SUMMARY OF FOCUSED WORKSHOP ON CD PLATING ALTERNATIVES

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Keith Legg

ASETSDefense Technical Manager

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Keith Legg, klegg@rowantechnology.com, 847-680-9420

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1. Agenda

Overview	
Introduction and Purpose	Bruce Sartwell - SERDP-ESTCP
Overview of Options, Issues, and RDT&E	Keith Legg - ASETSDefense
Platform and Program Office Requirements	
Requirements for F-35 Joint Strike Fighter	Scott Fetter - Lockheed-Martin F-35 Program
Requirements for Naval Aircraft	Craig Matzdorf - NAVAIR
USMC Environmental and Corrosion Control Issues	Andrew Sheetz - USMC CPAC
Army Corrosion Prevention and Control Requirements	Dan Nymberg - TARDEC
Requirements and Options for Vessels	Jessica Klotz - NSWCCD
Electrical and Optical Connectors	
Requirements Specific to Electrical Connectors Corrosion Preventative Compounds (CPCs) Effect on Aircraft Electrical Wiring Components	Rich Misiaszek - Raytheon
Use of Cadmium on Naval Connectors (Electrical and Optical)	Jerilyn Brunson - NSWC
Ongoing and Planned Connector Testing	Steve Brown - NAVAIR PAX
Fasteners	
Vehicle Fastener Data and Ongoing Testing	Dan Nymberg - TARDEC
Adoption of Dip Spin Fasteners for Vehicles	Peter Wan - BAE US Combat Systems
Testing for ZnNi on Aerospace Fasteners (Threaded and Non-Threaded)	Louie Tran - Boeing
SBIR Project Testing on ZnNi for Fasteners	Fred Laguines - ES3
Structural Components (Primarily Aircraft)	
Alternative Material Systems for the F-35	Terry Chambers - Lockheed-Martin F-35 Program
USAF Landing Gear ZnNi Testing, Completed and Planned	Dave Frederick - OO-ALC
Comments on Alternatives and Testing	Steve Gaydos - Boeing
Planned Testing at NAVAIR	Jack Benfer, Ruben Prado - NAVAIR JAX
Miscellaneous	
Findings on Electrical Connectors and Fasteners	Keith Legg - ASETSDefense
Qualification of Trivalent Chromate as a Hexavalent Chromate Alternative for Propellant and Cartridge Actuated Devices	Harry Archer - NSWC-IH

Note that a number of briefings have not yet been given public release. These will be added to the online table as soon as they are available.

There are several cadmium alternatives that are moving towards production in different applications, but all of them have technical issues. The workshop was intended to arrive at a good understanding of the issues and options, definitions of requirements for the different applications, and a plan for coordinating RDT&E.

The primary issues discussed were:

1. Apprise everyone of what is going on in Cd replacement, what data is available, what is being approved or implemented, and the general advantages and limitations of each solution.
2. Ascertain what information is really needed by the decision makers for each application in order to accept or reject use of the different alternatives that vendors are proposing.
3. Provide information and opportunities for coordination on development and testing programs under way in different DoD and OEM organizations.

2. Briefings and discussions

2.1. Platform approaches

F-35 Joint Strike Fighter (Scott Fetter):

The remaining uses of Cd are on components and electrical connectors. The F-35 does not use Cd-plated fasteners, which are all CRES alloys (Ti or stainless steel) because of the composite skin (which contains carbon fibers that are highly cathodic). Many of the electrical connectors are composite, and many of the aluminum connectors are coated with electroless nickel-PTFE (mostly the JCP3 coating from CSL, Inc). One problem with the F-35 that is not shared with most other weapons systems is that it is manufactured in a variety of locations across the world, where not all coating alternatives are available.

This program has a Banned Substances List and a Restricted Substances List. Materials on the Banned Substances List cannot be used, whereas those on the Restricted Substances List can be used with permission, although that permission is often temporary until a permanent alternative can be qualified. Like most new weapons systems the JSF uses performance-based specs, which are flowed down to suppliers. The weapons system also has a Corrosion Control Plan. Corrosion control requirements are imposed on weapon system suppliers.

Alternatives: AlumiPlate (electroplated aluminum) is used on several air vehicle subsystems during system development. It is on six landing gear parts (torque arms and pins) and has just been approved for use on the Leading Edge Flap Actuator System (LEFAS), which is a very difficult application because it comprises a variety of alloys in close proximity. AlumiPlate was chosen based on the supplier's corrosion performance testing which demonstrated that Alumiplate provided equivalent or better performance to the F-35 requirements. Other alternatives (such as LHE ZnNi) would be acceptable provided they meet the performance requirements. In fact, alternatives that could be used in Europe would be a big advantage (AlumiPlate is not available in Europe because no company has been able or willing to make the necessary investment).

