AEROSPACE INFORMATION REPORT

AIR5479 REV. A

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Superseding AIR5479

(R) Environmentally Compliant Processes for Landing Gear

RATIONALE

AIR5479A has been reaffirmed to comply with the SAE five-year review policy.

TABLE OF CONTENTS

1. SCOPE

This SAE Aerospace Information Report (AIR) describes the performance of platings and coatings for landing gear that potentially provide environmental compliance benefits versus the current baseline processes. The hazardous systems addressed in this version of the document include cadmium plating, chromated primers, and high VOC (volatile organic compounds) topcoats.

Available data are presented for various standard tests in order to compare the replacement candidates. Conclusions are made as to the best performer(s) for each test section presented. These conclusions are not to be regarded as recommendations for or against any of the candidates.

The AIR applies to landing gear structures and mechanisms for all types of civil and military aircraft. The potential replacements apply to both original equipment manufacturer (OEM) hardware and overhaul of in-service landing gears.

1.1 Background

This document addresses a number of materials and processes used in landing gear manufacturing and overhaul including cadmium, chromium, and volatile organic compounds (VOC). In the United States, these substances are controlled in three primary areas: (1) the Occupational Safety and Health Administration (OSHA) oversees exposure in the workplace, (2) the Environmental Protection Agency (EPA) oversees airborne emissions via the Clean Air Act, and (3) the EPA also oversees waterborne effluent via the Clean Water Act.

Cadmium is widely used as a sacrificial coating for corrosion protection of steel alloys. However, cadmium is easily removed during paint stripping operations, resulting in contamination of stripping media and large volumes of hazardous waste. Because low embrittlement cadmium is a soft, easily removable coating, it contaminates virtually everything it physically contacts (e.g., wiping rags, hydraulic oil, masking materials). The 1992 OSHA Expanded Standard for Cadmium established a permissible exposure limit (PEL) of 5 $\mu g/m^3$ and reduced the Action Level (AL) to 2.5 $\mu g/m^3$. This standard went into effect in 1996 and put nearly all overhaul operations at risk of violating AL and/or PEL, requiring the use of continually more stringent overhaul process control, worker medical surveillance and record keeping. Cadmium levels in effluent are regulated by the Clean Water Act, but the needs and capabilities of the local waste water treatment authority require their involvement in establishing individual discharge standards. The European Union (EU) has already banned the use of cadmium for various applications but exempted flight safety critical parts. European airlines expect the exemption to be phased out and are requesting (a) harmonization of maintenance procedures and processes in which cadmium is involved, (b) a policy commitment to replace cadmium for aircraft, engines and components and c) consensus on selection of cadmium alternatives.

Hexavalent chromium is a corrosion inhibitor used in chromated conversion coatings and chromated primers. Hexavalent chromium is a known carcinogen and a suspected human mutagen. It is the most dangerous form of chromium compounds. Once in metallic form, such as hard chrome plate, chromium is not considered a significant environmental problem. Other forms of chromium: metallic as in plated hard chrome, or as an ingredient in corrosion-resistant steels; trivalent, as in trivalent chrome conversion coatings or solutions, are not considered a significant health, safety, or environmental problem.

The new OSHA Cr^{6+} PEL (permissible exposure limit) issued on February 28, 2006 lowers the upper limit for exposure of workers to hexavalent chromium (as Cr) to 5 $\mu g\ m^{-3}$ from its previous 52 $\mu g\ m^{-3}$, measured as 8-h time-weighted averages. This drastic reduction affects any industrial process that could generate Cr^{6+} air emissions, including hard chrome plating, chromic acid anodizing, priming and painting, chromate conversion, welding, and rework of materials containing chromium. The limit applies to all forms of Cr^{6+}, including chromium trioxide, chromic acid and chromates.

In addition to reducing the PEL for Cr^{6+}, the new OSHA rule places a number of burdens on employers, who are now required to:

- Monitor employee exposure to Cr^{6+}
- Establish separate regulated areas when Cr^{6+} levels are expected to exceed the PEL
- Provide respirators for workers exposed above the PEL
- Provide other PPE (personal protective equipment) as necessary for eye and skin protection, together with change rooms and wash facilities
- Institute housekeeping activities to control spills and releases of Cr^{6+}
- Provide medical surveillance for employees who are exposed above the PEL, show signs or symptoms of Cr^{6+} exposure, or are exposed in an emergency
- Train workers about Cr^{6+} hazards, and use signs and labels to communicate the hazards
- Keep records of exposure, surveillance and training.

The PEL action level, which is the threshold that determines when ongoing monitoring is necessary, is 50% of the PEL or 2.5 µg m^{-3}. However, if Cr^{6+} concentrations are shown to be <0.5 µg m^{-3} under all expected conditions, then the OSHA rule does not apply at all.

The Environmental Protection Agency (EPA) has finalized a National Emission Standard for Hazardous Air Pollutants (NESHAP) that includes coating operations at aerospace manufacturing and rework facilities. The standard requires existing and new major sources to control emissions to the level achievable by the Maximum Achievable Control Technology (MACT) consistent with section 112(d) of the Clean Air Act. The Hazardous Air Pollutants (HAPs) covered by this final rule include chromium, cadmium, methylene chloride, toluene, xylene, methyl ethyl ketone, ethylene glycol and glycol ethers. For existing sources, the requirements of this rule became effective September 1998. The NESHAP limits on VOC are 420 g/L for topcoats and 350 g/L for primers.

2. APPLICABLE DOCUMENTS

2.1 Applicable Regulations

- Occupational Exposure to Hexavalent Chromium – Federal Register #71:10099-10385, issued 28-Feb-2006.
- Occupational Safety & Health Act, 19 U.S.C. s/s 61 et seq (1970)
- Clean Air Act, 42 U.S.C. s/s 7401 et seq (1970)
- Clean Water Act, 33 U.S.C. s/s 121 et seq (1977)
- Pollution Prevention Act, 42 U.S.C. s/s 1361 et seq (1990) - includes listing of EPA 17 Industrial Toxics

The Fall 2000 EPA/OSHA Unified Agenda Includes the following items:

Directive 1.2.3.3 – “Amendments to the Aerospace Manufacturing and Rework Facilities NESHAP for the HAP and VOC Content Limits for Primer Operations and Stay of Compliance”

Directive 2.1.1.1 – “Effluent Guidelines and Standards for the Metal Products and Machinery Category, Phase 1 and 2”

Directive 1.2.8.1 – "NESAHP: Miscellaneous Metal Parts and Products (Surface Coating)"

Directive 4.1.1.1 – "Hazardous Waste Identification Rule: Identification and Listing of Hazardous Wastes"

Directive 1.2.5.1 – "MACT (Maximum Achievable Control Technology) Standards Review (Residual Air Toxics Risk)"

Directive 3.1.1.7 – "Occupational Exposure to Hexavalent Chromium (Preventing Occupational Illness: Chromium)"

2.2 Sources of Data

"High Strength Steel Joint Test Protocol for Validation of Alternatives to Low Hydrogen Embrittlement Cadmium for High Strength Steel Landing Gear and Component Applications", Report of Phase I of III, Joint Cad Alternative Team, July 2003

"Validation of Alternatives to Electrodeposited Cadmium for Corrosion Protection and Threaded Part Lubricity Applications", Engineering and Technical Services for Joint Group on Pollution Prevention (JG-PP) Projects Joint Test Report BD-R-1-1, December 9, 2002.

"Elimination of Environmentally Hazardous Materials From the Landing Gear Overhaul Process", Boeing Report MDC 98X0003 rev A, March 1999.

"Pollution Prevention Through Source Elimination: Environmentally Compliant Part Processing Sequence", Boeing Report MDA 98P0067, October 1998.

"C-17 Pollution Prevention Non Chromated Primer Tests Report JGAPP/MDA Pilot Program", Boeing Report MDC 98X0012, April 1997.

"C-17 Airlifter Weapon System Pollution Prevention Program", contract CCP no. C-17A-0190C1 Task Order 012, September 1997.

2.3 Specifications

2.3.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AMS 2417E Plating, (Alkaline) Zinc-Nickel Alloy

AMS 6345 Steel, Sheet, Strip, and Plate 0.95Cr - 0.20Mo (0.28-0.33C) (SAE 4130) Normalized or Otherwise Heat Treated

AMS 6350 Steel, Sheet, Strip, and Plate 0.95Cr - 0.20Mo (0.28-0.33C) (SAE 4130)

AMS 6351 Steel, Sheet, Strip, and Plate 0.95Cr - 0.20Mo (0.28-0.33C) (SAE 4130) Spheroidized

AMS 6417E Steel, Bars, Forgings, and Tubing … Electrode Vacuum Remelted

2.3.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM E 8	Standard Test Methods for Tension Testing of Metallic Materials
ASTM G 85	Standard Practice for Modified Salt Spray (Fog) Testing
ASTM B 117	Standard Practice for Operating Salt Spray (Fog) Apparatus
ASTM F 519	Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation
ASTM D 1654	Evaluation … Specimens Subjected to Corrosive Environments
ASTM D 2794	Standard Test Method for Resistance … Effects of Rapid Deformation
ASTM D 3359	Standard Test Methods for Measuring Adhesion by Tape Test

2.3.3 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

QQ-P-416	Plating, Cadmium, Electrodeposited
MIL-PRF-23377G	Primer Coatings: Epoxy, High Solids
MIL-R-81294	Remover, Paint, Epoxy, Polysulfide and Polyurethane Systems
MIL-PRF-83282D	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base
MIL-DTL-83488	Coating, Aluminum, Ion Vapor Deposited
MIL-PRF-85285C	Coating: Polyurethane, High Solids
MIL-PRF-85582C	Primer Coatings: Epoxy, Waterborne

2.3.4 Other Publications

BAC 5637	Plating, (Acid) Zinc Nickel Alloy
MMS 423	Low VOC - Low Density Epoxy Primer
PS 21313	Coating Adhesion Tests
DMS 1786	Primer, Epoxy, Fluid Resistant

3. REPLACEMENTS FOR CADMIUM

3.1 Historical Data – JCAT Test Data

This section is provided as reference material and covers the cad plating test program conducted by the Joint Cad Alternate team (JCAT) and discusses Phase I test results as reported in November 2005. Due to the this test program still being underway and only Phase I test results finalized for the downselection of further testing, only a summary of the test results and the test array are shown in this document. Additional details may be found in. “High Strength Steel Joint Test Protocol for Validation of Alternatives to Low Hydrogen Embrittlement Cadmium for High Strength Steel Landing Gear and Component Applications”, dated July 2003. Phase II testing is underway, however results will not be available until much later than release of this document revision. Test status may be checked at the Joint Group on Pollution Prevention (JG-PP) website at www.jgpp.com, under the Joint Cadmium Alternatives Team project.

These test results and recommendations should be used with caution as the test program has not been completed in its entirety and actual test results are not detailed and may not portray the specific requirements for all application conditions, which are not provided in this summary.

3.1.1 Candidates

Candidate cad plating alternatives were taken from recommendations from JCAT team members and consists of seven (7) primary and four (4) repair coatings. The following finishes were selected and tested:

Primary Coatings:

- Low Hydrogen Embrittlement (LHE) Cadmium (baseline cad plating)
- IVD Aluminum (baseline, unpeened)
- Sputtered Aluminum
- Electroplated Aluminum
- LHE Zn-Ni
- AlumiPlate
- “Acidic” Zn-Ni
- Sn-Zn

Repair Coatings

- Brush LHE Cadmium (SIFCO 2023) (baseline brush cad plating),
- Brush Zn-Ni (SIFCO 4018)
- Brush Sn-Zn (LDC 5030)
- Spray Sermetel 249/273

All candidate platings, coatings were applied to 0.5 mil thickness, post-plate bakeout (if applicable), chromate conversion coated, no underplate and surface preparation included abrasive grit blast, except for Sn-Zn.

