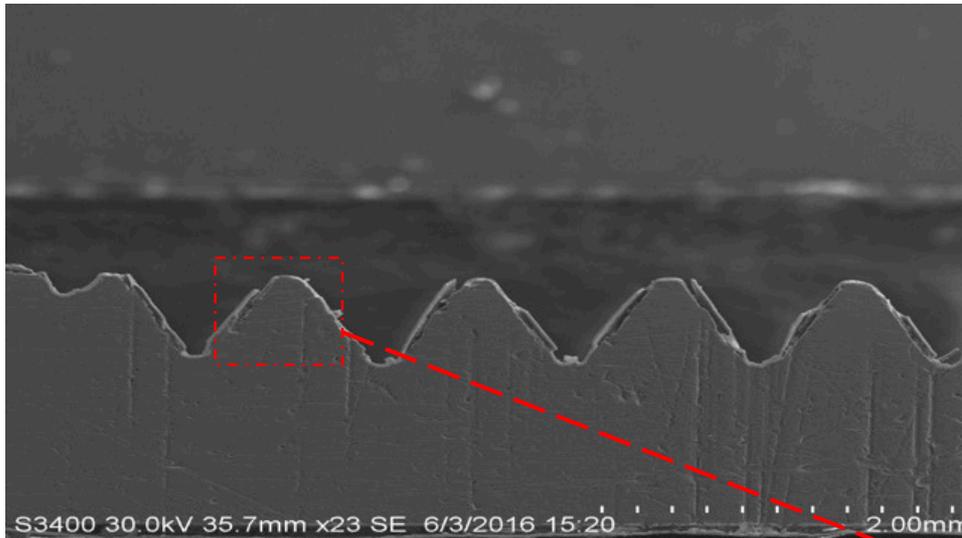
Continuation of Area 4 in the previous slide

Com grade-Al base, Ni-PTFE

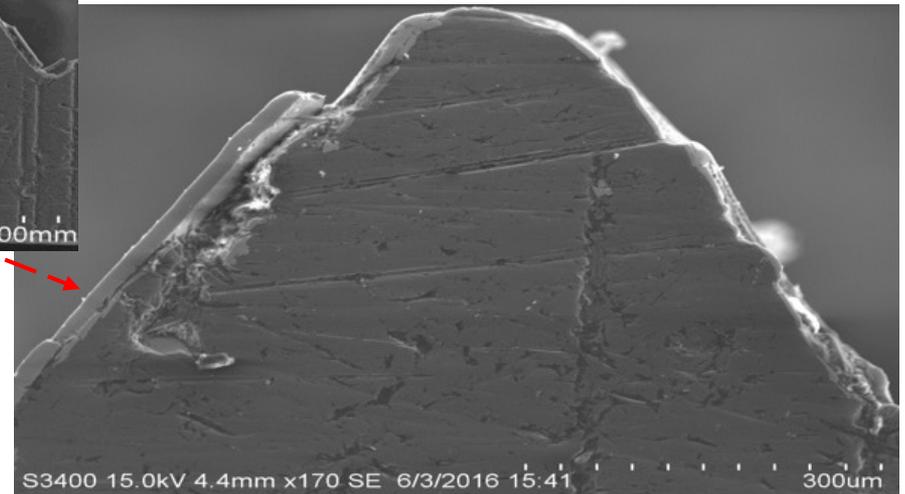


Complete interfacial separation of the coating on the outer shell as well as the teeth

