Chromate-free inhibitor and non-chrome fuel tank coatings

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Challenge of Corrosion to DoD

Corrosion of metals is costly:

>$276 billion dollars annually in the U.S.

>$20 billion per year cost to DoD

Aircraft use high strength, light-weight aluminum (AA-2024, AA7075) made by alloying with copper

Unfortunately, Cu alloy additives make this metal especially vulnerable to corrosion

Current Chromate Technology

Hexavalent chromate corrosion inhibitors have a long history of proven performance as corrosion inhibitors

Used throughout the aircraft:

- Exterior and interior epoxy coatings
- Fuel tank coatings

Chromates are known carcinogens and are heavily regulated

New OSHA regulations reduce exposure levels to 5 mg/m^3 (ppm) with 25 mg/m^3 (ppm) exception for aerospace industry

Aircraft Fuel Tank Coatings

- **Polyurethane coating protects AA 7075 fuel tanks**
- **Long-term corrosion protection critical for structural integral fuel tank**
- **Current paint (AMS-C-27725) contains chromates**
- **JSF program goal is to use chromate-free corrosion-inhibiting fuel tank coating, but none are available**

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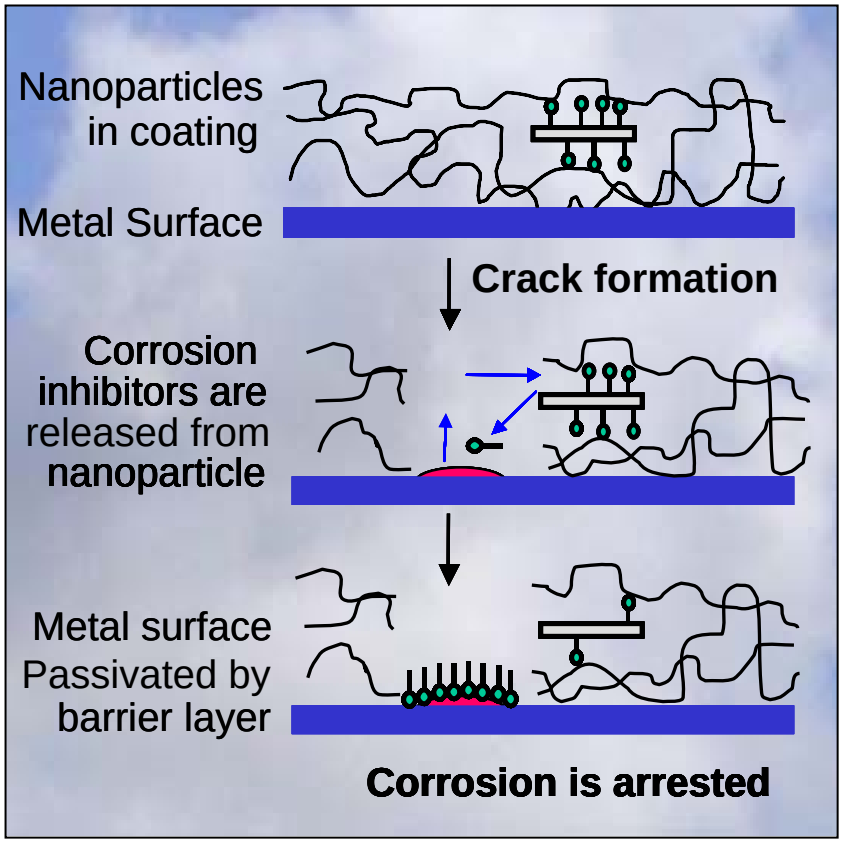
Nanoparticle-based Solution

Nanoparticle inert used as carrier for organic inhibitor in the coating

Inhibitor release is triggered by corrosion process

TDA offers a "SMART" inhibition process with a release on demand mechanism



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Nanoparticle Scale up at TDA

- Nanoparticle synthesis transitioned from glass to stainless steel reactor
- Demonstrated process small (3L) scale first
- Produced in a 20 L SS reactor at TDA
- Nanoparticles production scaled up 8 lb per batch

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Non-chrome Fuel Tank Coating Formulation Approach

Patented nanoparticle corrosion inhibitors were integrated into an already qualified fuel tank coating resin system (<420 g/l VOC)