3.1.2 Test Matrix and Acceptance Criteria

Subject test plan calls for three (3)-phases of testing as follows:

- Phase I: Hydrogen Embrittlement and Re-embrittlement
- Phase II: General Properties, Adhesion, Corrosion, Lubricity, Repairability
- Phase III: Fatigue

At time of release of this publication, only test results from Phase I are available and are summarized in Table 1A. Subject testing was conducted at NAVAIRPaxRiver and Army Research Lab and was conducted on the seven (7) primary and four (4) repair coatings noted in 3.1.1, and compared to a baseline of cad plated test specimens. Only candidates that pass Phase I acceptance criteria are scheduled for testing in Phase II as down selected by JCAT team members.

TABLE 1A - PHASE I TEST RESULTS AND ACCEPTANCE CRITERIA

Test	Test Results	Acceptance Criteria
Hydrogen Embrittlement	All candidates passed except for Sn-Zn. Note: Further testing (such as re-embrittlement) not conducted on Sn-Tn since it did not pass this test.	NFS of bare and coated specimens within 10 ksi of average reported by manufacturer for bare, and four of four specimens sustain 75% NFS for 200 h SLT without fracture; OR only one of four specimens fracture in less than 200 h and the remaining three sustain at least 1-h at 90%.
Hydrogen Re-Embrittlement	• Alumiplate performed best compared to all candidates, including LHE Cad. • LHE Zn-Ni also performed very well with only slight decrease in performance compared to LHE Cad. • IVD and Sputtered Aluminum performed similarly, both providing significantly less protection from in-service re-embrittlement than LHE Cad. • "Acidic" Zn-Ni provided the least protection.	• ASTM F 519 Type 1a.1 Notched Round Bars, 45/24/5 RSL Test • Average load and time to fracture greater than or equal to LHE Cad when tested in 1 MΩ reagent water. • Test specimens immersed in fluid entire length of test. • Loading profile: 45% NFS for 24 h, step 5% per hour until failure.
Hydrogen Re-Embrittlement/Stress Corrosion Cracking	• Lab reported that test was too severe to adequately discriminate coating performance. • Alumiplate outperformed all coatings by a large margin, including Cd.	• Reference GM 9540P • Based on time to failure for the cadmium plated test specimens.
Bend Adhesion	• IVD Aluminum, Brush LHE Cadmium and Sermetel 249/273 did not meet the acceptance criteria. • All others passed, however Alumiplate was noted to have minor peeling at a broken edge.	• No separation (flaking, peeling, or blistering) of the coating from the basis metal or from any underplating at the rupture edge. • Cracking is acceptable in the bend area if the coating cannot be peeled back with a sharp instrument. • Specimens are bent back through 180 degree rotation along centerline of specimen until coating or basis metal failure.

3.2 Historical Data – JG-PP Test Data

This section covers the cad plating test program conducted by Engineering and Technical Services for Joint Group on Pollution Prevention (JG-PP) and reported in 2002. Subject test program was approved by a committee comprised of representatives from Boeing and the U.S. government. Due to the length of this report, only a summary of the test results and the test array are shown in this document. Details may be found in “Validation of Alternatives to Electrodeposited Cadmium for Corrosion Protection and Threaded Part Lubricity Applications”, Engineering and Technical Services for Joint Group on Pollution Prevention (JG-PP) Projects Joint Test Report BD-R-1-1, December 9, 2002.

3.2.1 Candidates

Further testing is recommended to determine acceptability of the following coatings on threaded components, however test results under this program showed that zinc-nickel plating applied from either a Dipsol of America alkaline or Boeing process and IVD aluminum would be acceptable coatings to replace cadmium on component parts made of low strength steel (less than 200,000 lb/in^2 [ksi]), stainless steel, aluminum, and copper alloys. These three candidate coatings passed the tests of adhesion to substrate, corrosion resistance, and paint adhesion. Tin-zinc plating coupons showed red rust in the scribed corrosion test and developed resistance values greater than cadmium in the galvanic corrosion test. For this reason it cannot be recommended for use on component parts. IVD aluminum and Boeing zinc-nickel coatings passed the lubricity tests. The tin-zinc and alkaline zinc-nickel coatings on the fasteners were too thick rendering the test results for these coatings invalid. The run-on/break-away characteristics of the candidate coatings differ from that of cadmium.

For high strength steel applications (greater than 200-ksi-strength level) tin-zinc, IVD aluminum, and Boeing zinc-nickel are candidate coatings. These three coatings passed the sustained tensile load test in the as-coated condition and had equivalent performance to cadmium in the rotating beam fatigue test. The alkaline zinc-nickel plating failed sustained tensile load and showed decreased fatigue life relative to cadmium plating. The potential use of alkaline zinc-nickel plating on system critical components should be carefully reviewed. All of the candidate coatings showed acceptable processing characteristics, fluid resistance, and repairability. Zinc-nickel brush plating is recommended for use as a repair method on cadmium and all of the candidate coatings tested during this study.

These test results and recomendations should be used with caution as the actual test results are not detailed and may not portray the specific requirements for all application conditions, which are not provided in this summary.

3.2.2 Test Matrix and Acceptance Criteria

Table 1B outlines the test matrix used for verifying the feasibility of using the candidate coatings listed in 3.1.1 in lieu of cadmium plating.

TABLE 1B - ENGINEERING AND PERFORMANCE TEST REQUIREMENTS

Engineering Requirement	Test	Application Categories	Acceptance Criteria	References
General Properties	Appearance	GS, TP	Coating is continuous, smooth, adherent, uniform in appearance, free from blisters, pits, nodules, burning, contaminants, excessive powder, and other apparent defects, which could reduce serviceability or protection.	AMS-QQ-P-416 (was FED-STD-QQ-P-416F)
General Properties	Bent Cathode Thickness Uniformity	GS, TP	Plating thickness remains within class when measured after plating. Composition of the coating must stay within the process range when measured using the X-ray Fluorescence Alloy Composition Uniformity Test.	AMS-QQ-P-416 (was FED-STD-QQ-P-416F)
General Properties	X-ray Fluorescence Alloy Composition Uniformity	GS	Composition stays within the process specification requirements.	ASTM B 568-91 ASTM E 1621
General Properties	Repairability	GS, TP	Repair performance meets or exceeds performance of experimental control specimens.	MIL-STD-865
Sacrificial Corrosion Protection	Unscribed Salt Spray (Fog) Sacrificial Corrosion Protection	GS, TP	Minimum of 3000 h exposure before appearance of red rust.	ASTM B 117-94
Sacrificial Corrosion Protection	Scribed Salt Spray (Fog) Sacrificial Corrosion Protection	GS	Minimum of 1000 h exposure before appearance of red rust.	ASTM B 117-94
Sacrificial Corrosion Protection	Galvanic Corrosion Resistance	GS, TP	Alternative meets or exceeds cadmium in appearance and corrosion resistance.	ASTM B 117-94
Corrosion Resistance (Fluid)	Fluid Corrosion Resistance	GS, TP	No coating degradation greater than that of cadmium plated control specimens.	MIL-PRF-5624 MIL-H-6083 MIL-H-53282
Adhesion	Bend Adhesion	GS	No separation (flaking, peeling, or blistering) from the basis metal or from any underplating at the rupture edge. Cracking is acceptable in the bend area if the coating cannot be peeled back with a sharp instrument.	ASTM B 571-91
Adhesion	Water Boil Adhesion	GS	No separation (flaking, peeling, or blistering) from the basis metal or from any underplating at the edge.	ASTM B 571-91
Adhesion (Paint)	Wet Tape Paint Adhesion	GS	Adhesion not less than that of the cadmium coated control specimens when immersed for 24 h at 23 °C.	ASTM D 3359-95 FED-STD-141C MIL-PRF-85582B
Lubricity	Run-on and Breakaway Torque	TP	During installation, the maximum locking torque shall not exceed 30 in-lb. During removal, the minimum breakaway torque shall not be less than 3.5 in-lb. After 15 cycles of the locking torque test, nut and bolt threads shall remain in serviceable condition; when examined at 10 times magnification, thread peel, missing segments, cracks, galling, or splits are unacceptable.	MIL-N-25027H MIL-STD-1312
Lubricity	Torque Tension	TP	Torque-tension for candidate material is within the range for cadmium plated fasteners. Fastener does not yield or fracture, threads do not strip.	MIL-N-25027H MIL-STD-1312
Resistance to Embrittlement	Sustained Tensile Load	GS	No test specimen fracture within the 200-h exposure time.	ASTM F 519-93
Fatigue Resistance	Rotating Beam	GS, TP	Fatigue values to be comparable to cadmium plated coupons.	ASTM E 468 ISO 1143
Temperature Requirements	Temperature Limitations	GS, TP	Temperature limitation shall be suitable for the intended application.	None

Engineering Requirement	Test	Application Categories	Acceptance Criteria	References
General Properties	Strippability	GS, TP	Candidate coating should be removed from the test coupon in two hours or less using appropriate removal method, such that the surface meets requirements of MIL-S-5002D. Reapplied coating meets the Acceptance Criteria of Section 3.1.9 Bend Adhesion.	ASTM B 571-91
Sacrificial Corrosion Protection	Scribed SO2 Salt Spray	GS, TP	No blistering or lifting of coating greater than control specimens. No substrate corrosion greater than control specimens.	ASTM D 1654-92
Sacrificial Corrosion Protection	Scribed Carrier Exposure Corrosion Resistance	GS	No blistering or lifting of coating. No excessive substrate corrosion after one carrier deployment (6 months to 12 months).	ASTM D 1654-92
Fatigue	Tension-Tension Fatigue	GS, TP	Fatigue values to be comparable to cadmium plated coupons.	ASTM E 4 ASTM E 380 ASTM E 467

GS = general surface applications
TP = threaded part applications

3.3 Historical Data – Boeing Test Reports

This section covers historical test data for potential cad plating replacements based upon Boeing reports through 1999 and was included in the original publication of this document.

3.3.1 Candidates

LE Cad (Baseline): Boeing PS13144 (QQ-P-416 equivalent). Iridite 8-P is used for chromate conversion coating unless otherwise specified.

IVD Aluminum: Ion vapor deposited aluminum per MIL-DTL-83488; requires dedicated vacuum chamber; cannot be applied to deep internal surfaces. No environmental hazard other than the possible use of chromated conversion coatings although non-chromated conversion coatings are acceptable. Iridite 14-2 is used for conversion coating unless otherwise specified.

Alkaline ZnNi: AMS 2417E w/ 24 hour hydrogen removal bake, chemical bath process. Zinic IZ-260 is the plating product name. Ni is a potential future hazard for EPA. Zinic IZ-268S is the conversion coating unless otherwise specified.

Acid ZnNi: BAC 5637, chemical bath process. Current specification limits use to low strength steels (<220 ksi) only. Ni is a potential future hazard for EPA. Corroban is the conversion coating unless otherwise specified.

Sermetel 984/985: Aluminum ceramic coating; 984 is primary coat; 985 is seal coat. Both coatings contain Cr, 985 is easily removed by mechanical means.

SnZn: BAC 5899, chemical bath process. Current specification limits use to low strength steels ($\leq$180 ksi) and not for use with electrical applications (enclosures and connectors).

Sputtered Aluminum: Aluminum deposition by linear magnetron sputtering.

Xylar 1/101: Aluminum ceramic coating. Xylar 1 is the base coat, while Xylar 101 is the seal coat.

Alseal 518: Aluminum ceramic coating. Alseal 598 is the seal coat.

Sermetel 249: Aluminum ceramic coating. Recommended as brush repair.

Sifco 4018: ZnNi brush repair to be used with the Zn-Ni plating process. Sifco 5030 is the conversion coating. Ni is a potential future hazard for EPA.

EM 6287: from EM Lubricants Inc.

3.3.2 Unscribed Neutral Salt Corrosion Resistance

Conclusions: Most candidates were satisfactory with respect to the cadmium baseline except for Sermetel 984 by itself, EM6287, and Alseal 518SC. All repair systems performed very well except for Sermetel 249 over the alkaline ZnNi.