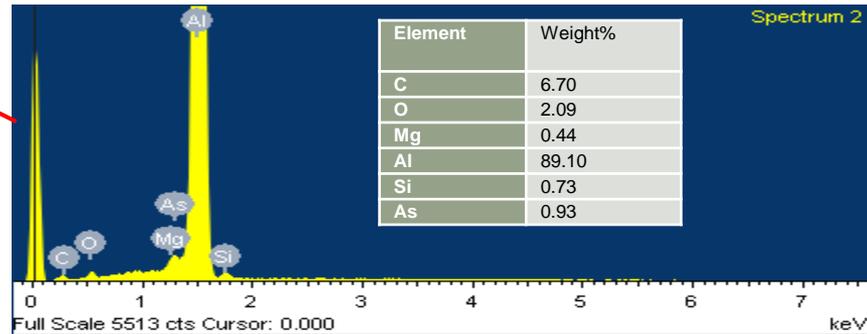
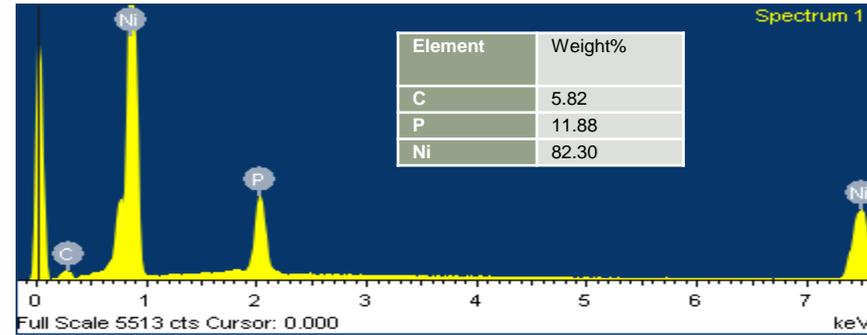
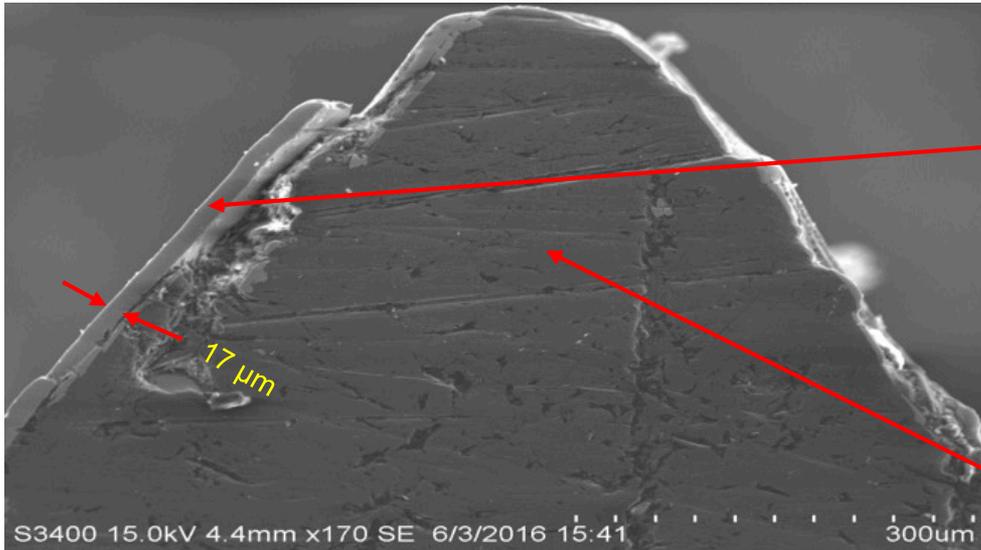
Area 6 -Com grade- Al base, Ni-PTFE



- Disbonded Ni PTFE coating on part of the outer tooth and significant erosion of coating on the rest of the tooth



Area 6 -Com grade- Al base, Ni-PTFE



Plating Thickness Comparison for Ni-PTFE Coated Connectors

Area	Layer	Military	Commercial
Outer Thread	PTFE	6.6 μm	-
	Electrolytic Nickel	2 μm	-
	Electroless Nickel	27 μm	17 μm
Inner Thread	PTFE	12.4 μm	-
	Electrolytic Nickel	4.4 μm	-
	Electroless Nickel	27 μm	19 μm
External Thread	PTFE + Electrolytic Nickel	7.9 μm	-
			-
	Electroless Nickel	25.3 μm	19 μm

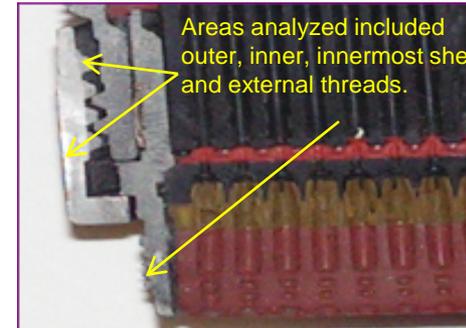
Connector Post 528 Hours Sand-Salt-Humidity/UV Mil grade-Al base, ZnNi