TDA Research Corrosion Inhibitors →

ANAC Advanced Coatings →

TDA partnered with AkzoNobel Aerospace Coatings in development and evaluation – current DoD supplier

Performance Specifications

Features	Advantages	Benefits
Triggered release	Smart delivery of corrosion inhibitors when needed	Long lasting, targeted corrosion protection for life of aircraft
Nanoparticle carrier	High surface area	Allows very high loading of corrosion inhibitor
Patented nanoparticle surface functionalization	Dispersible into already qualified resin system	Reduced development time by at least a year

Non-chrome Fuel Tank Coating Quality and Use

Nanoparticle corrosion inhibitors do not adversely affect coating properties

Coating looks and handles like current AMS-C-27725 fuel tank coating

Designed to have the same application protocols

- Pot-life
- Viscosity
- Spray-ability
- Dry time
- Cure time

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Coating Performance Testing

Full range of coating properties evaluated

- Pot Life
- Hot box stability
- Wet and dry adhesion
- Salt water and fuel resistance
- 30-day commercial hydraulic fluid
- Impact
- Sealant peel test

Salt Fog Testing at TDA, ANAC, Lockheed Martin, and Northrop Grumman

Testing at TDA & ANAC

Substrate

- Aluminum 7075 T6
- Aluminum 2024 T3
- 3 coupons per test group

Surface Preparation

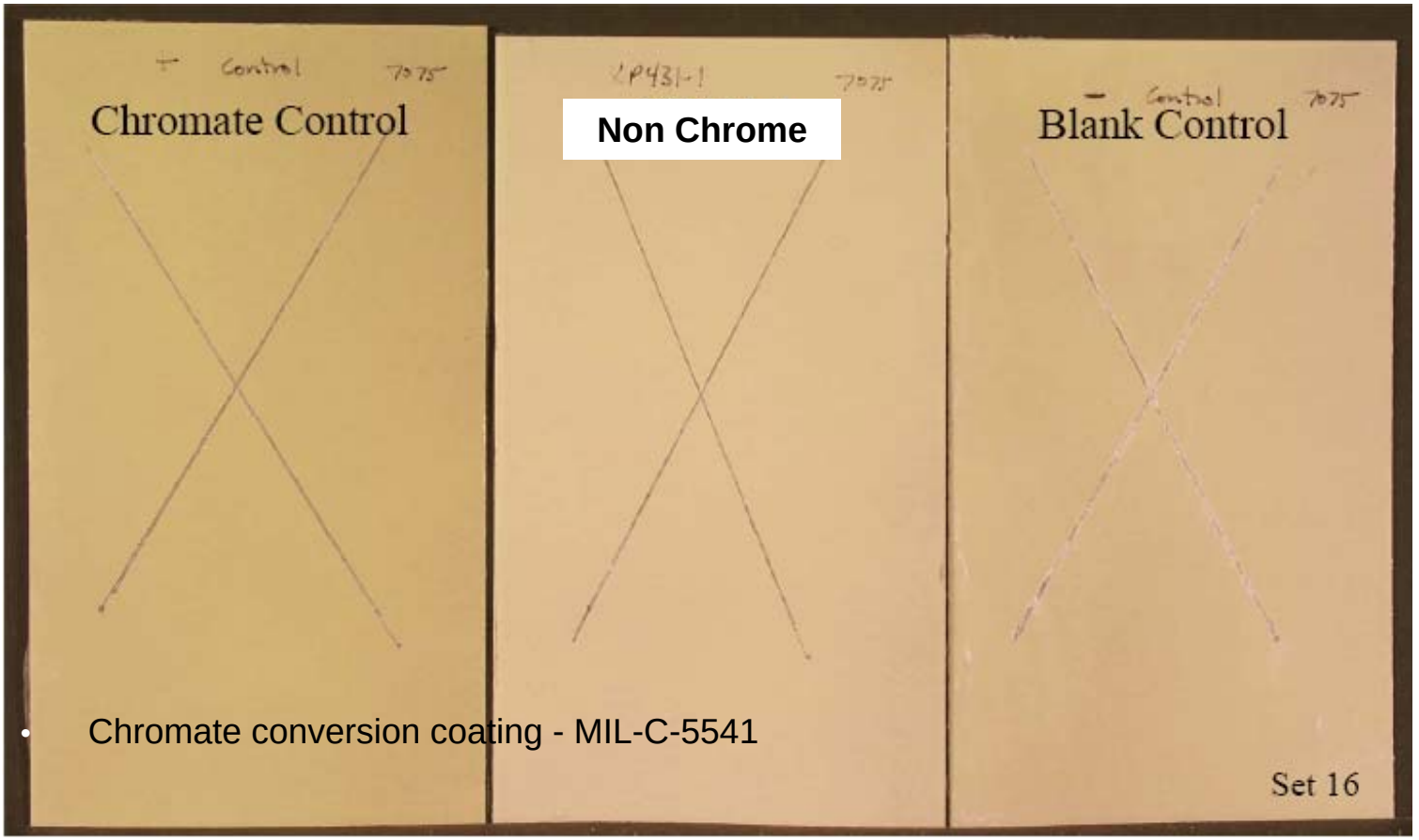
- Chemical treatment in accordance with MIL-C-5541. Sulfuric acid anodized in accordance with AMS 2471.