On the canopy actuator gears and links, Cd has been replaced by PVD TiN. This is a highly unusual approach, but it works very well for this application

Requirements: Qualification requirements are that coated components and subsystems must successfully pass functional testing, which includes endurance testing and SO_2 salt fog corrosion testing (NAVAIR requirement), after which the components must still function properly. There is a requirement for back-compatibility with existing coatings and/or connectors.

Environmental pressures: Because the F-35 is an international program, with components being manufactured in North America, Europe, and Australia, with sales in all of those areas, it is quite strongly affected by the European REACH requirements. Although cadmium is currently permitted on aircraft in Europe we expect that cadmium and its salts will become classified as SVHCs (Substances of Very High Concern) over the next few years, which would lead to strong pressure to remove it from the aircraft.

Naval Aircraft (Craig Matzdorf):

Cd is found on components, fasteners, and electrical connectors. However, the depots only deposit Cd on components; electrical connectors and fasteners are OEM items.

Alternatives: The fleet readiness centers primarily use electroplated cadmium, but they also use a significant amount of IVD Al, some vacuum cadmium, stylus (brush) cadmium, and Dipsol-Gumm ZnNi (not LHE ZnNi) for low strength steels (see Figure 1).

NAVAIR would like to find satisfactory alternatives to both cadmium and the chromate conversion coatings, which are used on Cd plate. NAVAIR is implementing ZnNi for low strength alloys and IVD Al for high-strength alloys, and has recently authorized AlumiPlate. They are currently evaluating LHE ZnNi and cold spray Al, as well as a new low-temperature carburization process developed by Swagelok for stainless steel[1].

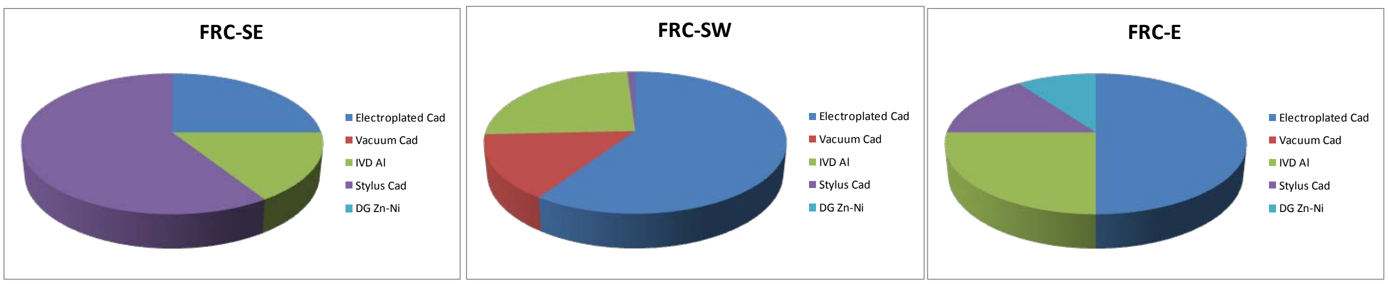

Figure 1. Sacrificial coatings used at the NAVAIR FRCs (Craig Matzdorf).

Requirements: For non-critical applications – pass MIL-SPEC, NAVAIR screening tests, and 2-year in-service testing, with 2 carrier/ship deployments on a minimum of 2 vehicles; alternative must show equivalent or better performance than Cd. For flight-critical components – add fatigue and other lab tests, flight clearance, more extensive lab and service testing.

The implementation path for components involves

- Sign-off
  - NAVAIR PAX Materials (Structures, Subsystems, Systems, Aeromechanics if necessary)
  - FRC/ISSC Materials
  - Program (FST/Class Desk/OEM).
- Spec revisions
  - Local/MIL/AMS, etc.)
  - NAVAIR "509 & 540" Corrosion Control Manuals via Interim Rapid Action Change or "IRAC".
- The implementation path for connectors and fasteners is through the suppliers and OEMs.

In evaluating performance it is necessary to take into account the performance of the entire coating system, including passivation treatment for the coating, and adhesion and performance of the paint system.

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[1] See, for example, www.swagelok.ch/downloads/webcatalogs/EN/Cao-AM-03.pdf

Vehicles (Andrew Sheetz, Dan Nymberg)

For Army and USMC vehicles the primary uses of Cd are on fasteners and electrical connectors.

