Cadmium and Hexavalent Chromium Alternatives Implementation Plan for Fleet Readiness Center Southeast

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Executive Summary

The Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) Weapons Systems and Platforms Program Area initiated an effort to develop a strategy to eliminate >90% of cadmium (Cd) and hexavalent chromium (Cr^{6+}) in use at Department of Defense (DoD) maintenance depots over the next five years. To that end, the research team visited Fleet Readiness Center Southeast (FRCSE) on 25-26 March 2015, in the preparation of this FRCSE Implementation Plan. This plan identifies and describes the processes observed at FRCSE, documents the Cd and Cr^{6+} containing materials used in these processes, identifies potential alternatives, and outlines a strategy and roadmap to achieve >90% reduction of Cd and Cr^{6+} at FRCSE over the next five years. The FRCSE processes and alternatives are shown in Figure ES-1.

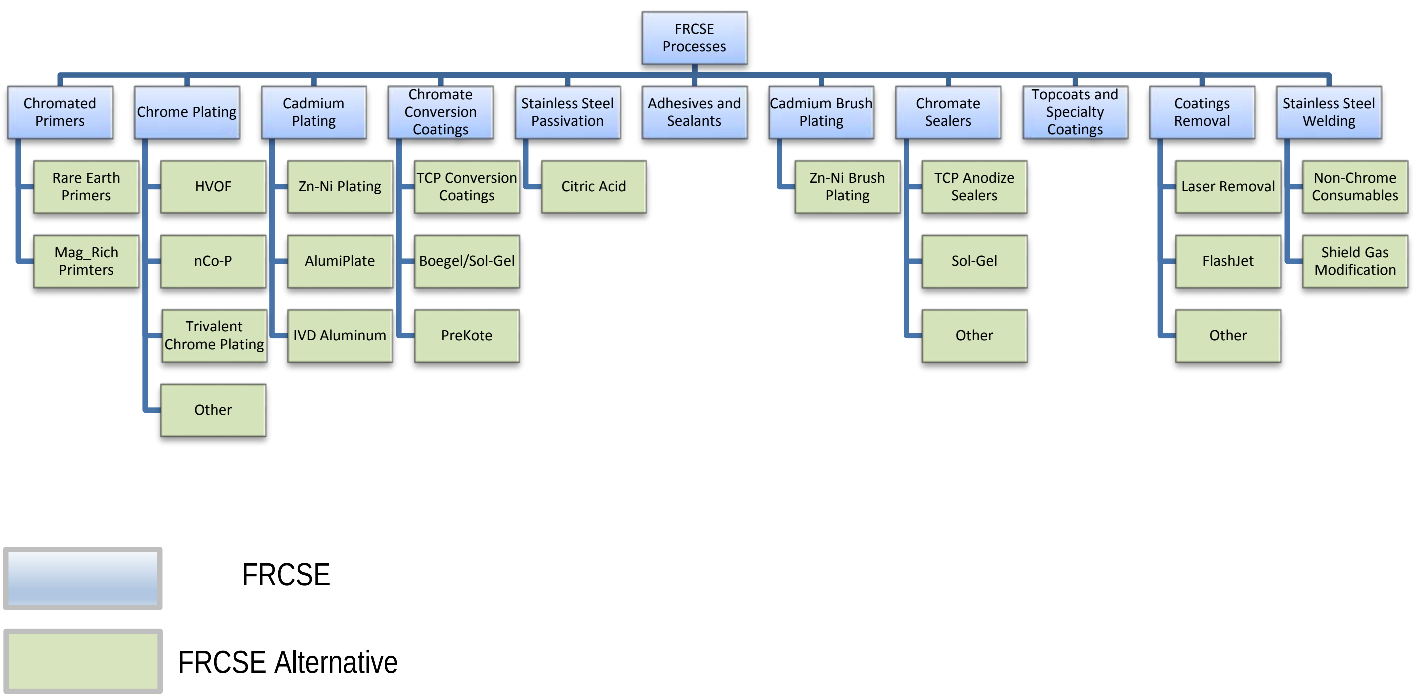

Figure ES-1. FRCSE Cd and Cr^{6+} Process and Alternatives

Cr^{6+} and Cd-reduction initiatives have been prioritized using a relative scoring methodology. Four metrics were selected for analysis in the prioritization process: 1) Impact to Readiness; 2) Likelihood of Implementation; 3) Return on Investment; and 4) Impact to Goals. Each metric was qualitatively analyzed.

Tier 1 priority initiatives are critical to achieving Cr^{6+} and Cd reduction goals. If these initiatives are not successfully implemented, the reduction goals cannot be achieved. These initiatives will typically have far reaching impact to other depots, addressing similar critical usages, emissions, exposures, and/or waste streams. Tier 1 priority processes typically have high impacts to readiness, though this is not always the case. Seven of the recommended initiatives are considered Tier 1 priorities and, therefore, critical to achieving reduction goals at FRCSE.

Tier 2 Priority Initiatives are those not critical to achieving Cr^{6+} and Cd reduction goals at FRCSE, but address significant usages, emissions, exposures, and/or waste streams. These initiatives may impact similar processes at other depots, therefore, increasing the legitimacy of expending resources to identify and implement alternatives. These initiatives typically have moderate impact to readiness, but may exhibit strong ROIs. Four initiatives are considered Tier 2 priorities at FRCSE.

Tier 3 priority initiatives are not critical to achieving Cr^{6+} and Cd reduction goals and address usages, emissions, exposures, and/or waste streams minor enough to call into question the merit of expending resources to identify alternatives. These processes are typically localized, impacting only a single depot or shop and have little impact to readiness. Two initiatives are considered Tier 3 priorities for FRCSE and is described in greater detail below.

Most of FRCSE's Cr^{6+} and Cd stream reduction goals can be met by leveraging ongoing or past initiatives. 90% Cr^{6+} and Cd usage reduction can be achieved the Tier 1 initiatives, most leveraging ongoing work either within NAVAIR, the Army or, in the case of cadmium brush plating, the Air Force. However, six new starts are recommended, though only two of those are Tier 1 priority initiatives. Table ES-1 captures the FRCSE Implementation Plan. The table includes the recommended initiative and is linked to the full description in Section 4. The table also links the initiative to a specific process observed at FRCSE and a detailed description in Section 2. A brief description of the initiative and the identified success metric is also included. Baseline usage data is also reported in Table ES-1 and it is linked to the supporting usage information from the Hazardous Materials Management System (HMMS) reported in Section 2. The table recommends a timeframe for initiation and outlines potential alternatives for each initiative. These potential alternatives are linked to descriptions, related efforts, and points of contact in Section 3.

Table ES-1. FRCSE Implementation Plan

Initiative	Process	Description	Success Metric	Baseline	Initiate	Potential Alternatives
Tier 1 Priority Initiatives						
Non-Chromate Primer on Aircraft Outer Mold Line (OML)	Chromated Primers	NAVAIR is also currently evaluating Hentzen 17176KEP primer on V-22 Osprey Helicopter, H-46 Sea Knight Helicopter, H-53 Sea Stallion Helicopter, and F/A-18A-D Hornet aircraft. Unlike the gloss paint scheme aircraft, which are primarily aluminum on the OML, the OML tactical paint scheme of these aircraft is also incorporates composite substrates. Upon successful demonstration, NAVAIR anticipates authorizing the Type II primer for tactical aircraft as well. Once signed and released, each applicable Program will have the option to implement the primer at OEM and depot level. FRCSE should continue with ongoing testing of the Hentzen 17176KEP primer on the F/A-18-D Hornet and H-46 Sea Knight as a replacement of the chromated primer on tactical aircraft as well as those with gloss schemes would eliminate chrome primers from the OML. Other primer options are also being tested under an ongoing ESTCP project led by NAVAIR and successfully tested primers from this program should also be flight tested. In addition, FRCSE should consider working with OC-ALC and others on total chrome-free systems, eliminating the chromate conversion coating as well.	Usage: Reduction in the pounds of Cr^{6+} species (e.g., strontium chromate) as compared to the baseline	979 lbs	Ongoing	Rare Earth Primers: • PPG Deft 02GN084 • Hentzen 17176KEP Metal-Rich Primers • Al-Rich Primers2
Non-Chrome Chemical Conversion Coatings for Aluminum	Chromate Conversion Coatings	The US Army Research, Development, and Engineering Command (RDECOM) and Army Research Laboratory (ARL) have an ongoing initiative to address elimination of Cr^{6+} in military surface finishing processes. This initiative was prompted by and addresses AERTA requirement PP-2-02-04 by eliminating Cr^{6+} in pretreatments, Defense Federal Acquisition Regulation Supplement: Prohibition (223.7302), and OSHA Regulation 1910.1026. OC-ALC should consider involvement, joint testing, or at least monitoring the US Army RDECOM initiative. While the Air Force does have some unique requirements, many of the material substrates and necessary testing will be addressed at the aviation sites listed above. Additional Air Force specific testing would be minor in comparison with the overall initiative. Testing with painting systems used in the Air Force would probably be one of the major additions and alterations. Involvement in this initiative and leveraging the Army's efforts could save months or even years of work in identifying an alternative. In addition, an upcoming ESTCP project is investigating TCP as an alternative to chromate conversion coatings.	Usage: Reduction in the pounds of Cr^{6+} species (e.g., chromic acid) as compared to the baseline Infrastructure: Reduction in the infrastructure dedicated to the process as compared to the baseline.	146 lbs 12,153 gal	2016	Rare Earth Conversion Coatings • PPG 11-TGL-27 • Bonderite 5700/5200 • Iridite NCP • Recc 3021 • Recc 3024 Cr^{3+} conversion coatings • NAVAIR TCP • Metalast TCP • Alodine T5900 Boegel/Solgel • AC-130/131
Alternative to Cd Brush Plating	Cd Brush Plating	ESTCP Project WP-201412 focuses on elimination of toxic and carcinogenic cadmium (Cd) material for brush plating repair operations, and reduction of solid waste associated with adsorbents used to contain solution leakage attributed with traditional brush plating repair processes. The technical objectives are to: • Demonstrate the commercial off-the-shelf (COTS) brush plating tool Dalistick® Station for selective plating, ensuring its safety and cost effectiveness for Department of Defense (DoD) maintenance, repair, and overhaul operations. • Test and evaluate the COTS Zinidal Aero (code 11040) zinc-nickel (Zn-Ni) brush plated coating as a Cd replacement on high strength steels (HSS) for repair applications on weapon systems parts and components (landing gear, terminal assemblies, landing gear doors, bushings, etc. In addition, FRCSE is initiating a SBIR 2.5 project to investigate the use of Zn-Ni plating using the Dalistick® technology.	Usage: Reduction in pounds of Cd species (e.g., cadmium sulfamate) as compared to the baseline.	45 lbs	Ongoing	Zn/Ni brush plating (Dalistick®)
Alternative Coatings Removal Processes to Reduce Cr^{6+}-Containing Waste Streams	Coatings Removal and Cleaners	This initiative should be implemented in phases. The first phase is an in-depth study of the coatings removal processes at OC-ALC. This study should identify, in great detail, the components being processed. This detail should include the components, substrate, coatings being removed, and the number of components. In addition, details on the blast media cabinets should be gathered including the type of media used, the purpose of the blasting, the type of cabinet, the recycle ratios, and the configuration of the cyclone systems, filters, and pressure systems. Where possible, components containing Cr^{6+} or Cd should be segregated into specific cabinets connected to separate filters, cyclones, and pressure systems. Where this is not possible, investigation of coating removal technologies such as hand-held lasers or robotic lasers can be considered.. Each of these technologies result in a dramatic reduction in the amount of waste from the stripping operations.	Waste Streams: Reduction in pounds of Cr^{6+} laden solid hazardous waste as compared to the FY15 baseline. Exposure Potential: Reduction in man-hours related to media blasting and hand-sanding as compared to FY15 baseline.		2016	Laser Coating Removal Systems Atmospheric Plasma

Initiative	Process	Description	Success Metric	Baseline	Initiate	Potential Alternatives
			Infrastructure: Reduction in the infrastructure dedicated to the process as compared to the baseline.	10,485 gals		
Alternative to Chrome Plating	Chrome Plating	There are two ongoing efforts that OC-ALC should monitor and, if possible, become involved in as a testing and demonstration participant. The first is Nanocrystalline cobalt-phosphorus plating (nCoP) testing and demonstration at FRC SE. nCoP is commercially available as an environmentally compliant alternative to hard chrome plating. The other is trivalent hard chrome plating at CCAD. The trivalent hard chrome plating technology is still in its development phase as an alternative to hard chrome plating with hexavalent chromium. Both technologies show promise for replacing some or all hard chrome plating applications. Involvement in one or both of the initiative would allow OC-ALC to leverage completed and ongoing work to more quickly and less expensively implement an alternative to hard chrome plating. However, both of these technologies produce coatings that do change with temperature, so coatings on engine parts may see relatively high temperatures would have to be qualified.	Usage: Reduction in the pounds of Cr^{6+} species (e.g., chromic acid) as compared to the baseline Infrastructure: Reduction in the infrastructure dedicated to the process as compared to the baseline.	1 lbs 8,886 gals	Ongoing	HVOF nCoP plating Cr^{3+} electroplating
Alternative to Cadmium Plating	Cadmium Plating	ESTCP Project WP-201107, "Demonstration/Validation of Zinc-Nickel as a Replacement for Cadmium/Cyanide Plating Process for Air Force Landing Gear" tested and validated LHE Zn-Ni, a cyanide-free plating process that demonstrates excellent throwing power and meets the requirements for a non-embrittling process per American Society for Testing and Materials (ASTM) Specification F519. The coating consists of a zinc alloy containing 12-20% nickel and demonstrates excellent sacrificial corrosion protection for steels. This project installed a production-ready LHE Zn-Ni plating line at Hill Air Force Base's landing gear overhaul facility for demonstration and validation of the plating process and provided landing gear components for field service evaluation. The technology has since been approved for use on all landing gear with the exception of the C-17, which is awaiting engineer approval and changes to the drawings. FRCSE should continue to pursue the ONR RIF project investigating LHE Zn-Ni as an alternative to Cd tank plating. In addition, they should follow and participate in other DoD Cd tank plating replacement efforts (e.g., OO-ALC) to capture lessons-learned and leverage data on shared substrates and requirements.	Usage: Reduction in the pounds of Cd species (e.g., cadmium sulphamate) as compared to the baseline Infrastructure: Reduction in the infrastructure dedicated to the process as compared to the baseline.	0 lbs 5,758 gals	2016	Zn-Ni Plating AlumiPlate Other
Non-Chromate Primer on Aircraft non-OML, Components, and Commodities	Chromated Primers	NAVAIR is also currently evaluating Hentzen 17176KEP primer on V-22 Osprey Helicopter, H-46 Sea Knight Helicopter, H-53 Sea Stallion Helicopter, and F/A-18A-D Hornet aircraft. Unlike the gloss paint scheme aircraft, which are primarily aluminum on the OML, the OML tactical paint scheme of these aircraft is also incorporates composite substrates. Upon successful demonstration, NAVAIR anticipates authorizing the Type II primer for tactical aircraft as well. Once signed and released, each applicable Program will have the option to implement the primer at OEM and depot level. This testing should be extended to non-OML applications.	Usage: Reduction in the pounds of Cr^{6+} species (e.g., strontium chromate) as compared to the baseline	979 lbs	Ongoing	Rare Earth Primers • PPG Deft 02GN084 • Hentzen 17176KEP Metal-Rich Primers • Al-Rich Primers2
Tier 2 Priority Initiatives						
Non-Chrome Aluminum Deoxidizer	Coatings Removal	The replacement of chromate-based deoxidizing/desmutting formulations in the aerospace industry has been difficult. This is primarily due to the nature of the aluminum alloys used for aerospace applications-specifically, alloying with copper. These alloys make the use of deoxidizing/desmutting formulations based on nitric or sulfuric acid infeasible. However, there has been some research in this area. Boeing and Parker-Amchen investigated the use of a two-step system for deoxidizing/desmutting. The first step is a fluoride-based chemistry that deoxidizes the aluminum alloy, but does relatively little to desmut the aluminum. The second step is a nitric acid-based chemistry that desmuts the aluminum, but does not attack the alloy as it is already in a deoxidized state. In addition, Henkel holds a patent on a non-chrome deoxidizer for aluminum that has been around since 1990. The Henkel technology is also a two step process, in which the aluminum is first cleaned in a dilute acidic or alkaline solution and then deoxidized in an acidic solution of hydrogen peroxide or heteropoly vanadic acids or their salts. Finally, Oakite has a non-chrome deoxidizer called Oakite Deoxidizer LNC that is approved to Boeing Process Specification BAC 5765, Cleaning and Deoxidizing Aluminum Alloys, and can be used to meet the requirements of SAE-AMS-W-6858, Welding, Resistance: Spot and Seam.	Usage: Reduction in the pounds of Cr^{6+} species (e.g., strontium chromate) as compared to the baseline Infrastructure: Reduction in the infrastructure dedicated to the process as compared to the baseline.	206 lbs 3,710 gals	2017	Alternatives
Reduction of Cr^{6+} Emissions from Stainless Steel Welding Operations	Stainless Steel Welding	FRCSE should first conduct a comprehensive survey of their stainless steel welding operations. Where down-draft tables and other emissions controls are not being used, and are feasible, they should be put into place. In addition, FRCSE should investigate the use of non-chrome consumables, though this will require testing against material requirements of the weapon systems in question. The use of non-chrome consumables will eliminate Cr^{6+} usage and exposure, meeting both goals. If the use of a non-chrome consumable is not feasible, then the use of a precursor in the shield gas should be considered to reduce the Cr^{6+} emissions and exposure potential.	Usage: Reduction in the pounds of Cr^{6+} species (e.g., strontium chromate) as compared to the baseline	291 lbs	2017	Non-Chrome Consumables Shield Gas Modification
Non-Chrome Stainless Steel Passivation	Stainless Steel Passivation	AMCOM and CCAD are currently considering a project to test, demonstrate, and implement citric acid passivation for stainless steel components. The project will most likely initiate in the third quarter of Fiscal Year 2016 and is scheduled to last for one year. The objective	Usage: Reduction in the pounds of Cr^{6+} species (e.g.,	1 lbs	2016	Citric Acid Passivation

