



SURFACE FINISHING AND REPAIR ISSUES FOR SUSTAINING NEW MILITARY AIRCRAFT

**Workshop held February 26-28, 2008
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1. Agenda

Day 1, February 26		
Session 1. Introduction and general information on specific platforms		
Introduction - workshop purpose and structure	Keith Legg	Rowan
Intro to SERDP/ESTCP and ASETS Defense	Bruce Sartwell	SERDP/ESTCP
Management of toxic materials in DoD	Carole LeBlanc	Emerging Contaminants
Air Force Corrosion Prevention and Control Program	Capt. Daniel Doak	WR-ALC, AF Corrosion Office
F-35 philosophy for manufacture and sustainment, CuBe replacement	Scott Fetter, Robert Trice	Lockheed-Martin
Boeing Rotorcraft	Bob Schreiber, Douglas Knapp	Boeing
F-22 sustainability - Supporting mission and operational success	Arline Denny	Lockheed-Martin
Boeing Commercial Aircraft	Joe Osborne	Boeing
Session 2. New materials		
Corrosion resistant steels and CuBe alternatives	Charles Kuehmann	QuesTek Innovations
Progress on S53 for Rotary Gear Actuators	Ryan Josephson, Keith Legg	Ogden ALC, Rowan
Session 3. Cleaning		
Navy cleanability, corrosion and mildew issues	Craig Matzdorf	NAVAIR PAX
Joint Solvent Substitution Working Group	Wayne Ziegler	Army Research Lab
Dem-val of high performance CPCs for interiors	EI Sayed Arafat	NAVAIR PAX
Session 4. NDI		
Microwave NDE for detecting various conditions under coatings, inc corrosion, fasteners, and coating thickness	Gary Schmidt	SMRC
Infrared NDI of corrosion under coatings	John Weir	Northrop-Grumman
Laser-Ultrasonic Evaluation of Thermal Spray Coatings	Silvio Kruger	NRC-IMI

Day 2, February 27**Hard chrome replacements**

HVOF implementation issues for OEMs	Silvain St-Onge	Messier-Dowty
HVOF implementation at Hill AFB – update	Ryan Josephson and Richard Vander Straten	Hill AFB, ES3
Nano-Composite thermal spray alternative to Cd and Cr	Greg Engleman	Powdermet Inc
Cold Plasma, New levels of control over coating stress and Substrate Temperature	David Hawley	Sulzer Metco
Summary of HCAT Helicopter Dynamic Components Project	Keith Legg	Rowan
Repair of hard chrome and HVOF by brush Ni	Mary Gilman	Boeing
Properties of Electroless Ni deposits	Kurt Weamer	Electronic Chemicals OMG
Nanophase Co-P electroplate status	Diana Facchini	Integran Technologies
Development of nCo-P plating as a replacement for hard chrome for engine components	Nihad Ben-Salah	P&W Canada

Cd replacements

JCAT update on Cd alternatives	Elizabeth Berman, Steve Brown	AFRL
Results of Cd alternatives testing - PAX	Steve Brown	NAVAIR
AlumiPlate Cd alternative performance and usage on F-35 and F-22	Kelly Donaldson	AlumiPlate
Cd alternatives: ZnNi electroplate performance, repair of Al coatings	Steve Gaydos	Boeing, St Louis
Repair of IVD Al and Mg alloys using portable Kinetic Metallization	Ralph Tapphorn	Innovati
Low pressure cold spray systems for corrosion protection	Julio Villafuerte	Centerline Ltd
Nanostructured Zn-Ni alloys for Cd replacement on fasteners	Jonathan McCrea	Integran Technologies

Cr6+ surface treatments and process control

Getting good performance with Cr6+ alternative treatments	Steve Gaydos	Boeing
Surface preparation for repair bonding	Kay Blohowiak	Boeing Seattle
Non-chromate implementation	Craig Matzdorf	NAVAIR
Optimising tooling for plating processes	Alan Rose	Elsyca NV
Process analysis and control for minimizing waste in depot operations	Peter Gallerani	Integrated Technologies
Low Cr and non-Cr metallic-ceramics	Bruce Bodger	DemVal Inc.