Alternatives: That are various alternatives to Cd-plated fasteners used on different vehicles, including dip-spin coatings, AlumiPlate, and in some cases COTS fasteners such as black oxide (which can create major corrosion problems). While a number of new systems use alternatives, cadmium tends to find its way back into the systems through parts bins at the depots. TARDEC has put forward a single replacement policy to replace cadmium plated fasteners with AlumiPlate, and service testing of this approach has been very successful.

Requirements: The requirements for Army and USMC vehicles are essentially the same. A major issue is ensuring that fastener replacements are available through the supply chain. Absent a requirement to eliminate cadmium, there is very little in the way of a driver to do so.

The needs of the user community are simple and straightforward:

- Equipment that works well (avoids corrosion)
- Minimal environmental or health exposure
- Minimal repair and maintenance
- Avoid specialized parts, or logistics chains to perform maintenance and repair.

The Army requires that each vehicle program have a Corrosion Prevention and Control Program (CPAC). Vehicles are not expected to be free of corrosion, but they are expected to be free of corrosion failures, typically for 20 years with routine maintenance.

Naval Vessels (Jessica Klotz, Jerilyn Brunson)

The primary application for cadmium in ships and submarines is for electrical and fiber-optic connectors. There is very little use on components or fasteners.

There are no standard lists of banned or restricted materials – restrictions vary from one program to another. There appears to be more potential for maintainer exposure than occurs in vehicles and aircraft, since sailors must periodically check the integrity of connectors by undoing them, examining them, and reconnecting them by hand.

Requirements: The specifications are owned by NAVAIR, not NAVSEA. The only unique requirements in NAVSEA are for submerged connectors. There is a requirement for backward-compatibility with existing connectors. There are dozens of connector specifications.

- Direction has been given in new programs to eliminate cadmium and hexavalent chromium from all connectors, especially on new programs
  - Many programs face conflicting requirements that require waivers. There are nine active ship programs that restrict Cd, including the Ohio replacement.
  - The NAVSEA electrical connector warrant holder wants the insertion of a Cd-free definition in connector specs to prohibit Cd unless approved by NAVSEA
  - Alternatives are being selected on the basis of availability rather than

performance

- Different programs are making different choices
- Those tasked with making selections often know very little about their options

2.2. Electrical and optical connectors

Briefers:

- Rich Misiaszek (Raytheon) is a member of the SAE AE8-C1 Connector Committee.
- Jerilyn Brunson (NAVSEA, Dahlgren) has carried out a broad study of the use of Cd on shipboard connectors.
- Terry Chambers (Lockheed-Martin) chairs the Corrosion Prevention Advisory Board (CPAB) for the F-35.
- Steve Brown (NAVAIR PAX) ran the Joint Cadmium Alternatives Team, and is carrying out cadmium alternatives testing.

Specifications:

DLA and SAE have changed nearly every connector and backshell specification and slash sheet to add alternate finishes to cadmium:

Mil-DTL-38999 and associated slash sheets and MS sheets

MIl-PRF-28840 and associated slash sheets

MIL-DTL-26482 and associated MS sheets

MIL-DTL-83723 and associated slash sheets

MIL-DTL-22992 and associated MS sheets

MIL-PRF-83513 and associated slash sheets

MIL-PRF-24308 and associated slash sheets

MIL-DTL-83733 and associated slash sheets

Mil-PRF-28876

SAE AS85049 backshell spec is changed and most of over 100 slash sheets are complete.

SAE AS50151 is scheduled for update to add alt finishes in 2011.

Although these specs permit alternative finishes, there are no definitive guidelines for usage of the different alternatives. There are no qualified sources for most connector specs except for 38999 and 83513. In addition these specifications do not cover coating chemistries or processes.

General requirements (based on Cd capabilities):

- Thickness: 0.0002-0.0008”, with good throwing power for fine and coarse threads and complex geometries.
- Thread lubricity: 500 mating cycles minimum
- Coupling and uncoupling torque: Continues to meet spec after exposure to

severe corrosion environments

- Corrosion resistance: 50 mating cycles prior to salt spray test, 500-1000 hrs min neutral salt spray, followed by 452 mating cycles. Must retain mating torque and shell to shell conductivity
- Galvanic compatibility: Compatible with cable shield materials (tin, silver and nickel), stainless steel coupling nut retaining rings, cable shield bands, EMI spring fingers, EMI shielding gaskets and aluminum mounting panels
- Compatible with hermetic connectors with fused tin on carbon steel
- Resistant to solvents
- Conductivity for EMI shielding, electrical bonding and lightning strike: 2.5 milliohms max shell to shell resistance
- Non reflective finish, able to be permanently marked and able to bond to plastic and silicone grommets
- Meets vibration, shock, humidity, EMI shielding, bending moment and other connector performance requirements

Jeri Brunson has carried out a very extensive analysis of Navy electrical and optical connectors, and provided a table of all of the requirements for all of the different specifications for electrical connectors, as well as a table of all the allowable finishes. A report is not yet releasable, but may be at a future date. Navy programs are being required to replace cadmium, but there is no consensus on the alternative, and alternatives are being chosen on the basis of availability rather than performance. There been no official NAVAIR or NAVSEA instruction or guidance on Cd replacements for electrical or fiber optic connectors, backshells and accessories.