Initiative	Process	Description	Success Metric	Baseline	Initiate	Potential Alternatives
		of the project is to qualify and implement citric acid passivation for stainless steels at CCAD. In addition, FRCSE is initiating a project through NESDI to test and implement citric acid passivation. FRCSE should consider collaborating with AMCOM and CCAD.	chromic acid) as compared to the baseline **Infrastructure:** Reduction in the infrastructure dedicated to the process as compared to the baseline.	1,480 gals		
Non-Chrome Sealer	Chrome Sealers	The objective of ongoing projects at OO-ALC and OC-ALC are to identify, demonstrate/validate and transition alternatives to sodium dichromate sealer for anodized aluminum components. The technical approach includes: determining OO-ALC and OC-ALC sealing requirements; Identifying alternatives to sodium dichromate seal; evaluating alternative sealers through screening and performance tests; conducting a cost-benefit analysis; conducting additional testing; and conducting technology transfer activities.	**Usage:** Reduction in the pounds of Cr^{6+} species (e.g., sodium dichromate) as compared to the baseline **Infrastructure:** Reduction in the infrastructure dedicated to the process as compared to the baseline.	1 lbs 6,282 gals	2016	Cr^{3+} sealers • NAVAIR TCP • Metalast TCP • Alodine T5900 Permanganate sealer SURTEC 580
Tier 3 Priority Initiatives						
Non-Chrome Anodize Dye	Specialty Coatings	The preferred approach would be to identify a commercially available non-chrome anodize dye that meets FRCSE color and material requirements. There are non-chrome anodize dyes commercially available, but none have been tested against FRCSE requirements. It is recommended that FRCSE research potential alternatives and test them against the requirements of the existing process.	**Usage:** Reduction in the pounds of Cr^{6+} species (e.g., chromic acid) as compared to the baseline	12 lbs	2018	None identified.
Non-Low-Chrome Sermetel Alternative	Specialty Coatings	Ceral 34 is an inorganic ceramic aluminum coating consisting of very fine aluminum powder suspended in a chromate/phosphate binder (MIL-C-81751). It is used primarily as a corrosion and erosion-resistant coating on Ni-based alloys (e.g., turbine blades), and steel parts operating in environments up to 1100°F. Ceral 34 is a low-chrome coating that replaced the high-chrome coatings previously used on engines at OC-ALC (Sermetel). It is a low-chrome formulation, not non-chrome. It is normally applied by conventional spray techniques, although brushing and dipping are also possible. Coating components are dried and furnace-cured in order to fuse the binder and form a homogeneous coating. The coating provides a barrier between the substrate and the environment, and can be made conductive (usually by glass bead blasting) to provide galvanic and sacrificial protection.	**Usage:** Reduction in the pounds of Cr^{6+} species (e.g., strontium chromate) as compared to the baseline	4 lbs	2018	Ceral 34

Definitions and Terms

Term used in Report	Meaning in this report	Synonyms [Comment]
Hexavalent chrome, Chromate	Chromium compound in the hexavalent state	Hex Chrome, hexavalent chromium, Cr6, CrVI, Cr^{6+} [not used to refer to trivalent materials]
Chromate conversion coating	Chromate treatment used passivate aluminum and magnesium	Chromate passivation, Alodine,
Passivate (hexavalent, trivalent, non-chrome)	Surface treatment to reduce the corrosion rate of aluminum, magnesium, stainless steels, etc.	conversion coating
Sealer	Treatment used to seal porosity in anodized, phosphated, or plated surfaces.	Chromate sealer, dichromate sealer
Sealant	Material used to fill macro-scale gaps and porosity; typically an organic, polymeric material	gap filler
Wash primer	Chemical treatment used for paint adhesion and corrosion protection, usually on steels	
Primer	Organic coating used to improve paint adhesion and corrosion protection	
Specialty coating	Coating used for unusual or low-volume application	[In this report it does not refer to low observable coating]
Coating removal	Coating removal by any means – Mechanical, chemical, laser, etc.	Stripping, depaint
Brush plating	Localized electroplating using a pad known as a brush or stylus	Stylus plating, selective plating
Chrome Plating	Electrochemical deposition of a hard or industrial chrome surface treatment	Hard chrome plating, electroplated hard chrome

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List of Acronyms

AERTA	Army Environmental Requirements and Technology Assessments
AETC	Air Education and Training Command
AFMC	Air Force Material Command
AFRL	Air Force Research Laboratory
ALC	Air Logistics Complex
AMCOM	US Army Air and Missile Command
ANAD	Anniston Army Depot
ARL	Army Research Laboratory
ASETSDefense	Advanced Surface Engineering Technologies for a Sustainable Defense
CARC	Chemical agent resistant coatings
CCAD	Corpus Christi Army Depot
CONUS	Continental United States
COTS	Commercial off-the-shelf
Cr^{+3}	trivalent chromium
Cr^{6+}	hexavalent chromium
CTIO	Coatings Technology Integration Office
DLA	Defense Logistics Agency
DoD	Department of Defense
EMI	Electromagnetic interference
ESTCP	Environmental Security Technology Certification Program
eTCP	Enhanced trivalent chromium process
FRC	Fleet Readiness Center
HAP	Hazardous Air Pollutant
HEPA	High efficiency particulate air
HMMWV	High-Mobility, Multipurpose, Wheeled Vehicle
HSS	High strength steel
LCMC	Life-Cycle Management Command
LCRS	Laser coating removal system
LEAD	Letterkenny Army Depot
LEV	Local exhaust ventilation

MIG	Metal inert gas
NAVAIR	Naval Air Systems Command
NSN	National stock number
OC-ALC	Oklahoma City Air Logistic Complex
OCONUS	Outside Continental United States
OEM	Original equipment manufacturer
OML	Outer-mold line
OO-ALC	Ogden Air Logistics Complex
OSD	Office of the Secretary of Defense
OSHA	Occupational Safety and Health Administration
PLCRS	Portable laser coating removal system
PEO	Program Executive Office
PI	Principal Investigator
PM	Program Manager
PMB	Plastic media blasting
POC	Point of contact
PPE	Personal protection equipment
R&D	research and development
RDECOM	US Army Research, Development, and Engineering Command
RRAD	Red River Army Depot
RSW	Resistant spot welding
SERDP	Strategic Environmental Research & Development Program
SMAW	Shielded metal arc welding
SON	Statement of Need
TACOM	Tank and Automotive Command
TCP	Trivalent chromium process
TIG	Tungsten inert gas
TMR	Toxic Metals Reduction
TYAD	Tobyhanna Army Depot
UA	Unmanned Aircraft
VOC	Volatile Organic Compound
WR-ALC	Warner Robins Air Logistics Complex

WSDC	Weapon System Designator Code

1 Introduction

The Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) Weapons Systems and Platforms Program Area supports the development and demonstration of innovative advanced coating technologies that enable the Department of Defense (DoD) to:

- reduce or eliminate the use of hazardous materials in its production and maintenance processes;
- reduce hazardous waste streams; and,
- understand and mitigate emissions and other environmental impacts that result from its operations.

The objective of this project is to develop a strategy to eliminate >90% of cadmium (Cd) and hexavalent chromium (Cr^{6+}) in use at Department of Defense (DoD) maintenance depots over the next 5 years. The strategy will include a roadmap to demonstrate how this reduction can be achieved through multiple site demonstrations, leveraging DoD resources to replicate the process across the DoD depot community, and developing a future path for success in the advanced coatings area. As part of this effort, installation-specific implementation plans are being developed in coordination with multiple DoD industrial maintenance depots. The Implementation Plans track back to the overall Advanced Coating 5-Year Strategy and Roadmap, maintaining consistency with DoD's strategic vision as it pertains to Cr^{6+} and Cd reduction.

NAVAIR Fleet Readiness Center Southeast (FRCSE) was visited by our research team on 25-26 March 2015. Visits to two other industrial depots were conducted during the month before and in the months after. Jack Benfer (Engineering) provided a preliminary discussion of activities and arranged a tour of industrial operations where Cd and Cr^{+6} materials are used. Support was also received from Joeseph Campisano (Industrial Hygiene) and Amy Smith (Safety). The Implementation Plan identifies and describes the processes observed at FRCSE, documents the Cd and Cr^{6+} containing materials used in these processes, identifies potential alternatives, and outlines a strategy and roadmap to achieve >90% reduction of Cd and Cr^{6+} at FRCSE over the next 5 years.

1.1 Fleet Readiness Center Southeast

Mission Statement[1]

Our mission is to maintain capability for and perform a complete range of depot-level rework operations on designated weapon systems, accessories and equipment; to manufacture parts and assemblies as required; to provide engineering services in the development of changes of hardware design; to furnish technical and other professional services on aircraft maintenance and logistics problems; to perform, upon specific request or assignment, other levels of aircraft

[1] http://www.navair.navy.mil/

maintenance for eligible activities, and to perform all other functions and tasks as may be assigned by higher authority.

FRCSE (Figure 1) is the largest tenant command aboard Naval Air Station Jacksonville, Fl., with several offsite locations. Established in 1940, the facilities at FRCSE have turned out almost every type of Navy aircraft - fighter and attack planes, patrol, antisubmarine, reconnaissance, transport, trainer, special configuration and helicopters. The overall workload for FRCSE has expanded to include the rework of engines, components, and ground support equipment, plus other support functions vital to the Fleet.

Figure 1. Aerial View of FRCSE on Naval Air Station Jacksonville

With a workforce of almost 3,000 civilian employees, 1,000 military personnel, and 1,000 contractors, FRCSE is the largest industrial employer in Northeast Florida and Southeast Georgia. The employees represent 118 trades and occupations. FRCSE covers 127 acres and occupies 70 buildings with more than 2.5 million square feet of industrial, office and warehouse space.

1.2 Fleet Readiness Center Southeast Mission

FRCSE is a full spectrum aircraft maintenance operation, possessing all of the key capabilities required to maintain high-performance tactical aircraft. Capabilities include comprehensive in-service engineering and logistics services for support of assigned air vehicles, engines and weapons systems. Maintenance is performed on the P-3 Orion Antisubmarine Patrol Aircraft, F/A-18 Hornet Carrier-based Electronic Warfare Aircraft, and SH-60 Seahawk Utility/Assault Helicopter, and associated engines and engine modules. FRCSE performs complete overhaul of structural, mechanical, and avionics for multiple Navy and Air Force aviation engines and components.

- **Aircraft Program**: Phased Depot Maintenance (PDM) and Planned Maintenance Intervals (PMI) repair, conversion, modernization, Integrated Maintenance Concept (IMC), Baseline Program, and In-Service Repair (ISR) on the following types of aircraft: P-3 Orion, F/A-18 Hornet, EA-6B Prowler, SH-60 Seahawk.
- **Aircraft Modification Program**: turnkey operations from design and installation to documentation and flight testing. Examples of some of the modifications include P-3 Electronic Flight Display System, EA-6B Improved Capability (ICAP) III upgrade, F/A-18 aircraft PMI 1 and 2 upgrades and Center Barrel Replacement Plus (CBR+).
- **Engine Program**: complete overhaul capabilities for most repairable components, assemblies, and accessories for engines including F414, F404, J52, T700, T56, and TF34.
- **Components**: intermediate and depot level repair for the structural mechanical, avionics, and engine component programs and range from miniature to sizeable electronic and mechanical parts that make-up aircraft, engine, and weapon systems.
- **Support**: calibration, support equipment, and manufacturing as well as engineering and logistics support for aircraft, engines, systems and equipment. Systems covered include those repaired and modified by FRCSE as well as other primary Naval systems such as the T-45 Goshawk training aircraft, the E-6B Mercury TACAMO strategic communications aircraft, the T-56 engine that powers the P-3 aircraft as well as E-2, C-2, and C-130 aircraft, and the Navy's Adversary aircraft (Navy versions of the F-5 and F-16 aircraft and their engines).

Core DoD weapon systems identified at FRCSE are listed by type in Table 1. The list provides weapon system identifiers from the Weapons System Impact Tool (WSIT), which is managed by the Defense Logistics Agency (DLA).

Table 1. Core FRCSE Weapon Systems

Type	WSDC	Description
AIRCRAFT	35N	AIRCRAFT, P-8A POSEIDON
	40A	HELICOPTER, BLACK HAWK UH-60A
	43N	AIRCRAFT, HORNET F/A-18

Type	WSDC	Description
	45N	AIRCRAFT, PROWLER EA-6B
	63N	AIRCRAFT, ORION P-3
	VUN	AIRCRAFT, HORNET F/A-18 (E/F)
	YLN	HELICOPTER, SEAHAWK, H-60
		AIRCRAFT, TRAINER T-45
ENGINES	49N	ENGINE, AIRCRAFT J-52
	69N	ENGINE, AIRCRAFT F-404 (F/A-18 A-D)
	73N	ENGINE, AIRCRAFT TF34

2 Fleet Readiness Center Southeast Processes

The FRCSE Implementation Plan outlines a strategy and provides a roadmap to meet the goals established in the Advanced Coatings 5-Year Strategy and Roadmap. These goals are >90% reduction in the use of Cd and Cr^{6+} in processes across the depot and >90% reduction in Cd and Cr^{6+} emissions, exposures, and waste streams. The strategy addresses both production processes that use materials containing Cd or Cr^{6+} (e.g., chrome plating) and processes that potentially cause emissions, exposures or waste streams based on legacy materials used on weapon systems (e.g., abrasive blasting). The strategy and roadmap outlined in this implementation plan is a component of the larger DoD strategy. The FRCSE Implementation Plan is composed of four parts:

- **Processes, Weapon Systems and Components, and Materials** – This section of the Implementation Plan describes each of the individual Cd and Cr^{6+} processes at FRCSE, the weapon systems and components being maintained in each of these processes, and the materials used in the process.
- **Alternatives** – This section of the Implementation Plan briefly describes available and in-process alternatives to each of the Cd and Cr^{6+}-using processes identified at FRCSE. An effort is made to examine the applicability of alternatives to FRCSE applications and to identify potential barriers to implementation.
- **Fleet Readiness Center Southeast Roadmap** – This section of the Implementation Plan prioritizes recommended initiatives to help FRCSE achieve the >90% use and emissions, exposures, and waste stream reduction goals for Cd and Cr^{6+}. The prioritization methodology is described and the initiatives are documented on a timeline to provide a visual for implementation.

2.1 Processes, Weapon Systems and Components, and Materials

FRCSE has over 20 distinct processes in 3 different buildings that use Cd and Cr^{6+}-containing materials. The 20 distinct processes are grouped into process categories consistent with those established in the Advanced Coatings 5-Year Strategy and Roadmap. The process categories observed at FRCSE and included in this report are:

- Chromated Primers

- Chrome Plating
- Cadmium Plating
- Chromate Conversion Coatings
- Stainless Steel Passivation
- Adhesives and Sealants
- Cadmium Brush Plating
- Chromate Sealers
- Topcoats and Specialty Coatings
- Coatings Removal (Chemical and Physical)
- Stainless Steel Welding

The following core FRCSE weapon systems, listed in tables 2 and 3 by Weapon System Designator Code (WSDC), have been identified as having components that will require either Cr^{+6} or Cd compound coatings applied at FRCSE.