Coatings

- TDA/AkzoNobel non-chrome fuel tank coating
- Commercial ANAC AMS-C-27725 fuel tank coating (Positive control)
- Modified coating with no inhibitor (Negative Control)

Neutral Salt Fog – ASTM B-117

Evaluation at TDA
4000 hr salt fog Al7075 -CCC



- Chromate conversion coating - MIL-C-5541

No pitting or blistering after 4000 hrs

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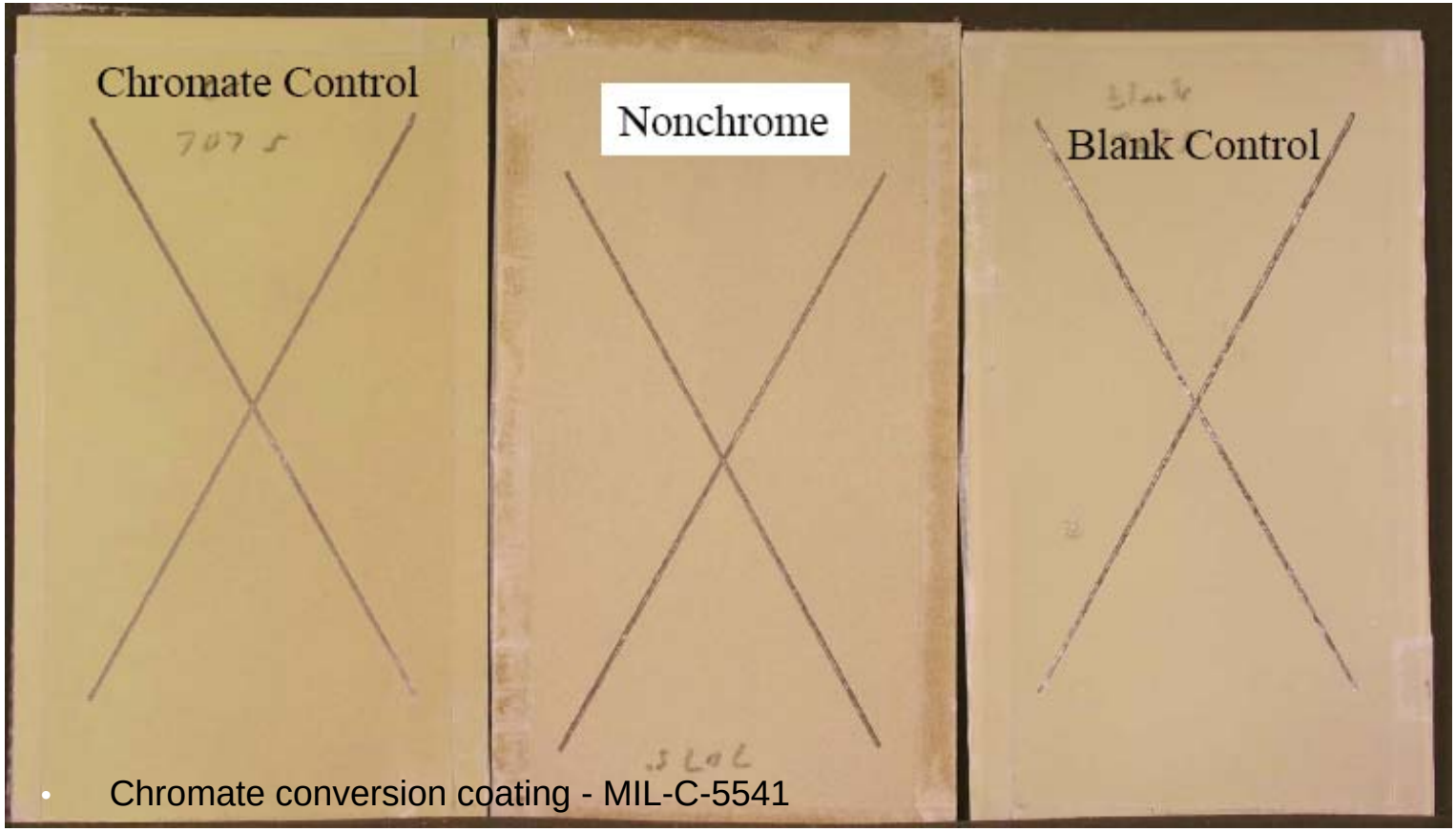
Evaluation at TDA & ANAC
4500 hr at ANAC + 1000 hrs at TDA (5500 hr)