Alternatives: Three coatings are considered viable commercial Cd alternatives:

1. Electroless Nickel PTFE.
2. Pure Al with a dry film thread lubricant. However, Al is incompatible with tin and nickel cable shields and crimp rings.
3. ZnNi (note that since connector shells are not high strength steel, LHE ZnNi is not necessary, although it could be used). However, ZnNi has shown incompatibility with Cd and thread seizing after salt spray, as well as below-spec electrical conductivity after corrosion. ZnNi also probably requires a dry film thread lubricant.

Electroless Nickel PTFE: Studies by SAE, Amphenol, and Radiall have all identified electroless nickel PTFE as the best alternative. The major issue with this material is its potential for galvanic corrosion against other system components. However there appears to be a consensus in SAE that Electroless Nickel PTFE does not pose a severe galvanic problem; it is thought that this may be because the PTFE (which is in the form of PTFE particles co-deposited with the electroless nickel) may cover a large portion of the surface, thereby rendering it essentially inert (however no one appears to have measured galvanic potentials or galvanic currents). Testing done by Lockheed seems to bear out this belief since electroless nickel coated connectors on an aluminum ground plate produce no more corrosion of the ground plate than Cd coated connectors, and did not appear to create significant additional corrosion on Cd-plated mating connectors.

Note that not all electroless nickel PTFE coatings are alike. The original coating from CSL, Inc. was called TTH (aka ICORE), and this is available for general use. A new version was developed from Lockheed called JCP3, which incorporates a proprietary nanophase layer on the surface, which probably changes its galvanic properties. Durmalon (from Amphenol) is likely to be somewhat different, while Radiall uses what is probably yet a different version. Additionally, one attendee said that PTFE itself has also changed over the last few years so that newer coatings may behave differently from older ones. SAE plans to issue an electroless nickel PTFE plating spec in 2011.

Testing planned/needed:

Because cadmium alternatives have evolved over the past 10 years or so, much of the earlier testing is probably no longer relevant. Electroless nickel PTFE has certainly changed significantly, while ZnNi could well be significantly different depending upon the chemistry chosen.

It is clear from the information presented that galvanic compatibility is a particular concern, not just with the obvious electroless nickel coatings, but also with zinc nickel and any other alternative. There has been some testing of back compatibility between different coatings and cadmium, but this type of testing has been limited.

- Jeri Brunson is planning to carry out a fairly extensive series of connector tests. The test protocol has not yet been established. The testing will be primarily for fiber-optic connectors, which do not have electrical conductivity requirements.
- Steve Brown currently has beach testing in progress for various connector finishes on connector shells.
- Craig Matzdorf is planning to carry out galvanic compatibility testing.
- Dan Nymberg plans electrical connector testing that will include outdoor exposure.

The most important outstanding testing appears to be galvanic testing, not just of electroless nickel coatings, but of all coatings, including their galvanic compatibility with Cd-plated connectors. Testing should also include conductivity testing and should involve the entire system, including all of the components of connector systems together with the backplanes, electrical boxes, etc. in which they will reside.

It should be possible to coordinate between these different test programs to ensure that we gather sufficient data to provide the information needed for adoption of the best options for the different platforms.

It appears from all of the testing and discussion that electroless nickel PTFE would be the best option if we could be sure that there would not be significant galvanic problems. No testing has been done for electrical connectors coated with the new Zn(14-16%)Ni coatings, and one might expect that the higher Ni content would improve the post-corrosion conduction, which has been a problem for the Zn8Ni commonly used for connectors.

2.3. Fasteners

Briefers:

- Dan Nymberg (TARDEC)
- Peter Wan (BAE Systems)
- Louie Tran (Boeing)

- Fred Laguines (ES3)

Specifications: Cd alternatives on fasteners are primarily specified by drawings such as

- US Army Tank-Automotive Command DWG No.12469117
- ASTM F1137 Type 3 (Magni); ASTM F1136 (GEOMET)
- ISO 10683 (Magni); ISO 240h-L, 480h-L,720h-L,960h-L (GEOMET)
- BAE Developed a series of drawings[2]
  - 1 drawing for each fastener family (e.g. screw, hex head, grade 8, coarse thread)
  - Covers coating and requirements
- Rock Island Arsenal has also adopted Magni 575N via a drawing

Requirements: Although in some ways one may consider coatings on fasteners to be a relatively straightforward issue compared with electrical connectors, the principal issues with fasteners are friction/torque requirements and galvanic corrosion (see Figure 2). Changing finishes may cause inadequate clamp load, joint loosening, stripped threads, or broken fasteners. Some dip-spin finishes are thicker, which can cause difficulty in assembly.

