

The background of the slide is a composite image. The top half shows a close-up of industrial machinery with two circular gauges and various pipes. The bottom half is filled with a dense spray of bright orange and yellow sparks, likely from a welding or grinding process, set against a dark blue background.

Tagnite and Keronite Assessment on Magnesium & Aluminum

ASETSDefense 2014: Sustainable Surface Engineering for Aerospace and
Defense - 19 NOVEMBER 2014

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Project Team

- COTR – Tom Lorman (LCMC/WNVV)
- Project Manager - Jim Tankersley
- Technical Task Managers – John Stropki, Jill Gregory
- Additional Stakeholders
 - OO-ALC (Wayne Patterson 809 MXSS/MXDEC)
 - F-16, F-35, and F-22 Program Offices
 - Lockheed-Martin Aerospace
 - USAF Corrosion Prevention and Control Office (AFCPCO)
 - US Army AMRDEC

Objective and Goal

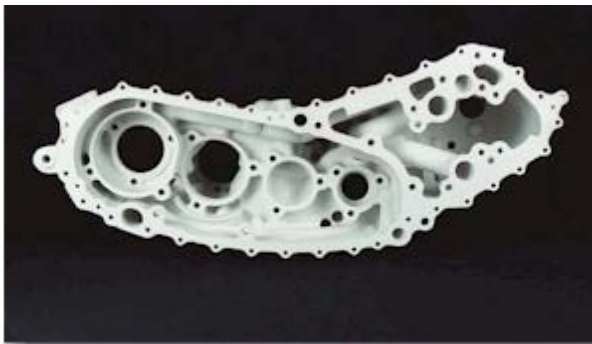
- **Objective:** Conduct a Qualification Operational Test and Evaluation (QOT&E) of the Tagnite® and Keronite® surface treatments as an alternative to current chromated conversion coatings (Dow 7) and anodizing treatments (Dow 17). The experimental coating systems will be compared to existing MIL-SPEC coating systems currently being applied to Mg and Al off-aircraft component parts at Hill AFB.
- **Goal:** Validate a non-chrome containing surface pretreatment/primer coating and powder coating system for use on magnesium and high strength cast and wrought aluminum parts.

Background – Technology Solution

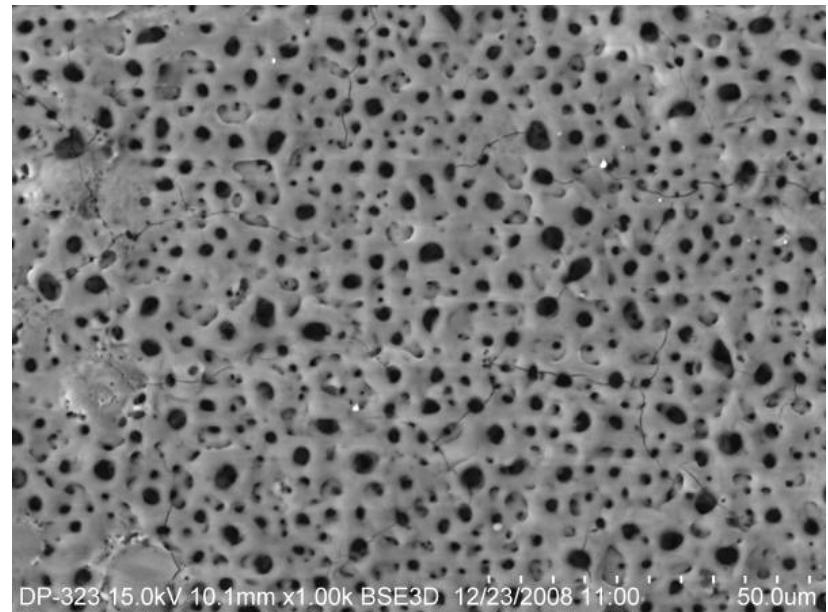
- NAVAIR has conditionally approved Tagnite® and Keronite® treatments for all Mg alloys.
- AFCEE funded Leidos (SAIC) to comparatively assess Tagnite® and Keronite® on Mg alloys only:
 - Literature review, experimental test plan, cost benefit analysis
 - Funding did not support fabrication or testing panels or parts at Hill AFB
- Air Force (LCMC/WNVV) funded Battelle to evaluate Tagnite® and Keronite® on Mg and Al alloys
 - Battelle responsible for fabrication/coating all test panels, performing B117, Adhesion, and strippability on Hill AFB (Leidos) panels
 - Battelle and Leidos will not duplicate efforts

Background – Tagnite® Coating

- Hard anodized coating developed in the 1990's
- No heavy metals or chromates
- Deposited as columnar and porous film
- Electrolyte's pH is 12.8 - 13.2 and operates below room temperature (40° – 60° F)
- 8 tank process line

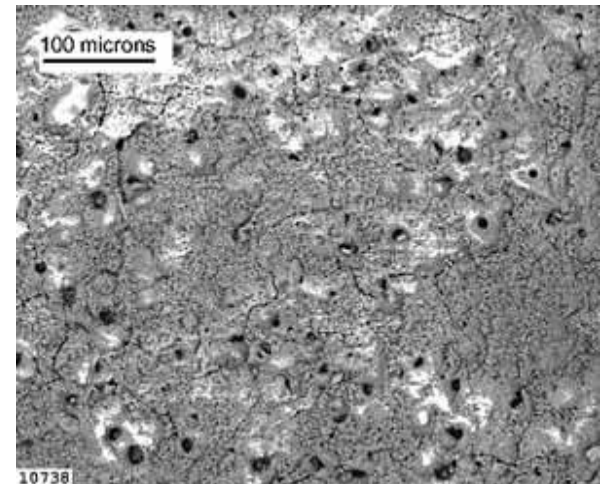


***Sand Cast Magnesium
Gearbox For a Jet Engine***



Background - Keronite® Coating

- *Initial Treatments:* Clean parts with alkaline degreaser (less stringent requirements). Etching not required.
- *Processing Treatment:* PEO uses different electrolytes and higher current densities to achieve microscopic plasma discharges for modifying oxide film (micro-arc fusing of oxide layers)
- *Coating Growth:* Typical oxide film thickness for Mg is 0.4 – 0.8 mils, and 1.0 – 1.5 mils for Al alloys
- *Target Alloys:* AZ31B Mg Alloy, as well as 6061-T6, 7075-T6 and 2024-T3 aluminum alloys



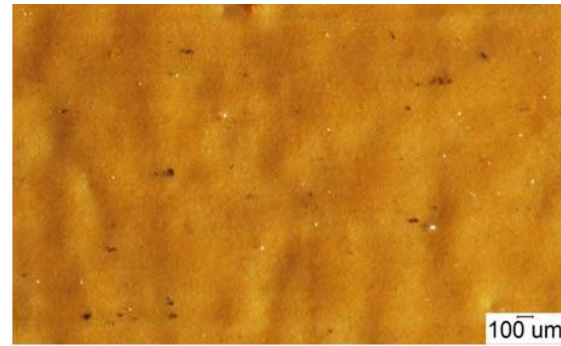
Technical Approach

- Identify Mg and Al alloys and parts being conversion coated and/or chromic acid anodized at Hill AFB.
- Work with Hill AFB and Leidos to update draft Test Plan to include several aluminum aerospace alloys.
- Prepare and test panels and condemned off-aircraft parts w/ complex geometries.
- Define compatibility, adhesion and corrosion resistance of alternative surface treatments with powder coatings being investigated by Hill AFB.
- Develop a technology transition plan that identifies licensing options and costs, as well as equipment, facility and personnel investments.