Still excellent corrosion performance

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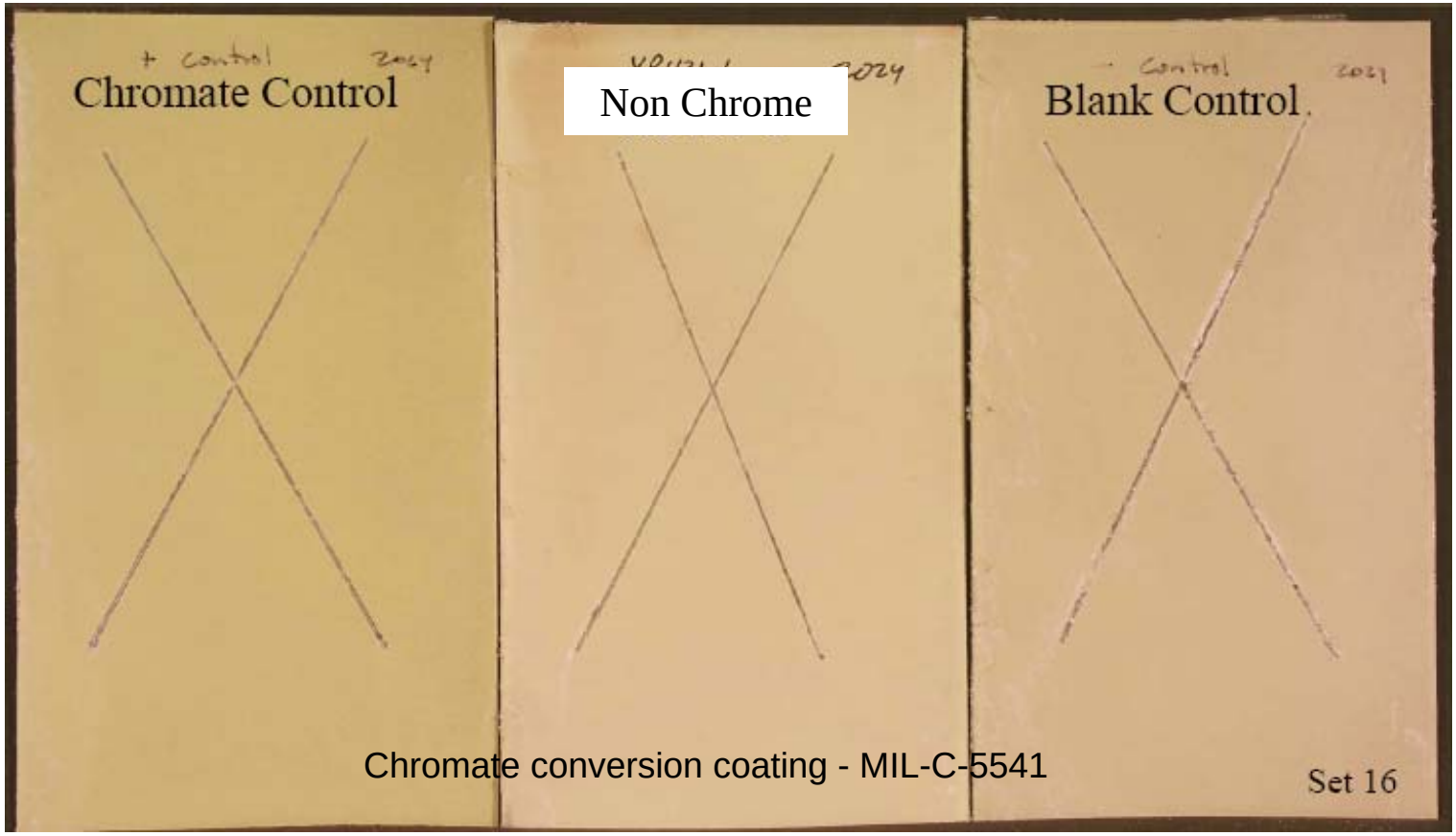
Al2024 Salt Fog
4000 hr ASTM B-117 -CCC