Boeing has carried out extensive testing, including performance and usability with production assembly tools:

- Corrosion
- Fatigue of fastener
- Tensile Strength of fastener
- Torque-Tension with or without friction modifiers
- Locking and Break-away Torque
- Corrosion and Torque Effectivity (Ground Stud)
- Push-in Installation Force of Hi-Loks fasteners, including with Rivet Gun
- High RPM Installation Force with nuts runners

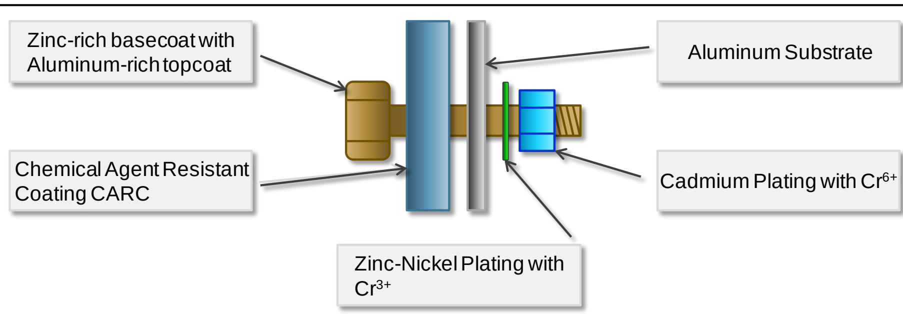

Figure 2. Example of galvanic materials issues with fasteners (Dan

Alternatives:

Note that there are significant galvanic issues with fasteners, just as there are with electrical connectors, and that systems may include various substrates and coatings (see Figure 2).

[2] An example of such a drawing was given by Angela Ton at the ASETSDefense Vehicle Workshop (2010),

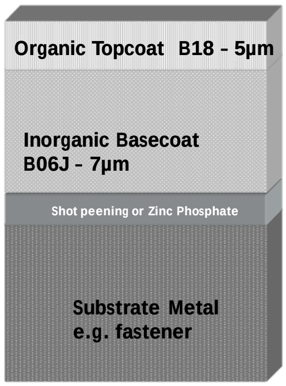

Figure 3. Magni 565 dip-spin coating.

Three alternative coatings were described:

1. Dip-spin coatings such as Magni 565 (inorganic zinc-rich basecoat and aluminum-rich epoxy topcoat, see Figure 3) Geomet, or numerous other similar coatings. Magni 565 has been implemented by BAE Systems to replace all fasteners on MMPV.

   Advantages: Widely available, topcoat can be adjusted to meet friction/torque requirements, fasteners can be color-coded, good corrosion resistance.

   Disadvantages: Can experience some thread filling and gauging uses, difficulty with coating washers, care is needed for use on <1/4" fine threads.

2. Electroplated Aluminum (AlumiPlate). Service tested by TARDEC on Stryker lug nuts, and used on various aircraft components, including threaded components.

   Advantages: Same coating as now qualified for components, very good corrosion resistance, including much better SO_2 salt fog and environmental embrittlement than Cd (recommended by TARDEC as single alternative to Cd)

   Disadvantages: Requires friction modifier, sole source, limited production capacity at present time

3. Electroplated alkaline LHE ZnNi (Atotech Reflectalloy ZNA without brighteners, 14-16%Ni). Extensively evaluated by Louie Tran at Boeing for commercial aircraft fasteners (not yet qualified, but likely to be in the next year or so). Undergoing testing by ES3 at Robins AFB.

   Advantages: Same coating as now qualified for components at Hill AFB

   Disadvantages: Requires friction modifier (Ecoalube 643 works best in ES3 tests), performance in SO_2 salt fog uncertain (from testing by ES3/Hill AFB)

In many situations (especially GTEs, which are heavily dependent on Ni alloys, and aircraft with composite skins such as the F-35) CRES fasteners are proving to be the best approach.

Testing planned/needed:

Boeing is completing testing, after which it is expected that LHE ZnNi will be qualified for use on commercial aircraft fasteners.

ES3 is testing Dipsol LHE ZnNi at Robins AFB under an SBIR program.

AlumiPlate has been field-tested on Stryker vehicles, and TARDEC is seeking ways to replace Cd-plated bolts with AlumiPlate and bolts on Army vehicles during reset.