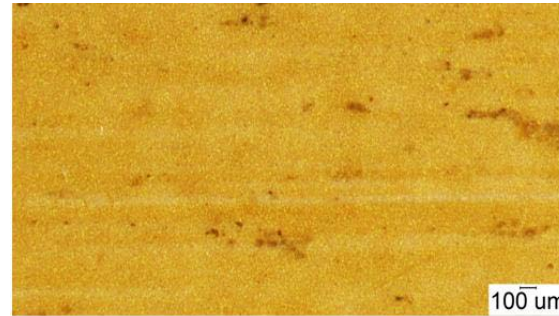
The matrix of substrates and coatings provided comprehensive stackups that span baseline, chrome, and chrome-free combinations.

| Substrate | Surface Treatment | Sealer | Primer | Topcoat |
|--|---|--|--|---|
| <ul style="list-style-type: none">• Al 2024• Al 6061• Al 7075• Mg AZ31B | <ul style="list-style-type: none">• Dow 17• PreKote• Alodine 5900• Keronite• Tagnite 8200 | <ul style="list-style-type: none">• Rockhard 576-450-002 | <ul style="list-style-type: none">• MIL-PRF-23377 (chrome) | <ul style="list-style-type: none">• MIL-PRF-85285• TCI Powder Coat |

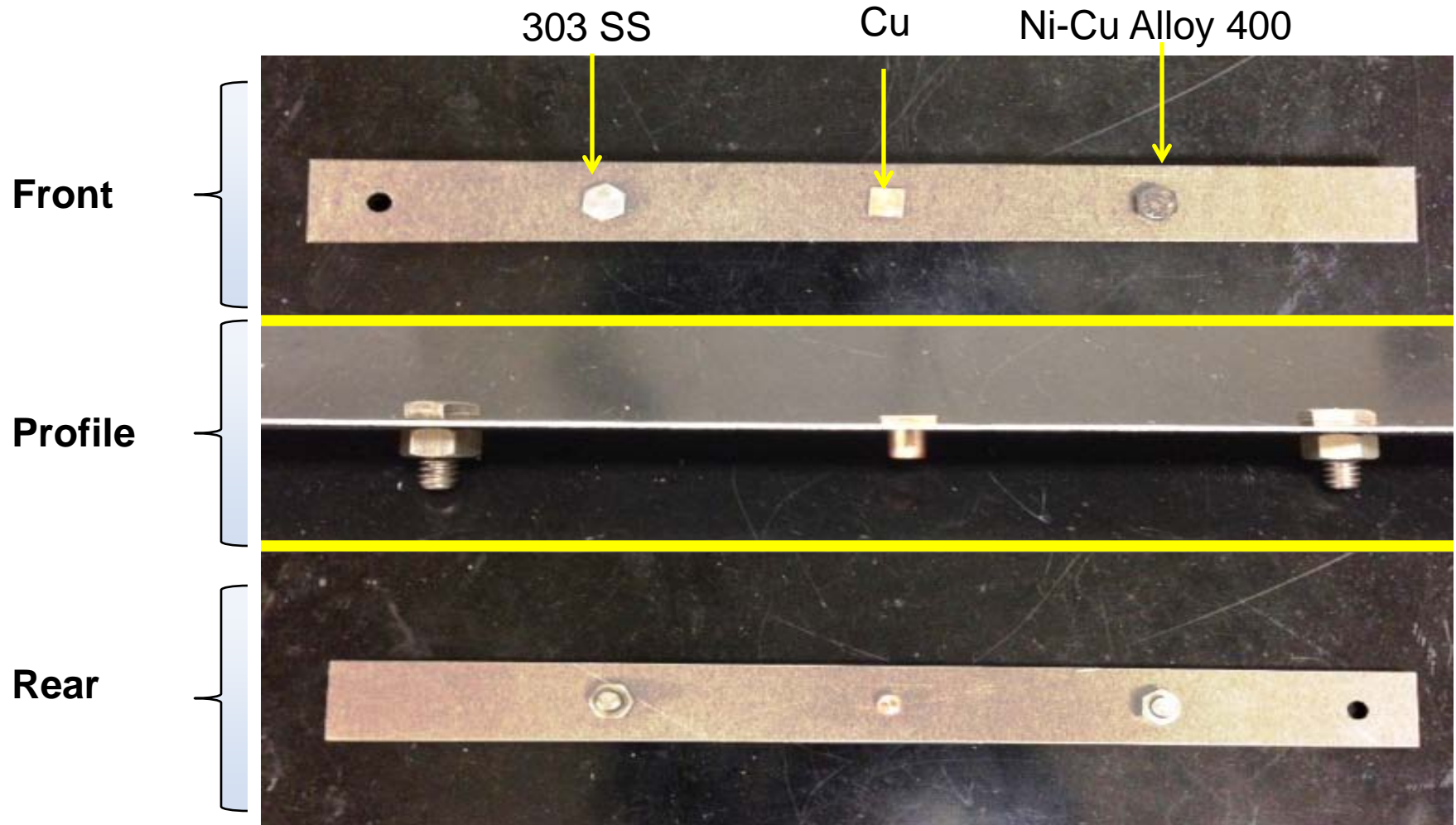
Visual of Keronite and Rockhard surface treatments



Visual of Tagnite and Rockhard surface treatments



Dissimilar Metal Panels



Mounting orientation of dissimilar metals panels created corrosive environment for exposed dissimilar metals