Table 2: Core FRSCE Weapon Systems, Cadmium

WSDC	Weapon System Description
43N	AIRCRAFT, HORNET F/A-18
45N	AIRCRAFT, PROWLER EA-6B
63N	AIRCRAFT, ORION P-3
VUN	AIRCRAFT, HORNET F/A-18 (E/F)
YLN	HELICOPTER, SEAHAWK, H-60
49N	ENGINE, AIRCRAFT J-52
69N	ENGINE, AIRCRAFT F-404 (F/A-18 A-D)
73N	ENGINE, AIRCRAFT TF34

Table 3: Core FRCSE Weapon Systems, Chromium

WSDC	Weapon System Description
35N	AIRCRAFT, P-8A POSEIDON
40A	HELICOPTER, BLACK HAWK UH-60A
43N	AIRCRAFT, HORNET F/A-18
45N	AIRCRAFT, PROWLER EA-6B
63N	AIRCRAFT, ORION P-3
VUN	AIRCRAFT, HORNET F/A-18 (E/F)
YLN	HELICOPTER, SEAHAWK, H-60
49N	ENGINE, AIRCRAFT J-52
69N	ENGINE, AIRCRAFT F-404 (F/A-18 A-D)
73N	ENGINE, AIRCRAFT TF34

Table 4 attempts to tie each process to the core weapon systems on which it is used. The list of weapon systems is not exhaustive, but captures those systems that drive the FRCSE workload.

Table 4. FRCSE Processes and Core Weapon Systems

	E-3A AWACS	EA-6B Prowler	F/A-18 Hornet	H-60 Seahawk	P-3 Orion	P-8A Poseidon	UH-60A Black Hawk	J-52 Engine	F-404 Engine	TF34 Engine
Chromate Primers	●	●	●	●	●	●	●			
Chrome Plating	●	●	●	●	●	●	●	●	●	●
Cadmium Plating				●			●	●	●	●
Chromate Conversion Coatings	●	●	●	●	●	●	●			
Stainless Steel Passivation				●			●			
Adhesives and Sealants	●	●	●	●	●	●	●			
Cadmium Brush Plating	●	●	●	●	●	●	●	●	●	●
Chromate Sealers	●	●	●	●	●	●	●			
Topcoats and Specialty Coatings	●	●	●	●	●	●	●	●	●	●
Coatings Removal (Physical/Chemical)	●	●	●	●	●	●	●	●	●	●
Stainless Steel Welding				●			●			

Table 5 presents the total pounds of Cd or Cr^{6+}-containing products and species (e.g., strontium chromate, barium chromate, sodium dichromate) used in each of the process categories listed above. The data provided is from the Hazardous Materials Management System (HMMS) and reflects totals for Calendar Year 2014.

Table 5. Process Cd and Cr^{6+} Usage

Process	Contains	Lbs Product	lbs Species
Chromated Primers	Cr^{6+}	5,242.20	978.98
Chrome Plating	Cr^{6+}	1.01*	1.01*
Cadmium Plating	Cd	0**	0**
Chromate Conversion Coating	Cr^{6+}	9,190.89	145.6
Stainless Steel Passivation	Cr^{6+}	1.01*	1.01*
Adhesives and Sealants	Cr^{6+}	6.04	15.15
Cadmium Brush Plating	Cd	96.27	14.97
Chromate Sealers	Cr^{6+}	1.01*	1.01*
Topcoats and Specialty Coatings	Cr^{6+}	183.01	16.86
Coatings Removal	Cr^{6+}	1,032	206.4
Stainless Steel Welding	Cr^{6+}	3,365	291.29
Total All		19,118.44	1,672.28

Total Cd		96.27	14.97
Total Cr		19,022.17	1,657.31

*The same chemical/product is used to supplement the baths for chrome plating, stainless steel passivation, and chromate sealers (chromic acid). The data reflected in HMMS does not distinguish between the processes, therefore, the 1.01 pounds of chromic acid was attributed to each process. The small amount of material is a result of the process baths not needing to be recharged often.

**During Calendar Year 2014, the cadmium bath was not recharged nor were the Cd ball anodes replaced resulting in no chemical usage attributed to this process.

Figures 2, 3, and 4 illustrate comparisons between the processes based on pounds of Cr^{6+} or Cd species. Figure 2 compares all of the process categories used at FRCSE. Figures 3 and 4 compare the Cr^{6+} and Cd processes respectively.

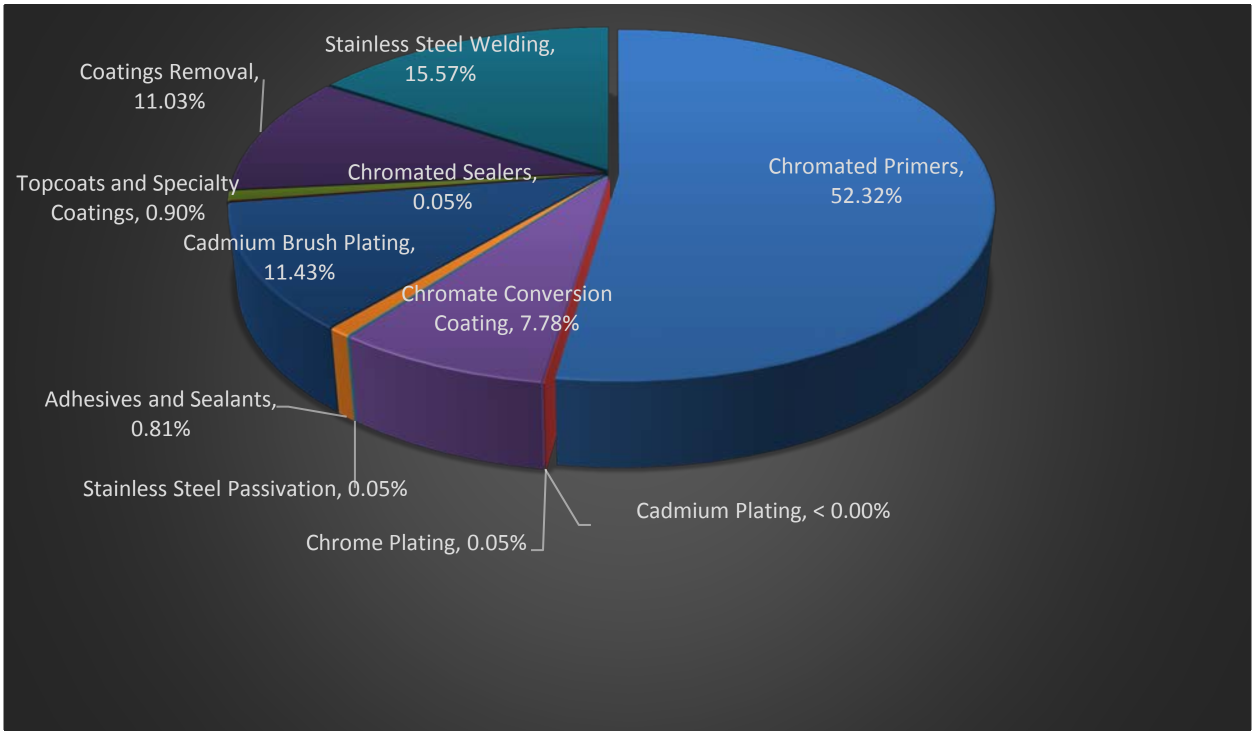

Figure 2. Process Usage at FRCSE (based on pounds of Cr^{6+} and Cd species)

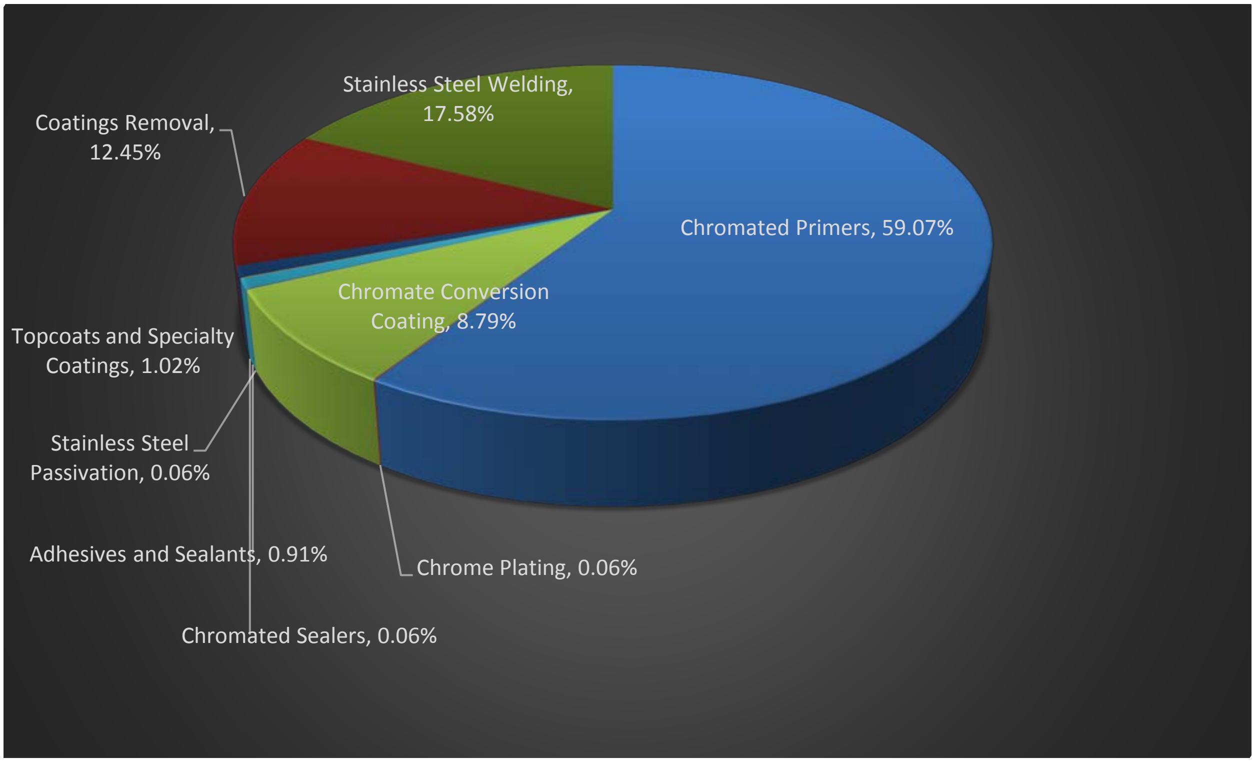

Figure 3. Cr^{6+} Process Usage at FRCSE (based on pounds of Cr^{6+} species)

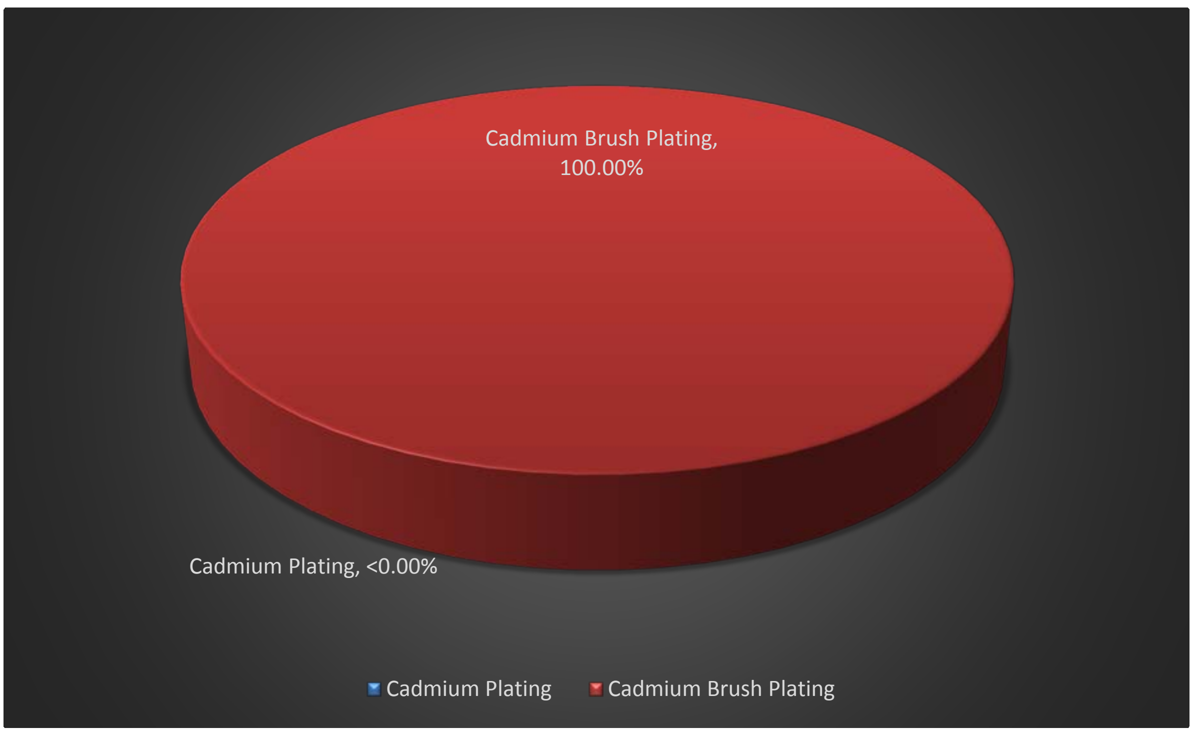

Figure 4. Cd Process Usage at FRCSE (based on pounds of Cd species).

Since some processes did not require supplementation or replacement during Calendar Year 2014, hazardous materials usage does not adequately describe the scope of the Cr^{6+} and Cd issues associated with FRCSE processes. FRCSE also analyzed the infrastructure associated with each of the processes. Specifically, they focused on the dedicated tankage (in gallons) for each of the processes. Table 6 lists each of the processes for which the infrastructure was analyzed and the tankage associated with each.

Table 6. FRCSE Process Infrastructure

Process	Species	Tankage (gallons)
Chrome Plating	Cr^{6+}	8,662
Chromate Conversion Coatings		13,633
Aluminum	Cr^{6+}	12,153
Magnesium	Cr^{6+}	1,480
Chromated Sealer		9,996
Anodize Sealer	Cr^{6+}	7,738
Cd Post Treatment	Cr^{6+}	2,258
Coatings Removal		4,345
Aluminum Deoxidation	Cr^{6+}	3,710
Cr^{6+} Rinse	Cr^{6+}	635
Stainless Steel Passivation	Cr^{6+}	1,480
Cadmium Plating	Cd	5,740
Total		43,856

The distribution of infrastructure is illustrated graphically in Figure 5 below.

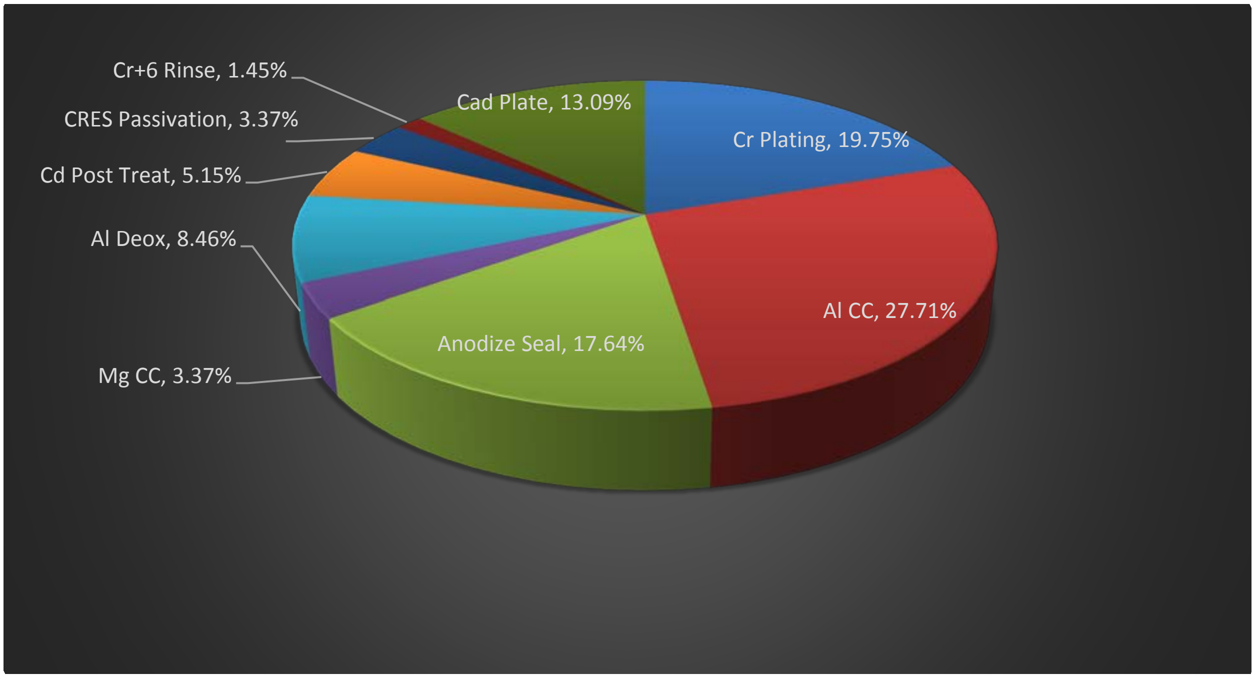

Figure 5. FRCSE Surface Finishing Infrastructure Totals

The hazardous materials data from HMMS represents actual chemical purchase and usage, but the infrastructure represents the level of liability with regard to potential exposure, spills, and waste streams. Following this logic, chromate conversion coatings represent the single largest liability associated with a process category on FRCSE, accounting for 13,633 gallons of tankage in a. This data will be weighed and accounted for in the Roadmap as initiatives are defined and prioritized.