Day 3, February 28**Systems and components**

PEWG developments	Mickey Conklin	PEWG
Precoated fasteners	Fred Lancaster	NAVAIR
NDI and repair of Tagnite coated Mg	Stephen (Scott) Howison	AMCOM
Cold spray for repair of Mg gearboxes and other applications	Phil Leyman	ARL

Paints, primers and sealants

Non-Cr primer performance and specification - F-35 Break	Robert Trice	Lockheed-Martin
U.S. Army Aviation & Missile Command Hexavalent Chromium Coatings Replacement Program	Paul Robinson	Mantech SRS
UV curable paint systems	Nese Orbey	Foster-Miller
Multifunctional UV coatings and Ce-based materials	Matt O'Keefe	U. Missouri - Rolla
Organic coatings projects	Mary Gilman	Boeing C-17
Environmentally advantaged powder coating for aerospace applications	Chris Geib	SAIC

Coating removal, stripping

Water jet stripping of HVOF and other coatings	Jay Randolph, Mohan Vijay	ES3, VLN Advanced Technologies
Compliant Removers for Aircraft Sealants and Specialty Coatings - ESTCP project ongoing	James Tankersley	Battelle

2. Workshop purpose

For 10 years or more the Hard Chrome Alternatives Team (HCAT) has been holding annual workshops to discuss the development and implementation of technologies for replacing hard chrome plate, with a primary focus on HVOF thermal spray. HVOF is now used in all new landing gear programs and many other aircraft components, both by OEMs and by overhaul shops. Thus the demonstration and validation of the technology, which had been primarily funded by SERDP and ESTCP, had ended successfully. However, the HCAT team was found to provide an excellent milieu for coordinating DoD and industry projects and sharing information at an engineering level. The HCAT was renamed Advanced Surface Engineering Technologies for a Sustainable Defense (ASETS Defense), reflecting its broader mission to develop and implement clean coatings and surface treatments of all kinds. This was the first workshop to follow on from the HCAT under the ASETS Defense organization.

With new military aircraft adopting cleaner and better materials and surface treatments, their sustainment presents new challenges. Some of the new materials and coatings require different technologies for flaw detection and repair (e.g. composite structures and HVOF coatings), while others require much greater emphasis on process control and surface cleanliness (e.g. Cr⁶⁺-free finishes). As DOD moves into the sustainment phase of all these new programs it is imperative that the most effective NDI methods be defined, and repair technologies be developed and approved that are clean, cost-effective and can be done at the depot and operational levels. This means that repair organizations must be able to handle the new materials, and inspect and repair them, without having to resort to the old standbys of chrome and Cd plating, chromate conversion, and other processes that create environmental and health problems. The workshop was designed to address the various technologies and issues related to the use and sustainment of clean materials on new aircraft.

This report is not intended to provide an exhaustive summary of the workshop, but rather to touch on some of the newest issues and findings. All of the briefings are attached to this report and can be referred to for more details.

3. Sustainment issues and technologies

New technologies are being brought into the DoD environment at both the OEM level in new weapons systems and at the sustainment level, through new coatings and treatments.

This summary is arranged by technology and application rather than by briefing.

3.1. New materials

New weapons systems are adopting a variety of new materials, often for reasons of weight or performance, but in some cases to overcome ESOH concerns.

3.1.1. Carbon Fiber Composites

Composites are being used increasingly for weight reduction in aircraft skins, airframes, blades, electrical boxes and electrical connectors. Right-sized repair kits are being adopted for composite repair in order to reduce waste volumes. Where composites are used in electrical systems, such as connectors and electrical boxes, a conductive coating is required for EMI control.

- AlumiPlate electroplated Al is now commercially available on connectors and being evaluated (as well as flame spray Al) for electrical boxes.
- Conductive gap fillers are required between composite OML panels on aircraft to maintain low observability. These compounds are currently filled with Ni, but new materials are being developed¹ because of ESOH concerns (unalloyed Ni is a restricted material for F-35).
- Lockheed reported a fluidized bed reactor method for disposing of composites with LO coatings.