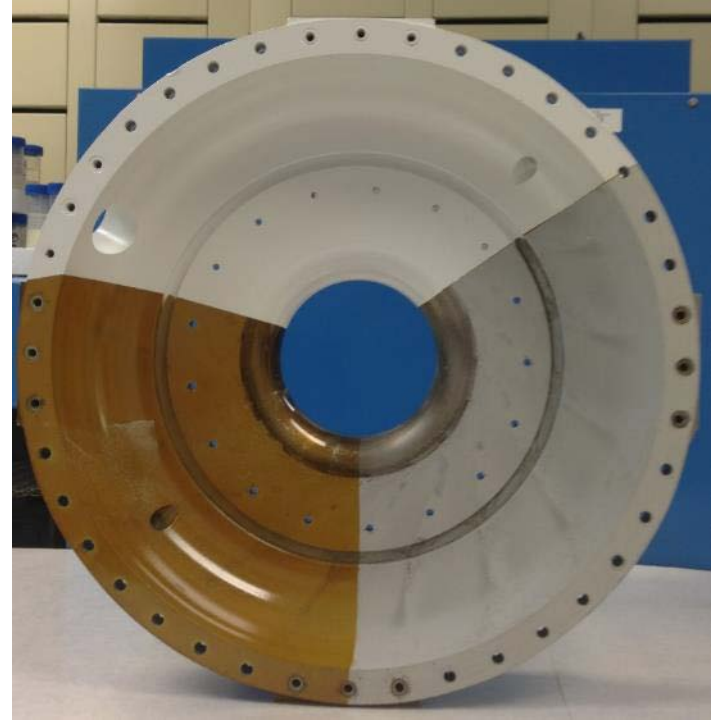
Tagnite without/with Rockhard | Keronite without/with Rockhard



Keronite Coated Aircraft Parts



C-130 Gearbox Housing (AZ91C-T6 Mg)



C-130 Diffuser Housing (Cast Al)

Tagnite Coated Aircraft Part



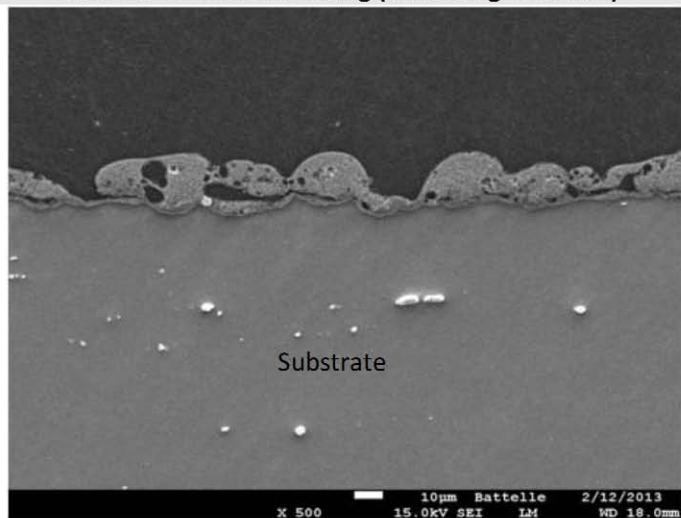
C-130 Gearbox Housing (AZ91C-T6 Mg)

COATING SURFACE ANALYSIS

SEM/EDS Results

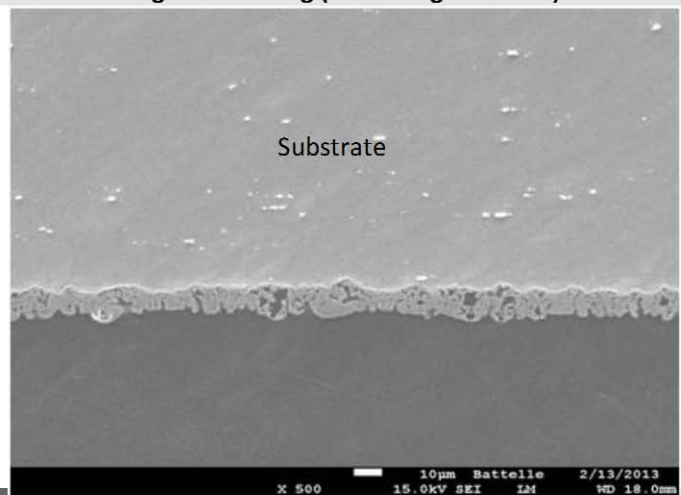
SEM/EDS Coating Surface Analysis

Dow 17[®] Anodized Coating (500X Magnification)



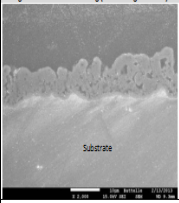
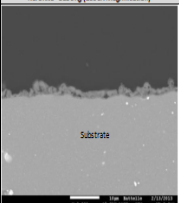
| Substrate | Film Thickness, µm | Chemistry, wt % | Comments |
|-----------|--------------------|---|--|
| Mg AZ31B | 5 - 30 | C : 2.9 – 4.2 O: 19.5 – 19.6 F: 12.7 – 14.0 Na: 4.8 – 5.2 Mg: 28.1 – 29.9 Al: 0.4 – 0.6 P: 15.3 – 15.4 Cr: 12.9 – 14.1 | <ul style="list-style-type: none"> • Very porous • Irregular • Non-uniform • Globular • Cracking • 2-4 µm dense coating on substrate • Mg and Cr⁺⁶ oxides provide corrosion protection |

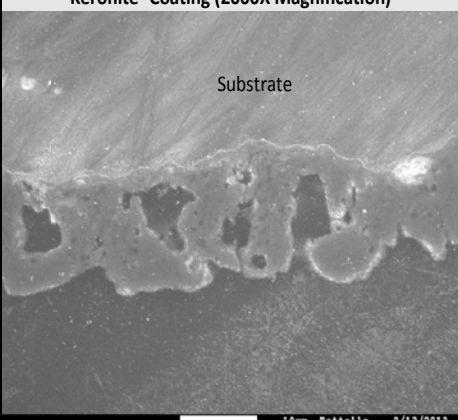
Tagnite[®] Coating (500X Magnification)



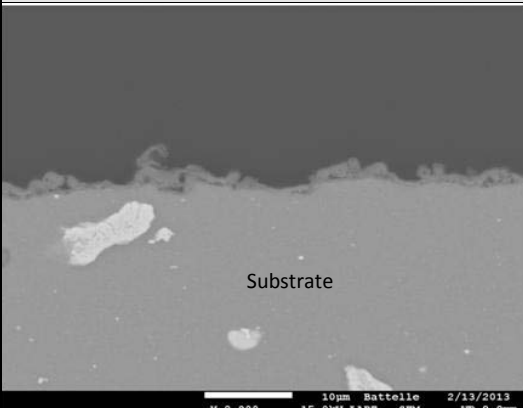
| Substrate | Film Thickness, µm | Chemistry | Comments |
|-----------|--------------------|---|---|
| Mg AZ31B | 4 - 10 | C : 3.2 – 3.5 O: 24.6 – 26.6 F: 3.5 – 7.6 Na: 0.4 Mg: 48.5 – 49.9 Al: 1.5 – 2.1 Si: 12.8 – 14.9 K: 0.5 – 1.3 | <ul style="list-style-type: none"> • Very porous • Semi-uniform • .5-1 µm dense coating on substrate • Thicker Mg oxide with Al oxides • Si from electrolyte |