In the Table 1C tests, 4 in x 6 in 0.040 thick panels were used as the test specimens. The panel material was 4130 steel in the normalized state per AMS 6345, AMS 6350, or AMS 6351. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. The testing consists of exposing the test panels to a pH neutral corrosive environment in a test chamber over an extended period of time. Red rust is the failure criterion.

In the Table 2 tests, 4 in x 6 in 0.040 thick panels were used as the test specimens. The panel material was 4130 steel in the normalized state per AMS 6345, AMS 6350, or AMS 6351. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. The testing consists of exposing the test panels to a pH neutral corrosive environment in a test chamber over an extended period of time. Red rust is the failure criterion.

In the Table 3 tests, 4 in dia. 0.065 in thick tubes were used as the test specimens. The tube material was welded low carbon steel sheet per SAE 1010. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. The testing consists of exposing the test panels to a pH neutral corrosive environment in a test chamber over an extended period of time. Red rust is the failure criterion.

In the Table 4 tests, 4 in x 6 in 0.040 thick panels were used as the test specimens. The panel material was 4130 steel in the normalized state per AMS 6345, AMS 6350, or AMS 6351. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. The testing consists of exposing the test panels to a pH neutral corrosive environment in a test chamber over an extended period of time. Red rust is the failure criterion.

TABLE 1C - UNSCRIBED NEUTRAL SALT CORROSION RESISTANCE

Reference: ASTM B117
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: McDonnell Douglas, 1996

System	Specimen	Results Hrs to Failure	Prepared by	Comments
LE Cad	4130 panel	10000	MDA	
LE Cad	4130 panel	10000	MDA	
LE Cad	4130 panel	10000	MDA	
LE Cad	4130 panel	10000	MDA	
IVD Alum	4130 panel	10000	MDA	
IVD Alum	4130 panel	10000	MDA	
IVD Alum	4130 panel	10000	MDA	
IVD Alum	4130 panel	10000	MDA	
ZnNi (BAC5637)	4130 panel	10000	Pure	
ZnNi (BAC5637)	4130 panel	10000	Pure	
ZnNi (BAC5637)	4130 panel	10000	Pure	
ZnNi (BAC5637)	4130 panel	10000	Pure	
Serm 984 / 985	4130 panel	10000	Sermatech	
Serm 984 / 985	4130 panel	10000	Sermatech	
Serm 984 / 985	4130 panel	10000	Sermatech	
Serm 984 / 985	4130 panel	10000	Sermatech	
ZnNi (AMS 2417E)	4130 panel	8106	Courter Hall	Dipsol Gumm
ZnNi (AMS 2417E)	4130 panel	8106	Courter Hall	Dipsol Gumm
ZnNi (AMS 2417E)	4130 panel	6066	Central Metal	McGean Rocho
ZnNi (AMS 2417E)	4130 panel	4386	Central Metal	McGean Rocho
ZnNi (AMS 2417E)	4130 panel	3384	Courter Hall	Dipsol Gumm
ZnNi (AMS 2417E)	4130 panel	2284	Courter Hall	Dipsol Gumm

TABLE 2 - UNSCRIBED NEUTRAL SALT CORROSION RESISTANCE

Reference: ASTM B117
Source: USAF C-17 Pollution Prevention Program
Tested by: McDonnell Douglas, 1997

System	Specimen	Results Hrs to Failure	Prepared by	Comments
Serm 984/985	4130 panel	> 4000		
Serm 984/985	4130 panel	> 4000		
Serm 984/985	4130 panel	> 4000		
Serm 984/985	4130 panel	> 4000		
IVD + 518 / 598	4130 panel	> 4000		
IVD + 518 / 598	4130 panel	> 4000		
Alseal 518 / 598	4130 panel	> 4000		
Alseal 518 / 598	4130 panel	3120		
Zn-Ni (AMS 2417E)	4130 panel	3120		Dipsol Gumm
Zn-Ni (AMS 2417E)	4130 panel	2424		Dipsol Gumm
Zn-Ni (AMS 2417E)	4130 panel	2424		Dipsol Gumm
IVD + Alseal 518 SC	4130 panel	2424		
IVD + Serm 984/985	4130 panel	2304		
IVD + Xylar 1/101	4130 panel	2184		
IVD + EM 6287	4130 panel	2184		
IVD + EM 6287	4130 panel	2184		
Zn-Ni (AMS 2417E)	4130 panel	2112		Dipsol Gumm
Xylar 1/101	4130 panel	1776		
Xylar 1/101	4130 panel	1776		
Xylar 1/101	4130 panel	1776		
Xylar 1/101	4130 panel	1776		
LE Cad	4130 panel	1512		
LE Cad	4130 panel	1344		
E/M 6287	4130 panel	840		
E/M 6287	4130 panel	840		
E/M 6287	4130 panel	840		
IVD + Serm 984/985	4130 panel	840		
E/M 6287	4130 panel	744		
Alseal 518 SC	4130 panel	576		

TABLE 3 - UNSCRIBED NEUTRAL SALT CORROSION RESISTANCE

Reference: ASTM B117
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: McDonnell Douglas, 1997

System	Thick, mils	Specimen	Results Hrs to Failure	Prepared by	Comments
Sputtered Al		1010 tube	Pass 1680	Surface Solns	
Sputtered Al		1010 tube	Pass 1680	Surface Solns	
Sputtered Al		1010 tube	Pass 1680	Surface Solns	
Sputtered Al		1010 tube	Pass 1680	Surface Solns	
Ecoat + Boostercoat		1010 tube	Pass 1680	MDA	
Ecoat + Boostercoat		1010 tube	Pass 1680	MDA	
Ecoat + Boostercoat		1010 tube	Pass 1680	MDA	
Ecoat + Boostercoat		1010 tube	Pass 1680	MDA	
LE Cad		1010 tube	Pass 1680	MDA	
LE Cad		1010 tube	Pass 1680	MDA	
LE Cad		1010 tube	Pass 1680	MDA	
LE Cad		1010 tube	Pass 1680	MDA	
ZnNi (AMS 2417E)	0.55	1010 tube	Pass 1680	Courter Hall	Dipsol Gumm
ZnNi (AMS 2417E)	0.43	1010 tube	Pass 1680	Courter Hall	Dipsol Gumm
ZnNi (AMS 2417E)	0.82	1010 tube	Pass 1680	Courter Hall	Dipsol Gumm
ZnNi (AMS 2417E)	0.81	1010 tube	Pass 1680	Courter Hall	Dipsol Gumm
Serm 984	0.97	1010 tube	Pass 1680	Sermatech	
Serm 984	1.17	1010 tube	288	Sermatech	
Serm 984	1.24	1010 tube	480	Sermatech	
Serm 984	1.2	1010 tube	216	Sermatech	

TABLE 4 - UNSCRIBED NEUTRAL SALT CORROSION RESISTANCE

Reference: ASTM B117
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: McDonnell Douglas, 1997

System	Specimen	Results Hrs to Failure	Prepared by	Comments
Brush Cd / Cd	4130 panel	>10000	MDA	
Brush Cd / Cd	4130 panel	>10000	MDA	
Brush Cd / Cd	4130 panel	>10000	MDA	
Brush Cd / Cd	4130 panel	>10000	MDA	
Serm 249 / IVD	4130 panel	>10000	MDA	
Serm 249 / IVD	4130 panel	>10000	MDA	
Brush ZnNi / IVD	4130 panel	>10000	MDA	
Brush ZnNi / IVD	4130 panel	>10000	MDA	
Serm 249 / acid ZnNi	4130 panel	>10000	MDA	
Serm 249 / acid ZnNi	4130 panel	>10000	MDA	
Brush ZnNi / acid ZnNi	4130 panel	>10000	MDA	
Brush ZnNi / acid ZnNi	4130 panel	>10000	MDA	
Brush ZnNi / Serm	4130 panel	>10000	MDA	
Brush ZnNi / Serm	4130 panel	>10000	MDA	
Brush ZnNi / alk ZnNi	4130 panel	>10000	MDA	
Brush ZnNi / alk ZnNi	4130 panel	>10000	MDA	
Serm 249 / Serm	4130 panel	>10000	MDA	
Serm 249 / Serm	4130 panel	>10000	MDA	
Serm 249 / alk ZnNi	4130 panel	1536	MDA	
Serm 249 / alk ZnNi	4130 panel	912	MDA	

3.3.3 Scribed Neutral Salt Corrosion Resistance

Conclusions: Many candidates were satisfactory, but generally not equal to cadmium for sacrificial corrosion protection. The barrier coatings failed immediately as expected. The aluminum coatings (IVD and sputtered) performed well as did most of the ZnNi platings. Sermetel 984/985 had results ranging from extremely poor to very good.

In the Table 5 tests, 4 in x 6 in 0.040 thick panels were used as the test specimens. The panel material was 4130 steel in the normalized state per AMS 6345, AMS 6350, or AMS 6351. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. Scribed tests call for making an “x” scribe that penetrates to the substrate of the specimen using the ASTM D 1654 scribe tool. The testing consists of exposing the test panels to a pH neutral corrosive environment in a test chamber over an extended period of time. Red rust is the failure criterion.

In the Table 6 tests, 4 in x 6 in 0.040 thick panels were used as the test specimens. The panel material was 4130 steel in the normalized state per AMS 6345, AMS 6350, or AMS 6351. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. Scribed tests call for making an “x” scribe that penetrates to the substrate of the specimen using the ASTM D 1654 scribe tool. The testing consists of exposing the test panels to a pH neutral corrosive environment in a test chamber over an extended period of time. Red rust is the failure criterion.

In the Table 7 tests, 4 in dia. 0.065 in thick tubes were used as the test specimens. The panel material was welded low carbon steel sheet per SAE 1010. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. Scribed tests call for making an “x” scribe that penetrates to the substrate of the specimen using the ASTM D 1654 scribe tool. The testing consists of exposing the test panels to a pH neutral corrosive environment in a test chamber over an extended period of time. Red rust is the failure criterion.

In the Table 8 tests, 4 in dia. 0.065 in thick tubes were used as the test specimens. The panel material was welded low carbon steel sheet per SAE 1010. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. Scribed tests call for making an “x” scribe that penetrates to the substrate of the specimen using the ASTM D 1654 scribe tool. The testing consists of exposing the test panels to a pH neutral corrosive environment in a test chamber over an extended period of time. Red rust is the failure criterion.

3.3.4 SO_2 Corrosion Resistance

Conclusions: The cadmium baseline performs relatively poorly in the sulfuric corrosion tests and some candidates easily surpassed that performance. The best sacrificial systems were the aluminum coatings (IVD and sputtered) followed by the Sermetel system. The ZnNi platings’ performance was typically comparable to that of cadmium.

In the Table 9 tests, 4 in x 6 in 0.040 thick panels were used as the test specimens. The panel material was 4130 steel in the normalized state per AMS 6345, AMS 6350, or AMS 6351. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. The testing consists of exposing the test panels to an aggressive acidic corrosive environment in a test chamber over an extended period of time. Red rust is the failure criterion.

In the Table 10 tests, 4 in x 6 in 0.040 thick panels were used as the test specimens. The panel material was 4130 steel in the normalized state per AMS 6345, AMS 6350, or AMS 6351. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. The testing consists of exposing the test panels to an aggressive acidic corrosive environment in a test chamber over an extended period of time. Red rust is the failure criterion.

In the Table 11 tests, 4 in dia. 0.065 in thick tubes were used as the test specimens. The tube material was welded low carbon steel per SAE 1010. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. The testing consists of exposing the test panels to an aggressive acidic corrosive environment in a test chamber over an extended period of time. Red rust is the failure criterion.