3.1.2. High strength corrosion resistant steels

A new ultrahigh strength corrosion resistant steel called S53 has been developed as a Cd-free alternative for landing gear. The alloy was developed by QuesTek Innovations LLC under SERDP/ESTCP funding and is currently being validated for landing gear and rotary gear actuators^{2,3}. Its mechanical properties are essentially the same as 300M landing gear steel.

3.1.3. CuBe replacements

CuBe alloys are widely used for actuator bushings, but wear creates toxic Be dust. Lockheed reported two alternatives:

- Nitronic 60 for bushings <2.5" dia. (larger diameters cannot be cold worked sufficiently for strength). Nitronic 60 is now specified for most previously BeCu bushings on the F-35.
- CoCrMo (Biodur) appears to be significantly better than BeCu in functional

testing, and is not limited to small bushings. Test and evaluation are continuing¹.

3.2. Cleaning

Cleaning is becoming an increasingly important issue because many of the new surface treatments (particularly chromate conversion alternatives) require far cleaner surfaces for successful application. In addition, cleaners must work effectively with new materials and coatings without posing additional VOC, toxicity and waste issues.

NAVAIR is heavily involved in the development of better cleaners, mildew removers⁴ and paint and adhesive removers.

3.3. Corrosion control

Corrosion control is one of the major issues with sustainability, especially in view of the need to replace the old standbys of Cd and Cr⁶⁺.

3.3.1. Corrosion Preventive Compounds (CPCs)

CPCs are temporary corrosion control materials typically used to inhibit corrosion in complex areas such as under flooring or inside vehicle bays. NAVAIR has developed new, cleaner, better performing CPCs that are available under the trade name Navguard^{5,6}.

3.3.2. Cd alternatives

The most commonly used option for eliminating Cd plating is CRES alloys, such as composites, stainless steels and Ti alloys. The F-35, for example, uses only stainless steel and Ti fasteners, while most actuators are now made of PH15-5 or other stainless steels.

The latest findings from the Joint Cd Alternatives Team (JCAT) are showing the best overall performance is for AlumiPlate, while LHE ZnNi is essentially equivalent to Cd in performance. LHE ZnNi is plated from aqueous solution in a standard plating tank, while AlumiPlate is plated from an organic solution in an inert atmosphere^{7,8}.

AlumiPlate

Electroplated Al (AlumiPlate) meets MIL-DTL-83488 and is now specified on several F-22 and F-35 components, including landing gear parts and electrical connectors⁹. Earlier issues of embrittlement and fatigue debit have been solved by eliminating the Ni strike and tooling is now being developed to allow AlumiPlate coating of all the components in an F-35 landing gear ship set. The material is in direct comparative flight testing on the F-35 main landing gear, with the upper torque arm

being Cd plated and the lower being AlumiPlated.

LHE ZnNi electroplate

This low hydrogen embrittlement coating was developed by collaboration between Boeing and Dipsol of America and is sold as Dipsol IZ-C17. Its performance is generally equivalent to Cd¹⁰. Boeing is working with ES3 to try to evaluate ZnNi with the ultimate aim of installing ZnNi plating capability at Ogden ALC.

A new method of depositing nanostructured ZnNi using pulse electroplating is being developed by Integran under a new SERDP program, and a kickoff meeting was held during the course of the workshop¹¹.

Cold spray

Cold spray coatings such as pure Al or Al alloys are being developed and evaluated by several groups and companies (ARL, DSTO Australia, Inovati, Centerline^{12,13,14}) as alternatives to Cd and to Cr⁶⁺ processes such as the Dow treatments for Mg. These coatings cannot be sprayed as thin as Cd (0.0003"), but they can be used to fill damaged or corroded areas while providing sacrificial corrosion resistance.

A side meeting was held during the workshop to discuss establishing an HCAT-like team for development and implementation of cold spray, concentrating initially on Mg gearboxes.

3.3.3. Cr⁶⁺ alternatives

The issues and progress of Cr⁶⁺ were covered at some depth in the [Workshop on Chromates](#) held in Ogden, UT, May 2007.