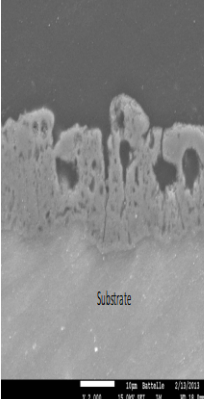
SEM/EDS Coating Surface Analysis

| Tagrite® Rockhard® Coating (2000X Magnification) | | | | | Substrate | Film Thickness, μm | Chemistry | Comments |
|---|--|--|--|--|-----------|-------------------------------|---|---|
|  | | | | | Mg AZ31B | 7-15 | C: 3.8-11.6 O: 24.2-24.8 F: 4.9-5.5 Na: 0.5 Mg: 43.8-49.3 Al: 1.1-1.6 Si: 12.4-14.1 K: 0.7-0.8 | <ul style="list-style-type: none"> • Porous • Semi-uniform • 1-2 μm dense coating on substrate • Rockhard is organic sealer that fills in pores and is not detectable |
| Keronite® Coating (2000X Magnification) | | | | | Substrate | Film Thickness, μm | Chemistry | Comments |
|  | | | | | AZ31B-T3 | 1-3 | C: 10.5-26.7 O: 29.1-31.5 Mg: 0.7-1.3 Al: 14.4-47.5 Si: 8.9-27.5 P: 0.7-1.5 | <ul style="list-style-type: none"> • Porous • Semi-uniform • Globular • 3-5 μm dense coating on substrate • Al and Si oxides provide corrosion protection |

| Keronite® Coating (2000X Magnification) | | | | | Substrate | Film Thickness, μm | Chemistry | Comments |
|--|--|--|--|--|-----------|-------------------------------|---|--|
|  | | | | | Mg AZ31B | 10-15 | C: 2.9-4.9 O: 26.0-27.0 F: 0.7-1.3 Na: 1.2-1.6 Mg: 47.3-52.4 Al: 11.1-12.8 P: 3.2-5.5 | <ul style="list-style-type: none"> -Very porous -Irregular, globular -1-2 μm dense coating on substrate -Mg and Al oxides provide corrosion protection |

SEM/EDS Coating Surface Analysis

| Keronite® + Rockhard® Coating (2000X Magnification) | Substrate | Film Thickness, μm | Chemistry | Comments |
|---|-----------|-------------------------------|--|--|
|  | Al 2024 | 1-3 | C: 10.6-26.7 O: 29.1-31.5 Mg: 0.7-1.3 Al: 14.4-47.5 P: 8.9-27.6 Si: 0.7-1.6 | -Porous -Semi-uniform, globular -0.3-0.5 μm dense coating on substrate -Al oxides provide corrosion protection |

| Keronite® + Rockhard® Coating (2000X Magnification) | Substrate | Film Thickness, μm | Chemistry | Comments | Substrate | Film Thickness, μm | Chemistry | Comments |
|--|-----------|-------------------------------|---|---|-----------|-------------------------------|---|---|
|  | MgAZ31B | 10-15 | C: 3.5-7.9 O: 25.1-25.9 F: 0.8-1.3 Na: 1.3-1.5 Mg: 43.7-49.5 Al: 11.8-17.7 P: 3.0-4.6 | <ul style="list-style-type: none"> Very porous Cracking Semi-uniform Globular 1-2 μm dense coating on substrate Mg and Al oxides provide corrosion protection | MgAZ31B | 10-15 | C: 3.5-7.9 O: 25.1-25.9 F: 0.8-1.3 Na: 1.3-1.5 Mg: 43.7-49.5 Al: 11.8-17.7 P: 3.0-4.6 | -Very porous -Cracking -Semi-uniform, globular -1-2 μm dense coating on substrate -Mg and Al oxides provide corrosion protection |

12-MONTH OUTDOOR EXPOSURE RESULTS

Aluminum and Magnesium Panels

All tested conversion coatings, with the exception of Tagnite and Keronite surface treatments, required a chromated primer with the powder coat.



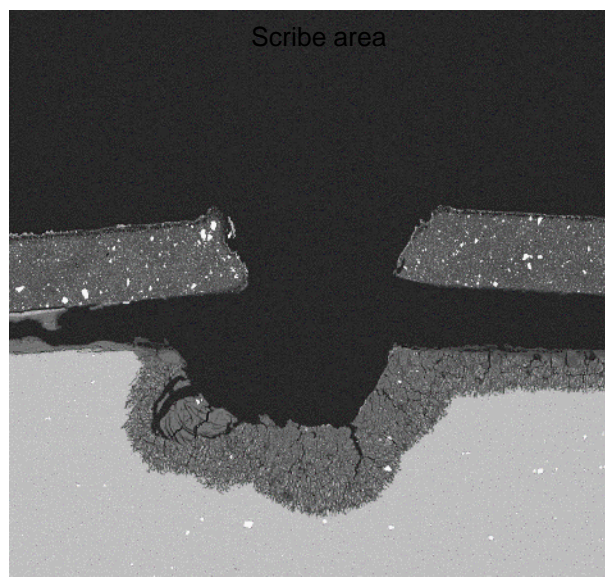
Keronite with powder coat was the best performing non-chrome stackup for aluminum panels



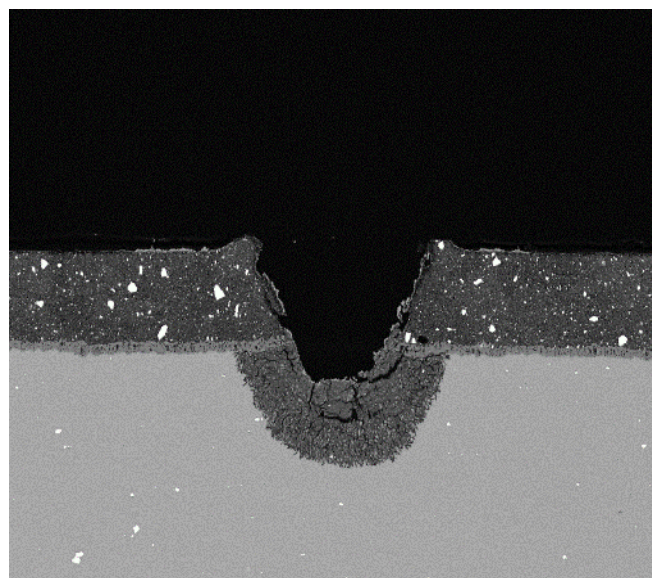
Tagnite with Rockhard and powder coat was the best performing non-chrome stackup for Mg AZ31B panels