Sections 2.1.1 through 2.1.11 describe each of the processes in greater detail and, when possible, describe the weapon system components that are maintained. This section also correlates the process to the materials or trade name products used at FRCSE.

2.1.1 Chromated Primers

Process Description.

A primer or undercoat is a preparatory coating product applied to improve the adhesion of topcoat or finishing paint and, in many cases, provides additional environmental corrosion resistance. Primers are designed to adhere to surfaces and to form a binding layer that is better prepared to receive the paint. Because primers do not need to be engineered to have durable, finished surfaces, they can instead be engineered to have improved filling and binding properties with the substrate. Chromated primers contain hexavalent chrome compounds (e.g., zinc chromate, strontium chromate, and magnesium chromate) as the primary pigment and corrosion inhibitor.

At FRCSE, chromated primers are applied primarily to the outer mold line (OML) of aircraft, interior areas of aircraft, and steel and aluminum aircraft components within ventilated paint booths. Spray painting operations using chromated primers and paints can generate elevated airborne concentrations of Cr^{6+}. Based on past personal monitoring, there exists a high risk potential to exceed regulatory limits. All personnel involved participate in the Chromate Medical Surveillance Program.

Weapons Systems and Components

Chromated primers are applied to the OML, interiors, and components of fixed wing and rotary wing aircraft as well as to various commodity parts. Primers used at FRCSE are typically in accordance with (IAW) MIL-PRF-23377. The weapon systems to which chromated primers are applied at FRCSE include:

- F/A-18 Hornet
- EA-6B Prowler
- P-8A Poseidon
- P-3 Orion
- E-3A AWACS
- UH-60A Blackhawk
- H-60 Seahawk

Materials

FRCSE uses chromated primers IAW MIL-PRF-23377 (various types and classes), and MIL-PRF-85582. The products, national stock numbers (NSN), and usage (Calendar Year 2014) in pounds of product and Cr^{6+} are listed in Table 7.

Table 7. Chromate Primers Materials/Products

Trade Name	NSN	Usage (lbs product)	Usage (lbs Cr^{6+})
EPOXY PRIMER COATING GREEN 44GN007 1 QT KIT	8010012180856	335.49	23.48
EPOXY PRIMER TYPE II, CLASS C1 BASE COMPONENT (1GL KIT)	8010012180857	1477.59	295.52
44GN007, EPOXY PRIMER BASE (1-GL KIT)	8010012187354	2274.68	454.94
PRIMER COATING YELLOW (1-GL KIT; 1A/2B)	8010013577868	6.35	1.26
EPOXY PRIMER BASE COMPONENT TYPE I, CLASS C2 (1QT KIT)	8010014166557	23.79	4.76
EPOXY PRIMER COATING 10P20-13SC (16-OZ KIT)	8010015284864	400.21	80.04
EPOXY PRIMER GREEN BASE COMPONENT TYPE I CLASS C1 (1OZ KIT)	8010LLHAZ3111	2.85	0.04
EPOXY PRIMER GREEN 02GN070A (3.5-OZ KIT PREMIXED)	8010LLHAZ4224	408.62	81.72
YELLOW EPOXY PRIMER TYPE I CLASS C2 (2OZ KIT	8010LLHAZ4376	312.59	37.20

2.1.2 Chrome Plating

Process Description

Also known as engineered hard chrome or industrial chromium plating, hard chrome plating is applied as a fairly heavy coating, adding wear resistance and oil retention, reducing friction by increasing lubricity and increasing corrosion resistance. Based on the requirement for various applications like hydraulic cylinder rods, rollers, piston rings, mold surfaces, thread guides, gun bores and many more, the quality of plating varies. Variations of hard chrome plating include thin dense chrome or porous coatings for oil retention. Electrodeposited Hard Chrome (EHC) can be applied directly on the substrate, or on some substrates a Ni flash is used. For best corrosion resistance, and also for build-up its common in industry that sulfamate Ni is plated first, then EHC.

A typical hexavalent chromium plating process is: (1) activation bath, (2) chromium bath, (3) rinse, and (4) rinse. When applied to hardened steel, it renders a metallic appearance though it doesn't produce a reflective, decorative or leveling effect. The activation bath is typically a tank of chromic acid with a reverse current run through it. This etches the work-piece surface and removes any scale. In some cases the activation step is done in the chromium bath. The chromium bath is a mixture of chromium trioxide (CrO_3) and sulfuric acid (sulfate, SO_4), the ratio of which varies greatly between 75:1 to 250:1 by weight. This results in an extremely acidic bath (pH 0). The temperature and current density in the bath affect final coverage.

Industrial or Engineering hard chrome is an electroplated coating with thicknesses as little as 0.00002” (flash chrome) or as high as 0.060” (thin dense chrome (TDC) is a specialist process usually done by vendor). Standard Chromic acid / sulfate processes have a typical cathode efficiency of 10% to 12%. In other words for every 100 amps supplied only 10% to 12% of that current is actually depositing chromium at the cathode surface. The electrolytic bath temperatures range from 100 to 110°F. Chromium plating is resistant to abrasion, galling and wear and when plated over nickel or a copper/nickel strike layer is resistant to atmospheric corrosion.

On aluminum, various etching processes occur with sulfuric acid and nitric acid as well as zincate processes prior to actually plating the substrate. Chromium plating can also occur over existing chromium. Thicker deposits often require a post plating process. For build-up >0.015" typically sulfamate Ni is used to do the bulk of the build with 0.003" EHC (thickness left after finishing). These deposits can be cylindrically or surface ground and/or polished to specifications. An additional post plating process can require hydrogen embrittlement relief baking or "hydrogen baking."   The hydrogen bake process is used if steel strength is >180 ksi. The other essential post process is grinding, which is always used for thick coatings for wear resistance. It gets the dimensions correct and gets the right surface finish. Typical finishes are 16 microinch Ra, and 8 µ" for sliding wear surfaces such as hydraulics and LG inner cylinders,

Weapons Systems and Components

Hard chrome plating is applied to engine and commodities components of fixed wing and rotary wing aircraft. Chrome plating at FRCSE is applied IAW SAE-AMS QQ-C-320. The weapon systems to which hard chrome plating is applied at FRCSE include:

- J-52 Engine
- TF34 Engine
- H-60 Seahawk
- F-404 Engine
- UH-60A Blackhawk

Infrastructure

The hard chrome plating line is in Building 101, where 8,662 gallons of tankage is dedicated to the process, including all plating and rinse baths. Table 8 lists the chrome plating (including strip and rinse) tanks and their volume.

Table 8. Chrome Plating Infrastructure

Tank	Gallons	Material
Chrome Electroplating Tank(s)	987	Cr^{6+}
Chrome Electroplating Tank(s)	1728	Cr^{6+}
Chrome Electroplating Tank(s)	1481	Cr^{6+}
Chrome Plating Rinse Tank(s)	1400	Cr^{6+}
Chrome Strip Tank(s)	808	Cr^{6+}
Chrome Strip Tank(s)	658	Cr^{6+}
Chrome Strip Tank(s) - Rinse	1600	Cr^{6+}
Total Infrastructure	8662	

Materials

FRCSE applies hard chrome plating IAW SAE AMS QQ-C-320. The products, NSNs, and usage (Calendar Year 2014) in pounds of product and Cr^{6+} are listed in Table 9.

Table 9. Chrome Plating Materials/Products

Trade Name	NSN	Usage (lbs product)	Usage (lbs Cr^{6+})
CHROMIUM TRIOXIDE, ACS	6810LLLAB0620	1.10	1.10

2.1.3 Cadmium Plating

Process Description

Cd plating is a material deposition process which coats components with a thin protective layer of Cd metal. Cd coatings at FRCSE are applied by electroplating. The Cd electroplating process involves suspending components in a bath filled with a Cd salt solution with an alkaline cyanide base. A Cd anode is inserted into the bath, and a current is passed from it through the solution and to the components which serve as a cathode or negative point. Cd is attracted to and deposited on the components from the solution and replaced by material from the anode which is forced into solution. Electroplated cadmium is a robust and versitile metallic coating that, when plated onto steel gives plated components outstanding conventional and galvanic corrosion resistance and even a degree of sacrificial protection. To enhance the corrosion protection of Cd plating, chromate conversion coatings can be applied over the plated metal. In addition to corrosion protection, Cd plating offers low electrical resistance; outstanding conductivity; superior solderability; favorable galvanic coupling with aluminum; and excellent natural lubricity, which results in prevention of galling and a low coefficient of friction.

At FRCSE, Cd electroplating is performed on both aircraft and engine parts.

Weapons Systems and Components

The weapon systems which have components that are cadmium brush plated at FRCSE include:

- J-52 Engine
- TF34 Engine
- H-60 Seahawk
- F-404 Engine
- UH-60A Blackhawk

Infrastructure

The Cd electroplating line is in Building 101, where 5,740 gallons of tankage is dedicated to the process, including all process and rinse tanks. Table 10 lists the Cd plating (including rinse and strip) tanks and their volume.

Table 10. Cadmium Plating Infrastructure

Tank	Gallons	Material
Cadmium Electroplating Tank(s)	658	Cd
Tin-Cadmium Electroplating	-	Cd

Cadmium Rinse Tank	2400	Cd
Cadmium Strip Tank	1350	Cd
Total Infrastructure	5758	

Materials

FRCSE applies cadmium plated finishes in accordance with QQ-P-416-F. No products or materials were listed in HMMP for the process in Calendar Year 2014, indicating that the anode was still viable and that additional Cd salt was not required to replenish the bath.

2.1.4 Chromate Conversion Coating

Process Description

Chromate conversion is used to form an amorphous protective coating for enhanced corrosion protection and adhesion of subsequently applied sealants and topcoats on various metal surfaces. The process serves to inhibit corrosion and improve the adhesion of both paint and powder finishes and provides an added degree of protection. When the protective coating or paint is scratched, chromates from the conversion coating deposit on the bare metal recreating a corrosion-resistant layer at the exposed surface.

Chromate conversion coatings are produced by chemical treatment with hexavalent chromium compounds and other activators. When a metal is treated with this mixture, a layer of its surface (nano-meters in thickness) will dissolve, forming a protective film consisting of a complex mixture of both hexavalent and trivalent chromium compounds with the base metal. These coatings can be applied through immersion, spray, or wipe-on techniques.

The use of chemical conversion coatings for aluminum is governed by two specifications, MIL-DTL-5541E–Chemical Conversion Coatings on Aluminum and Aluminum Alloys and MIL-DTL-81706B–Chemical Conversion Materials for Coating Aluminum and Aluminum Alloys. Chromate conversion processes at FRCSE provide surface corrosion protection to aircraft and engine components. Processes are performed by immersion and spray-on methods using Alodine 600. In the Depaint shop of Building 101, aircraft are sprayed with Alodine 600 prior to priming and painting. Touch-N-Prep® Alodine 1132 pens are used throughout FRCSE to provide spot repair conversion coatings to surfaces as needed.

Weapons Systems and Components

Chromate conversion coatings are applied to almost every weapon system maintained at FRCSE. The weapon systems to which chromate conversion coatings are applied at FRCSE include:

- P-8A Poseidon
- EA-6B Prowler
- UH-60A Blackhawk
- P-3 Orion
- E-3A AWACS
- F/A-18 Hornet
- H-60 Seahawk

Infrastructure

Chromate conversion coating lines for both aluminum and magnesium operate at FRCSE in Building 101 using Alodine 600. In Building 101, there is 12,153 gallons of tankage dedicated to the chromate conversion coating of aluminum and 1,480 gallons of tankage dedicated to the chromate conversion coating of magnesium. Chromate conversion coating has the largest infrastructure requirements of any of the processes observed at FRCSE. Table 11 lists the chromate conversion coating (including rinse) tanks and their volume.

Table 11. Chromate Conversion Coating Infrastructure

Tank	Gallons	Material
Aluminum Conversion Coating	598	Cr^{6+}
Aluminum Conversion Coating	380	Cr^{6+}
Al CC Rinse Tank	1885	Cr^{6+}
Al CC Rinse Tank	380	Cr^{6+}
Conversion Coating - Spray/yr	1485	Cr^{6+}
CC - Spray Rinse Water	7425	Cr^{6+}
Total Al CCC	12,153	
Magnesium Treatment	740	Cr^{6+}
Magnesium Treatment - Rinse	740	Cr^{6+}
Total Mg CCC	1,480	
Total Infrastructure	13,633	

Materials

FRCSE applies chromate conversion coatings IAW MIL-DTL-5541E–Chemical Conversion Coatings on Aluminum and Aluminum Alloys and/or MIL-DTL-81706B–Chemical Conversion Materials for Coating Aluminum and Aluminum Alloys. The products, NSNs, and usage (Calendar Year 2014) in pounds of product and Cr^{6+} are listed in Table 12.

Table 12. Chromate Conversion Coatings Materials/Products

Trade Name	NSN	Usage (lbs product)	2014 Usage (lbs)
ALODINE 600 RTU PINTS CORROSION RESISTANT COAT, 16 OZ	6850LLHAZ3852	622.34	3.11
ALODINE 600 RTU CORROSION RESISTANT COAT (DISPENSED PT) REPL LLHAZ1582; DISP LLHAZ3488	6850LLHAZ3852	177.81	88.91
ALODINE MAGNESIUM TREATMENT KIT (8OZ)	8030015122416	1.08	0.003
CORROSION RESISTANT COAT ALODINE 600 RTU 55-GL	8030LLHAZ3488	8363.52	41.82
CORROSION RESISTANT COATING ALODINE 600 LAB-MIXED (16 OZ)	8030LLLAB0719	26.14	11.76

2.1.5 Stainless Steel Passivation

Process Description

According to ASTM A 380, passivation is “the removal of exogenous iron or iron compounds from the surface of a stainless steel by means of a chemical dissolution, most typically by a treatment with an acid solution that will remove the surface contamination but will not significantly affect the stainless steel itself.” In addition, it also describes passivation as “the chemical treatment of a stainless steel with a mild oxidant, such as a nitric acid solution, for the purpose of enhancing the spontaneous formation of the protective passive film.” The passivation process returns the stainless steel back to its original specification by removing unwanted debris and oils from the surface and then submerging the part into a passivating bath. When a component is machined, various particles can permeate the surface of the base metal, weakening it’s resistance to corrosion and making the component more susceptible to environmental factors. Debris, dirt and other particles and residue such as free iron, grease and machining oils all affect the strength of the natural surface and can become embedded in the surface during the machining process.
The passivation of stainless steel is a process performed to make a surface passive, i.e., a surface film is created that causes the surface to lose its chemical reactivity. Stainless steel is already known as being corrosion-resistant, however the passivation process further strengthens its’ natural coating by improving the exterior surface of the overall part. The passivation process removes “free iron” contamination left behind on the surface of the stainless steel as a result of machining and fabricating processes. These contaminants are potential corrosion sites which, if not removed, result in premature corrosion and ultimately result in deterioration of the component. In addition, the oxygen absorbed by the metal surface, creates a monomolecular oxide film, resulting in the very much-desired low corrosion rate of the metal.