Dip-spin plated fasteners are widely used in the commercial automotive industry, and are readily available. No further development or testing appears necessary. This type of fastener would primarily be used for vehicles, and would not be used for aircraft because of concerns over lightning-strike performance.

Zinc nickel, AlumiPlate, or dip-spin coated fasteners are all viable options for vehicles, while ZnNi and AlumiPlate a viable options for aircraft.

2.4. Components

Briefers:

- Dave Frederick (Hill AFB)
- Steve Gaydos (Boeing St Louis)
- Harry Archer (NSWC Indian Head)
- Ruben Prado (RFC-SE)

Specifications:

At the present time there are no specifications for LHE ZnNi, or for ZnNi in the region above 12%Ni. Moves are afoot with the ASTM B08 committee to try to make changes to ASTM B841, which covers ZnNi electroplating in the range 8-12%Ni (Don Snyder at Atotech). We have suggested to Don that the spec expand the range for Ni to 17% and include a Class for LHE ZnNi.

The following specifications are used for zinc nickel:

- AMS 2417
- Air Force Drawing 201027456 for Dipsol LHE ZnNi
- Boeing Spec BAC5680 for Atotech LHE ZnNi

AlumiPlate is used under the same MIL-DTL-83488 specification as IVD aluminum.

Requirements:

The requirements for cadmium on components depend on the application, but in general they require passing the following:

- Coating adhesion
- Paint adhesion
- Hydrogen embrittlement
- Environmental embrittlement with maintenance fluids
- Liquid and solid metal embrittlement
- Substrate fatigue
- B117 salt fog corrosion resistance
- G-85 SO_2 salt fog corrosion resistance
- Beach exposure corrosion
- Filiform corrosion resistance
- Repairability (e.g. Brush plating)
- Producibility
- Service testing

NAVAIR requires SO_2 salt fog, and at least two years of service testing that includes two carrier deployments for two air vehicles.

Alternatives:

IVD Al: IVD has been used for many years. It is a rather porous coating, and has poor throwing power. It is easily damaged by alkaline cleaners. However several of the depots have IVD Al chambers and use IVD in place of Cd for some components.

LHE ZnNi: Hill AFB has qualified Dipsol IZ-C17+ alkaline LHE ZnNi with a trivalent sealer for use on landing gear at overhaul. The results of their testing are available online from the ASETSDefense website, including the Final Report. (The Final Report is Distribution D (DoD and US DoD contractors only – anyone requiring access can contact either Dave Frederick at Hill or ASETSDefense for a username and password to download the report.)

Following publication of the report the meeting was held at WPAFB, where a number of issues were brought up. These were all answered by Dave Frederick in his briefing:

1. The main concern was very rapid environmental embrittlement of the ZnNi-coated specimens, which turned out to be caused by a combination of bath contamination, surface preparation, and inconsistent coatings within the notch. (Note: satisfactory coatings in the notch have always been an issue with ASTM F-519 specimens.) This problem was overcome by using ring anodes designed using a computational electroplating approach (Elsyca). ZnNi passed 150 hours in 3.5% salt water, while Cd failed.
2. A secondary concern was the effect of ZnNi on substrate fatigue. All of the data were checked and the landing gear industry was engaged on this issue. There appear to be no significant concerns. There may be a need for some additional testing of other R ratios.

A prototype line is being installed at Hill AFB, and Hill intends to go forward with qualification and implementation. Boeing Seattle has also qualified LHE ZnNi for components such as landing gear, using the Atotech version. At least one landing gear maker is planning to install a similar plating line (either the Dipsol or Atotech LHE ZnNi version).

Harry Archer (Indian Head) has developed a ZnNi coating system for steel in propellant-actuated devices based on a Zn5%Ni electroplate, phosphate treated and TCP-sealed[3]. Zn12%Ni shows improved resistance to SO_2 salt fog corrosion. Information on this is available on the ASETSDefense database as well as in the briefing presented.

AlumiPlate: The F-35 program uses AlumiPlate in a number of locations in place of cadmium. AlumiPlate has been qualified on the landing gear torque arms (it has been removed as a small cost reduction, but analysis of lifecycle cost is being put forward to show a significant life cycle saving). Recently AlumiPlate has been qualified to replace cadmium on the F-35 LEFAS. The design of this actuator is very similar to that used on the F-18 and other aircraft, which have had significant corrosion and corrosion fatigue issues when using Cd.

In testing carried out under the JCAT program, neither Cd nor ZnNi perform well in the SO_2 salt fog test required by NAVAIR, while AlumiPlate performs very well in this test. AlumiPlate also performs better than LHE ZnNi in environmental embrittlement tests. However, the performance of LHE ZnNi is at least comparable with Cd in SO_2 salt fog, and much better in environmental embrittlement.