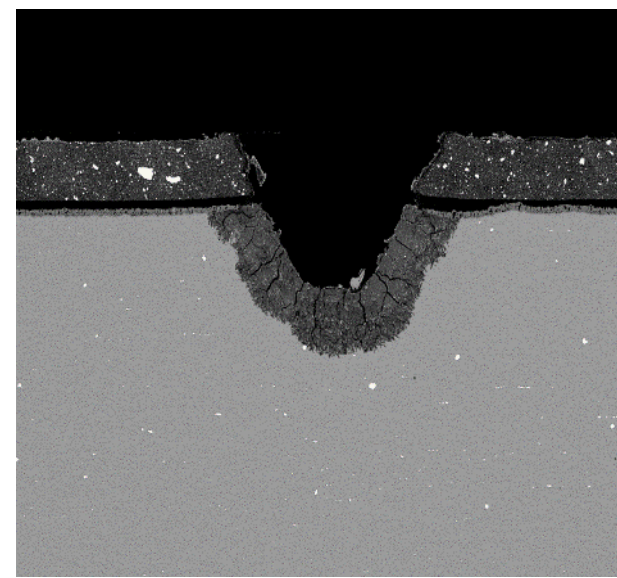
SEM analysis of scribe cross section showed complete powder coat adhesion loss with Alodine 5900, and very minimal with Keronite and Tagnite.



Cross-section AZ31B Mg panel treated with Alodine T5900 and powder coat



Cross-section AZ31B Mg panel treated with Keronite and powder coat



Cross-section AZ31B Mg panel treated with Tagnite, Rockhard, and powder coat

12-MONTH OUTDOOR EXPOSURE RESULTS

Dissimilar Metal Panels

Keronite-only panels showed moderate corrosion at the interface and exposed substrate from maskant removal



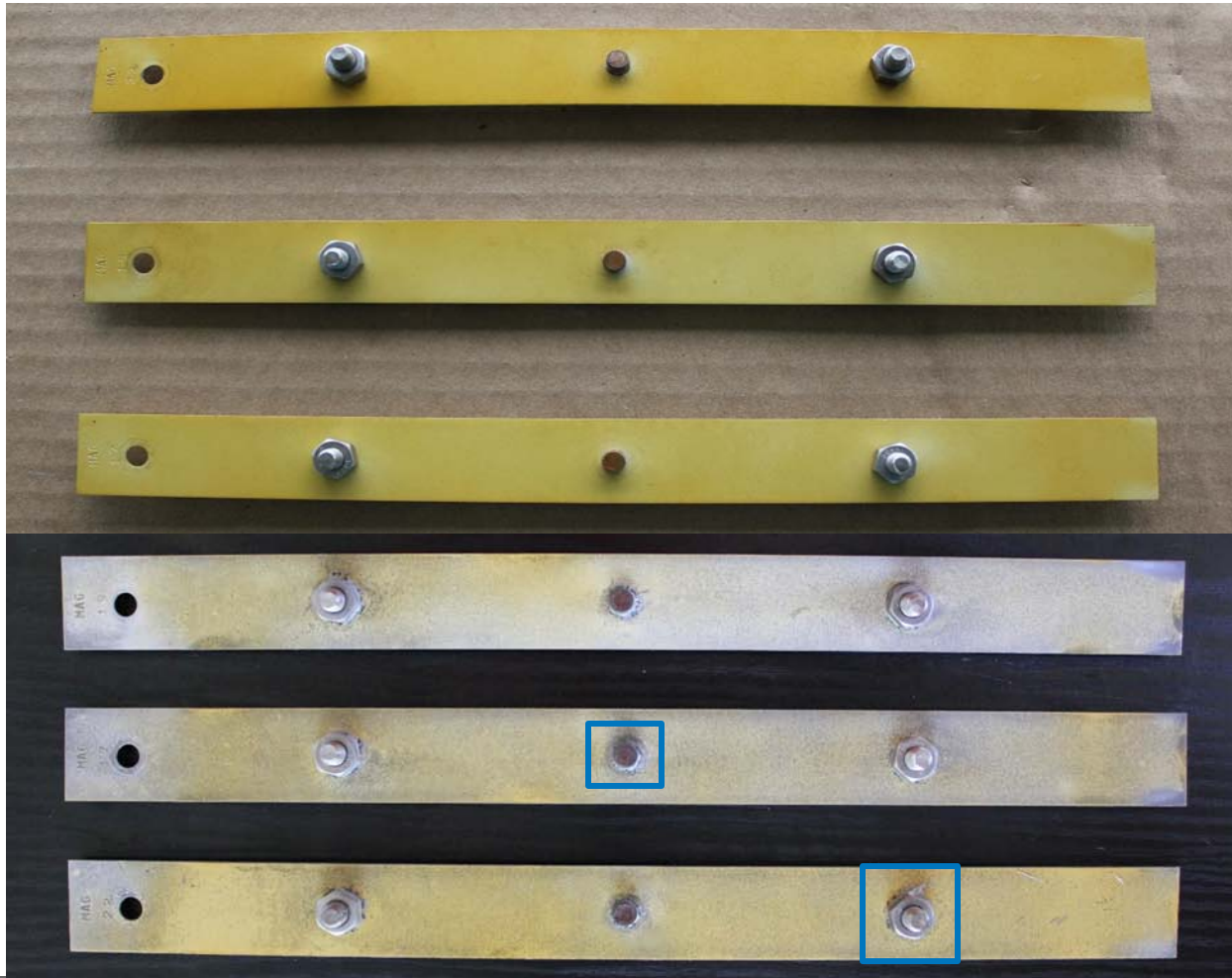
Keronite + Rockhard panels showed moderate corrosion at the interface and exposed substrate from maskant removal



Tagnite-only dissimilar metals panels exhibited corrosion around dissimilar metal interfaces, especially the copper fitting



Tagnite + Rockhard dissimilar metals panels exhibited corrosion around dissimilar metal interfaces, with significant fading of the Rockhard coating.



LABORATORY TEST RESULTS

ASTM B117 Salt Fog

ASTM B117 Salt Fog Testing



| Cycle | Time | RH | Temperature |
|--------------------------|----------|------|-------------|
| Salt Fog Simple Solution | 24 hours | 100% | 35°C |

Several baseline panel sets exhibited severe corrosion and were removed from the chamber



Mg Alloy Panel after 48 hrs.