The current status of chromate replacements is summarized in Table 1:

- Non-chromate primer has been approved for all support equipment applications.
- TCP has been approved in place of chromate conversion of Al alloys, provided a chromated primer is used.
- TCP has been authorized pending review of final data for sealing of anodize, Cd, IVD Al and ZnNi coatings, and for Mg alloys.

However, like other non-Cr⁶⁺ treatments, TCP is more sensitive to surface cleanliness and process parameters.

The sol-gel paint adhesion promoter developed by Boeing, AC131 (originally called Boegel and sold as AC130 for paint adhesion) has proved been approved for bonding repair of Ti, Al and composites.

Table 1. Current status of chromate alternatives testing and qualification at NAVAIR (Matzdorf).

Alternative Implementation Status			
M&P Area	Sub Area	Location	Process Status
Painting	Support Equipment	Depot and Field	Non-chromate primer in use (MIL-C-53022) for all applications
	Aircraft and Components	Depot and Field	Non-chromate primer authorized only for scuff sand and overcoat
Bonding		Depot and Field	Alternative not authorized
Aluminum Pretreatment	Avionics/Electrical	Depot and Field	Alternative not authorized
		Cherry Point-Aircraft re-paint (spray)	Authorized for use under chromated primer (TCP)
	North Island- Aircraft re-paint (spray)		
	Jacksonville- Aircraft re-paint (spray)		
	Cherry Point- Component Immersion tanks		
	North Island- Component Immersion tanks		
	Jacksonville- Component Immersion tanks		
Field			
Aluminum Anodizing	Sealing Type II	Cherry Point	Authorization of alternative (TCP) pending final test report
		North Island	
		Jacksonville	
	Sealing Type IC	Cherry Point	Authorization of alternative (TCP) pending final test report
		North Island	
		Jacksonville	
	Sealing Type IIB	Cherry Point	Type IIB not authorized currently. Dem/val underway to produce data for potential authorization as Type IC alternate. Being considered by Jacksonville as part of single tank Type II, IIB and III anodize system. Authorization of alternative (TCP) pending final test report
		North Island	
		Jacksonville	
Sacrificial Coatings	Cadmium Post Treatment	Cherry Point	Authorization of alternative (TCP) pending review of available data
		North Island	
		Jacksonville	
	IVD Aluminum Conversion	Cherry Point	Authorization of alternative (TCP) pending review of available data
		North Island	
		Jacksonville	
Zn-Ni Post Treatment	Cherry Point	Authorization of alternative (TCP) pending review of available data	
	Jacksonville		
Magnesium Conversion Coating		Cherry Point	Authorization pending for alternative use in component recoating and touch up (Alodine 5700 and TCP)
		Field	Authorization pending for alternative use in component coating touch up (Alodine 5700 and TCP)
Titanium Conversion Coating		Depot and Field	Alternatives not authorized
Phosphating	Steel, "rinse"	North Island	Mn-phosphate process with chromate rinse. New alternative being assessed (ChromiPhos).
		Cherry Point	Zn-phosphate process with chromate rinse. New alternative being assessed (ChromiPhos).

3.3.4. Non-chrome primers

Lockheed-Martin has issued a policy that requires the use of non-chromate primer unless specifically authorized by upper management.

Deft water-reducible 44GN098 non-chrome primer is used throughout the F-35. The visit to Boeing Mesa showed that the same primer is now widely used on the Apache after repair and upgrade.

NSNs for non-chrome primers are available and are being added to the AMCOM Authorized Users List¹⁵:

MIL-PRF-23377 Type I and II Class N NSNs

- ❑ Type I – 8010-01-555-3381 (1 Gal Kit)
 - Mfr P/N 16708TEP/16709CEH Hentzen
 - Mfr P/N 02GN084 (Deft)
- ❑ Type II – 8010-01-555-3383 (1 Gal Kit)
 - Mfr P/N – 17176KEP/16709CEH (Hentzen)

MIL-PRF-85582 Type I and II Class N NSNs

- ❑ Type I – 8010-01-555-3385 (1 Gal Kit)