At FRCSE, stainless steel passivation is performed primarily on aircraft parts.

Weapons Systems and Components

Stainless steel passivation impacts components on the following weapon systems at FRCSE:

- H-60 Seahawk
- UH-60A Black Hawk

Infrastructure

The passivation line is in Building 101, where 1,480 gallons of tankage is dedicated to the process, including all process and rinse tanks. Table 13 lists the passivation (including rinse) tanks and volume.

Table 13. Stainless Steel Passivation Infrastructure

Tank	Gallons	Material
CRES Passivation	740	Cr^{6+}
CRES Passivation-rinse	740	Cr^{6+}
Total Infrastructure	1,480	

Materials

FRCSE passivates stainless steel in accordance with ASTM A967 and AMS 2700 using chromic acid baths. The products, NSN, and Calendar Year 2014 usage in pounds of product and Cr^{6+} are listed in Table 14.

Table 14. Stainless Steel Passivation Materials/Products

Trade Name	NSN	Usage (lbs product)	Usage (lbs Cr^{6+})
CHROMIUM TRIOXIDE, ACS	6810LLLAB0620	1.10	1.10

2.1.6 Adhesives and Sealants

Process Description

Organic adhesives and sealants are used broadly throughout the aerospace industry and have many applications at FRCSE. Polymeric adhesives are used for a variety of structural and non-structural bonding applications on aircraft components and for repair of composite materials that can be damaged in service. Maintaining corrosion resistance at the bond line is critical to maintaining performance, but this is often achieved through the use of adhesive bond primers that contain hexavalent chromium.

The primary use of sealants is to provide an electrically insulating, corrosion-resistant barrier between dissimilar metals and for sealing electrical equipment. The preferred corrosion inhibitors for sealants in the past have all been hexavalent chrome-containing compounds. In addition these sealants typically contain high VOC solvents (toluene and MEK), which are necessary for processing and curing. Chromated corrosion-inhibiting sealants are typically applied to most aircraft faying surfaces. All military aircraft are required to use this type sealant in dry bay areas, wheel wells, cargo bays, radomes, and access panels. Commercial aircraft employ these sealants in the same general areas, but the requirements are less stringent. Sometimes these materials are also used to wet-install fasteners, overcoat fasteners, and fillet-seal seams. In addition to these uses, a minor quantity can be found in weapons systems that are exposed to non-benign environmental situations.

Weapons Systems and Components

Polymeric adhesives and sealants are applied primarily to aircraft and aircraft components at FRCSE. The weapon systems to which adhesives and sealants are applied at FRCSE include:

- P-8A Poseidon
- EA-6B Prowler
- UH-60A Blackhawk
- P-3 Orion
- E-3A AWACS
- F/A-18 Hornet
- H-60 Seahawk

Materials

FRCSE applies adhesives and sealants IAW various specifications and standards, including MIL-A-5540, MIL-A-9117, MMM-A-121, and MMM-A-134. The products, national stock numbers (NSN), and Calendar Year usage in pounds of product and Cd or Cr^{6+} are listed in Table 15.

Table 15. Adhesives/Sealants Materials/Products

Trade Name	NSN	Species	Usage (lbs product)	Usage (lbs)
JOINTING COMPOUND, MASTINOX YELLOW (MSDS CONTAINS 2 PARTS)	8010LLHAZ3053	Cr^{6+}	5.91	0.89
3M AEROSPACE SEALANT AC-655 B-1/2 AND B-2 BASE (1PINT KIT)	8030000087198	Cr^{6+}	28.25	0.85
SEALING COMPD 90-006-2 PART B (6-OZ SEMKIT)	8030001450372	Cr^{6+}	0.38	0.02
SEALING COMPD WS-8070 B-1/2 BASE 3.5-OZ SEMKIT	8030011840329	Cr^{6+}	3.62	0.63
SEALING COMPD PR1764 B2 PART A 6OZ KIT	8030013190829	Cr^{6+}	1.35	0.27
SEALING CMD, 21347 PRIMER N 7649 (1.75-OZ)	8030013885606	Cr^{6+}	1.73	0.00
CONDUCTIVE SEALANT, PR-2225 B-1 (3.5-OZ SEMKIT)	8030014990438	Cr^{6+}	12.96	0.32
SEALING COMPD PR-1764 B-2 (4-CC KIT)	8030LLHAZ4274	Cr^{6+}	0.20	0.04

2.1.7 Cadmium Brush Plating

Process Description

Brush plating (sometimes called stylus plating) is a localized form of electroplating, in which the surface is cleaned and often etched to activate it, and then the coating is deposited electrolytically. The primary difference with tank plating is that brush plating is a manual process that is carried out over a limited area to correct damage or replace lost coatings. The basic items needed are a power pack, plating tools, masking materials and solutions. The plating is achieved by passing an electric current, via a hand-held anode, through a liquid solution which contains the desired material. The part becomes the cathode and is connected to the negative terminal of the power pack. The appropriate solution -- which can be fed with a pump -- completes the electrical circuit. The deposition rates can be about 0.035 inches/hour, which means quick plating of the part. Brush techniques are suitable for simple geometric shapes such as outer diameters, interior diameters, cylindrical surfaces, and flat surfaces.

Cadmium functions as a sacrificial coating against uniform and galvanic corrosion, when plated onto steel, providing protection for the surface even if the coating is damaged. Because its galvanic potential is very similar to aluminum, it is often used to prevent galvanic corrosion between steel or stainless steel and aluminum or magnesium. It offers consistent torque tension values on threaded fasteners, low-volume corrosion products, and consistently low electrical impedance, even after corrosion. It is applied to base metal, except in the case of parts made from corrosion resistant alloys on which a preliminary plating of nickel (or strike layer) of copper or nickel may be necessary, or on parts made of aluminum on which a preliminary treatment, such as the zincate process may be necessary. Cadmium offers an exceptional bonding surface for adhesives and is a preferred coating for harsh marine environments. Some cadmium brush plated (Type II) components require a chromate seal finish.

Weapons Systems and Components

Cadmium brush plating is applied to both engine and aircraft components at FRCSE. The weapon systems to which cadmium brush plating is applied at FRCSE include:

- P-8A Poseidon
- EA-6B Prowler
- UH-60A Blackhawk
- P-3 Orion
- J-52 Engine
- E-3A AWACS
- F/A-18 Hornet
- H-60 Seahawk
- TF34 Engine
- F-404 Engine

Materials

FRCSE applies cadmium brush plated finishes in accordance with MIL-STD-865. The products, national stock numbers (NSN), and Calendar Year 2014 usage in pounds of product and Cd are listed in Table 16.

Table 16. Cadmium Brush Plating Materials/Products

Trade Name	NSN	Usage (lbs product)	Usage (lbs Cd)
SIFCO PROCESS CADMIUM (NO BAKE) (DALIC) (4L)	6850LLHAZ3337	106.27	14.98

2.1.8 Chromate Sealers

Process Description

Chromate sealers are used where enhanced corrosion resistance is required and where the imparted yellowish color to the coating is important, such as military and industrial applications requiring exceptional corrosion resistance. Furthermore, these types of seals are often one part of what is referred to as a “duplex” sealing process. Dichromate seals are often used in conjunction with either nickel acetate (NiAc) or near boiling deionized water sealing processes. The order of sealing may be dichromate followed by water or NiAc or the dichromate may come after either of those processes. Potassium or sodium dichromate is usually the preferred chemistry to use for this type of sealing.

Many surface treatment processes (e.g., anodizing, phosphate, black oxide, cadmium brush plating) call for a post treatment chromate seal to enhance the corrosion prevention capabilities of the coating. The application may be done through immersion of the component, but spray or brush-on techniques are also widely used. In addition, to enhancing the corrosion protection of cadmium plated components, a chromate sealer finish coating can be applied over the plated metal to prevent the formation of white corrosion products on surfaces exposed to marine environments or high humidity atmospheres.

Weapons Systems and Components

Chromate sealers are applied primarily to aircraft and commodities components at FRCSE. The weapon systems to which chromate sealers are applied at FRCSE include:

- P-8A Poseidon
- EA-6B Prowler
- UH-60A Blackhawk
- P-3 Orion
- E-3A AWACS
- F/A-18 Hornet
- H-60 Seahawk

Infrastructure

The chrome sealer lines for anodize and cadmium post treat are in Building 101, where 6,282 gallons of tankage is dedicated to the process, including all process and rinse tanks. Table 17 lists the chrome sealer (including rinse) tanks and volume.

Table 17. Chrome Sealer Infrastructure

Tank	Gallons	Material
Anodize Seal	1885	Cr^{6+}
Anodize Seal	259	Cr^{6+}
Anodize Seal - Rinse	1885	Cr^{6+}
Cadmium Post Treatment	658	Cr^{6+}
Cad Post Treatment - Rinse	1600	Cr^{6+}
Total Infrastructure	6,282	

Materials

FRCSE applies a chromate sealer according to the specifications of the base surface treatment-MIL-STD-865, MIL-A-8625, etc. The products, NSNs, and usage (Calendar Year 2014) in pounds of product and Cr^{6+} are listed in Table 18.

Table 18. Chrome Sealers Materials/Products

Trade Name	NSN	Usage (lbs product)	Usage (lbs Cr^{6+})
CHROMIUM TRIOXIDE, ACS	6810LLLAB0620	1.10	1.10

2.1.9 Topcoats and Specialty Coatings

Process Description

Specialty coatings are those process and material combinations that do not fit into any of the more widely used process categories. FRCSE uses several products that fall into the specialty coatings category. Those with the most significant contribution to Cr^{6+} usage include: Sermetal and Sanodal Deep Black MLW Dye.

2.1.9.1 Sermetel

Sermetel is an unusual inorganic slurry comprising finely divided aluminum metal pigments in an aqueous chromate/phosphate binder solution. When thermally cured the slurry becomes a tenaciously bonded thin film coating having superior oxidation resistant and corrosion resistant properties. (MIL-C-81751). It is used primarily as a corrosion and erosion-resistant coating on Ni-based alloys (e.g., turbine blades), and steel parts operating in environments up to 1100°F. FRCSE uses both Sermetel W (approximately 5% chromic acid by weight) and Sermetal 750. It is normally applied by conventional spray techniques, although brushing and dipping are also possible. Coating components are dried and furnace-cured in order to fuse the binder and form a homogeneous coating. The coating provides a barrier between the substrate and the environment, and can be made conductive (usually by glass bead blasting) to provide galvanic and sacrificial protection. It is an overlay coating relying on physical and chemical bonding for adhesion. There is no metallurgical bond, allowing the coating to be easily stripped without degradation of the substrate. It is resistant to hydraulic fluids, fuel and hot water, and is highly resistant to thermal shock and impact damage.

2.1.9.2 Sanodal Deep Black MLW Dye

Sanodal Deep Black MLW Dye is used throughout the anodizing industry to create a uniform, black anodize on aluminum. Sanodal Deep Black MLW has excellent light and weather fastness properties and is suitable for indoor or outdoor applications. The anodize dye contains chromic acid

Weapons Systems and Components

Topcoats and specialty coatings are applied to every weapon system maintained at FRCSE. Rain erosion coatings are primarily applied to radomes and leading edges. Sermetel is applied to just about all of the engines maintained at FRCSE. Sanodal Deep Black MLW dye is used in the anodize shop on aluminum components. The weapon systems to which topcoats and specialty coatings are applied at FRCSE include:

- P-8A Poseidon
- EA-6B Prowler
- UH-60A Blackhawk
- P-3 Orion
- J-52 Engine
- E-3A AWACS
- F/A-18 Hornet
- H-60 Seahawk
- TF34Engine
- F-404 Engine

Materials

FRCSE applies topcoats and specialty coatings IAW multiple specifications. The products, NSNs, and usage (Calendar Year 2014) in pounds of product and Cr^{6+} or Cd are listed in Table 19.

Table 19. Topcoats and Specialty Coatings Materials/Products

Trade Name	NSN	Species	Usage (lbs product)	Usage (lbs)
SANODAL DEEP BLACK MLW DYE (11LBS)	6820LLHAZ4038	Cr^{6+}	22.0	12.1
POLYURETHANE COATING CAAPCOAT FP-70 (1-PT KIT)	8010015613658	Cr^{6+}	6.59	0.13
COATING, RAIN EROSION RESIST (14 PART KIT)	8010LLHAZ3236	Cr^{6+}	13.74	0.05
CORROSION PREV COMPOUND SERMETEL W 1GL	8030001450039	Cr^{6+}	110.59	3.32
CHO-SHIELD 2001 FLUOROPOLYMER COATING PART A (3PART KIT)	8030013321557	Cr^{6+}	19.44	0.4
CORROSION PREV COMPOUND SERMETEL 750 (1-PT)	8030013646453	Cr^{6+}	3.46	0.62
CHO-SHIELD 2003 FLUOROPOLYMER COATING PART A (3PART KIT)	8030013942514	Cr^{6+}	5.18	0.16

2.1.10 Coatings Removal

Traditional coating removal (including removal of inorganic coatings, desmut, and deoxidizing) methods employed throughout DoD involve the use of hazardous chemical or abrasive blast media. These conventional stripping methods result in major waste streams consisting of toxic chemicals and spent blast materials. The chemicals that are typically used in this process are high in VOCs and HAPs, both of which are targeted for reduction by environmental regulation. In addition, some chemical strippers and deoxidizers use sodium dichromate (Cr^{6+}) or chromic acid as an active ingredient. Prior to inspection, overhaul and repair of equipment or component parts, surfaces are washed and stripped of existing primers, paint, anodize, plating finishes, and corrosion prior to rework. Coating removal processes are conducted at locations throughout FRCSE.

2.1.10.1 Physical Coatings Removal

Process Description

Based on component size or geometry, many parts are stripped by mechanical means of dry surface sanding and abrasive blasting. Abrasive cleaning consists of forceful application of abrasive particles against the surface of metal parts. Typical uses include the removal of organic or inorganic coatings, corrosion, and surface conditioning for subsequent finishes. Plastic media blasting (PMB) is designed to replace chemical paint stripping operations and conventional sand blasting. This process uses soft, angular plastic particles as the blasting medium, and has proven more efficient than chemical paint removal, with the advantages of reusable media and reduced necessity of chemical use and storage.

PMB is well suited for stripping paints, since the low pressure (less than 40 psi) and relatively soft plastic medium have little effect on the surfaces beneath the paint. Used media is typically passed through a reclamation system consisting of a cyclone centrifuge, air wash, vibrating classifier screen, dense particle separator and a magnetic separator. More dense particles, such as paint chips, sand, grit, and aged sealant particulate, are separated. Typically, media can be recycled ten to twelve times prior to degradation. PMB facilities typically use a single type of plastic media for all of their blasting work. The majority of DoD PMB facilities use either Type II or type V media. Type V media is more gentle on aircraft substrates and not as hard as Type II, which is more commonly used on steel surfaces.

Abrasive blasting operations can generate elevated airborne concentrations of Cd, Cr^{6+} and Cr-compounds. Significant concentrations of both cadmium and chromate-contaminated dusts can also be generated during these and subsequent clean-up processes. This dust can be carried into break rooms, office areas, and other unregulated areas of the plant, and are often the source of OSHA citations at depots. FRCSE performs these tasks onsite within specified working areas designed to capture dusts in ventilated enclosures (i.e., walk-in booths, drive-through bays, abrasive blasting cabinets, and glove boxes). Most abrasive operations are enclosed to maximize capture efficiency. However sanding or grinding often takes place outside of ventilated areas using hand or pneumatic sanders based on component size, shape, or access to hard-to-reach areas. At FRCSE, hand-sanding is done as a touchup process and the mechanical sanders are equipped with a vacuum system and collection bags.

Abrasive blasting cabinets and glove boxes throughout FRCSE utilize Glass Beads for corrosion removal and Type V (Acrylic Thermoplastic) Plastic Abrasives to remove surface coatings from weapon systems and components. A significant amount of waste containing cadmium and hexavalent chromium is generated through the disposal of blast media and dusts generated from these processes. Changing of waste collection drums for the media can also generate airborne concentrations of heavy metals including Cd and Cr^{6+}. Spent PMB is captured and recycled after undergoing a cleaning process

A significant concern for all DoD depots that perform the removal of Cd- or chromate-contaminated coatings is the management of the airborne particulates. These airborne particulates are major cause of citations from OSHA for violations related to facility housekeeping.