Mg+PreKote+Primer+Topcoat

Severe corrosion and coating failure noted on magnesium panel with Alodine 5900 and powder coat after 700 hrs, while no corrosion noted on Al 2024 stackup after 1,500 hrs



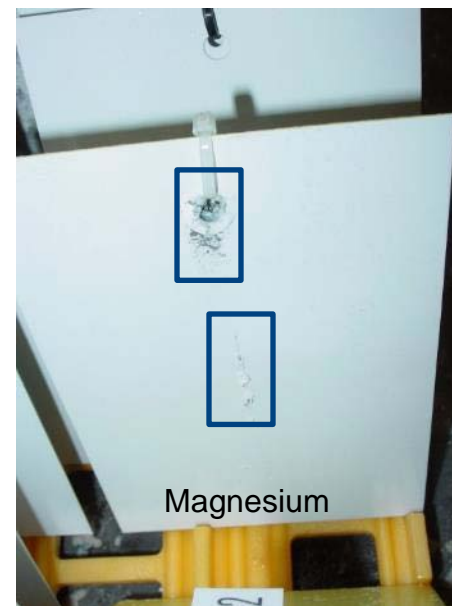
Mg AZ31B + Alodine 5900 + Powder Coat



Al2024 + Alodine 5900 + Powder Coat

All chrome-free magnesium stackups failed the ASTM B117 2,000 hour salt fog test

- Tagnite non-chrome stackup (Tag+R+PC): all magnesium panels failed at the scribe line and edges by 2,000 hours.
- Keronite non-chrome stackup (K+PC): all aluminum panels passed at 2,000 hours, while all magnesium panels failed.



ASTM B117 Salt Fog Test Summary

- Extensive corrosion and coating disbondment for a majority of the AZ31B Mg test panels treated with Dow 17, PreKote, and Alodine T5900 after ~700 hours of exposure
- All Al alloy test panels treated with the Dow 17, PreKote and Alodine T5900 passed the 2,000 hour test with only minimal coating blisters and localized corrosion along the edges and hole cut.
- The majority of surface area on all AZ31B Mg panels treated with Tagnite and Keronite were in fair condition following 2,000 hours. Localized corrosion and coating disbondment was confined to the edge, scribe and hole cut surfaces.
- All aluminum alloy panels treated with Tagnite and Keronite had only minimal scribe corrosion following 2,000 hours.
- The Rockhard coating did appear to reduce scribe corrosion for the Keronite treated panels.

LABORATORY TEST RESULTS

ASTM D3359 Adhesive Testing

ASTM D3359 Adhesion Tests

Passed: All substrates with Keronite/Tagnite, Rockhard, and powder coat

- Failures:
 - Al 2024/6061/7075 and Mg, Keronite, Rockhard, Primer, Topcoat
 - Mg, Tagnite, Rockhard, Primer, Topcoat
 - Al 2024/6061 and Mg, PreKote, Primer, Topcoat
 - Mg, PreKote, Powder coat
 - Mg, Primer, Powder coat
 - Mg, Dow 17
 - Al 2021/6061 and Mg, Alodine 5900, Primer, Powder coat
 - Mg, Alodine 5900, Primer, Topcoat
 - Mg, Alodine 5900, Primer, Powder coat

LABORATORY TEST RESULTS

Type II Dry Media Coating Removal

Type II Dry Media Coating Removal

- Specifications

- Type II Urea dry media, 3/8" nozzle, 10" standoff, 80 degree angle, & 25 psi nozzle pressure
- Acceptable coating removal rate determined to be between 0.3-0.5 ft²/min

- Results

- Testing confirmed the Keronite and Tagnite surface treatments cannot be removed with Type II media without damaging the Al or Mg test panels.
- Selective removal of organic coatings possible due to porous and irregular surface morphology for all Mg and Al panels coated with the Tagnite and Keronite surface treatments (with and without Rockhard).
 - Powder coating removal rates were very low (0.06 ft²/min)
 - MIL-SPEC primer + topcoat rates were higher (0.33 ft²/min)



BUSINESS CASE ANALYSIS

Keronite implementation for aluminum components at Hill AFB

Business Case Analysis Overview

- Battelle assessed the business case for Hill AFB to transition to the Keronite process for aluminum parts
 - Supplements Leidos BCA conducted under separate Task Order for Keronite and Tagnite for magnesium parts
- Battelle baselined paint operations for two aluminum component process lines at Hill AFB
 - Propulsion Directorate (Bldg 238) – Alodine T5900 conversion coating
 - Landing Gear Shop (Bldg 507) - Type II Sulfuric acid anodizing
- The following slides convey the baseline assessment and the advantages and disadvantages of transitioning to the Keronite technology.

Business Case Analysis

Summary of Results

- Keronite with powder coat offers the only chrome-free coating system for aluminum alloys with comparable performance to the baseline chrome-containing stackup. Time and cost savings are associated with the elimination of the chromated primer.
- Keronite electricity usage is an order of magnitude higher than the anodizing line or the Alodine process. The electricity usage is dependent on component substrate, surface area, and desired coating thickness.
- Keronite electrolyte consumption is significantly higher than the anodizing line or the Alodine process. Both baseline processes added approximately one 55-gallon drum of material to the bath per year.
 - The electrolyte consumption is based on component substrate, surface area, and desired coating thickness; however, the range for aluminum is anywhere from 0.02-0.22 liters/ft².

Business Case Analysis

Summary of Results – Cont'd

- The Keronite system is based on a lease-license agreement where the base would rent the equipment from Keronite for a period of at least 5-years. This contract is negotiable.
 - Keronite also offers subcontracting to their Greenwood, Indian facility.
- The results of Keronite process investment indicate an increase in annual costs by as much as \$100,000.00, in addition to approximately \$54,000.00 in one-time start-up costs.
 - This could be partially offset by the benefits of reduced hazardous material exposure, treatment costs at the IWTP, reduction of time/costs to apply primer, and nominally-reduced permitting requirements.

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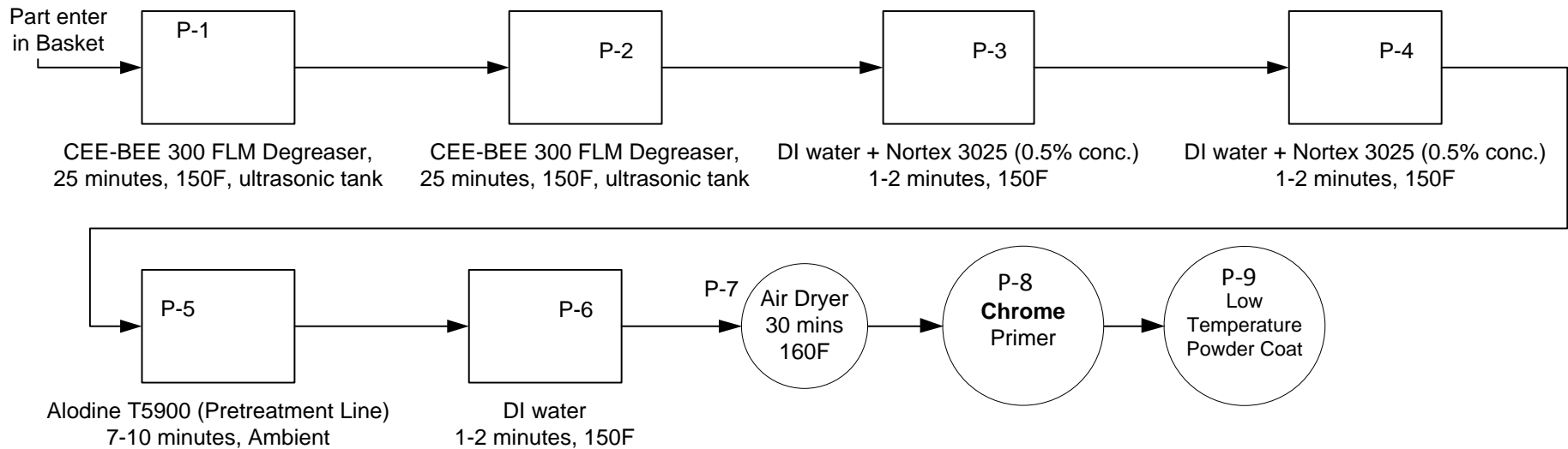
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Back-up Slides