Testing planned/needed:

- Hill AFB/ES3 will probably carry out additional fatigue testing, and will be qualifying LHE ZnNi on numerous components, including flight testing over the next few years

[3] Pat # 7,514,153 and 7,803,428

- FRC-SE will be testing the Dipsol LHE ZnNi for Naval aircraft components
- Atotech LHE ZnNi is already qualified for components at Boeing.

LHE ZnNi appears to be the best available drop-in option since it is an aqueous process that can easily be adopted by OEMs and depots. AlumiPlate is qualified for a number of applications, and it is particularly useful where very high performance is required, especially where components are relatively small.

2.5. Testing and qualification

Need for better corrosion testing: It was generally agreed that if there is a need for corrosion testing that is faster and more accurate than the current ASTM B117 salt fog and SO_2 acidified salt fog. Bruce Sartwell pointed out that SERDP/ESTCP is funding the development of better testing, but as Craig Matzdorf noted it will probably be 5-10 years before any new test is accepted by the community.

For all of the applications and alternatives there is a need to ensure galvanic compatibility with all mating components and materials in all of the likely environments. This is important both for back-compatibility and to ensure long-term system safety and performance.

2.6. Implementation in the supply chain

Fasteners: More than other components, fasteners are supplied through DLA. Some attendees felt that it would be easiest to leave the same NSNs, while changing the finish. DLA pointed out that this is not a viable option. However, DLA can assign an interchangeable number. When an order is made against an old NSN, the new material will be shipped rather than the old, until eventually the old NSN falls into disuse and is removed from the system. DLA did point out that it is very important when developing a new NSN for a Cd-free alternative to specify that this is a "green" material so that it is properly indicated as such.

As Andy Sheetz has pointed out, even eliminating Cd-plated fasteners at the OEM level will still allow them to creep back in during depot repair and reset, unless an approach is taken such as that suggested above by DLA, where interchangeable NSNs are assigned in order to eventually remove plated Cd-fasteners from the supply chain.

OEMs will need to work with fastener industry spec committees to develop satisfactory fastener specs. Mary Gilman may be able to help find the right people.

Rich Misiaszek has contacted Robert E Hedges at Raytheon, who represents Raytheon at the GIFWG and NAS fastener committee meetings, to begin discussing fastener needs and specs with the fastener community.

Connectors: Rich Misiaszek is involved with the SAE AE8-C1 Connector Committee and was involved with producing the SAE AIR 5919 document on Alternatives to Cadmium Plating for electrical connectors.

Keith Legg will be briefing an industry connector meeting in October that is being set up by MacDermid, and will discuss the results of this meeting there with the connector manufacturers and coating companies.

Components: LHE ZnNi is being moved into the supply chain through the landing gear makers, and will probably eventually be implemented on Boeing aircraft once it is fully qualified and available from suppliers. In the USAF it will begin appearing on landing gear first as Hill brings it on-line.

AlumiPlate is being implemented on F-35. LHE ZnNi could also be implemented on the F-35 pending the outcome of further testing and evaluation.

3. Going forward

If one were forced to choose a single cadmium drop-in replacement that could work for all applications, the logical candidate would be LHE ZnNi with a trivalent sealer. However what we are seeing in the market is that each of the applications has a favored approach:

- Electrical Connectors – Connector manufacturers are coalescing around electroless nickel PTFE. Data presented at the meeting suggests that the expected galvanic interactions are not seen in practice. The most reasonable explanation to account for this is that PTFE largely covers and "inerts" the surface.

  If it transpires that there are applications or environments where EN-PTFE is not a good option, then ZnNi or AlumiPlate would be alternatives, but it will be necessary to overcome the downsides with these two coatings outlined in Section 2.2 above.

  If this type of coating is to be adopted safely, we will need to develop a clear understanding of galvanic interactions that covers all of the systems and environments in which these coatings will be used. Craig Matzdorf plans work along these lines.

- Fasteners – There is a clear difference between fastener requirements in vehicles and aircraft. It appears that vehicle fasteners could largely adopt dip spin coatings, of which there are many different suppliers and chemistries. If this is done, however, the logistical issues will become overwhelming unless users agree on a basic set of requirements that can be met by a number of different interchangeable products on the market.

  An alternative for vehicle fasteners is AlumiPlate, which is favored by TARDEC as a logical and universal drop-in alternative.

  Aircraft are increasingly using the various aluminum and CRES alloys, especially for composite aircraft structures and engines.