Weapons Systems and Components

Physical coatings removal, abrasive blasting and/or hand-sanding, is used on every weapon system maintained at FRCSE. The weapon systems on which abrasive blasting and/or hand-sanding is used at FRCSE include:

- P-8A Poseidon
- EA-6B Prowler
- UH-60A Blackhawk
- P-3 Orion
- J-52 Engine
- E-3A AWACS
- F/A-18 Hornet
- H-60 Seahawk
- TF34 Engine
- F-404 Engine

Materials

There are no material inputs to the process that contains Cd or Cr^{6+}. However, as described above, each coatings removal process results in significant emissions, exposure potential, and/or waste streams.

2.1.10.2 Chemical Strip

Process Description

The bulk of coatings removal at FRCSE is performed by PMB. However, Cd and Cr^{6+} platings, anodized coatings, and others are removed in chemical dip tanks. In addition, cleaning, desmutting, and deoxidizing of components are also done in chemical dip tanks. Removable and small parts are immersed into heated solutions and agitated to enhance the stripping, cleaning, or deoxidizing process. Agitation ensures that newly formed emulsions and soaps are washed away from surfaces, applying fresh chemical stripping agents to the exposed layers of paint, which speeds the process. In conjunction with filtration systems and skimmers, the chemical solutions may be recycled for extended use. Most of the aqueous strippers are alkaline in nature. These strippers are different from acid strippers in that acid strippers may attack the metal surfaces, causing structural weakening (hydrogen embrittlement). Acid strippers normally require neutralization after the process. No solvent waste streams are generated with the use of hot tanks and biodegradable cleaning agents. Effluent waste streams comprise the aqueous solutions and sludge products composed of paint, grease, oil, and dirt. The aqueous solutions may be recycled, or discharged into the local sewer system. Sludge products collected from the tanks require proper disposal. Spent stripping solutions are subject to RCRA requirements.

Weapons Systems and Components

Chemical coatings removal, whether spray-on or in a dip-tank application, is used on every aircraft maintained at FRCSE. The weapon systems on which chemical coatings removal is used at FRCSE include:

- P-8A Poseidon
- EA-6B Prowler
- UH-60A Blackhawk
- P-3 Orion
- J-52 Engine
- E-3A AWACS
- F/A-18 Hornet
- H-60 Seahawk
- TF34 Engine
- F-404 Engine

Infrastructure

The chemical stripper lines for chrome strip, deoxidation, and anodize strip are in Building 101, where 10,485 gallons of tankage is dedicated to the process, including all process and rinse tanks. Table 17 lists the chemical stripper (including rinse) tanks and volume.

Table 20. Chemical Stripper Infrastructure

Tank	Gallons	Material
Chrome Strip Tank(s)	808	Cr^{6+}
Chrome Strip Tank(s)	658	Cr^{6+}
Chrome Strip Tank(s) - Rinse	1600	Cr^{6+}
Anodize Strip	1885	Cr^{6+}
Anodize Strip	259	Cr^{6+}

Anodize Strip - Rinse	785	Cr^{6+}
Anodize Strip - Rinse	780	Cr^{6+}
Aluminum Deoxidizing	1885	Cr^{6+}
Aluminum Deoxidizing	260	Cr^{6+}
Aluminum Deoxidizing - Rinse	785	Cr^{6+}
Aluminum Deoxidizing - Rinse	780	Cr^{6+}
Total Infrastructure	10,485	

Materials

FRCSE uses a Turco deoxidizer that contains Cr^{6+}. None of the other coatings removal products contain Cd or Cr^{6+}. The product, NSN, and usage (Calendar Year 2014) in pounds of product and Cr^{6+} are listed in Table 21.

Table 21. Coatings Removal Materials/Products

Trade Name	NSN	Usage (lbs product)	Usage (lbs Cr^{6+})
TURCO DEOXIDIZER 6 MAKEUP	6850LLHAZ3742	1,032	206.4

2.1.11 Stainless Steel Welding

Process Description

Currently, the DoD spends approximately $36 million annually on personal protective equipment for welding operations. Stainless steel welders can easily be exposed to hexavalent chrome above the OSHA PEL. Welding is a common repair and maintenance operation throughout DoD depots and shipyards. It uses mild or stainless steel filler material to join like metals. The energy expended during the weld process results in the formation of high concentrations of nano-sized particles (fumes) loaded with Cr^{6+}, nickel, manganese, and other toxic metals. Hexavalent chromium fume is always produced when welding stainless steel because Cr metal is a primary constituent of filler material used in the welding electrode. The intense heat of the process vaporizes the chromium and subsequently oxidizes the vaporized atoms to form Cr^{6+} molecules. Fume particulates are respirable in size and able to travel deeply into the respiratory system, interacting with human cells. Welding fume generation rates, particulate characteristics, and weld quality are affected by current, voltage, and shielding gas flow rates.

Throughout DoD maintenance depots, electric arc welding such as TIG, MIG, SMAW, and resistance spot welding (RSW) are the primary means of welding stainless steel. In lesser amounts, DoD maintenance depots and research laboratories may also employ radiation energy (laser) welding and other techniques not fully described here. Welding operations range from small component repair, production workload, to full asset modification and repair.

Tungsten Inert Gas (TIG) welding maintains energy between a tungsten or tungsten alloy electrode and the work piece, under an inert or slightly reducing atmosphere. The workpiece is struck by the electrons to enhance penetration while the electrode, which is generally made of 2% thoriated tungsten, undergoes very little wear. Filler metals are employed in the form of either bare rods or coiled wire for automatic welding. The arc zone is protected from ambient air with an inert gas flow, enabling a more stable arc. Shielding gases consist mainly of mixtures of argon (Ar), helium (He), and hydrogen (H_2).

Metal Inert Gas (MIG) welding uses a continuously fed consumable metal wire electrode, producing an arc between it and the workpiece under a shielding gas. Most MIG welding is operated manually, but can be fixed to a carriage for automation and use of higher welding power. High current densities in the electrode wire (>90 Amp/mm^2) provide high temperatures to ensure rapid melting of the electrode wire. An argon (Ar) shielding gas is required to prevent oxidation in the welding arc.

Shielded Metal Arc Welding (SMAW) has been employed for over 100 years, yet still remains the most common technique employed in the field due to its flexibility and simplicity of use. The electrode consists of a metal core, usually a solid stainless steel wire rod, covered with a layer of flux. The flux serves to initiate and stabilize the arc, control the viscosity and surface tension of slag, and metallurgically is involved in chemical exchanges in refining of the weld metal.

Resistance Spot Welding (RSW) is extensively used across DoD maintenance depots for joining thin stainless steel sheets. Heat is generated with the passing of a high-current at low-voltage through the workpiece in a small area of contact between the electrodes. Generally, electrodes are copper, cobalt, and beryllium alloys, whose tips form a truncated cone to minimize surface area of the weld. In many DoD processes, this type of welding is performed manually.

Weapon Systems and Components

The weapon systems on which stainless steel welding is conducted at FRCSE include:

- H-60 Seahawk
- UH-60A Black Hawk

Materials

Stainless steel welding at FRCSE is conducted in accordance with MIL-E-19933E or MIL-E-22200/2, depending upon the stainless steel substrate. The products, NSNs, and usage (Calendar Year 2014) in pounds of product and Cr^{6+} are listed in Table 22.

Table 22. Stainless Steel Welding Materials/Products

Trade Name	NSN	Usage (lbs product)	Usage (lbs Cr^{6+})
TURBALOY 4130 WELDING ROD, 10LBS	3439010132797	60	0.66
WELDING POWDER DURABRADE 2311CC (10-LB)	3439013806646	300	11.25
DIAMALLOY 3001	3439014075053	315	55.13
WELDING POWDER 3007 (5-LB)	3439014782817	300	127.5
ELECTRODE WELDING, AMS 5823 SZ .030 (5-LB)	3439LLHAZ3621	10	1.25
DURABRADE 2311CA WELDING POWDER (10LB)	3439LLHAZ4280	2360	88.5
WELDING RODS, 0.063" 14" LONG SZ (STELLITE 6)	3439LLHAZ4431	20	7.0

3 Alternatives

This section describes past and ongoing initiatives and potential alternatives available or in current development for each of the processes identified in Section 2.1. Numerous pollution prevention activities have been initiated to eliminate Cd, $Cr^{6+,}$ HAPs, VOCs, and other toxic or regulated hazardous materials or impact major processes. Past and ongoing initiatives that impact the Cd and Cr^{6+} Strategy and Roadmap and, more specifically, the Implementation Plan for FRCSE are included in Table 23.

Table 23. Past and Ongoing Initiatives Targeting Cd and/or Cr^{6+} Reduction

Initiative	Lead	Process	Description/Outcome
Non-Chrome Primers on OML of Gloss-Finish Aircraft	NAVAIR	Chrome Primers	NAVAIR has successfully demonstrated the PPG Deft 02-GN-084 non-chromated primer on the E-2C Hawkeye, P-3C Orion, T-6 Texan, T-34 Mentor, T-44 Pegasus, and T-45 Goshawk aircraft. Service inspections done post-deployment documented good corrosion and adhesion performance. As a result, in 2014 NAVAIR drafted an authorization letter[2] for the use of this primer over conversion coatings qualified to MIL-DTL-81706, Type I, Class 1A, on the outer-mold-line (OML) of all Navy gloss paint scheme aircraft.
Non-Chrome Primers on OML of Tactical Aircraft	NAVAIR	Chrome Primers	NAVAIR is currently evaluating Hentzen 17176KEP primer on V-22 Osprey Helicopter, H-46 Sea Knight Helicopter, H-53 Sea Stallion Helicopter, and F/A-18A-D Hornet aircraft. Unlike the gloss paint scheme aircraft, which are primarily aluminum on the OML, the OML tactical paint scheme of these aircraft is also incorporates composite substrates. Upon successful demonstration, NAVAIR anticipates authorizing the Type II primer for tactical aircraft as well. Once signed and released, each applicable Program will have the option to implement the primer at OEM and depot level. NASA previously implemented a Hentzen non-chromate primer on the shuttle fuel tanks however, they are no longer in service.
Electrodeposition of Nanocrystalline Co-P Coatings as a Hard Chrome Alternative (ESTCP WP-2009936)	ESTCP August 2009-Ongoing	Chrome Plating	This project will demonstrate/validate and qualify pulse-electroplating technology for deposition of nanocrystalline cobalt-phosphorus (nCo-P) coatings as a replacement for electrolytic hard chrome (EHC) plating for weapon systems. nCo-P coatings were successfully developed under SERDP project WP-1152 and scaled up in ESTCP project WP-200411. These projects showed that the nCo-P coatings have properties that are equivalent to and in many ways better than EHC. The nCo-P coatings are produced by electrodeposition from a fairly standard aqueous solution using cobalt rounds as anodes. Like the EHC electrodeposition coating process, nCo-P deposition is an aqueous bath process. The deposit is very similar in appearance to EHC; however, nCo-P has a nanocrystalline grain structure with an average gain size of 5-15 nm. The reduced grain size results in improved material properties, including enhanced corrosion protection, sliding wear performance, hardness, and tensile strength. Since nCo-P deposition is an aqueous method, it can be used in any application currently served by EHC and likely also any application in which thin dense chrome (TDC) is presently used. It has even been brush plated, making it a viable option for localized intermediate-level repair, which is very important for battle readiness in systems deployed overseas. High-velocity oxygen fuel (HVOF) thermal spray is being broadly implemented by the depots in place of EHC on line-of-sight surfaces due to its improved performance, especially in situations where EHC experiences high wear. This project addresses the following remaining needs for hard chrome replacement: (1) a depot maintenance EHC alternative for non-line-of-sight surfaces, and (2) a single process for simultaneous plating of both internal and external surfaces of complex components. It does not address TDC, which is not used in depots, or brush plating.

[2] http://db2.asetsdefense.org/fmi/webd#Surface%20Engineering

Initiative	Lead	Process	Description/Outcome
			The nCo-P plating process was developed under SERDP project WP-1152. The data showed that the performance of the material is essentially equivalent to EHC in sliding wear and better in corrosion and hydrogen embrittlement, although embrittlement performance appeared to change under modified deposition conditions. Abrasive wear performance of tested coatings was somewhat lower than EHC, but performance of the fully optimized material will depend on its hardness and hence on the P content, which can be increased, although that reduces the strain tolerance of the coatings. Scale-up and further demonstration of the nCo-P technology was conducted under ESTCP project WP-200411. As part of this project, the nCo-P system was successfully scaled up at Integran to a 300-gallon demonstration system. This system has been in operation for 44 months, with no major deviations in deposit quality to date. Operating parameters and process sensitivity have been defined. This system was used to plate coupons for performance testing in accordance with a Joint Test Protocol. In addition to scale-up at Integran, the nCo-P technology was transferred to the Navy's Fleet Readiness Center - Southeast (FRC-SE) in Jacksonville, Florida. A 250-gallon demonstration system was installed and selected aircraft components have been successfully coated.
Nanocrystalline Cobalt Alloy Plating for Replacement of Hard Chrome and Thin Dense Chrome on Internal Surfaces (ESTCP WP-200411)	ESTCP 2004-2010	Chrome Plating	The objectives of this project were to demonstrate and validate (1) pulsed electrodeposition of nanocrystalline cobalt-phosphorus (nCo-P) coatings, either in bath or brush plating, as a viable alternative to electrolytic hard chrome (EHC) plating on internal surfaces and complex geometries; and (2) nCo-P coatings as a viable replacement for thin dense chrome (TDC) on selected components for new military aircraft. Nanocrystalline cobalt-phosphorus coatings were developed under the SERDP project WP-1152. This technology uses pulse plating to control the nucleation and growth of grains within the coating, creating a nanocrystalline structure. Testing indicated that coating application does not cause hydrogen embrittlement of high-strength steels, which is a significant problem with EHC plating. Performance testing showed that the nCo-P coatings demonstrated superior salt-fog corrosion and pin-on-disk wear behavior compared to EHC coatings, with abrasive wear performance slightly less than for EHC coatings. The nCo-P coatings can be deposited to thicknesses ranging from 0.0001 to 0.020 inches, making them potential alternatives to both EHC and TDC. This technology is a direct drop-in for the existing EHC process and may be incorporated into existing plating lines, although this would require replacement of plating power supplies. In this project, a 100-gallon nCo-P demonstration plating tank was installed at Naval Ammunitions Depot (NADEP) Jacksonville and a brush plating system installed at Ogden Air Logistics Center (ALC). A demonstration plan, incorporating a joint test protocol (JTP), was developed by stakeholders. The JTP includes both materials and component tests, utilizing EHC as a baseline. The environmental and cost impact of inserting this technology into repair depots was evaluated, including implementation, processing and life-cycle costs, and waste reduction. The nCo-P coatings also was assessed as a replacement for TDC on the ring gear of the Joint Strike Fighter leading edge flap actuator. Other potential TDC replacement applications were determined. Successful demonstration and validation of the nCo-P plating technology should lead to its implementation at several military repair depots, since it functions as a direct drop-in replacement to EHC. This will eliminate environmental and worker safety concerns associated with the hexavalent chromium found in EHC. Since the coating does not contain nickel, environmental concerns related to the nickel content of EHC alternative coatings also will not be an issue. The superior corrosion and sliding wear performance should lead to reduced life-cycle

Initiative	Lead	Process	Description/Outcome
			costs, and the elimination of hydrogen embrittlement concerns will result in significantly reduced turnaround times for component repairs.
ZnNi Plating as a Replacement for Cd Plating	NAVAIR through Office of Navy Research (ONR) Rapid Innovation Fund (RIF)	Cd Plating	New atart.
ZnNi/Dalistick® Station as Replacement for Cd Brush Plating	NAVAID through Small Business Innovative Research (SBIR) 2.5	Cd Brush Plating	New start.
TCP as Replacement for Chromate Conversion Coating on Al	ESTCP	Chromate Conversion Coating	New start.
Citric Acid Passivation	NAVAIR through NESDI	Stainless Steel Passivation	New start.

Sections 2.3.1 through 2.3.11 present a summary of potential alternatives, applicability to FRCSE processes, known barriers to the technology or implementation, and recommendations for initiatives, studies, and/or implementation. Table 24 provides a non-exhaustive list of potential alternatives for each of the processes at FRCSE.