TABLE 5 - SCRIBED NEUTRAL SALT CORROSION RESISTANCE

Reference: ASTM B117
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: McDonnell Douglas, 1996

System	Specimen	Results Hrs to Failure	Prepared by	Comments
Serm 984 / 985	4130 panel	5130	Sermatech	3rd attempt Sermetel
Serm 984 / 985	4130 panel	5130	Sermatech	3rd attempt Sermetel
Serm 984 / 985	4130 panel	5130	Sermatech	3rd attempt Sermetel
Serm 984 / 985	4130 panel	5130	Sermatech	3rd attempt Sermetel
LE Cad	4130 panel	2376	MDA	
LE Cad	4130 panel	2376	MDA	
LE Cad	4130 panel	2376	MDA	
LE Cad	4130 panel	2376	MDA	
IVD Alum	4130 panel	2376	MDA	
IVD Alum	4130 panel	2376	MDA	
ZnNi (BAC5637)	4130 panel	2376	Pure	
ZnNi (BAC5637)	4130 panel	2376	Pure	
ZnNi (BAC5637)	4130 panel	2376	Pure	
IVD Alum	4130 panel	1704	MDA	
IVD Alum	4130 panel	1368	MDA	
ZnNi (AMS 2417E)	4130 panel	1032	Courter Hall	Dipsol Gumm
ZnNi (AMS 2417E)	4130 panel	1032	Courter Hall	Dipsol Gumm
ZnNi (AMS 2417E)	4130 panel	1032	Courter Hall	Dipsol Gumm
ZnNi (BAC5637)	4130 panel	816	Pure	
ZnNi (AMS 2417E)	4130 panel	816	Courter Hall	Dipsol Gumm
ZnNi (AMS 2417E)	4130 panel	360	Central Metal	McGean Rocho
ZnNi (AMS 2417E)	4130 panel	360	Central Metal	McGean Rocho
Serm 984 / 985	4130 panel	24	Sermatech	1st attempt Sermetel
Serm 984 / 985	4130 panel	24	Sermatech	1st attempt Sermetel
Serm 984 / 985	4130 panel	24	Sermatech	1st attempt Sermetel
Serm 984 / 985	4130 panel	24	Sermatech	1st attempt Sermetel
Serm 984 / 985	4130 panel	24	Sermatech	2nd attempt Sermetel
Serm 984 / 985	4130 panel	24	Sermatech	2nd attempt Sermetel
Serm 984 / 985	4130 panel	24	Sermatech	2nd attempt Sermetel
Serm 984 / 985	4130 panel	24	Sermatech	2nd attempt Sermetel

TABLE 6 - SCRIBED NEUTRAL SALT CORROSION RESISTANCE

Reference: ASTM B117
Source: USAF C-17 Pollution Prevention Program
Tested by: McDonnell Douglas, 1997

System	Specimen	Results Hrs to Failure	Prepared by	Comments
LE Cad	4130 panel	> 5000		
LE Cad	4130 panel	> 5000		
LE Cad	4130 panel	> 5000		
LE Cad	4130 panel	> 5000		
IVD + 518/598	4130 panel	4584		
IVD + 518/598	4130 panel	3744		
IVD + Alseal 518	4130 panel	3120		
IVD + Alseal 518	4130 panel	3120		
ZnNi	4130 panel	2952		Dipsol Gumm
ZnNi	4130 panel	2928		Dipsol Gumm
ZnNi	4130 panel	2808		Dipsol Gumm
ZnNi	4130 panel	2592		Dipsol Gumm
IVD + Serm 984/985	4130 panel	2184		
IVD + Serm 984/985	4130 panel	2184		
IVD + Serm 984/985	4130 panel	2184		
IVD + Xylar 1/101	4130 panel	2184		
IVD + Xylar 1/101	4130 panel	2184		
IVD + Zn-Ni (AMS2417E)	4130 panel	1632		
IVD + Zn-Ni (AMS2417E)	4130 panel	1632		
IVD + Serm 984/985	4130 panel	1512		
SermeTel 984/985	4130 panel	1248		
IVD + E/M 6287	4130 panel	1248		
IVD + E/M 6287	4130 panel	1248		
IVD + E/M 6287	4130 panel	1248		
IVD + E/M 6287	4130 panel	1248		
SermeTel 984/985	4130 panel	1128		
SermeTel 984/985	4130 panel	744		
SermeTel 984/985	4130 panel	672		
Xylar 1/101	4130 panel	576		
Xylar 1/101	4130 panel	312		
Xylar 1/101	4130 panel	312		
Alseal 518 SC	4130 panel	264		
Alseal 518 SC	4130 panel	216		
E/M 6287	4130 panel	72		
E/M 6287	4130 panel	72		
E/M 6287	4130 panel	72		
E/M 6287	4130 panel	72		
Alseal 518 SC/598	4130 panel	72		
Alseal 518 SC/598	4130 panel	72		
Xylar 1/101	4130 panel	72		

TABLE 7 - SCRIBED NEUTRAL SALT CORROSION RESISTANCE

Reference: ASTM B117
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: McDonnell Douglas, 1997

System	Thick, mils	Specimen	Results Hrs to Failure	Prepared by	Comments
Sputtered Al	0.69	1010 Tube	2000+	Surface Solns	
Sputtered Al	0.56	1010 Tube	2000+	Surface Solns	
LE Cad		1010 Tube	2000+	MDA	
LE Cad		1010 Tube	2000+	MDA	
LE Cad		1010 Tube	2000+	MDA	
ZnNi (AMS 2417E)	0.71	1010 Tube	1368	Courter Hall	
LE Cad		1010 Tube	1170	MDA	
ZnNi (AMS 2417E)	0.65	1010 Tube	1104	Courter Hall	
Sputtered Al	0.69	1010 Tube	1008	Surface Solns	
Sputtered Al	0.52	1010 Tube	1008	Surface Solns	
ZnNi (AMS 2417E)	0.71	1010 Tube	1008	Courter Hall	
ZnNi (AMS 2417E)	0.67	1010 Tube	960	Courter Hall	
Sermetel 984	0.92	1010 Tube	216	Sermatech	
Sermetel 984	1.07	1010 Tube	192	Sermatech	
Sermetel 984	1.19	1010 Tube	120	Sermatech	
Sermetel 984	0.93	1010 Tube	24	Sermatech	
Ecoat + Boostercoat		1010 Tube	24	MDA	Barrier for IVD
Ecoat + Boostercoat		1010 Tube	24	MDA	Barrier for IVD
Ecoat + Boostercoat		1010 Tube	24	MDA	Barrier for IVD
Ecoat + Boostercoat		1010 Tube	24	MDA	Barrier for IVD

TABLE 8 - SCRIBED NEUTRAL SALT CORROSION RESISTANCE, PUDDING

Reference: ASTM B117
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: McDonnell Douglas, 1997

System	Thick, mils	Specimen	Results Hrs to Failure	Prepared by	Comments
LE Cad		1010 Tube	3000	MDA	
LE Cad		1010 Tube	3000	MDA	
Sputtered Al	0.63	1010 Tube	3000	Surface Solns	
ZnNi (AMS 2417E)	0.58	1010 Tube	2520	Courter Hall	
Sputtered Al	0.54	1010 Tube	2020	Surface Solns	
ZnNi (AMS 2417E)	0.76	1010 Tube	1032	Courter Hall	
Sermetel 984	1.14	1010 Tube	24	Sermatech	
Sermetel 984	1.09	1010 Tube	24	Sermatech	
Ecoat + Boostercoat		1010 Tube	24	MDA	Barrier for IVD
Ecoat + Boostercoat		1010 Tube	24	MDA	Barrier for IVD

TABLE 9 - UNSCRIBED SO_2 CORROSION RESISTANCE

Reference: ASTM G85
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: McDonnell Douglas, 1996

System	Specimen	Results Hrs to Failure	Prepared by	Comments
IVD Alum	4130 panel	2016	MDA	
IVD Alum	4130 panel	1344	MDA	
Serm 984 / 985	4130 panel	1200	Sermatech	
Serm 984 / 985	4130 panel	1200	Sermatech	
Serm 984 / 985	4130 panel	1104	Sermatech	
IVD Alum	4130 panel	936	MDA	
IVD Alum	4130 panel	936	MDA	
Serm 984 / 985	4130 panel	696	Sermatech	
LE Cad	4130 panel	112	MDA	
LE Cad	4130 panel	96	MDA	
LE Cad	4130 panel	96	MDA	
LE Cad	4130 panel	96	MDA	
ZnNi (BAC5637)	4130 panel	72	Pure	
ZnNi (BAC5637)	4130 panel	72	Pure	
ZnNi (BAC5637)	4130 panel	72	Pure	
ZnNi (AMS 2417E)	4130 panel	72	Courter Hall	
ZnNi (BAC5637)	4130 panel	48	Pure	
ZnNi (AMS 2417E)	4130 panel	48	Courter Hall	
ZnNi (AMS 2417E)	4130 panel	48	Courter Hall	
ZnNi (AMS 2417E)	4130 panel	48	Courter Hall	

TABLE 10 - UNSCRIBED SO_2 CORROSION RESISTANCE

Reference: ASTM G85
Source: USAF C-17 Pollution Prevention Program
Tested by: McDonnell Douglas, 1997

System	Specimen	Results Hrs to Failure	Prepared by	Comments
IVD + EM 6287	4130 panel	672		
IVD + EM 6287	4130 panel	504		
Serm 984/985	4130 panel	384		
IVD + EM 6287	4130 panel	384		
Serm 984/985	4130 panel	312		
Serm 984/985	4130 panel	312		
IVD + Xylar 1/101	4130 panel	312		
IVD + Xylar 1/101	4130 panel	312		
IVD + EM 6287	4130 panel	312		
Alseal 518 SC	4130 panel	240		
E/M 6287	4130 panel	240		
E/M 6287	4130 panel	240		
E/M 6287	4130 panel	240		
E/M 6287	4130 panel	240		
IVD + Xylar 1/101	4130 panel	240		
IVD + Alseal 518 SC	4130 panel	240		
IVD + Alseal 518 SC	4130 panel	240		
IVD + 518/598	4130 panel	240		
IVD + Serm 984/985	4130 panel	192		
IVD + Xylar 1/101	4130 panel	192		
IVD + 518/598	4130 panel	192		
IVD + Serm 984/985	4130 panel	144		
IVD + Serm 984/985	4130 panel	144		
IVD + Serm 984/985	4130 panel	144		
Serm 984/985	4130 panel	144		
Alseal 518 / 598	4130 panel	96		
Alseal 518 / 598	4130 panel	96		
LE Cad	4130 panel	96		
LE Cad	4130 panel	96		
LE Cad	4130 panel	96		
LE Cad	4130 panel	96		
Xylar 1/101	4130 panel	96		
Xylar 1/101	4130 panel	96		
Xylar 1/101	4130 panel	96		
Xylar 1/101	4130 panel	96		
Zn-Ni (AMS 2417E)	4130 panel	96		
Zn-Ni (AMS 2417E)	4130 panel	96		
Zn-Ni (AMS 2417E)	4130 panel	96		
Zn-Ni (AMS 2417E)	4130 panel	96		
Alseal 518 SC	4130 panel	48		
IVD + ZnNi	4130 panel	48		
IVD + ZnNi	4130 panel	48		
IVD + ZnNi	4130 panel	48		
IVD + ZnNi	4130 panel	48		

TABLE 11 - UNSCRIBED SO_2 CORROSION RESISTANCE

Reference: ASTM G85
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: McDonnell Douglas, 1997

System	Thick, mils	Specimen	Results Hrs to Failure	Prepared by	Comments
Ecoat + Booster		1010 tube	3500+	MDA	
Ecoat + Booster		1010 tube	3500+	MDA	
Ecoat + Booster		1010 tube	3500+	MDA	
Ecoat + Booster		1010 tube	3500+	MDA	
Sputtered Al	0.78	1010 tube	912	Surface Solns	
Sputtered Al	0.85	1010 tube	768	Surface Solns	
Sputtered Al	0.71	1010 tube	648	Surface Solns	
Sputtered Al	0.63	1010 tube	648	Surface Solns	
Serm 984	0.99	1010 tube	216	Sermatech	
Serm 984	1.03	1010 tube	240	Sermatech	
Serm 984	1.15	1010 tube	120	Sermatech	
Serm 984	1.09	1010 tube	120	Sermatech	
ZnNi (AMS 2417E)	0.48	1010 tube	48	Courter Hall	Dipsol Gumm
ZnNi (AMS 2417E)	0.57	1010 tube	48	Courter Hall	Dipsol Gumm
ZnNi (AMS 2417E)	0.48	1010 tube	48	Courter Hall	Dipsol Gumm
ZnNi (AMS 2417E)	0.36	1010 tube	48	Courter Hall	Dipsol Gumm
LE Cad		1010 tube	48	MDA	
LE Cad		1010 tube	24	MDA	
LE Cad		1010 tube	24	MDA	
LE Cad		1010 tube	24	MDA	

3.3.5 Adhesion to Substrate

Conclusions: Care should be taken to draw conclusions from the following adhesion data as the test is extremely severe relative to the service environment. The brittle metallic ceramic coating of Sermetel was not expected to pass this test but its adhesion has been proven through other tests. Also, IVD aluminum routinely passes steel adhesion tests in production and these failures were likely due to processing problems. All the repair systems failed except for the ZnNi systems with ZnNi repair.