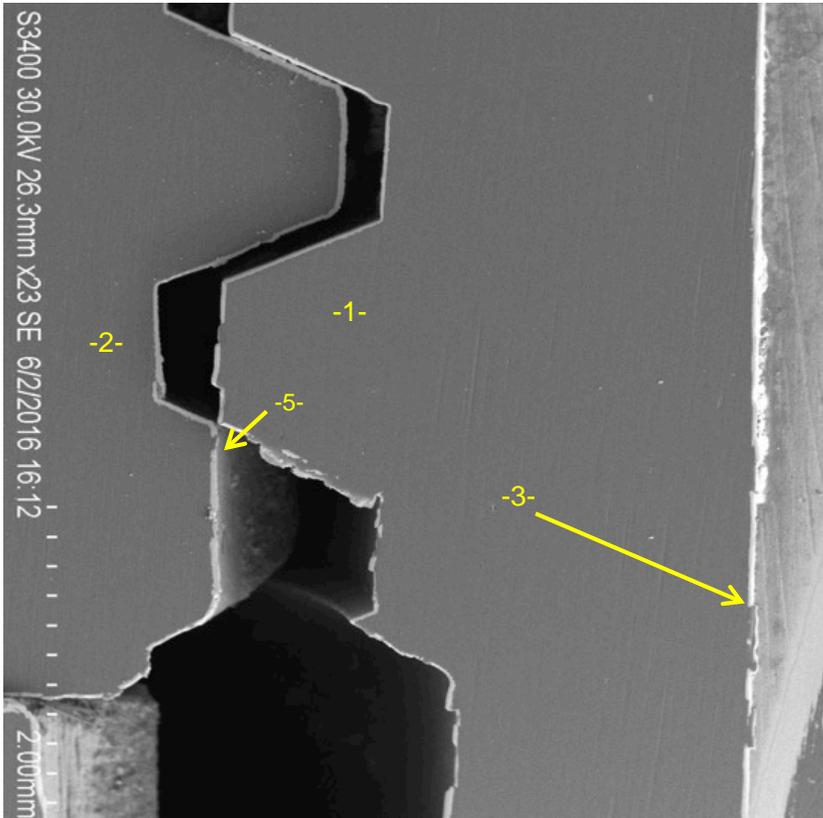
ZnNi
plated
sample



ZnNi
plated
sample

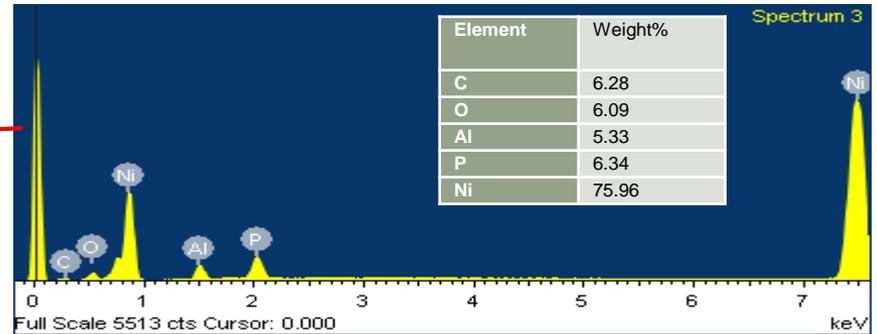
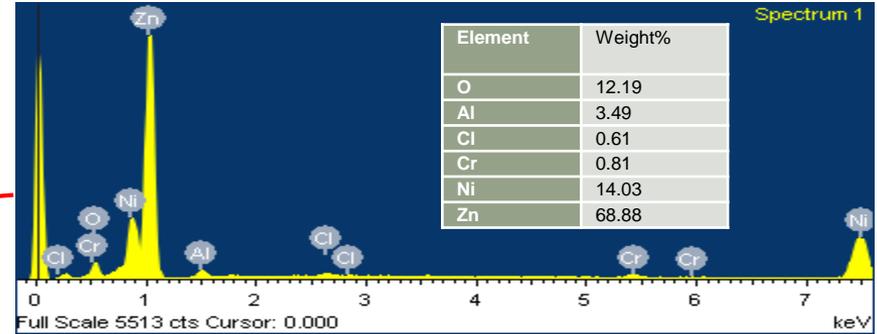
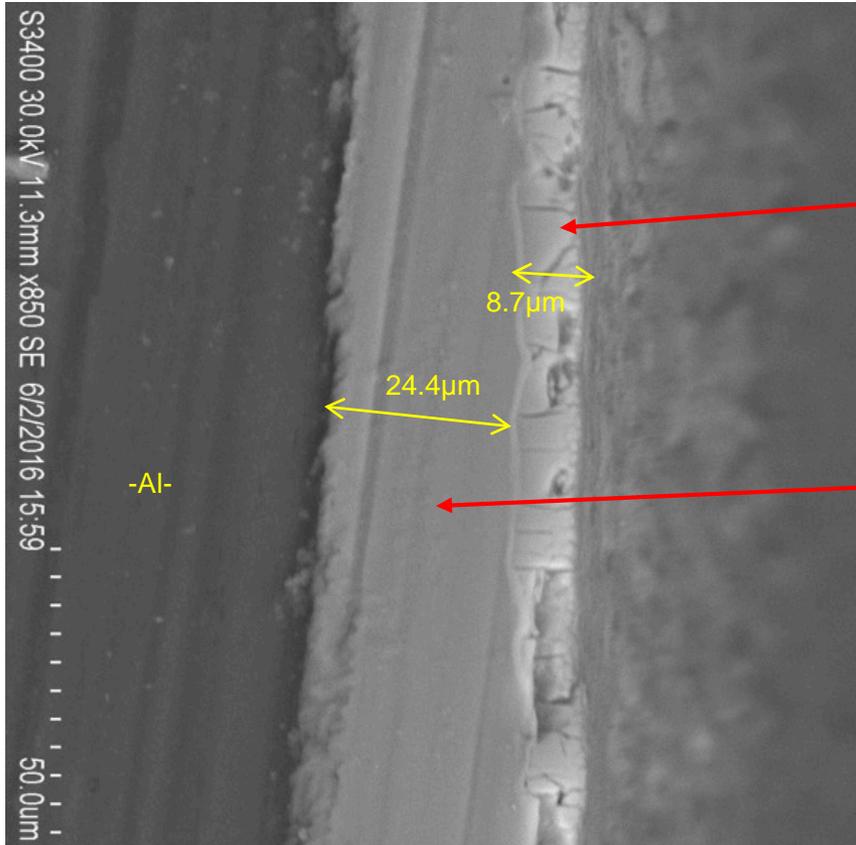