Corrosion inhibition demonstrated on 2024 as well

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Evaluation at Lockheed Martin

- Testing begin in early 2007
- Completed all test in AMS-C-27725 specification
- Neutral salt fog ASTM B-117
  - 4000 hours (7075, 2024)
- Acidic salt fog ASTM G85 A4
  - 1000 hours (7075, 2024)
- Ongoing/planned tests
  - Long-term fuel exposure (puffer box)
  - Beach exposure
  - Corrosion resistance on chromic acid anodized
  - Galvanic corrosion

Test Panel Preparation for salt fog tests

Fuel Tank Coatings

- TDA/AkzoNobel non-chrome fuel tank coating
- PRC Desoto 823-011/910-0099/020-037 Integral Fuel Tank Coating (Control)

Substrates

- 7075 aluminum alloy
- 2024 Aluminum alloy

Surface Preparation

- Chem-film surface preparation in accordance with MIL-DTL-5541 Class 1A.
- Thin Film Sulfuric Acid Anodize per LMA-PH090.

Results on Al7075
4700 hrs ASTM B-117 chem-film

Figure 1 - 4700 Hour Neutral Salt Fog Exposure (Chem-Film TDA/Akzo Sample)

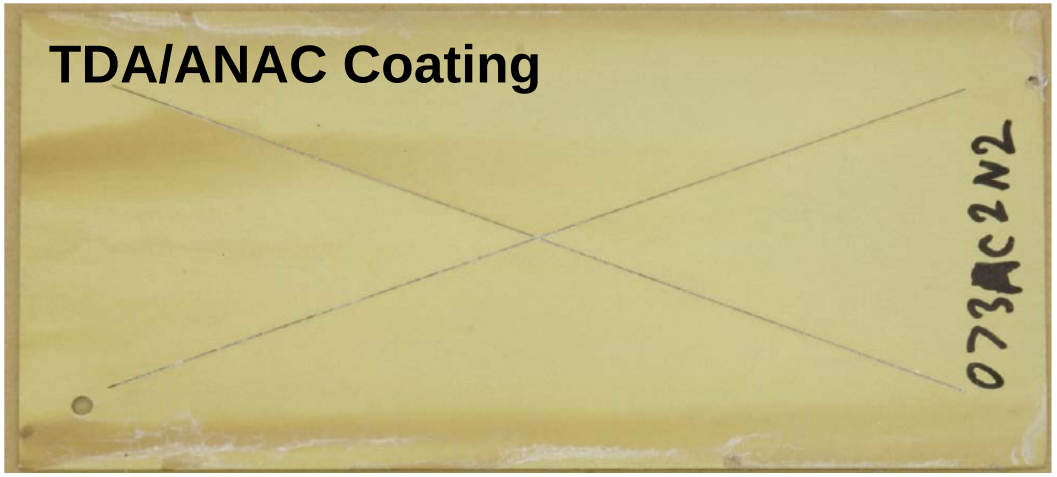
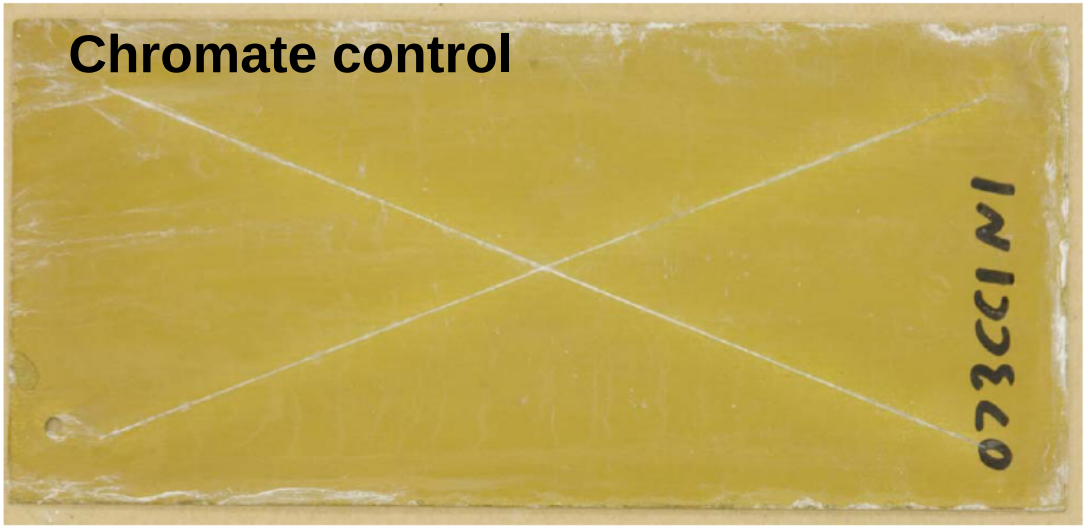


Figure 2 – 4700 Hour Neutral Salt Fog Exposure (Chem-Film Control)



- No indication of corrosion or pitting
- Slight salt build up only on both samples

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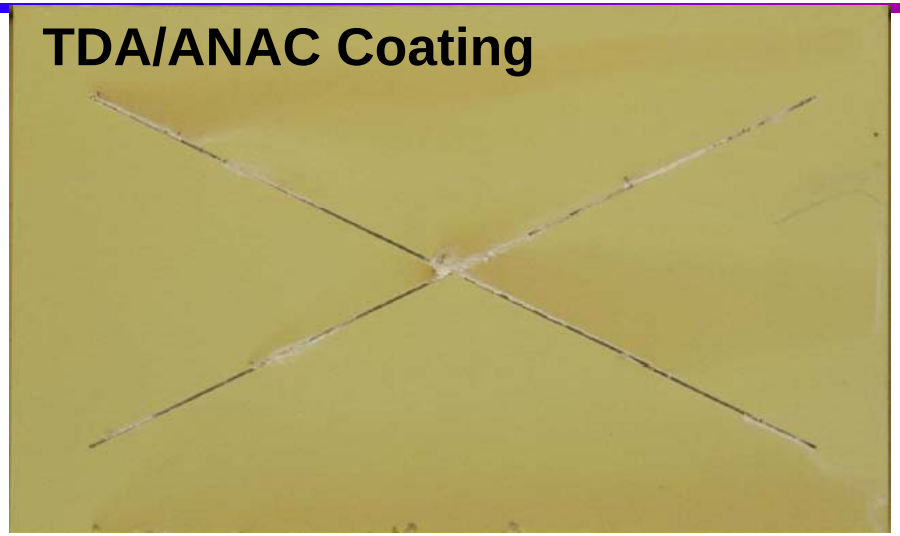
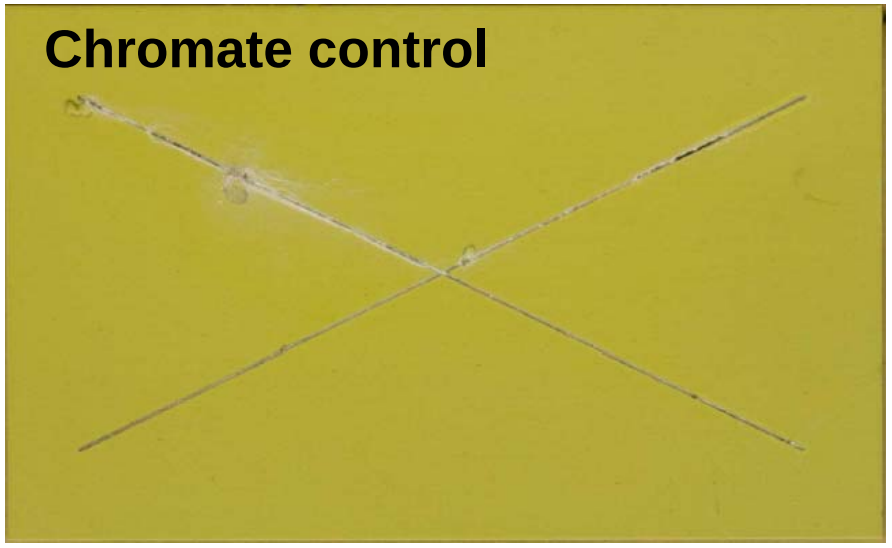
Results on Al2024
4000 hrs ASTM B-117 anodized