3.3.6 Hydrogen Embrittlement

Conclusions: Cadmium and IVD aluminum appear to pass HE testing regularly. Several repeat tests were required with different baking and processing steps to enable the Sermetel and ZnNi systems to pass reliably.

In the Table 14 tests, notched round bar were used as the test specimens. The material was AISI 4340 steel heat treated to attain 50-53 HRC. Specimen machining was performed by Dirats Laboratories using a special grinding technique, which minimizes compressive residual stresses. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. The success criterion for the standard dry test requires that the specimen withstand 200 h of sustained load at 75% of the notch fracture point.

In the Table 15 tests, notched round bar were used as the test specimens. The material was AISI 4340 steel heat treated to attain 50-53 HRC. Specimen machining was performed by Dirats Laboratories using a special grinding technique, which minimizes compressive residual stresses. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. The success criterion for the standard dry test requires that the specimen withstand 200 h of sustained load at 75% of the notch fracture point.

TABLE 12 - BEND TO BREAK ADHESION

Reference: QQ-P-416 rev F
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: McDonnell Douglas, 1996

System	Specimen	Results Pass or Fail	Prepared by	Comments
LE Cad	4130 coupon	Pass	MDA	
LE Cad	4130 coupon	Pass	MDA	
LE Cad	4130 coupon	Pass	MDA	
LE Cad	4130 coupon	Pass	MDA	
ZnNi (BAC5637)	4130 coupon	Pass	Pure	
ZnNi (BAC5637)	4130 coupon	Pass	Pure	
ZnNi (BAC5637)	4130 coupon	Pass	Pure	
ZnNi (BAC5637)	4130 coupon	Pass	Pure	
ZnNi (AMS 2417E)	4130 coupon	Pass	Courter Hall	
ZnNi (AMS 2417E)	4130 coupon	Pass	Courter Hall	
ZnNi (AMS 2417E)	4130 coupon	Pass	Courter Hall	
ZnNi (AMS 2417E)	4130 coupon	Pass	Courter Hall	
IVD Alum	4130 coupon	Fail	MDA	
IVD Alum	4130 coupon	Fail	MDA	
IVD Alum	4130 coupon	Fail	MDA	
IVD Alum	4130 coupon	Fail	MDA	
Serm 984 / 985	4130 coupon	Fail	Sermatech	
Serm 984 / 985	4130 coupon	Fail	Sermatech	
Serm 984 / 985	4130 coupon	Fail	Sermatech	
Serm 984 / 985	4130 coupon	Fail	Sermatech	
IVD Alum	4130 coupon	Fail	MDA	2nd attempt for IVD Alum
IVD Alum	4130 coupon	Fail	MDA	2nd attempt for IVD Alum
IVD Alum	4130 coupon	Fail	MDA	2nd attempt for IVD Alum
IVD Alum	4130 coupon	Fail	MDA	2nd attempt for IVD Alum

TABLE 13 - BEND TO BREAK ADHESION FOR REPAIRS

Reference: QQ-P-416 rev F
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: McDonnell Douglas, 1996

System	Specimen	Results Pass or Fail	Prepared by	Comments
BAC5637 + ZnNi	4130 coupon	Pass	Pure	
BAC5637 + ZnNi	4130 coupon	Pass	Pure	
AMS 2417E + ZnNi	4130 coupon	Pass	Courter Hall	
AMS 2417E + ZnNi	4130 coupon	Pass	Courter Hall	
BAC5637 + Serm 249	4130 coupon	Fail	Pure	
BAC5637 + Serm 249	4130 coupon	Fail	Pure	
AMS 2417E + Serm 249	4130 coupon	Fail	Courter Hall	
AMS 2417E + Serm 249	4130 coupon	Fail	Courter Hall	
Cad + brush Cd repair	4130 coupon	Fail	MDA	
Cad + brush Cd repair	4130 coupon	Fail	MDA	
Cad + brush Cd repair	4130 coupon	Fail	MDA	
Cad + brush Cd repair	4130 coupon	Fail	MDA	
IVD + ZnNi repair	4130 coupon	Fail	MDA	
IVD + ZnNi repair	4130 coupon	Fail	MDA	
IVD + Serm 249	4130 coupon	Fail	MDA	
IVD + Serm 249	4130 coupon	Fail	MDA	
Serm 984/985 + ZnNi	4130 coupon	Fail	Sermatech	
Serm 984/985 + ZnNi	4130 coupon	Fail	Sermatech	
Serm 984/985 + S249	4130 coupon	Fail	Sermatech	
Serm 984/985 + S249	4130 coupon	Fail	Sermatech	

TABLE 14 - HYDROGEN EMBRITTLEMENT

Reference: ASTM F519, Dry, Para. 3.1
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: Dirats Laboratories, 1996

System	Specimen	Results Pass or Fail	Prepared by	Comments
LE Cad	1a, 4340, Dirats	Pass	MDA	
LE Cad	1a, 4340, Dirats	Pass	MDA	
LE Cad	1a, 4340, Dirats	Pass	MDA	
LE Cad	1a, 4340, Dirats	Pass	MDA	
IVD Alum	1a, 4340, Dirats	Pass	MDA	
IVD Alum	1a, 4340, Dirats	Pass	MDA	
IVD Alum	1a, 4340, Dirats	Pass	MDA	
IVD Alum	1a, 4340, Dirats	Pass	MDA	
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	
ZnNi (BAC5637)	1a, 4340, Dirats	Pass	Central Metal Fin	
ZnNi (BAC5637)	1a, 4340, Dirats	Pass	Central Metal Fin	
ZnNi (BAC5637)	1a, 4340, Dirats	Pass	Central Metal Fin	
ZnNi (BAC5637)	1a, 4340, Dirats	Fail (64 hrs)	Central Metal Fin	
Serm 984 / 985	1a, 4340, Dirats	Fail (7.7 hrs)	Sermatech	
Serm 984 / 985	1a, 4340, Dirats	Fail (5 hrs)	Sermatech	
Serm 984 / 985	1a, 4340, Dirats	Pass	Sermatech	
Serm 984 / 985	1a, 4340, Dirats	Fail (9 hrs)	Sermatech	

TABLE 15 - HYDROGEN EMBRITTLEMENT

Reference: ASTM F519, Dry, Para. 3.1
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: OO-ALC, 1997

System	Specimen	Results Pass or Fail	Prepared by	Comments
Serm 984	1a, 4340, Dirats	Pass	Sermatech	Omission of 985 seal coat
Serm 984	1a, 4340, Dirats	Pass	Sermatech	Omission of 985 seal coat
Serm 984	1a, 4340, Dirats	Pass	Sermatech	Omission of 985 seal coat
Serm 984	1a, 4340, Dirats	Pass	Sermatech	Omission of 985 seal coat
Serm 984	1a, 4340, Dirats	Pass	Sermatech	Omission of 985 seal coat
Serm 984	1a, 4340, Dirats	Pass	Sermatech	Omission of 985 seal coat
Serm 984	1a, 4340, Dirats	Pass	Sermatech	Omission of 985 seal coat
Serm 984	1a, 4340, Dirats	Pass	Sermatech	Omission of 985 seal coat
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	addl 23 hr relief bake
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	addl 23 hr relief bake
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	addl 23 hr relief bake
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	addl 23 hr relief bake
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (0.5 hrs)	Courter Hall	
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (1.3 hrs)	Courter Hall	
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (1.3 hrs)	Courter Hall	
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (1.5 hrs)	Courter Hall	

In the Table 16 tests, notched round bar were used as the test specimens. The material was AISI 4340 steel heat treated to attain 50-53 HRC. Specimen machining was performed by Dirats Laboratories using a special grinding technique, which minimizes compressive residual stresses. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. The wet re-embrittlement test requires that the specimen be exposed to the embrittling agent (in this case Daraclean 232GF) while under 45% load, then withstand 200 h of sustained load at 75% of the notch fracture point.

In the Table 17 tests, notched round bar were used as the test specimens. The material was AISI 4340 steel heat treated to attain 50-53 HRC. Specimen machining was performed by Dirats Laboratories using a special grinding technique, which minimizes compressive residual stresses. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. The success criterion for the standard dry test requires that the specimen withstand 200 h of sustained load at 75% of the notch fracture point.

TABLE 16 - HYDROGEN EMBRITTLEMENT

Reference: ASTM F519, Wet Re-embrittlement, Appendix A5
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: OO-ALC, 1997

System	Specimen	Results Pass or Fail	Prepared by	Comments
Serm 984	1a, 4340, Dirats	Pass	Sermatech	
Serm 984	1a, 4340, Dirats	Pass	Sermatech	
Serm 984	1a, 4340, Dirats	Pass	Sermatech	
Serm 984	1a, 4340, Dirats	Pass	Sermatech	
Serm 984	1a, 4340, Dirats	Pass	Sermatech	
Serm 984	1a, 4340, Dirats	Pass	Sermatech	
Serm 984	1a, 4340, Dirats	Pass	Sermatech	
Serm 984	1a, 4340, Dirats	Pass	Sermatech	
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	after addl relief bake
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	after addl relief bake
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	after addl relief bake
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	after addl relief bake
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (4.3 hr)	Courter Hall	
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (4.2 hr)	Courter Hall	
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (3.7 hr)	Courter Hall	
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (198 hr)	Courter Hall	

TABLE 17 - HYDROGEN EMBRITTLEMENT

Reference: ASTM F519
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: OO-ALC, 1997

System	Specimen	Results Pass or Fail	Prepared by	Comments
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	48 hr bake after chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	48 hr bake after chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	48 hr bake after chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	48 hr bake after chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	24 hr bake after chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	24 hr bake after chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	24 hr bake after chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Pass	Courter Hall	24 hr bake after chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (8.3 hr)	Dipsol Gumm	24 hr bake before chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (17.8 hr)	Dipsol Gumm	24 hr bake before chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (11.7 hr)	Dipsol Gumm	24 hr bake before chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (8.3 hr)	Dipsol Gumm	24 hr bake before chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (0.1 hr)	Dipsol Gumm	3 hr bake before chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (0.1 hr)	Dipsol Gumm	3 hr bake before chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (0.1 hr)	Dipsol Gumm	3 hr bake before chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (0.1 hr)	Dipsol Gumm	3 hr bake before chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (22.2 hr)	Dipsol Gumm	24 hr bake after chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (15.2 hr)	Dipsol Gumm	24 hr bake after chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (22.0 hr)	Dipsol Gumm	24 hr bake after chromate
ZnNi (AMS 2417E)	1a, 4340, Dirats	Fail (17.8 hr)	Dipsol Gumm	24 hr bake after chromate

3.3.7 Fatigue Resistance

Conclusions: As expected, fatigue performance is not severely affected by the soft, ductile coatings such as cadmium and IVD aluminum. The hard metal platings had the poorest performance with the acid ZnNi fatigue lives well below those of the alkaline ZnNi or the Sermetel.