Mil grade- Al base, ZnNi

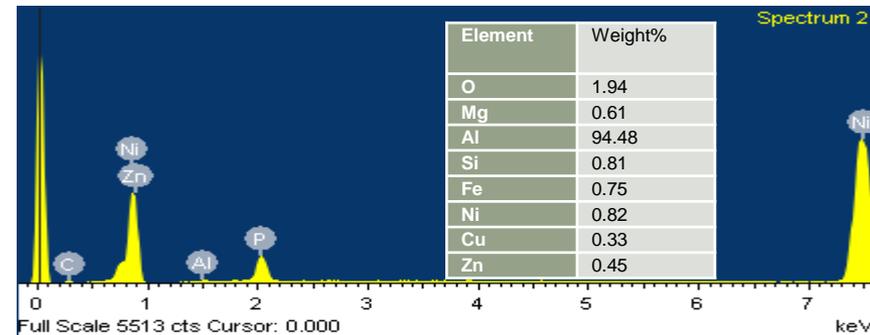
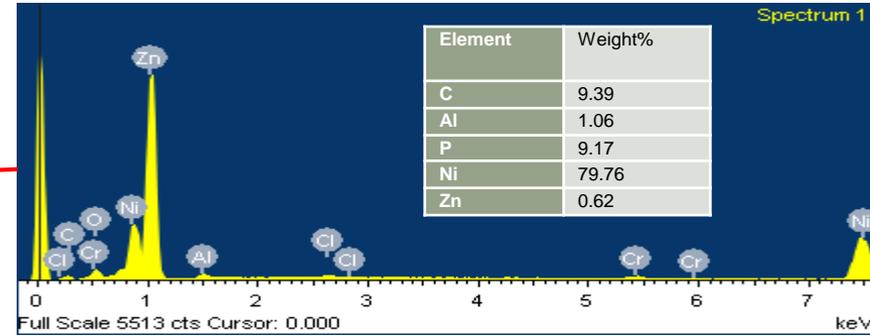
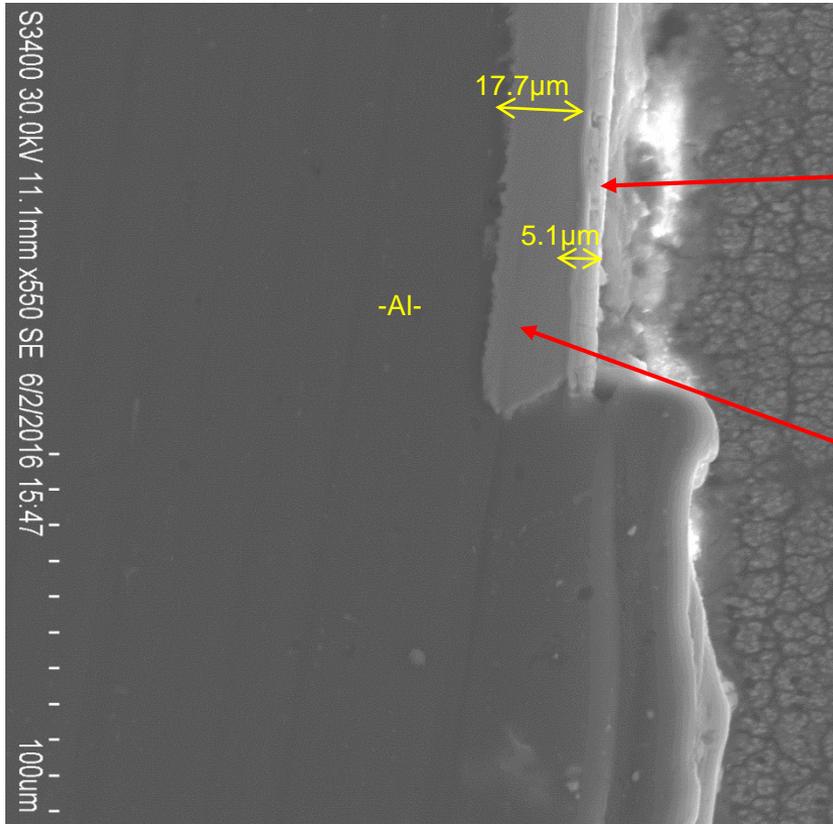


- Coating is compromised in Area 3
- Area 5 shows ZnNi coating cracking in the Zn layer.
- Zn layer of coating was compromised for most sections of the coating outer thread.