Business Case Analysis

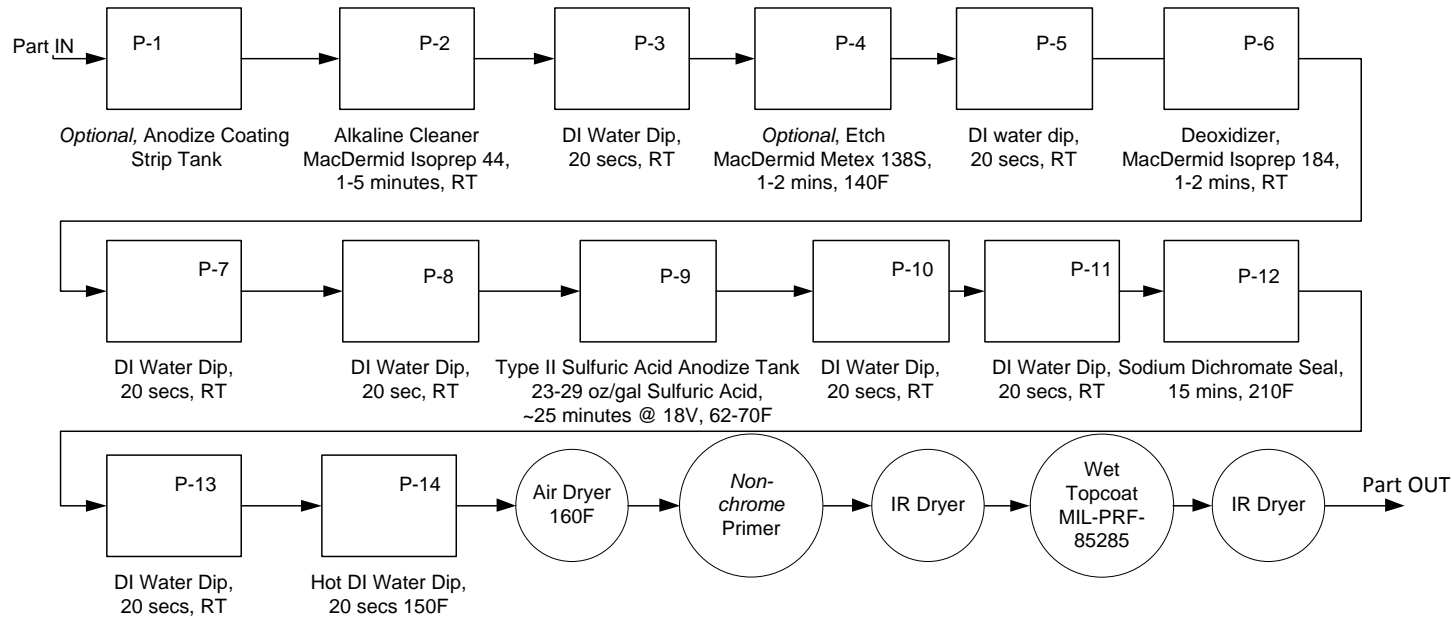
Baseline Processes – Propulsion Directorate



- Analyst data for the 309th maintenance wing suggested 15,387 aluminum parts were processed in a 12-month period with about 2.5% ($\pm 1\%$) scrapped for corrosion related issues.
- Topcoat and primer are always removed, however Alodine coating may remain prior to recoating
- Total process time ~1.5 hrs + 1-3 days for prime + powder coat

Business Case Analysis

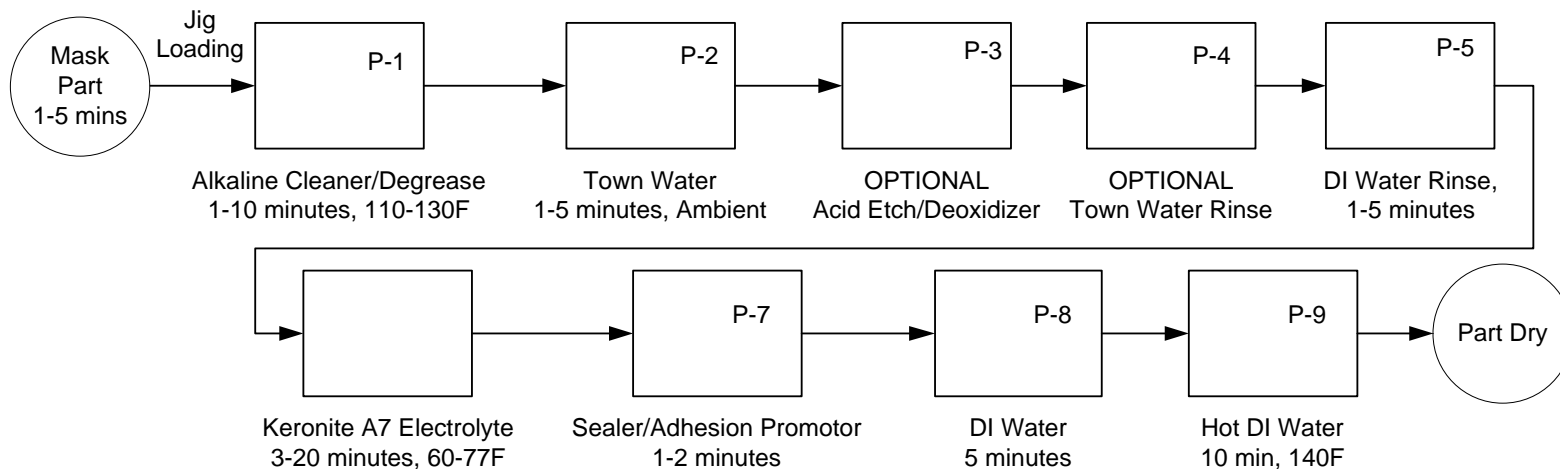
Baseline Processes – Landing Gear



- Primary parts are 2000 series aluminum wheels and struts
- FPI/NDI techniques used do not require complete removal of anodize coating.
- Parts with >10% bare metal undergo sulfuric acid anodize
- Total process time ~1 hr + 1 day primer/paint

Business Case Analysis

Baseline Processes – Keronite Process



- Preferential treatment on exposed substrates does not require complete stripping
- All dissimilar metals must be removed or masked
- Current pretreatment steps are suitable with Keronite process
- The Landing Gear anodizing line provided drop-in equipment for Keronite process
- Process time <1 hour

Implementation advantages of the Keronite process for aluminum components include selective coating removal and a chrome-free stackup.