Category: Unnotched Fatigue Resistance

Reference: ASTM E 8, constant amplitude, R=+0.1

Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process

Specimens: 300M round bar specimens, AMS 6417 heat treated to 280 ksi, degreased and deoxidized prior to coating

Tested by: Dirats Laboratories, Westfield, MA

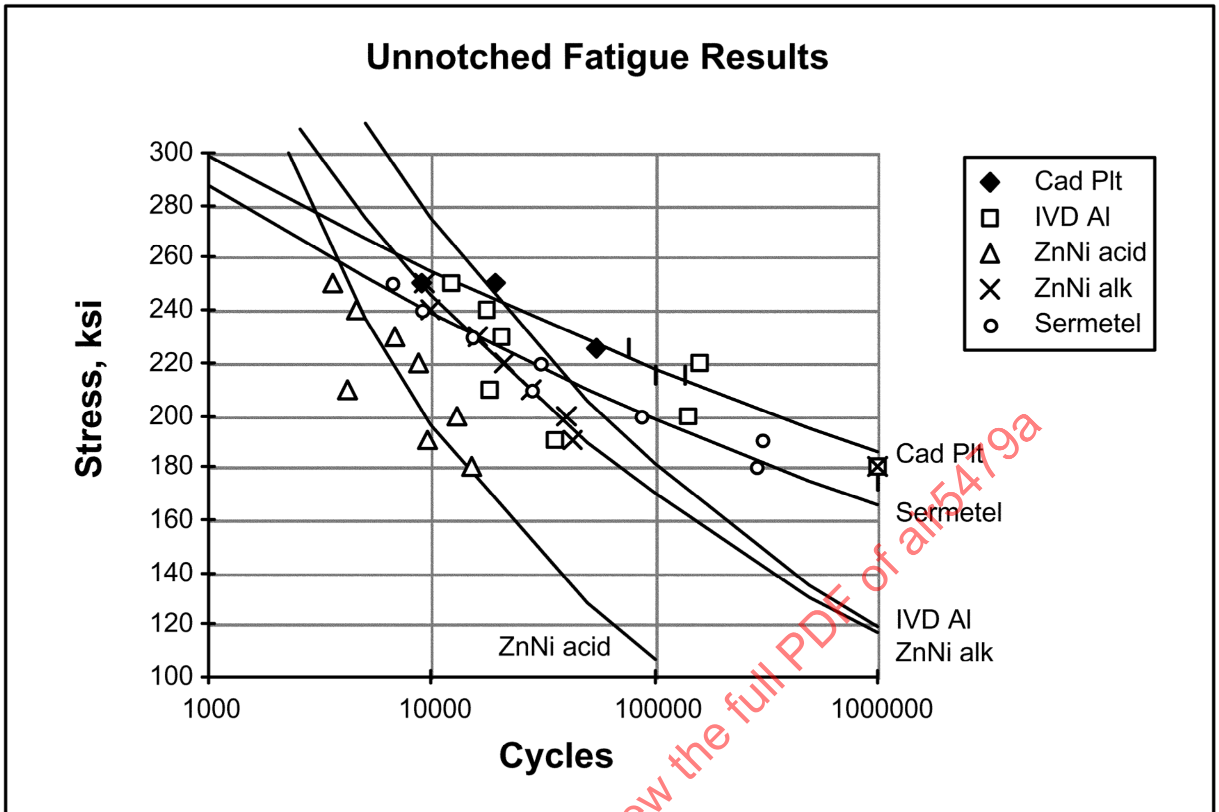

FIGURE 1 - UNNOTCHED FATIGUE RESULTS

Category: Notched Fatigue Resistance

Reference: ASTM E 8, constant amplitude, R=+0.1, Kt=3

Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process

Specimens: 300M round bar specimens, AMS 6417 heat treated to 280 ksi, degreased and deoxidized prior to coating

Tested by: Dirats Laboratories, Westfield, MA

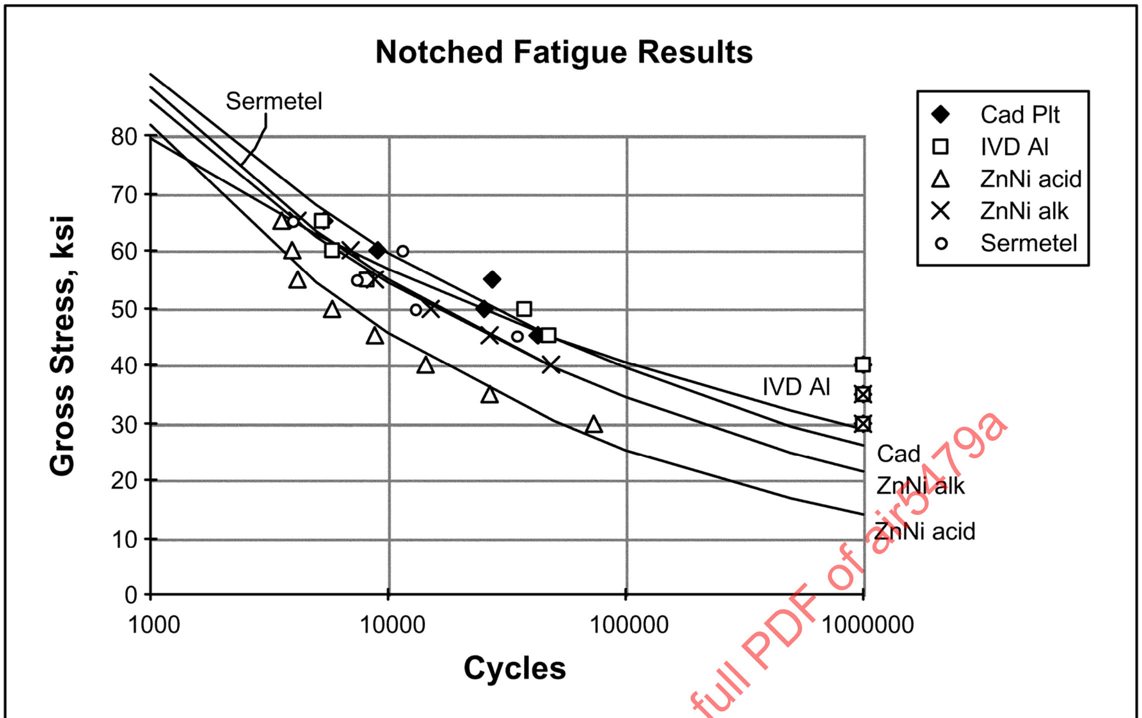

FIGURE 2 - NOTCHED FATIGUE RESULTS

3.3.8 Lubricity/Torque Tension

Conclusions: All candidates exhibited similar torque tension characteristics. Note: There are sufficient differences in Torque tension characteristics that exist between LE Cad and IVD Al, as well as any of the other candidates to warrant a case-by-case evaluation when considering changing from Cad to IVD, or other candidates.

In the Table 18 tests, four NAS 1308-10 bolts and four 47FLW-820 nuts were processed with each of the candidate replacements and with cadmium. The finished nuts were processed with a graphite dry film lubricant E/M 6286. MIL-T-5544 graphite petroleum lubricant was also brush applied to both the nuts and bolts prior to each of 15 remove/replace cycles. The test involved applying and measuring the torque required to reach a 20,000 lb tensile load.

3.3.9 Paint Adhesion

Conclusions: All candidates exhibited acceptable paint stripping characteristics.

In the Table 19 tests, 4 in x 6 in 0.040 in thick 4130 steel panels were processed with each of the candidate replacements. The panels were degreased and deoxidized with aluminum oxide grit prior to being primed with Deft 44GN36 epoxy primer. The panels were stripped using plastic bead media (MIL-R-81294 Type II urea, 12/16 mesh) at a pressure feed of 40 psi.

TABLE 18 - LUBRICITY/TORQUE TENSION

Reference: none
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: McDonnell Douglas, 1996

System	Specimen	Torque, in lb 1st Cycle	Torque, in lb 5th Cycle	Torque, in lb 10th Cycle	Torque, in lb 15th Cycle	Comments
Serm 984/985	nut/bolt, 20kips	875	885	860	860	
ZnNi (AMS 2417E)	nut/bolt, 20kips	770	875	875	850	
ZnNi (BAC 5637)	nut/bolt, 20kips	850	850	825	820	
IVD Alum	nut/bolt, 20kips	970	860	875	940	
LE Cad	nut/bolt, 20kips	750	800	810	850	

TABLE 19 - PAINT ADHESION, STRIPABILITY

Reference: none
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process
Tested by: McDonnell Douglas, 1996

System	Specimen	Results Avg. Stripping Time, sec		Comments
LE Cad	4130 panel	27	(3 panels)	PMB, 40 psi, 12/16 mesh
Serm 984/985	4130 panel	36	(1 panel)	PMB, 40 psi, 12/16 mesh
ZnNi (AMS 2417E)	4130 panel	37	(3 panels)	PMB, 40 psi, 12/16 mesh
IVD Alum	4130 panel	37	(4 panels)	PMB, 40 psi, 12/16 mesh
ZnNi (BAC 5637)	4130 panel	42	(3 panels)	PMB, 40 psi, 12/16 mesh

4. PRIMERS

4.1 Reverse Impact Flexibility

Conclusions: All candidates, except for the Ecoat, failed to meet the required impact energy level when the anodize was present. Without anodize, only the Ecoat and the control baseline consistently passed. As for the elongation test, the Ecoat would surely have passed, but of those tested, only the chromated baseline primer passed.

In the Table 20 tests, four 2024-T3 aluminum panels were sulfuric acid anodized and processed with each of the candidate primers. The panels were subjected to impact from a steel ball peen at increasing energy levels until primer failure occurred. The required energy level per MMS 423 is 20 in lb.

In the Table 21 tests, 2024-T3 aluminum panels were sulfuric acid anodized and processed with each of the candidate primers. The panels were subjected to increasing strain levels until primer failure occurred. The required elongation level per MIL-PRF-85582C is 10%.

In the Table 22 tests, four 2024-T3 bare aluminum panels were processed with each of the candidate primers. The panels were subjected to impact from a steel ball peen at increasing energy levels until primer failure occurred. The required energy level per MMS 423 is 20 in lb.

In the Table 23 tests, four 2024-T3 bare aluminum panels were processed with each of the candidate primers. The panels were subjected to impact from a steel ball peen at increasing energy levels until primer failure occurred. The required energy level per MMS 423 is 20 in lb.