  For aircraft threaded steel fasteners LHE ZnNi is a viable alternative that is close to qualification. Although this coating is only just coming onto the commercial market, it should become quite widely available, especially for DoD, since at least the Dipsol version was developed with DoD funding and is therefore available without high licensing fees. AlumiPlate also appears to be a viable option, but is a sole source option at this point.

  It appears that, between dip-spin and AlumiPlate coated fasteners, we have fully qualified solutions and there is no need for additional laboratory testing, although more service testing will probably be required. There is no qualified alternative for non-threaded aircraft fasteners.

- Components – LHE ZnNi has been qualified by both Boeing and Hill AFB, and appears to be an option that meets (and in some cases exceeds) all of the requirements for Cd on landing gear and other high-strength aircraft alloys. Since the environmental embrittlement concerns have been settled, the primary remaining issue is performance in the NAVAIR G85 SO_2 salt fog test.

AlumiPlate is fully qualified and already used on a number of aircraft components. It is limited primarily by the fact that it is sole-source and has a relatively small plating tank that can only coat objects up to the size of a fighter landing gear.

Between LHE ZnNi and AlumiPlate we now have solutions for almost all components. The remaining issues are performance in SO_2 salt fog, ensuring uniform alloy deposition on complex components, and of course service testing.

4. Attendees

Last Name	First Name	Organization	Email
Archer	Harry	NSWC	harry.archer@navy.mil
Bails	Steve	Stryker	Stephen.Bails@us.army.mil
Barbin	Robert	Excet	rbarbin@excetinc.com
Benfer	Jack	NAVAIR	john.benfer@navy.mil
Berman	Elizabeth	AFRL	elizabeth.berman@wpafb.af.mil
Brown	Steve	NAVAIR	steven.a.brown1@navy.mil
Brunson	Jerilyn	NAVSEA	jerilyn.brunson@navy.mil
Chambers	Terry	Lockheed Martin	terry.t.chambers@lmco.com
Chau	Eva	Honeywell	eva.chau@honeywell.com
Cramer	Randy	Naval Ordnance Safety & Security Activity	randall.cramer@navy.mil
Falknor	Mark	403 SCMS/GUED	mark.falknor@wpafb.af.mil
Fetter	Scott	Lockheed Martin	scott.d.fetter@lmco.com
Folk	Erika	Carderock	erika.folk1@navy.mil
Frederick	Dave	OO-ALC	David.Frederick@HILL.af.mil
Freedman	Michael	NSWCCD	Michael.G.Freedman@navy.mil
Gaydos	Steve	Boeing	stephen.p.gaydos@boeing.com
Gentry	Amanda	F-35 Program Office	amanda.gentry@jsf.mil
Gieseking	Chris	AMRDEC	chris.gieseking@us.army.mil
Gilman	Mary	Boeing	mary.a.gilman@boeing.com
Green	James	NAVAIR	james.l.green@navy.mil
Hazlett	Lauren	Carderock	lauren.hazlett@navy.mil
Hoffer	Lisa	DLA Land & Maritime Office	lisa.hoffer@dla.mil
Houff	Jeffrey	HGL, Inc.	jhouff@hgl.com
Klingenberg	Melissa	CTC	klingenb@ctc.com
Klotz	Jessica	NSWCCD	jessica.klotz@navy.mil
Laguines	Fred	ES3 Inc	Fred.Laguines@es3inc.com
Legg	Keith	Rowan Technology Group	klegg@rowantechnology.com
Matzdorf	Craig	NAVAIR	craig.matzdorf@navy.mil
Miller	Chet	Department of Energy	chester.miller@em.doe.gov
Misiaszek	Rich	Raytheon IDS	misiaszek@raytheon.com
Nymberg	Dan	TARDEC	daniel.nymberg@us.army.mil
Perkins	Larry	AFRL/RXS	larry.perkins@wpafb.af.mil
Pessetto	Craig	ES3 Inc	craig.pessetto@es3inc.com
Prado	Ruben	NAVAIR	ruben.prado@navy.mil
Randolph	Jay	ES3 Inc	jay.randolph@ES3inc.com
Reed	James	DLA	james.l.reed@dla.mil
Repp	John	Elzly Technology Corporation	jrepp@elzly.com
Rice	Veronica	HGL, Inc.	vrice@hgl.com
Rohan	Caitlin	HGL, Inc.	crohan@hgl.com
Sartwell	Bruce	SERDP/ESTCP	Bruce.Sartwell@osd.mil
Sheetz	Andy	NAVSEA	SheetzAD@navy.mil
Steensen	Eric	DLA	eric.steensen@dla.mil
Taylor	Patrick	Hughes Associates, Inc.	ptaylor@haifire.com