Table 14. Potential Alternatives to FRCSE Processes

Process	Alternative(s)
Chromated Primers	Deft non-Cr primer, BoeAero TC, BoeAero 7500h, Rare Earth Primers, Al-rich primers (Hentzen 16708TEP, NAVAIR Al-rich primer)
Chrome Plating	HVOF, Nanocrystalline Co-P, Trivalent Chromium Electroplating (Faraday), ElectroSpark
Cadmium Plating	LHE Zn-Ni Plating, IVD Al, AlumiPlate, CVD Al
Chromate Conversion Coatings (Alodine)	For Al Applications: X-Bond 4000 (Zirconium oxide)—PPG Industries, Recc 3012 (Rare earth/Cerium)—Deft/PPG, Bonderite/Oxsilan—Henkel/Chemetal NAVAIR TCP, Metalast TCP, Chemetall (Gardobond X-4707, Gardobond X-4650), Alodine 5200/5700 NC pretreat and Alodine 5900 Cr3 pretreat For Mg Applications: Tagnite, Keronite
Stainless Steel Passivation	Citric Acid Passivation
Adhesives/Sealants	3M AC130.
Cadmium Brush Plating	No-bake Zinc nickel brush plating (SIFCO, Dalistick)
Chromate Sealers	TCP, Hot water seal and Ni Acetate (anodize only), Chemetall (Gardolene D-6800/6, Gardolene D-6871, Gardolene D-6907, PhosGard 800HP); Heatbath Phoseal 25, Surtec 580
Topcoats and Specialty Coatings	No drop in replacements identified. Ceral 34, Ceral 66 and Alseal 5K
Coatings Removal	Organic Coatings: Laser Coatings Removal, Atmospheric Plasma Deoxidation: Turco Smut Go NC, Metalast 3300, Luster On XXYY Anodize Stripping: Metalast AOS 100, Stone Chem AN775, Isoprep 184

Process	Alternative(s)
Stainless Steel Welding	Down-draft tables, extractor hoods, ventilation, friction-stir welding, silica precursor (shield gas), Cr-free weld rods

3.1 Chromated Primers - Alternatives

Over the past two decades, significant effort has been spent on identifying, evaluating, and demonstrating non-chromated primers for application on DoD weapon systems. An ESTCP project (WP-201132)[3] will provide a comprehensive evaluation and assessment of non-chromated paint primers. Class N primers are currently undergoing validation by DoD Component Services and NASA. NAVAIR has successfully demonstrated the PPG Deft 02-GN-084 non-chromated primer on the E-2C Hawkeye, P-3C Orion, T-6 Texan, T-34 Mentor, T-44 Pegasus, and T-45 Goshawk aircraft. Service inspections done post-deployment documented good corrosion and adhesion performance. As a result, in 2014 NAVAIR drafted an authorization letter[4] for the use of this primer over conversion coatings qualified to MIL-DTL-81706, Type I, Class 1A, on the outer-mold-line (OML) of all Navy gloss paint scheme aircraft.

NAVAIR is currently evaluating Hentzen 17176KEP primer on V-22 Osprey Helicopter, H-46 Sea Knight Helicopter, H-53 Sea Stallion Helicopter, and F/A-18A-D Hornet aircraft. Unlike the gloss paint scheme aircraft, which are primarily aluminum on the OML, the OML tactical paint scheme of these aircraft also incorporates composite substrates. Upon successful demonstration, NAVAIR anticipates authorizing the Type II primer for tactical aircraft as well. Once signed and released, each applicable Program will have the option to implement the primer at OEM and depot level. NASA previously implemented a Hentzen non-chromate primer on the shuttle fuel tanks however, they are no longer in service.

Work has focused on both metal-rich as well as rare-earth materials. These technologies and efforts are summarized below.

3.1.1 *Alternative:* Rare-Earth and Other Metal Primers

Considerable research, development, testing and evaluation has focused on rare earth primers, most containing Praseodymium Oxide (CAS # 12036-32-7) as an active ingredient. Praseodymium is a rare earth metal under the Lanthanide group. This group consists of yttrium and the 15 lanthanide elements (lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium). Scandium is found in most rare earth element deposits and is sometimes classified as a rare earth element. The International Union of Pure and Applied Chemistry includes scandium in their rare earth element definition. The rare earth elements are all metals, and the group is often referred to as the "rare earth metals." These metals have many similar properties and that often causes them to be found together in geologic deposits. They are also referred to as

[3] https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Surface-Engineering-and-Structural-Materials/Coatings/WP-201132/WP-201132

[4] http://db2.asetsdefense.org/fmi/webd#Surface%20Engineering

"rare earth oxides" because many of them are typically mined and sold as oxide compounds." http://geology.com/articles/rare-earth-elements/

Cerium is the most abundant of the rare earth metals and is mined in the United States. The major producers of Praseodymium are China, Russia, and Malaysia.

Zirconium is also mined in the United States. The current permissible exposure limit for Zirconium compounds is 5 mg/m3. Tungsten and Molybdenum are not rare earth metals but are also important strategic metals in a market dominated by China. These metals along with Zirconium are often considered in the formulation of non-chromate conversion coating alternatives.

Related Efforts

PPG (previously Deft) rare earth primer 44-GN-098 is fully implemented on the F-35 Joint Strike Fighter, F-16, and F-22, while 02-GN-084 is used on a number of helicopter platforms. Table 25 is a list of efforts related to the research, development, testing, and evaluation of rare-earth primers. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 25. Rare Earth and Other Metal Primers Related Efforts

Effort	Systems	Technology	Points of Contact
Non-Chromate/No-VOC Coating System for DoD Applications (SERDP Project WP-1521)[5]	All	16708TEP/16709CEH EWDY048A/B EWAE118A/B 44GN098 02GN083 02GN084 65GN015	John La Scala US Army Research Laboratory jlascala@arl.army.mil 410-306-0687
Corrosion and Adhesion Testing of MIL-PRF-23377 Class N and MIL-P-53022 Primers (with and without a Zinc Rich Tie-coat) on Steel Substrates[6]	All aircraft	16708TPE/16709CEH 02GN083 02GN084	Steven Brown NAVAIR Patuxent River Aircraft Division Steven.a.brown@navy.mil 301-342-8101
Surface Treatment Implementation – Deft Non-Chrome Primer on F-35	F-35 JSF	44GN098	Scott Fetter Lockheed Martin Scott.d.fetter@lmco.com (817) 777-3791
Chromium Alternatives Qualification Testing		44GN098 02GN083 02GN084 02GN098	Concurrent Technologies Corporation (CTC) 814-266-2874

[5] https://www.serdp-estcp.org/content/download/7542/95669/file/WP-1521-FR.pdf

[6] http://db.materialoptions.com/ASETSDefense/SEDB/CrPrimer_VOC_Alts/Tech_Matls_Info/Non_CrPrimer/ NonCr_Primers_Steel_LR05_010.pdf

Effort	Systems	Technology	Points of Contact
Surface Treatment Implementation – AH-64 Deft Non-Chrome Primer	AH-64 Apache	44GN098	Ed Babcock Boeing Mesa Ed.a.babcock@boeing.com 480-891-3000
C-130J Phase I – ACFL07PV02	C-130	44GN098 02GN084 16708TEP/16709CEH Aerodur 2100 Mg-rich primer (Akzo Nobel)	Gene McKinley Wright Patterson AFB Gene.mckinley@wpafb.af.mil 937-255-3596
Authorization, implementation, 02GN084 non-Chrome Primer	UH-60 CH-47 AH-64 Apache OH-60 UH-1 H-60 Blackhawk	PPG-Deft 44-GN-098, 85582D, TY I, CL N PPG EWDY048A, 85582D, TY I, CL N PPG EWAE118A, 85582D, TY II, CL N PPG-Deft 44-GN-007, 85582D, TY I, CL C1 PPG-Deft 44-GN-008A, 85582D, TY II, CL C1 PPG-Deft 02-GN-083, 23377J, TY I, CL N PPG-Deft 02-GN-084, 23377K, TY I, CL N PPG-Deft 02-GN-084N, 23377K, TY I, CL N Hentzen 16708TEP, 23377J, TY I, CL N Hentzen 17176KEP, 23377J, TY II, CL N PPG CA 7233, 23377J, TY I, CL C2 PPG-Deft 02-Y-040B, 23377J, TY I, CL C2	Julia Russell NAVAIR Patuxent River julia.russell@navy.mil 301-342-8112

Applicability

FRCSE uses epoxy primers (MIL-PRF-23377 or MIL-PRF-85582) on aircraft OML, aircraft interiors and components, and commodities components. Any of the above alternative technologies are applicable to this application and some of the testing and evaluation of the alternatives have been performed on weapon systems maintained at FRCSE.

Barriers

Technical

To date, most non-chromate processes have failed to satisfy relevant engineering requirements, such as the American Society for testing and Materials Standard Practice for Modified Salt Spray (Fog) Testing (G85.A4), galvanic assemblies, and beach exposure.

Financial

Capital costs associated with alternative non-chromated primers should be minimal as most are implemented as drop-in replacements. There may be cost impacts based on chemical prices, but these should be offset by the decrease in medical monitoring, training, protective equipment and engineering controls necessary to meet OSHA "housekeeping requirements" which are some of the biggest costs and risks for the depots.

Acceptance

As these are drop-in replacement technologies, acceptance should not be an issue once it is confirmed that the alternatives meet corrosion and other standards.

Logistics

Once a non-chromated primer is qualified and accepted on weapon systems, the Technical Manuals and drawings may still need to be changed to reflect adoption of the new technology.

3.1.2 *Alternative:* Metal Rich Primers

Another approach to the development of non-chromated primers employs a sacrificial metal-rich primer in the overall protection scheme, like the use of zinc-rich coatings for steel substrates to provide galvanic corrosion protection. The metal in the coating of a galvanic protection system acts as an anode, which oxidizes preferentially to the substrate. The substrate acts as a cathode, and is protected from corrosion at the point of sacrifice of the anodic metal in the coating. High loading of metal particles (typically Mg or Al) in the primer coating ensures more contact between each particle and with the substrate. This electrical contact of metal particles is a key requirement in the corrosion protection mechanism. Improvements to metal-rich primers have increased their overall corrosion performance. In Navy operating environments, Mg-rich primers experience increased corrosion, so the focus has been on the develop of Al-rich primers for use on Navy aircraft.

Related Efforts

Table 26 is a list of efforts related to the research, development, testing, and evaluation of metal-rich primers. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 26. Metal Rich Primers Related Efforts

Effort	Systems	Technology	Points of Contact
Non-Chromate/No-VOC Coating System for DoD Applications (SERDP Project WP-1521)[7]	All	16708TEP/16709CEH EWDY048A/B EWAE118A/B	John La Scala US Army Research Laboratory jlascala@arl.army.mil 410-306-0687
Corrosion and Adhesion Testing of MIL-PRF-23377 Class N and MIL-P-53022 Primers (with and without a Zinc Rich Tie-coat) on Steel Substrates[8]	All aircraft	16708TPE/16709CEH	Steven Brown NAVAIR Patuxent River Aircraft Division Steven.a.brown@navy.mil 301-342-8101
C-130J Phase I – ACFL07PV02[9]	C-130	16708TEP/16709CEH Aerodur 2100 Mg-rich primer (Akzo Nobel)	Gene McKinley Wright Patterson AFB Gene.mckinley@wpafb.af.mil 937-255-3596
Naval Air Systems Command Implementation Plan for Non-Chromated Paint Primer	All aircraft	EWAE118A/B 10PW22-2	Jack Benfer NAVAIR Jacksonville, FL 32212 john.benfer@navy.mil Tel: (904) 790-6405
KC-135 Non-Chromate Primer Operational Test and Evaluation Initial Inspection for KC-135 Aircraft 59-1472[10]	KC-135, F-15, C-17, C-130, F-18	EWAE118A/B 10PW22-2	Larry Triplett The Boeing Company larry.triplett@boeing.com 314-232-2882
Improved Metal-Rich Primers for Corrosion Protection[11]	All aircraft All helicopters	Aerodur 2100 Mg rich primer (Akzo Nobel)	Craig Price NAVAIR Patuxent River 301-342-8050
Observations on the Testing of Mg-rich Primers for Total Chromate-free Corrosion Protection of Aerospace Alloys	All aircraft All helicopters	Aerodur 2100 Mg rich primer (Akzo Nobel)	Gordon Bierwagen North Dakota State University Gorden.bierwagen@ndsu.edu 701-231-8294
Battelle Magnesium Rich Primer Project	All aircraft	Aerodur 2100 Mg rich primer (Akzo Nobel)	Thomas Lorman Wright Patterson AFB Thomas.lorman@wpaft.af.mil 937-255-3530

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7 https://www.serdp-estcp.org/content/download/7542/95669/file/WP-1521-FR.pdf

8 http://db.materialoptions.com/ASETSDefense/SEDB/CrPrimer_VOC_Alts/Tech_Matls_Info/Non_CrPrimer/NonCr_Primers_Steel_LR05_010.pdf

9 http://db.materialoptions.com/ASETSDefense/SEDB/CrPrimer_VOC_Alts/RDTandE/ACFL07PV02C-130JphaseI.pdf

10 http://db.materialoptions.com/ASETSDefense/SEDB/CrPrimer_VOC_Alts/Qual_Eng_Data/KC-135_NonCr_Primer_FlightTest_Eval_2003.pdf

11 http://db.materialoptions.com/ASETSDefense/SEDB/CrPrimer_VOC_Alts/Qual_Eng_Data/Improved_metal-rich_Primers-Corrosion_protection-NAVAIR-Matzdorf.pdf

Effort	Systems	Technology	Points of Contact
– ACFL07PV59[12]			
Demonstration of a Nanomaterial Modified Primer for Use in Corrosion Inhibiting Systems[13]		Primer Zn-rich	Susan Drozdz US Army Engineer Research and Development Center Susan.A.Drozdz@usace.army.mil (217) 373-4467
Magnesium Rich Primers and Related Development for the Replacement of Chromium Containing Aerospace Primers	All aircraft All helicopters	Aerodur 2100 Mg rich primer (Akzo Nobel)	Akzo Nobel Aerospace Coatings (847) 623-4200
Active aluminum-rich primer for corrosion protection	All aircraft All helicopters	Lab development, no name assigned	Craig Matzdorf, NAVAIR Patuxent River, 301-342-9372, craig.matzdorf@navy.mil

Applicability

FRCSE uses epoxy primers (MIL-PRF-23377 or MIL-PRF-85582) on aircraft OML, aircraft interiors and components, and commodities components. The use of Mg-rich primers is not recommended on Navy aircraft because of the possibility that galvanic dissolution of the magnesium filler could be expected to increase the porosity of the primer, permitting water ingress. Therefore, Navy development has focused on Al-rich primers. Some of the testing and evaluation of the alternatives have been or are currently being performed on weapon systems maintained at FRCSE.

Barriers

Technical

While there is interest in metal-rich primers and there have been some successful testing conducted, other non-chromate processes have failed to satisfy relevant engineering requirements, such as the American Society for testing and Materials Standard Practice for Modified Salt Spray (Fog) Testing (G85.A4), galvanic assemblies.

Zn-rich materials would never be used on aircraft because of the H evolved from Zn dissolution that could create H embrittlement of high strength alloys.

12 http://db.materialoptions.com/ASETSDefense/SEDB/CrPrimer_VOC_Alts/RDTandE/ACFL07PV59 BattelleMgRichPrimer_Proj.pdf

13 http://www.dtic.mil/get-tr-doc/pdf?AD=ADA558997

Financial

Capital costs associated with alternative non-chromated primers should be minimal as most are implemented as drop-in replacements. There may be cost impacts based on chemical prices, but these should be offset by the decrease in medical monitoring, training, and protective equipment.

Acceptance

As these are drop-in replacement technologies, acceptance should not be an issue once it is confirmed that the alternatives meet corrosion and other standards.

Logistics

Once a non-chromated primer is qualified and accepted on weapon systems, the Technical Manuals and drawings may still need to be changed to reflect adoption of the new technology.

3.2 Chrome Plating – Process Improvements and Alternatives

Since at least the mid-1990s, the DoD and commercial entities have been testing and evaluating alternatives to hard chrome plating.

3.2.1 *Alternative:* High Velocity Oxy-Fuel (HVOF)

HVOF coatings are typically not a single material, but a process for depositing a range of coating chemistries. Most HVOF coatings are made using a continuous supersonic flame into which a powder is injected. All HVOF coatings are dense and well controlled and can impart many different properties to a surface (wear, corrosion resistance, thermal barrier, etc.). The basic principle of the thermal spray process involves heating a material (usually in powder form) to high temperature in a flame or plasma and using a thermal spray gun to spray it in a high speed gas stream onto the part to be coated. The hot powder particles compress into pancakes on impact and bond together to form a continuous coating that is dense and well-adhered.