TABLE 20 - REVERSE IIMPACT FLEXIBILITY

Reference: ASTM D2794
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process

System	Thick, mils	Results Impact, in-lb	Prepared by	Tested by	Test Date	Comments
Ecoat	0.58	80	MDA	MDA	1996	Cathoguard 310
Ecoat	0.54	80	MDA	MDA	1996	Cathoguard 310
Ecoat	0.55	80	MDA	MDA	1996	Cathoguard 310
Ecoat	0.56	80	MDA	MDA	1996	Cathoguard 310
Deft 44-GN-36	0.88	2	MDA	MDA	1996	
Deft 44-GN-36	0.87	2	MDA	MDA	1996	
Deft 44-W-16	0.98	2	MDA	MDA	1996	
Deft 44-GN-36	0.85	0	MDA	MDA	1996	
Deft 44-GN-36	0.85	0	MDA	MDA	1996	
Spraylat EWDY048	0.98	0	MDA	MDA	1996	
Spraylat EWDY048	0.82	0	MDA	MDA	1996	
Spraylat EWDY048	0.82	0	MDA	MDA	1996	
Spraylat EWDY048	0.68	0	MDA	MDA	1996	
Deft 44-W-16	1.10	0	MDA	MDA	1996	
Deft 44-W-16	1.04	0	MDA	MDA	1996	
Deft 44-W-16	0.90	0	MDA	MDA	1996	
Boostercoat	1.65	0	MDA	MDA	1996	
Boostercoat	1.67	0	MDA	MDA	1996	
Boostercoat	1.75	0	MDA	MDA	1996	
Boostercoat	1.80	0	MDA	MDA	1996	

TABLE 21 - PERCENT ELONGATION

Reference: MIL-PRF-85582C
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process

System	Thick, mils	Results % Elong	Prepared by	Tested by	Test Date	Comments
Deft 44-GN-36	0.85	10	MDA	MDA	1996	10% is Spec. Minimum
Deft 44-GN-36	0.90	10	MDA	MDA	1996	
Deft 44-GN-36	0.93	10	MDA	MDA	1996	
Deft 44-GN-36	0.78	10	MDA	MDA	1996	
Deft 44-W-16	1.06	5	MDA	MDA	1996	
Deft 44-W-16	1.02	5	MDA	MDA	1996	
Deft 44-W-16	1.17	5	MDA	MDA	1996	
Deft 44-W-16	1.09	5	MDA	MDA	1996	
Spraylat EWDY048	1.33	2	MDA	MDA	1996	
Spraylat EWDY048	1.40	2	MDA	MDA	1996	
Spraylat EWDY048	1.33	2	MDA	MDA	1996	
Spraylat EWDY048	1.20	2	MDA	MDA	1996	
Boostercoat	2.37	2	MDA	MDA	1996	
Boostercoat	2.41	2	MDA	MDA	1996	
Boostercoat	2.28	2	MDA	MDA	1996	
Boostercoat	2.39	2	MDA	MDA	1996	

TABLE 22 - REVERSE IMPACT FLEXIBILITY

Reference: ASTM D2794
Source: JGAPP (C-17 Pollution Prevention)

System	Specimen	Results	Tested by	Test Date	Comments
Courtaulds 513X332 / 910X457	bare 2024-T3	Pass	MDA	1996	control
Courtaulds 513X332 / 910X457	bare 2024-T3	Pass	MDA	1996	control
Deft 44-GN-36	bare 2024-T3	Pass	MDA	1996	control
Deft 44-GN-36	bare 2024-T3	Pass	MDA	1996	control
Courtaulds 515X386 / 910X831	bare 2024-T3	Pass	MDA	1996	control
Courtaulds 515X386 / 910X831	bare 2024-T3	Pass	MDA	1996	control
Spraylat EWDY048	bare 2024-T3	Pass	MDA	1996	Waterborne type I
Spraylat EWDY048	bare 2024-T3	Pass	MDA	1996	Waterborne type I
Deft 44-W-16	bare 2024-T3	Pass	MDA	1996	Waterborne type I
Deft 44-W-16	bare 2024-T3	Pass	MDA	1996	Waterborne type I
Deft 44-W-17	bare 2024-T3	Pass	MDA	1996	Waterborne type I
Deft 44-W-17	bare 2024-T3	Pass	MDA	1996	Waterborne type I
Crown Metro 10-PW22-2/ECW119	bare 2024-T3	Pass	MDA	1996	Waterborne type I
Crown Metro 10-PW22-2/ECW119	bare 2024-T3	Pass	MDA	1996	Waterborne type I
Ecoat: BASF G28AD012	bare 2024-T3	Pass	MDA	1996	Waterborne type I
Ecoat: BASF G28AD012	bare 2024-T3	Pass	MDA	1996	Waterborne type I
Sterling U-1201-NC/U-1202-F	bare 2024-T3	Pass	MDA	1996	High Solids
Sterling U-1201-NC/U-1202-F	bare 2024-T3	Pass	MDA	1996	High Solids
Spraylat EEAE136	bare 2024-T3	Pass	MDA	1996	High Solids
Spraylat EEAE136	bare 2024-T3	Pass	MDA	1996	High Solids
Crown Metro 10P22-3/EC-270	bare 2024-T3	Pass	MDA	1996	High Solids
Crown Metro 10P22-3/EC-270	bare 2024-T3	Pass	MDA	1996	High Solids
Spraylat EWDE 139A/EWAE 118B	bare 2024-T3	Pass	MDA	1996	Waterborne type II
Spraylat EWDE 139A/EWAE 118B	bare 2024-T3	Pass	MDA	1996	Waterborne type II
Courtaulds RW-3151/3151B001	bare 2024-T3	Fail	MDA	1996	Waterborne type I
Courtaulds RW-3151/3151B001	bare 2024-T3	Fail	MDA	1996	Waterborne type I
Sterling Lacquer U-4800-NC/U-4801	bare 2024-T3	Fail	MDA	1996	Waterborne type I
Sterling Lacquer U-4800-NC/U-4801	bare 2024-T3	Fail	MDA	1996	Waterborne type I
Lord Aeroglaze 9740	bare 2024-T3	Fail	MDA	1996	High Solids
Lord Aeroglaze 9740	bare 2024-T3	Fail	MDA	1996	High Solids

TABLE 23 - REVERSE IMPACT FLEXIBILITY

Reference: ASTM D2794
Source: JGAPP (C-17 Pollution Prevention)

System	Specimen	Results	Tested by	Test Date	Comments
Courtaulds 513X303 / 910X357	bare 2024-T3	Pass	MDA	1996	control
Courtaulds 513X303 / 910X357	bare 2024-T3	Pass	MDA	1996	control
Ecoat: BASF G28AD012	bare 2024-T3	Pass	MDA	1996	
Ecoat: BASF G28AD012	bare 2024-T3	Pass	MDA	1996	
Spraylat EWDY048	bare 2024-T3	Fail	MDA	1996	
Deft 44-W-16	bare 2024-T3	Fail	MDA	1996	
Deft 44-W-16	bare 2024-T3	Fail	MDA	1996	
Crown Metro 10-PW22-2/ECW119	bare 2024-T3	Fail	MDA	1996	
Crown Metro 10-PW22-2/ECW119	bare 2024-T3	Fail	MDA	1996	
Coutaulds RW-3181-64	bare 2024-T3	Fail	MDA	1996	
Coutaulds RW-3181-64	bare 2024-T3	Fail	MDA	1996	
Spraylat EWAE-118	bare 2024-T3	Fail	MDA	1996	
Spraylat EWAE-118	bare 2024-T3	Fail	MDA	1996	

4.2 Scribed Neutral Salt Corrosion

Conclusions: The baseline chromated primers were more successful in the scribed corrosion resistance tests. Of the non-chromated primers, only the Crown Metro was comparable to the baseline. On aluminum, the Boostercoat was the best of those primers tested.

In the Table 24 tests, four 7075-T6 aluminum panels were chromate conversion coated with Iridite 14-2 followed by application of each of the candidate primers. Panels were cured at room temperature for 2 weeks prior to test. The panels were scribed using an ASTM D 1654 scribe tool. The testing consisted of exposing the test panels to an aggressive acidic corrosive environment in a test chamber over an extended period of time. 2000 h exposure without any substrate corrosion is the success criterion of MIL-PRF-23377G and MIL-PRF-85582C.

In the Table 25 tests, three 4 inch x 6 inch x 0.040 inch thick steel panels were used as the test specimens. The panel material was 4130 steel in the normalized state per AMS 6345, AMS 6350, or AMS 6351. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. Panels were cured at room temperature for 2 weeks prior to test. The panels were scribed using an ASTM D 1654 scribe tool. 2000 hours exposure without any substrate corrosion is the success criterion of MIL-PRF-23377G and MIL-PRF-85582C.

TABLE 24 - SCRIBED NEUTRAL SALT CORROSION RESISTANCE

Reference: ASTM B117
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process

System	Thick, mils	Results Hrs to Failure	Prepared by	Tested by	Test Date	Comments
Deft 44-GN-36	0.88	Pass (>2000)	MDA	MDA	1996	
Deft 44-GN-36	0.92	Pass (>2000)	MDA	MDA	1996	
Deft 44-GN-36	0.97	Pass (>2000)	MDA	MDA	1996	
Deft 44-GN-36	1.03	Pass (>2000)	MDA	MDA	1996	
Boostercoat	2	Fail (1500)	MDA	MDA	1996	
Boostercoat	1.97	Fail (1500)	MDA	MDA	1996	
Boostercoat	1.95	Fail (1500)	MDA	MDA	1996	
Boostercoat	1.96	Fail (1500)	MDA	MDA	1996	
Spraylat EWDY048	0.83	Fail (1000)	MDA	MDA	1996	
Spraylat EWDY048	0.9	Fail (1000)	MDA	MDA	1996	
Spraylat EWDY048	0.85	Fail (1000)	MDA	MDA	1996	
Spraylat EWDY048	0.86	Fail (1000)	MDA	MDA	1996	
Deft 44-W-16	0.82	Fail (500)	MDA	MDA	1996	
Deft 44-W-16	0.91	Fail (500)	MDA	MDA	1996	
Deft 44-W-16	0.91	Fail (500)	MDA	MDA	1996	
Deft 44-W-16	0.9	Fail (500)	MDA	MDA	1996	
Ecoat	0.81	Fail (<500)	MDA	MDA	1996	
Ecoat	0.78	Fail (<500)	MDA	MDA	1996	
Ecoat	0.8	Fail (<500)	MDA	MDA	1996	
Ecoat	0.77	Fail (<500)	MDA	MDA	1996	

TABLE 25 - SCRIBED NEUTRAL SALT CORROSION RESISTANCE

Reference: ASTM B117
Source: JGAPP (C-17 Pollution Prevention)

System	Specimen	Results	Tested by	Test Date	Comments
Courtaulds 519X303 / 910X357	4130, Cd	Pass	MDA	1996	
Courtaulds 519X303 / 910X357	4130, Cd	Pass	MDA	1996	
Courtaulds 519X303 / 910X357	4130, Cd	Pass	MDA	1996	
Crown Metro 10-PW22-2/ECW119	4130, Cd	Pass	MDA	1996	
Crown Metro 10-PW22-2/ECW119	4130, Cd	Pass	MDA	1996	
Crown Metro 10-PW22-2/ECW119	4130, Cd	Pass	MDA	1996	
Deft 44-W-16	4130, Cd	Pass	MDA	1996	
Deft 44-W-16	4130, Cd	Pass	MDA	1996	
Deft 44-W-16	4130, Cd	Fail	MDA	1996	
Spraylat EWDY048	4130, Cd	Pass	MDA	1996	
Spraylat EWDY048	4130, Cd	Fail	MDA	1996	
Spraylat EWDY048	4130, Cd	Fail	MDA	1996	
Spraylat EWAE-118	4130, Cd	Pass	MDA	1996	
Spraylat EWAE-118	4130, Cd	Fail	MDA	1996	
Spraylat EWAE-118	4130, Cd	Fail	MDA	1996	
Coutaulds RW-3181-64	4130, Cd	Fail	MDA	1996	
Coutaulds RW-3181-64	4130, Cd	Fail	MDA	1996	
Coutaulds RW-3181-64	4130, Cd	Fail	MDA	1996	
Ecoat: BASF G28AD012	4130, Cd	Fail	MDA	1996	
Ecoat: BASF G28AD012	4130, Cd	Fail	MDA	1996	
Ecoat: BASF G28AD012	4130, Cd	Fail	MDA	1996	
Courtaulds 513X303 / 910X357	4130, IVD	Pass	MDA	1996	
Courtaulds 513X303 / 910X357	4130, IVD	Pass	MDA	1996	
Courtaulds 513X303 / 910X357	4130, IVD	Pass	MDA	1996	
Spraylat EWAE-118	4130, IVD	Pass	MDA	1996	
Spraylat EWAE-118	4130, IVD	Pass	MDA	1996	
Spraylat EWAE-118	4130, IVD	Pass	MDA	1996	
Crown Metro 10-PW22-2/ECW119	4130, IVD	Pass	MDA	1996	
Crown Metro 10-PW22-2/ECW119	4130, IVD	Pass	MDA	1996	
Crown Metro 10-PW22-2/ECW119	4130, IVD	Fail	MDA	1996	
Coutaulds RW-3181-64	4130, IVD	Pass	MDA	1996	
Coutaulds RW-3181-64	4130, IVD	Fail	MDA	1996	
Coutaulds RW-3181-64	4130, IVD	Fail	MDA	1996	
Deft 44-W-16	4130, IVD	Fail	MDA	1996	
Deft 44-W-16	4130, IVD	Fail	MDA	1996	
Deft 44-W-16	4130, IVD	Fail	MDA	1996	
Ecoat: BASF G28AD012	4130, IVD	Fail	MDA	1996	
Ecoat: BASF G28AD012	4130, IVD	Fail	MDA	1996	
Ecoat: BASF G28AD012	4130, IVD	Fail	MDA	1996	
Spraylat EWDY048	4130, IVD	Fail	MDA	1996	
Spraylat EWDY048	4130, IVD	Fail	MDA	1996	
Spraylat EWDY048	4130, IVD	Fail	MDA	1996	

4.3 Unscribed SO_2 Corrosion

Conclusions: Most non-chromated primers including Boostercoat, Ecoat, and the Crown Metro were superior to the baseline in this test. Boostercoat's success was possibly due to its unusually high thickness.