Process Changes from Program Depot Maintenance (PDM) Cycle 1 through Subsequent PDM Cycles

| Baseline CPC Operations | PDM Cycle 1 – Keronite Application | Potential Cost Increase/Reduction | Subsequent PDM Cycles | Potential Cost Increase/Reduction |
|-------------------------|--|-----------------------------------|---|-----------------------------------|
| Depainting | Strip to bare metal | Increase | Partial depaint (only powder coat and sealant removed) | Reduction |
| Inspect & Repair | No Change | Not Applicable | No Change | Not Applicable |
| Painting | Adds Keronite + Sealant; Removes Chrome Primer and/or Dichromate Sealant | Increase | Eliminates Keronite reapplication, only need provide touchup conversion coating & sealer. | Reduction |

The Keronite process energy is a significant increase in comparison to the Alodine T5900 process and the Type II sulfuric acid anodizing process.

C-130 cast aluminum diffuser housing with ~7.5 micron coating

| Substrate | Energy Consumption (kWh) | Electricity Cost per part (5.68¢/kWh ¹) |
|--|--------------------------|---|
| Keronite | 22 | \$ 1.25 |
| Alodine T5900 | 0 | \$ - |
| Type II Sulfuric Acid Anodize ² | 0.5 | \$ 0.03 |

¹ April 2014 average cost per kilowatt-hour for industrial entities in Utah. (U.S. EIA, 2014)

² Calculated using reported values of power supply set to 18V for 25 minutes and an average value of 13.5A/ft². Validated estimation with typical energy consumptions reported from sulfuric acid anodizing methods.

The required energy for the Keronite process is nearly 44 times the electricity consumption for the current anodizing process.

Important process variables (i.e. process time, electrolyte consumption, and energy usage) can be determined for each part.

| Parameter | Coating, 10 μm | | | Coating, 5 μm | | | Pre-treatment (<5 μm) | | |
|----------------------------------|---------------------------|------|------|--------------------------|------|------|-----------------------------------|------|------|
| Alloy | cast | 2xxx | 5xxx | cast | 2xxx | 5xxx | cast | 2xxx | 5xxx |
| | | 7xxx | 6xxx | | 7xxx | 6xxx | | 7xxx | 6xxx |
| Max load (ft ²) | 11 | 22 | 22 | 11 | 22 | 22 | 11 | 22 | 22 |
| Process Time (min) | 20 | 12.5 | 10 | 12 | 7.5 | 6 | 6 | 3.75 | 3 |
| Energy (kWh/ft ²) | 4.65 | 1.85 | 1.4 | 2.79 | 1.11 | 0.84 | 1.39 | 0.56 | 0.42 |
| Electrolyte (L/ft ²) | 0.22 | 0.09 | 0.07 | 0.13 | 0.05 | 0.04 | 0.07 | 0.03 | 0.02 |
| ft ² /shift | 191 | 567 | 676 | 293 | 837 | 976 | 490 | 1300 | 1460 |
| ft ² /month | 11k | 34k | 41k | 18k | 50k | 59k | 29k | 78k | 88k |

For example, the landing gear shop wheels are 2000 series aluminum which would require ~2.5 times less energy per square foot to coat than cast aluminum.

The Keronite process consumes orders of magnitude more material than the Alodine or sulfuric acid process; however, chrome and heavy metals are eliminated from all materials.

| Material | Bath Chemistry Check | Add Material/Replenish | Bath Replacement |
|-----------------------|----------------------|---------------------------------------|-------------------------|
| Keronite | weekly | Replenish: 21 kW/liter of electrolyte | every 3rd replenishment |
| Alodine T5900 | biweekly | Add ~55 gallons/year | N/A |
| Sulfuric Acid Anodize | weekly | Add ~50 gallons/year | ~10 years |

| Hazardous Material | Disposal Option |
|--------------------|---|
| Keronite | Suitable for Discharge to Drain permit (no heavy metals, chromium, acids, or ammonia) |
| Gardolene Seal | Suitable for Discharge to Drain permit (non-toxic, chromium-free, silane-based) |

| Paint Depot | Process Chrome Source | Product Name | Chromium Type |
|--------------|-----------------------|---|---|
| Propulsion | Conversion Coating | Alodine T5900 | 1-5% w/w Chromium compound (tri-chrome) |
| | Primer Coating | PPG Desoprime HS CA7233 (MIL-PRF-23377) | 20-25% w/w Strontium Chromate |
| Landing Gear | Anodize Sealant | Sodium Dichromate Sealant | <5% w/w sodium dichromate |

The Keronite process technology licensing costs incorporate equipment leasing/usage, maintenance, installation support, training, and transportation.

| Specifications | |
|--|-----------------|
| Lease Term (years) | 5 |
| Keronite Processing Unit Size (WxDxH) | 10.3'x4.7'x5.5' |
| Keronite PSU Size (WxDxH) | 11'x3'x7' |
| Tank size (liters) | 2000 |
| Equipment Costs | |
| Equipment Lease (1st term) | \$ 256,500.00 |
| Equipment Lease (2nd term) | \$ 128,250.00 |
| Equipment Lease (single year) | \$ 34,200.00 |
| Maintenance (single year, required) | \$ 8,550.00 |
| Startup Costs | |
| Packaging/Shipping | \$ 11,970.00 |
| Installation support, commissioning, training ¹ | \$ 42,750.00 |
| Usage Costs | |
| Equipment usage charge (\$/kWh) | \$ 0.10 |
| Electrolyte cost (\$/liter) | \$ 4.00 |

The estimated yearly cost of licensing and using the Keronite technology is roughly \$100,000.

| Summary of Estimated Costs (10 year rental) | |
|--|----------------------|
| Yearly Equipment Cost (10yr plan) | \$ 38,475.00 |
| Yearly Maintenance Visit Costs | \$ 8,550.00 |
| Estimated Yearly Equipment Usage Charge ² | \$ 14,040.00 |
| Estimated Yearly Electrolyte Cost ³ | \$ 42,832.00 |
| Estimated Yearly Cost⁴ | \$ 103,897.00 |
| One time installation cost | \$ 54,720.00 |

¹ 2-days training for 3 employees, 5 days tech assistance during commissioning

² Assumes 650 wheels/month, 5 µm coating, 18 kWh/part

³ Assumes complete tank refill twice per year and electrolyte consumption for 5 µm coated wheel

⁴ Assumes an exchange rate of 1 £ = 1.71 USD