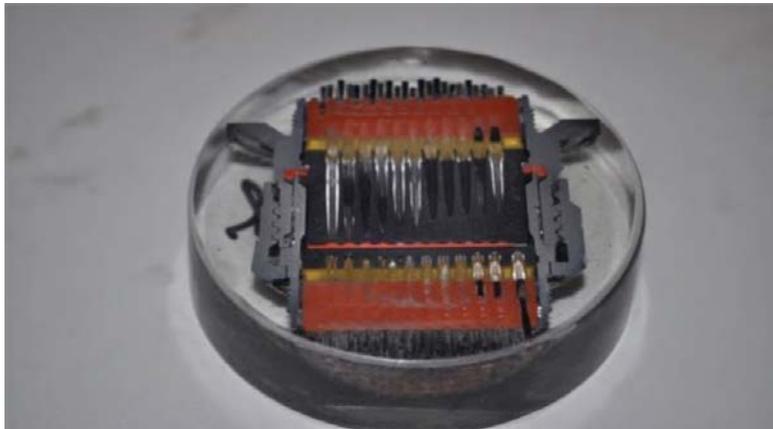
Area 5 - Mil grade- Al base, ZnNi



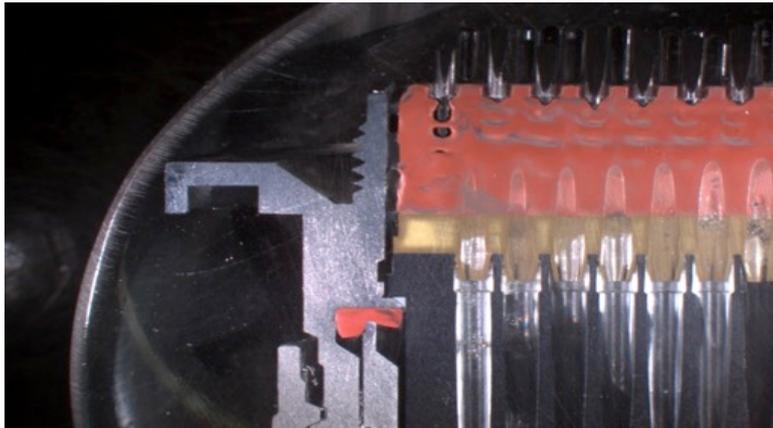
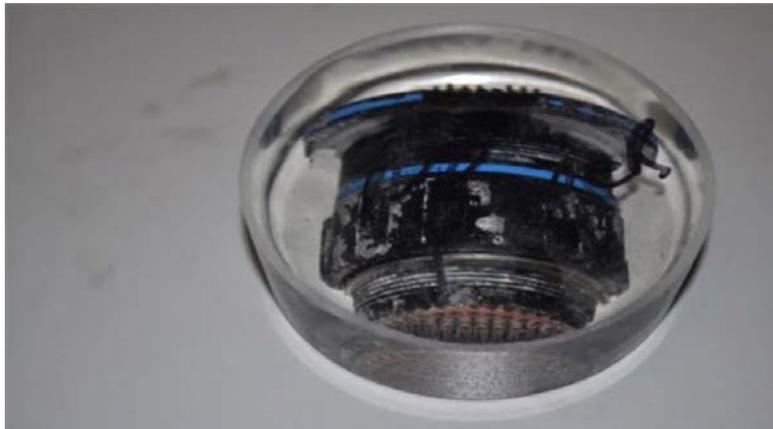
Area 3 - Mil grade- Al base, ZnNi



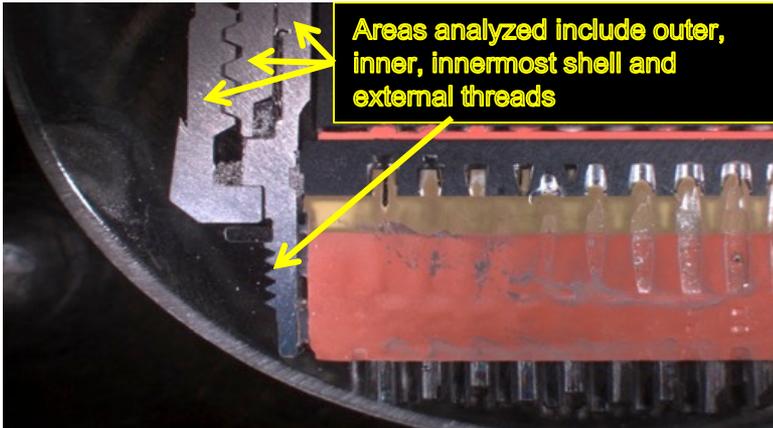
Connector Post 548 Hours Salt Fog Mil grade-Al base, ZnNi