In the Table 25 tests, three 4 in x 6 in x 0.040 in thick steel panels were used as the test specimens. The panel material was 4130 steel in the normalized state per AMS 6345, AMS 6350, or AMS 6351. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. After being primed, panels were cured at room temperature for 2 weeks prior to test. The testing consisted of exposing the test panels to an aggressive acidic corrosive environment in a test chamber over an extended period of time. 500 h exposure without any substrate corrosion is the success criterion.

TABLE 26 - UNSCRIBED SO_2 CORROSION RESISTANCE

Reference: ASTM G85
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process

System	Thick, mils	Results Hrs to Failure	Prepared by	Tested by	Test Date	Comments
Boostercoat	2.03	2000	MDA	MDA	1996	
Boostercoat	2.37	2000	MDA	MDA	1996	
Boostercoat	2.21	2000	MDA	MDA	1996	
Boostercoat	2.38	2000	MDA	MDA	1996	
Ecoat	0.58	288	MDA	MDA	1996	Cathoguard 310
Ecoat	0.52	240	MDA	MDA	1996	Cathoguard 310
Ecoat	0.78	168	MDA	MDA	1996	Cathoguard 310
Spraylat EWDY048	1.53	150	MDA	MDA	1996	
Spraylat EWDY048	1.36	150	MDA	MDA	1996	
Spraylat EWDY048	1.29	150	MDA	MDA	1996	
Spraylat EWDY048	1.77	150	MDA	MDA	1996	
Ecoat	0.45	120	MDA	MDA	1996	Cathoguard 310
Deft 44-GN-36	1.33	100	MDA	MDA	1996	
Deft 44-GN-36	1.38	100	MDA	MDA	1996	
Deft 44-GN-36	1.51	100	MDA	MDA	1996	
Deft 44-GN-36	1.31	100	MDA	MDA	1996	
Deft 44-W-16	1.56	60	MDA	MDA	1996	
Deft 44-W-16	1.44	60	MDA	MDA	1996	
Deft 44-W-16	1.55	60	MDA	MDA	1996	
Deft 44-W-16	1.46	60	MDA	MDA	1996	

In the Table 25 tests, three 4 in x 6 in x 0.040 in thick panels were used as the test specimens. The panel material was 7075-T6 aluminum. Prior to coating, specimens underwent degrease and deoxidize with aluminum oxide grit. After being primed, panels were cured at room temperature for 2 weeks prior to test. The testing consisted of exposing the test panels to an aggressive acidic corrosive environment in a test chamber over an extended period of time. 500 h exposure without any substrate corrosion is the success criterion.

TABLE 27 - UNSCRIBED SO_2 CORROSION RESISTANCE

Reference: ASTM G85
Source: JGAPP

System	Specimen	Results	Tested by	Test Date	Comments
Ecoat: BASF G28AD012	7075-T6	Pass	MDA	1996	Cr conversion coat
Ecoat: BASF G28AD012	7075-T6	Pass	MDA	1996	Cr conversion coat
Ecoat: BASF G28AD012	7075-T6	Pass	MDA	1996	Cr conversion coat
Crown Metro 10-PW22-2/ECW119	7075-T6	Fail	MDA	1996	Cr conversion coat
Crown Metro 10-PW22-2/ECW119	7075-T6	Pass	MDA	1996	Cr conversion coat
Crown Metro 10-PW22-2/ECW119	7075-T6	Pass	MDA	1996	Cr conversion coat
Courtaulds 519X303 / 910X357	7075-T6	Pass	MDA	1996	Cr conversion coat
Courtaulds 519X303 / 910X357	7075-T6	Fail	MDA	1996	Cr conversion coat
Courtaulds 519X303 / 910X357	7075-T6	Fail	MDA	1996	Cr conversion coat
Deft 44-W-16	7075-T6	Fail	MDA	1996	Cr conversion coat
Deft 44-W-16	7075-T6	Fail	MDA	1996	Cr conversion coat
Deft 44-W-16	7075-T6	Fail	MDA	1996	Cr conversion coat
Coutaulds RW-3181-64	7075-T6	Fail	MDA	1996	Cr conversion coat
Coutaulds RW-3181-64	7075-T6	Fail	MDA	1996	Cr conversion coat
Coutaulds RW-3181-64	7075-T6	Fail	MDA	1996	Cr conversion coat
Spraylat EWDY048	7075-T6	Fail	MDA	1996	Cr conversion coat
Spraylat EWDY048	7075-T6	Fail	MDA	1996	Cr conversion coat
Spraylat EWDY048	7075-T6	Fail	MDA	1996	Cr conversion coat
Spraylat EWAE-118	7075-T6	Fail	MDA	1996	Cr conversion coat
Spraylat EWAE-118	7075-T6	Fail	MDA	1996	Cr conversion coat
Spraylat EWAE-118	7075-T6	Fail	MDA	1996	Cr conversion coat

4.4 Adhesion

Conclusions: A variety of replacement candidates had satisfactory adhesion performance.

In the Table 28 tests, 4 in x 6 in x 0.125 in thick bare 7075-T6 aluminum panels were used as the test specimens. Prior to primer, specimens were conversion coated with Iridite 14-2. After being primed, panels were cured at room temperature for 2 weeks prior to test. For test, the panels were scribed with a razor knife, creating a scribe pattern per ASTM D 3359 resulting in 100 small patches. Tape was applied to the patched surface and removed. The number of patches remaining after the tape is the success criterion.

In the Table 29 tests, 4 in x 6 in x 0.040 in thick bare 2024-T3 aluminum panels were used as the test specimens. Prior to primer, specimens were conversion coated with Iridite 14-2. After being primed, panels were cured at room temperature for 2 weeks prior to test. The wet tape adhesion test involves soaking the target area of the specimen with a wet cheesecloth for 24 h, followed by application and abrupt removal of tape. The test is successful if the primer remains attached to the specimen.

TABLE 28 - CROSS HATCH TAPE ADHESION

Reference: ASTM D3359, Method B
Source: USAF Elimination of Environmentally Hazardous Materials from the LG Overhaul Process

System	Thickness, mils	Results Pass or Fail	Prepared by	Tested by	Test Date	Comments
Deft 44-GN-36	0.92	Pass	MDA	MDA	1996	
Deft 44-GN-36	0.98	Pass	MDA	MDA	1996	
Deft 44-GN-36	0.90	Pass	MDA	MDA	1996	
Deft 44-GN-36	0.91	Pass	MDA	MDA	1996	
Spraylat EWDY048	0.69	Pass	MDA	MDA	1996	
Spraylat EWDY048	0.78	Pass	MDA	MDA	1996	
Spraylat EWDY048	0.90	Pass	MDA	MDA	1996	
Spraylat EWDY048	0.86	Pass	MDA	MDA	1996	
Deft 44-W-16	0.82	Pass	MDA	MDA	1996	
Deft 44-W-16	1.01	Pass	MDA	MDA	1996	
Deft 44-W-16	1.17	Pass	MDA	MDA	1996	
Deft 44-W-16	1.03	Pass	MDA	MDA	1996	
Boostercoat	1.98	Pass	MDA	MDA	1996	
Boostercoat	1.91	Pass	MDA	MDA	1996	
Boostercoat	1.89	Pass	MDA	MDA	1996	
Boostercoat	1.75	Pass	MDA	MDA	1996	
Ecoat	0.80	Pass	MDA	MDA	1996	BASF G28AD012-2
Ecoat	0.79	Pass	MDA	MDA	1996	BASF G28AD012-2
Ecoat	0.77	Pass	MDA	MDA	1996	BASF G28AD012-2
Ecoat	0.76	Pass	MDA	MDA	1996	BASF G28AD012-2

TABLE 29 - SCRIBED WET TAPE ADHESION

Reference: PS 21313
Source: JGAPP

System	Specimen	Results	Tested by	Test Date	Comments
Courtaulds 513X332 / 910X457	bare 2024-T3	Pass	MDA	1996	control
Courtaulds 513X332 / 910X457	bare 2024-T3	Pass	MDA	1996	control
Deft 44-W-16	bare 2024-T3	Pass	MDA	1996	Waterborne type I
Deft 44-W-16	bare 2024-T3	Pass	MDA	1996	Waterborne type I
Ecoat: BASF G28AD012	bare 2024-T3	Pass	MDA	1996	Waterborne type I
Ecoat: BASF G28AD012	bare 2024-T3	Pass	MDA	1996	Waterborne type I
Sterling U-1201-NC/U-1202-F	bare 2024-T3	Pass	MDA	1996	High Solids
Sterling U-1201-NC/U-1202-F	bare 2024-T3	Pass	MDA	1996	High Solids
Spraylat EEAE136	bare 2024-T3	Pass	MDA	1996	High Solids
Spraylat EEAE136	bare 2024-T3	Pass	MDA	1996	High Solids
Crown Metro 10P22-3/EC-270	bare 2024-T3	Pass	MDA	1996	High Solids
Crown Metro 10P22-3/EC-270	bare 2024-T3	Pass	MDA	1996	High Solids
Lord Aeroglaze 9740	bare 2024-T3	Pass	MDA	1996	High Solids
Lord Aeroglaze 9740	bare 2024-T3	Pass	MDA	1996	High Solids
Spraylat EWDE 139A/EWAE 118B	bare 2024-T3	Pass	MDA	1996	Waterborne type II
Spraylat EWDE 139A/EWAE 118B	bare 2024-T3	Pass	MDA	1996	Waterborne type II
Deft 44-GN-36	bare 2024-T3	Fail	MDA	1996	control
Deft 44-GN-36	bare 2024-T3	Fail	MDA	1996	control
Courtaulds 515X386 / 910X831	bare 2024-T3	Fail	MDA	1996	control
Courtaulds 515X386 / 910X831	bare 2024-T3	Fail	MDA	1996	control
Spraylat EWDY048	bare 2024-T3	Fail	MDA	1996	Waterborne type I
Spraylat EWDY048	bare 2024-T3	Fail	MDA	1996	Waterborne type I
Deft 44-W-17	bare 2024-T3	Fail	MDA	1996	Waterborne type I
Deft 44-W-17	bare 2024-T3	Fail	MDA	1996	Waterborne type I
Crown Metro 10-PW22-2/ECW119	bare 2024-T3	Fail	MDA	1996	Waterborne type I
Crown Metro 10-PW22-2/ECW119	bare 2024-T3	Fail	MDA	1996	Waterborne type I
Courtaulds RW-3151/3151B001	bare 2024-T3	Fail	MDA	1996	Waterborne type I
Courtaulds RW-3151/3151B001	bare 2024-T3	Fail	MDA	1996	Waterborne type I
Sterling Lacquer U-4800-NC/U-4801	bare 2024-T3	Fail	MDA	1996	Waterborne type I
Sterling Lacquer U-4800-NC/U-4801	bare 2024-T3	Fail	MDA	1996	Waterborne type I