- Mfr P/N - 44GN098 (Deft)
- ❑ Existing NSNs for MIL-PRF-85582 Type I and II Class N
 - 8010-01-466-9037 (Type I 2-Gal/Kit)
 - 8010-01-466-9313 (Type II 2-Gal/Kit)

However, simply approving a new paint system for use does not guarantee that it will be successful in the field unless users are properly trained and equipped. An evaluation of an AMCOM facility brought out a number of deficiencies that are likely to be widely encountered and can lead to failure with new paint systems, including¹⁵:

- ❑ Proper paint storage and mixing
- ❑ Proper paint gun maintenance, including maintaining the correct tip orifice
- ❑ Proper paint agitation during application
- ❑ Properly maintained compressed air supply that is dry and oil-free
- ❑ Proper climate control in the booth and acclimatization of aircraft to booth climate

Significant strides are being made in the area of powder coating and UV curable paints. Powder coats generally have better performance than paints, but have always required too high a cure

temperature for use on high strength steels and Al alloys. A low temperature cure¹⁶ powder coat has now been developed GE Global Research that cures in 30 minutes at 250°F. it contains a corrosion inhibitor and does not require a primer.

UV curable paint systems have been developed by Foster-Miller¹⁷ and GE¹⁶. UV curing takes the cure time down from days to minutes, eliminating a major bottlenecks in repaint operations.

Ceral 34/50 is now available on the US market and appears to be a viable replacement for SermeTel W, which is widely used in engines, as well as for situations that demand a combination of corrosion resistance with abrasion resistance. It is not absolutely Cr⁶⁺-free, but contains two orders of magnitude less Cr⁶⁺ in the spray than SermeTel W, and only 10 ppm Cr⁶⁺ in the cured coating.

3.4. Hard chrome alternatives

HVOF is the coating method of choice for hard chrome replacement, used on all new military and commercial landing gear programs, including all variants of the F-35¹, the Boeing 787 and Airbus 380. In fact, as the B787 and A380 move into full scale production there is not enough capacity in Canada (where these gear are made) to meet demand¹⁸.

Ogden ALC is now qualifying HVOF for most landing gear components that they overhaul.

3.5. Coating repair

Al coatings are best repaired with brush SnZn, which requires a zincate preparation¹⁰. It can also be repaired by Sermetal or similar metallic-ceramics. Work is ongoing to evaluate the use of cold spray Al for repair of Al and Al coatings^{12,10,14,13}.

ZnNi is not as easy to use as brush SnZn, making it the best option for repair even of ZnNi coatings.

3.5.1. Stripping of paints and coatings

For paint repair Boeing C-17¹⁹ is experimenting with an intermediate coat and stripper that will allow the topcoat to be stripped for repaint without removing the primer, and is also evaluating ways of reactivating the topcoat for touch up to avoid scuff sanding.

A new acoustic water jet stripping method is on the market capable of stripping HVOF coatings, which water jets have never succeeded in doing before²⁰.

Strippers for sealants are under evaluation

3.6. Test methods

There has always been an issue of lack of correlation between accelerated corrosion testing and actual performance. Craig Matzdorf⁵ (NAVAIR) reported the results of testing comparing accelerated cabinet tests with beach tests for primers and paints. He found reasonable correlation by combining two Al alloys, two accelerated corrosion tests and one year of beach testing.

Note that this testing was only for paint systems and may not be valid for metallic or other coatings whose corrosion mechanisms are different.

4. Specific applications

4.1. Fasteners

There was no discussion of threaded fasteners, but there is increasing interest in precoated fasteners for wet installs²¹, with Mg-rich primer and SMRC coatings performing best in testing on rivets.

4.2. Mg gearboxes

Mg gearboxes are always present a serious corrosion problem. Work is under way to test the viability of cold spray coatings for this application (see above),

Mg gearboxes have traditionally been chromate converted and Rockhard coated, but are now increasingly supplied with Tagnite coatings, a type of high voltage anodize that creates a much more durable and corrosion-resistant surface. There have been concerns raised over whether FPI will detect cracks beneath Tagnite, how Tagnite can be repaired, and the fact that a gearbox cannot be re-Tagnited once it contains Cd-plated inserts and studs. Work is underway at AMCOM to resolve these issues²²

5. Summary of findings

There are now alternatives to hard chrome, Cd, most chromate treatments and chromated paints and primers. Lockheed-Martin has overcome the biggest barriers to the elimination of chromates by adopting a policy that upper management must approve the use of chromated primers.