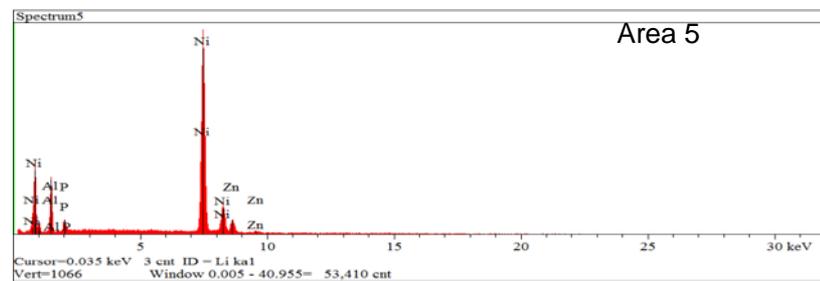
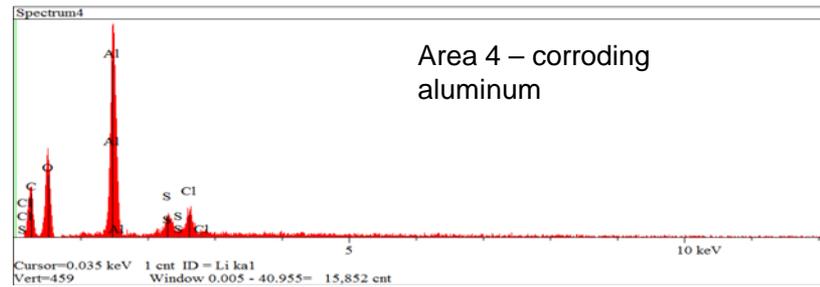
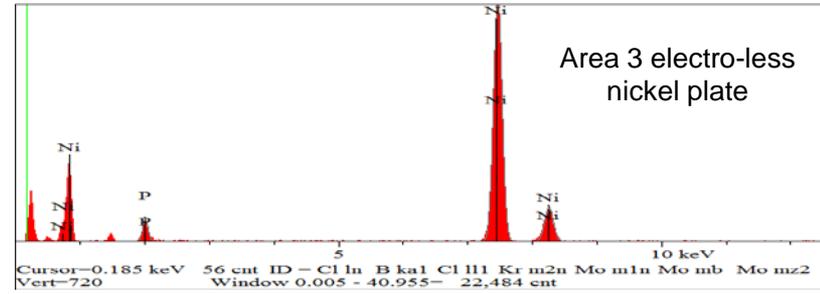
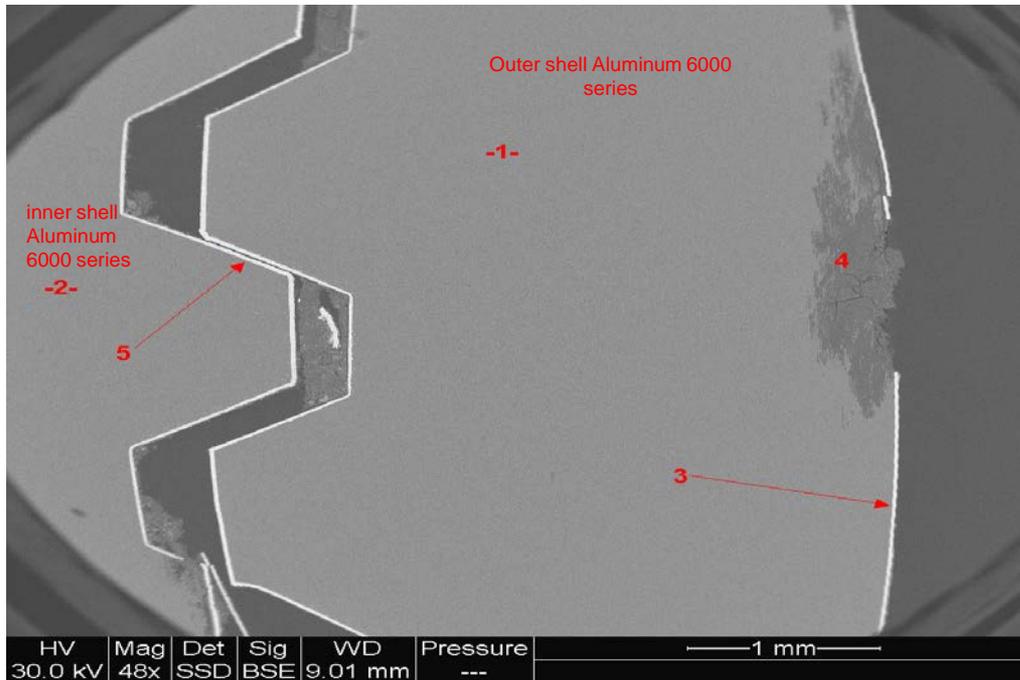
Zinc/Nickel plated sample