- TDA/ANAC coating performs close to chromate control

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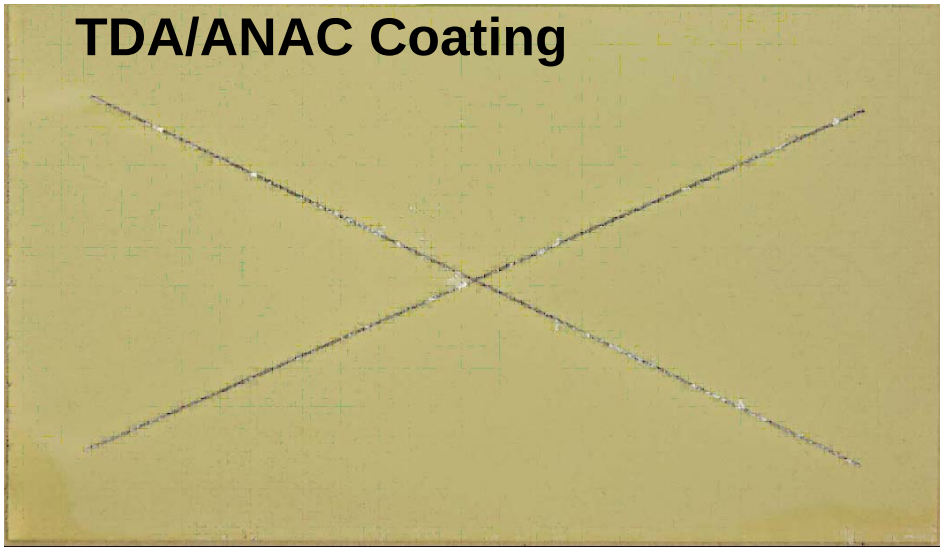
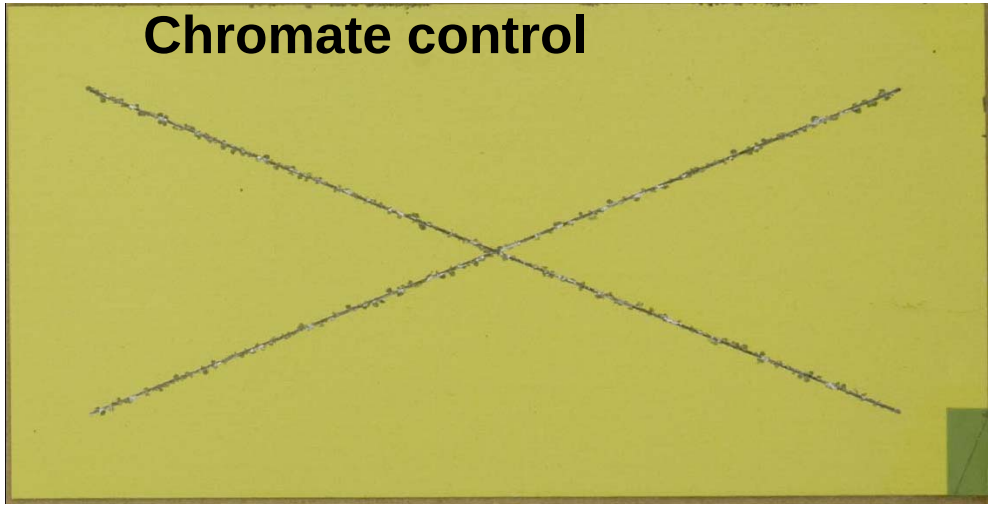
Acid Salt fog ASTM G85 A4 1000 hrs – Al2024 anodized