While many of the alternatives do have excellent performance (some significantly better than legacy technologies), most are not as forgiving as chromated coatings and other older technologies, requiring greater care over substrate cleaning and coating process control. This is true for trivalent sealers, electroless Ni coatings, Cr⁶⁺-free bond coats and chrome-free primers.

There are repair methods for some of the new materials and coatings, but not for all:

- Al and ZnNi can be repaired by brush SnZn
- Al coatings can be repaired by cold spray Al and Al alloys, but the coating is relatively thick (several thousandths of an inch).
- There is not yet an accepted repair for HVOF coatings.
- Trivalent and non-Cr sealers can be repaired with the same materials, as can chromate-free primers.
- Brush Tagnite is now available for repair of Tagnite on Mg.
- A low temperature cure Ceral coating is available to repair Ceral (or similar) Cr⁶⁺-free metallic ceramics.
- UV cure and low temperature cure paint systems are becoming available that are compatible with heat-sensitive alloys.

There are some new NDI methods that show promise for assessing surface conditions, corrosion beneath paints, and finding seams, fasteners, and fluid leakage. These will be valuable in finding problems and avoiding unnecessary stripping of paint systems.

Technology and Implementation Gaps: Several gaps became apparent from the briefings and discussions:

- There is no available repair for HVOF WC-Co and WC-CoCr coatings
- Semi-aqueous cleaners are not adequate for aircraft
- It is still uncertain whether chrome-free primers can meet corrosion requirements when used in conjunction with non-chromate metal finishes
- Better topcoats are needed for use with non chrome primers (solvent and water-based)
- Better clean strippers are needed for paints and adhesives
- When implementing new coatings such as tri-chrome pretreats and non-chrome primers, it is essential to ensure that good practices are followed, equipment is in good condition, and personnel are well-trained
- Training is an essential component in adopting new technologies, even where they are drop-ins, since they are less forgiving

References

- ¹ S. Fetter, R. Trice, "F-35 philosophy for manufacture and sustainment"
- ² C. Kuehmann, "Corrosion resistant steels and CuBe alternatives"
- ³ R. Josephson, K. Legg, "Progress on S53 for Rotary Gear Actuators"
- ⁴ C. Matzdorf, "Navy cleanability, corrosion and mildew issues"
- ⁵ C. Matzdorf, "Non-chromate implementation"
- ⁶ El S. Arafat, "Dem-val of high performance CPCs for interiors"
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- ⁹ K. Donaldson, "AlumiPlate Cd alternative performance and usage on F-35 and F-22"

- ¹⁰ S. Gaydos, "Cd alternatives: ZnNi electroplate performance, repair of Al coatings"
- ¹¹ J. McCrea, "Nanostructured Zn-Ni alloys for Cd replacement on fasteners"
- ¹² P. Leyman, "Cold spray for repair of Mg gearboxes and other applications"
- ¹³ R. Tapphorn, "Repair of IVD Al and Mg alloys using portable Kinetic Metallization"
- ¹⁴ J. Villafuerte, "Low pressure cold spray systems for corrosion protection"
- ¹⁵ P. Robinson, "U.S. Army Aviation & Missile Command Hexavalent Chromium Coatings Replacement Program"
- ¹⁶ C. Geib, "Environmentally advantaged powder coating for aerospace applications"
- ¹⁷ N. Orbey, "UV curable paint systems"
- ¹⁸ S. St-Onge, "HVOF implementation issues for OEMs"
- ¹⁹ M. Gilman, "Organic coatings projects"

²⁰ J. Randolph, M. Vijay, "Water jet stripping of HVOF and other coatings"

²¹ F. Lancaster, "Precoated fasteners"

²² S. Howison, "NDI and repair of Tagnite coated Mg"