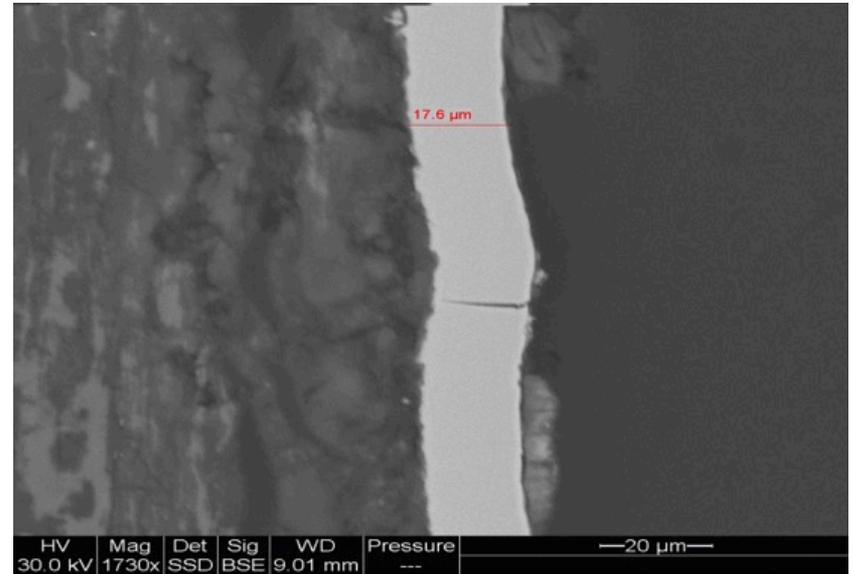
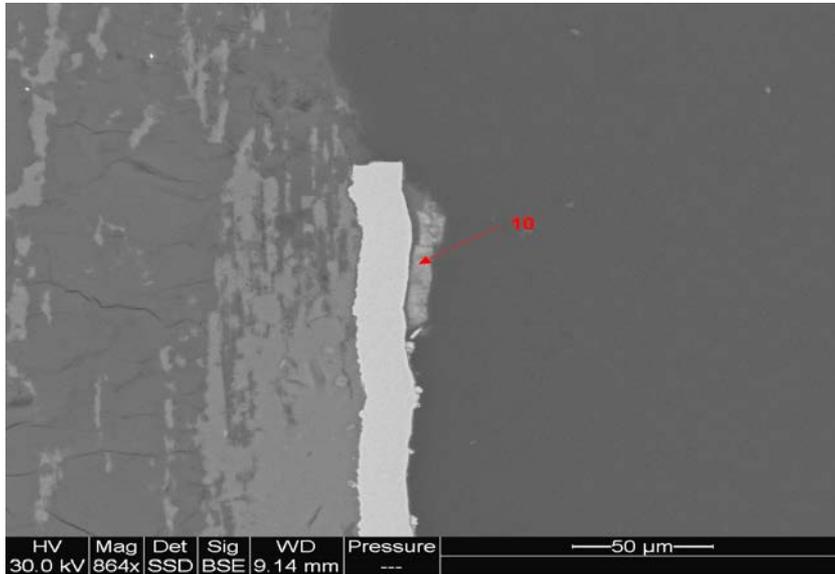
Zinc/Nickel plated sample



Mil grade- Al base, ZnNi Plated



Area 4 - Mil grade-Al base, ZnNi Plated

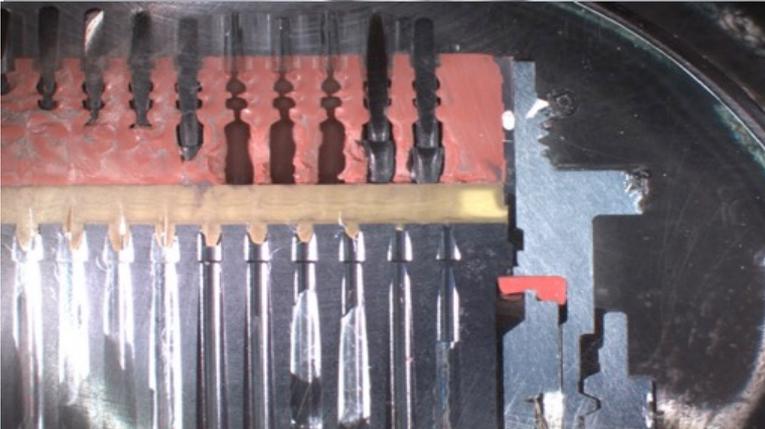


Exposed/external outer shell area shows electro-less nickel plate compromised, corroded aluminum, and the zinc plate consumed in this area.