- TDA/ANAC coating performs better than control
- 336 hr minimum exposure requirement

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Evaluation at Northrop Grumman

Objective:

- Evaluate non-chrome fuel tank coating to the performance requirements of MIL-PRF-85582D and MIL-PRF-23377J.

Approach:

- Perform a side by side evaluation of Non-Chrome fuel tank coatings to primers currently on the QPL.
- Perform corrosion resistance testing in ASTM-B117 salt spray
- Panels scribed, some topcoated

Specimen Fabrication and System Stack-up

Substrate

- Aluminum 2024 T(3), 6” X 3” X 0.040”
- 5 coupons per test group

Surface Preparation

- CCC to the requirements of MIL- C - 5441
- SAA to the requirements of MIL- A – 8625 Type II Sealed

Coatings

Primers:

- AKZO Nobel NC fuel tank coating / AMS-C-27727D - (#1)
- Non-Chrome Water Borne Primer / MIL-PRF-85582D - (#3)
- Non-Chrome Solvent Primer / MIL-PRF-23377 - (#4)
- Baseline Chromated Primer / MIL-PRF-85582D - (#5)

Topcoat:

- White #17925 Polyurethane / MIL-PRF-85285D - (TC)

Neutral Salt Fog Testing Conditions

- Salt Spray Chamber Parameters (ASTM B-117)
  - Salt Solution Make-up
    - 5 % salt solution in DI water
    - Ph – 6.5 ~ 7.2
  - Temperature 35 (+ - 2) Degrees (C)
  - Coupon Inclined (6 Degrees)
- Specimens Evaluated
  - Every 168 hrs
  - Reviewed and Results Documented
- Test ran for 43 weeks, 7224 hours
  - Failure at blister of 0.125".

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NG Salt Fog Results

NON-CHROME FUEL TANK VERSUS NON-CHROME PRIMER VERSUS CHROME CONTROL - SALT SPRAY RESULTS

ASTM-B117 EXPOSURE TIME (HOURS) / (WEEKS)

Aluminum Substrate 2024(T3)	500	668	840	1000	1176	1344	1500	1680	1848	2016	2520	2688	2856	3024	3192	3360	3528	3696	3864	4032	4200	4368	4536	4704	4872	5040	5208	5376	5544	5712	5880	6048	6216	6384	6552	6720	6888	7056	7224
Sample Set Each set has 5 samples	3	4	5	6	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
SAA XP-431-1 (#1)																																							
SAA XP-431-1 (#1)+ TC																									2				5				3						
SAA (#2)																																							
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CCC XP-431-1 (#1)+ TC																															1-5								
CCC (#2)																																							
CCC (#2) + TC																																	2,3,5						
CCC (#3)																	5											2,3					1						
CCC (#3) + TC											3								5									4			1,2								
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--- Sample # from test group removed due to blistering nonconformance (ASTM-B117)

TDA/AkzoNobel coating comparable or better than other primers

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Panels after 7224 hours
Al2024 sulfuric acid anodized

Summary

- Release-on-Demand nanoparticle corrosion Inhibitor developed
- Non-chrome inhibitors incorporated into Integral Fuel Tank Coating formulation
- Excellent corrosion performance demonstrated by ASTM B117 and ASTM G85
  - Tests up 43 week, 7224 hrs!
- Extensive validation testing at multiple locations
  - TDA, AkzoNobel, LM, NG

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- AkzoNobel Aerospace Coatings
- Lockheed Martin
- Northrop Grumman

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