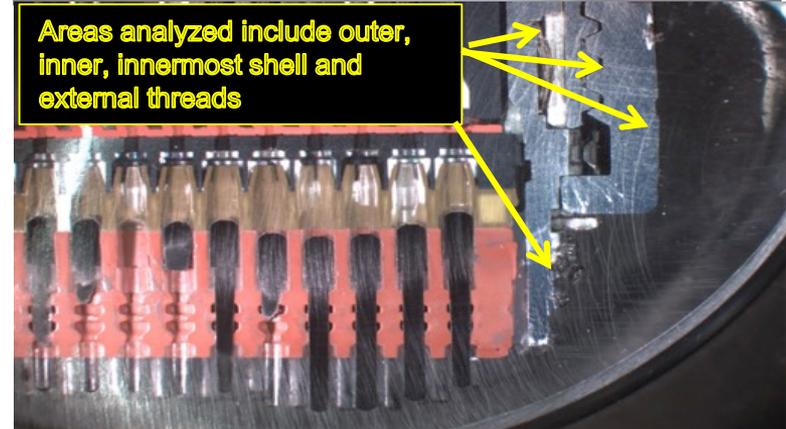
Connector Post 548 Hours Salt Fog Mil grade-Al base, Ni



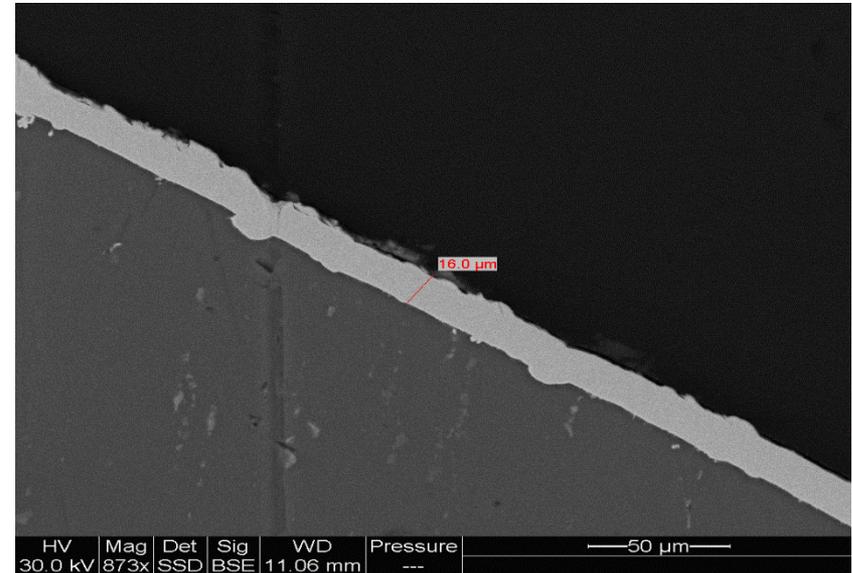
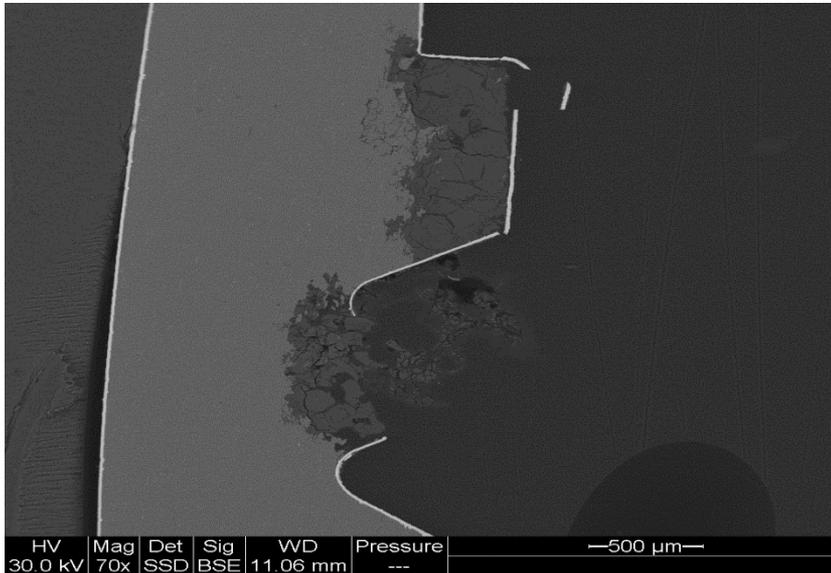
Nickel plated sample



Nickel plated sample



External thread Area - Mil grade-Al base, Ni Plated



Exposed external threads of innermost shell show compromised nickel plate (0.000640") and corrosion of the aluminum base material. Note the Commercial Nickel plated aluminum connectors we tested had over 2 mils (0.002") nickel which proved more corrosion resistant.

Questions?