The HVOF spray process is done in a very similar way to paint spraying. The hot particles come out of the gun in a narrow stream, which must be moved back and forth to cover the whole surface uniformly. For typical aerospace components such as landing gear or hydraulics, which are cylinders, the part is rotated and the gun moved up and down, usually using an industrial robot. The part to be sprayed is usually placed on a horizontal table so that it rotates vertically, or it is held in a lathe and rotated horizontally, while the robot arm moves the gun back and forth uniformly, sometimes pausing with the spray running off the part to allow it to cool down.

HVOF spraying is usually done in a walk-in booth that provides sound insulation, since the supersonic flame makes the process very loud. The booth is equipped with a louvered wall and high speed exhaust fans to pull air through the booth and carry away the overspray (powder that misses the part, or does not stick to the surface). This overspray (which can be up to half the powder sprayed) is caught in a dust collector, usually outside the building. If hydrogen is used as the fuel it is usually kept in a bulk liquid storage tank outside the building, as is the oxygen. Kerosene is held in a drum inside the building and fed to the gun by a pump.

Related Efforts

Table 27 is a list of efforts related to the research, development, testing, and evaluation of HVOF. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Many of these efforts have been completed and there is a significant amount of information available for HVOF. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 27. HVOF Related Efforts

Effort	Systems	Technology	Points of Contact
HVOF Process Development, Evaluation and Qualification Axial Fatigue Evaluation, The Canadian Hard Chrome Alternatives Team (HCAT) Joint Program	All aircraft	HVOF: WC-CoCr HVOF Coatings - all	C. Belter, P. Li, J. Dyer and P.C. Patnaik Magellan Aerospace Corp Mississauga, ON L4T 1A9 magellan.corporate@magellan.aero (905) 677 1889
Replacement of Chromium Electroplating on Gas Turbine Engine Components Using Thermal Spray Coatings	TF33 turbine engine	HVOF: WC-Co HVOF: Tribaloy T-400 HVOF: Tribaloy T-800 HVOF: Cr3C2-NiCr HVOF Coatings - all	Dr. Robin Nissan SERDP-ESTCP Nissan, Robin A CIV OSD OUSD ATL (US) robin.a.nissan.civ@mail.mil (571) 372-6399
Validation of HVOF Thermal Spray Coatings as a Replacement for Hard Chrome Plating on Helicopter Dynamic Components	All helicopters C-46 H-46 H-60 H-1	HVOF: WC-Co HVOF: WC-CoCr HVOF: Tribaloy T-400 HVOF Coatings - all	Dr. Robin Nissan SERDP-ESTCP Nissan, Robin A CIV OSD OUSD ATL (US) robin.a.nissan.civ@mail.mil (571) 372-6399
Validation of HVOF Thermal Spray Coatings as a Replacement for Hard Chrome Plating on Hydraulic/Pneumatic Actuators	All aircraft A-10 B-1 C-130 KC-135 F-15 F-18 T-38	HVOF: WC-CoCr HVOF: Tribaloy T-400 HVOF: Cr3C2-NiCr HVOF Coatings - all	Dr. Robin Nissan SERDP-ESTCP Nissan, Robin A CIV OSD OUSD ATL (US) robin.a.nissan.civ@mail.mil (571) 372-6399
Validation of HVOF WC/Co Thermal Spray Coatings as a Replacement for Hard Chrome Plating on Aircraft Landing Gear	All aircraft F-18 P-3	HVOF: WC-Co HVOF: WC-CoCr HVOF: Tribaloy T-400 HVOF Coatings - all	Dr. Robin Nissan SERDP-ESTCP Nissan, Robin A CIV OSD OUSD ATL (US) robin.a.nissan.civ@mail.mil (571) 372-6399
Replacement of Chromium Electroplating on C-2, E-2, P-3 and C-130 Propeller Hub Components Using HVOF Thermal Spray Coatings	C-130 C-2 E-2 P-3	HVOF: WC-Co HVOF: WC-CoCr HVOF: Tribaloy T-800 Ni Watts HVOF Coatings - all	Dr. Robin Nissan SERDP-ESTCP Nissan, Robin A CIV OSD OUSD ATL (US) robin.a.nissan.civ@mail.mil (571) 372-6399

Effort	Systems	Technology	Points of Contact
Chrome Replacements for Internals and Small Parts	All aircraft All helicopters All vehicles	Electroless Ni-P (acid) HVOF: WC-Co Trivalent chrome plate Laser cladding ESD Plasma nitriding Plasma spray: WC-Co PVD TiN HVOF Coatings - all	Keith Legg Rowan Technology Group klegg@rowantechnology.com (847) 680-9420
Field Repair of Chrome and Cadmium Replacements	F-35 JSF JSF, Joint Strike Fighter	AlumiPlate Al-Mn electroplate Electroless Ni-P (acid) Electroless Ni-B (alkaline) HVOF: WC-Co HVOF: WC-CoCr IVD Al Al-ceramic (chrome free) Sn-Zn electroplate Zn-Ni electroplate (acid) HVOF: Tribaloy T-400 Metal-flake (chrome free) ESD HVOF Coatings - all	Keith Legg Rowan Technology Group klegg@rowantechnology.com (847) 680-9420
Produceability Testing on WC-Co-Cr HVOF Coating for Landing Gears Application Surface Finishing	All aircraft All helicopters	HVOF: WC-CoCr HVOF Coatings - all	Nihad Ben-Salah Heroux-Devtek nihad.ben-salah@pwc.ca (450) 679-5450
Guidelines on the Specification and Use of HVOF Coatings	All aircraft All helicopters All vehicles All ships	HVOF: WC-Co HVOF: WC-CoCr HVOF: Tribaloy T-400 HVOF: Tribaloy T-800 HVOF: Cr3C2-NiCr HVOF Coatings - all	Keith Legg Rowan Technology Group klegg@rowantechnology.com (847) 680-9420
Validation of WC/Co and WC/CoCr HVOF Thermal Spray Coatings as a Replacement for Hard Chrome Plating On Aircraft Landing Gear - PART II: OPERATIONAL TESTING	F-18 C-130 CF-18 P-3 E-6	HVOF: WC-Co HVOF: WC-CoCr HVOF Coatings - all	Dr. Robin Nissan SERDP-ESTCP Nissan, Robin A CIV OSD OUSD ATL (US) robin.a.nissan.civ@mail.mil (571) 372-6399
Corrosion Testing of Advanced Coatings for Military Hydraulic Actuators	All aircraft All helicopters All vehicles All ships	Electroless Ni-P (acid) HVOF: WC-CoCr HVOF: Tribaloy T-400 HVOF: Cr3C2-NiCr HVOF Coatings - all	Concurrent Technologies Corporation (CTC) (727) 549-7246

Effort	Systems	Technology	Points of Contact
Component Testing on TF33 Gas Turbine Engine[14]	TF33 turbine engine B-52 C-141 E-3 KC-135	HVOF: WC-Co HVOF Coatings - all	Keith Legg Rowan Technology Group klegg@rowantechnology.com (847) 680-9420
Use of Thermal Spray as an Aerospace Chrome Plating Alternative	All aircraft All helicopters	HVOF: WC-Co HVOF: WC-CoCr HVOF: Tribaloy T-400 HVOF: Tribaloy T-800 HVOF: Ni5Al HVOF Coatings - all	Keith Legg Rowan Technology Group klegg@rowantechnology.com (847) 680-9420
High Cycle Fatigue Testing of (9 of 9) 1/2"-20 Threaded Smooth Specimens [15]	All aircraft All helicopters All vehicles	HVOF: WC-CoCr HVOF: Tribaloy T-400 HVOF: Cr3C2-NiCr HVOF Coatings - all	Metcut Research Inc. 3980 Rosslyn Dr, Cincinnati, OH 45209 (513) 271-5100
Application of Several HVOF Coatings on Different Base Materials	All helicopters	HVOF: WC-Co HVOF: WC-CoCr HVOF: Tribaloy T-400 HVOF Coatings - all	James Mallon Hitemco jim.mallon@hitemco.com (516) 752-7882
Surface Finishing of Tungsten Carbide Cobalt Coatings Applied By HVOF for Chrome Replacement Applications	Boeing 737 Boeing 757 Boeing 767	HVOF: WC-Co HVOF: WC-CoCr HVOF: Tribaloy T-800 HVOF Coatings - all	John Falkowski Boeing Commercial Aircraft john.falkowski@pss.boeing.com (206) 544-0897
Surface Treatment Implementation - F-35 LG HVOF	F-35 JSF JSF, Joint Strike Fighter	HVOF: WC-CoCr HVOF Coatings - all	Neil Harris Goodrich Corporation Neil.Harris@Goodrich.com (216) 429-4202

14 http://db.materialoptions.com/ASETSDefense/SEDB/EHC_Alts/Qual_Eng_Data/Reports/TF33%20 Rig%20Test%20from%20HVOF%20on%20GTE%20Components%20Final%20Report.pdf

15 http://db.materialoptions.com/ASETSDefense/SEDB/EHC_Alts/Qual_Eng_Data/Eng_Data/Fatigue %20and%20images%20HVOF%20on%20Actuator%20materials.pdf

Effort	Systems	Technology	Points of Contact
Surface Treatment Implementation - OC-ALC HVOF update[16,17]	A-10 T-38 F-15 F-16 C-5 KC-135 E-3 C-130 B-1 B-52	HVOF: WC-Co HVOF Coatings - all	Brad Martin Hill Air Force Base brad.martin@hill.af.mil (801) 777-7352
Surface Treatment Implementation - Sikorsky H-60 HVOF	H-60	HVOF: WC-CoCr HVOF Coatings - all	Robert Guillemette Sikorsky (United Technologies) rguillemette@sikorsky.com (203) 386-7559
Validation of HVOF Thermal Spray Coatings as a Replacement for Hard Chrome Plating on Helicopter Dynamic Components	All helicopters	HVOF: WC-Co HVOF: WC-CoCr HVOF: Tribaloy T-400 HVOF Coatings - all	Dr. Robin Nissan SERDP-ESTCP Nissan, Robin A CIV OSD OUSD ATL (US) robin.a.nissan.civ@mail.mil (571) 372-6399
Evaluation of Chrome Rod Alternative Coatings (Hydraulic Actuator Seal Testing)[18]	All aircraft	HVOF: WC-Co HVOF: WC-CoCr HVOF: Tribaloy T-400 HVOF Coatings - all	Tony DeGennaro Greene Tweed & Co (215) 256-9521

Applicability

HVOF is a line-of-sight (LOS) technology, so only those components with outside diameters or outside plated surfaces are candidates for HVOF. This includes actuator rods/cylinders, some engine components, and other LOS applications.

16 http://www.asetsdefense.org/documents/Workshops/SURF-FIN-TempeAZ-02-08/Briefings/Josephson-Hill_HVOF_implementation.pdf

17 http://www.asetsdefense.org/documents/Workshops/SustainableSurfaceEngineering2009/Agenda/We dnesday/Martin%20-%20For%20Posting.pdf

18 http://db.materialoptions.com/ASETSDefense/SEDB/EHC_Alts/Qual_Eng_Data/Reports/Evaluation %20of%20Chrome%20Rod%20Alternative%20Coatings%20for%20Actuators.pdf

Barriers

Technical

The F-18 Program Office has not approved HVOF for landing gear because it has a low strain to failure and can spall at stresses approaching Fty on landing gear.[19] Another significant technical challenge involves meeting the material standards (including coating thickness) for a given application. However, HVOF has been evaluated against similar components as those maintained at FRCSE and has met the material standards and been implemented.

Financial

There are significant capital costs associated with HVOF as the purchase of the booth and coating equipment (robotics, gun, etc.) are necessary. In addition, HVOF is usually the most expensive of the thermal spray processes (1-3 times the cost of hard chrome), although their better performance (and hence lower life cycle cost) often outweighs the increased cost of application.

Acceptance

Acceptance of HVOF as an alternative for hard chrome plating hinges on the technology's ability to meet the material standards (including adhesion, spalling, coating thickness) of various applications. However, even if the technology meets the standards, it is a very different process than hard chrome plating and will require extensive training and certifications.

Logistics

HVOF with tungsten based carbides (WC) and a softer metal binder (CoCr) has been qualified on defense and commercial aerospace components for a few years. Questions remain regarding whether it is the best option for a particular application. People are moving away from it as plating alternatives get qualified. Plating is a lot easier wherever it can be used.

3.2.2 *Alternative:* Nanocrystalline Cobalt-Phosphorus

Nanocrystalline cobalt-phosphorus plating (nCoP) is commercially available as an environmentally compliant alternative to hard chrome plating. As an electrodeposition process, nCoP is fully compatible with the existing hard chrome plating infrastructure, but exhibits higher cathodic efficiencies and deposition rates than hard chrome plating, thus yielding higher throughput, reduced facility footprint and reduced energy consumption. Further, nCoP offers significant performance enhancements over EHC including superior sliding wear, enhanced lubricity and corrosion resistance, and fatigue properties. nCoP was developed in cooperation with SERDP and ESTCP. A currently ongoing ESTCP program (WP-0936) along with leveraged support from the Navy's Environmental Sustainability Development to Integration (NESDI) program (Project #348) aims at fully qualifying nCoP through performance testing and demonstration/validation on a number of components from NAVAIR (air vehicle and ground

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19 http://db.materialoptions.com/ASETSDefense/SEDB/EHC_Alts/Qual_Eng_Data/Reports/HVOF%20spalling.pdf

support equipment) and NAVSEA (shipboard machinery components and ground support equipment).

Related Efforts

Table 28 is a list of efforts related to the research, development, testing, and evaluation of nCoP. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 28. nCOP Related Efforts

Effort	Systems	Technology	Point of Contact
Nanocrystalline Cobalt Alloy Plating for Replacement of Hard Chrome and Thin Dense Chrome on Internal Surfaces (WP-200936)	All aircraft All helicopters F-35 JSF JSF, Joint Strike Fighter	Nanophase Co-P electroplate	Ruben A. Prado FRC-SE Fleet Readiness Center - Southeast (Jacksonville) ruben.prado@navy.mil (904) 542-3444
Electrodeposition of Nano-crystalline Co-P Coatings as a Hard Chrome Alternative (WP-0936)[20]	All aircraft All helicopters	Nanophase Co-P electroplate	Ruben A. Prado FRC-SE Fleet Readiness Center - Southeast (Jacksonville) ruben.prado@navy.mil (904) 542-3444
Electroformed Nanocrystalline Coatings: An Advanced Alternative to Hard Chromium Electroplating[21]		Nanophase Co-P electroplate	Mr. Douglas Lee Babcock & Wilcox - Integran Phone: 519-621-2130 x2190 dlee@babcock.com
Optimize Deposition parameters & Coating Properties of Cobalt Phosphorus Alloy Electroplating for Technology Insertion Risk Reduction [22]	All aircraft J52 Engine	Nanophase Co-P electroplate	Ruben A. Prado FRC-SE Fleet Readiness Center - Southeast (Jacksonville) ruben.prado@navy.mil (904) 542-3444

Applicability

The primary testing of this technology is being performed on components at FRCSE. If the technology successfully meets the requirements of the NAVAIR components, it should be able to be implemented full-scale.

Barriers

Technical

The most significant technical challenges involve meeting the material standards of a given application. The most challenging characteristic to meet has been abrasive wear. FRCSE is

[20] https://www.serdp-estcp.org/content/download/35585/341291/file/Hexavalent%20Chrome%20Webinar%20Presentation.pdf

[21] https://www.serdp-estcp.org/content/download/6277/84269/file/PP-1152-FR-01.pdf

[22] http://www.dtic.mil/dtic/tr/fulltext/u2/a551726.pdf

continuing to address this, but has started to look toward applications that do not require strict abrasive wear standards.

Financial

There are significant capital costs associated with nCoP as the purchase of a pulsed rectifier and other electroplating equipment are necessary. The primary driver is the need to replace a simple rectifier with a much more expensive pulse power supply. These power supply systems are getting more powerful, but still a challenge for really big parts like landing gear. In addition, there are also some differences in the cost of chemicals for the plating bath, though nCoP demonstrates a lower life cycle cost and outweighs the increased cost of application.

Acceptance

Acceptance of nCoP as an alternative for hard chrome plating hinges on the technology's ability to meet the material standards of various applications, particularly abrasion resistance. Once the material standards are met, the process is very similar to hard chrome plating and should have little trouble finding acceptance.

Logistics

Once nCoP is qualified and accepted on weapon systems, the Technical Manuals and drawings may still need to be changed to reflect adoption of the new technology.

3.2.3 *Alternative:* Trivalent Chromium Electroplating

Trivalent hard chrome plating is still in its development phase as an alternative to hard chrome plating with hexavalent chromium. The most promising technology currently under development is the FARADAYIC® developed by Faraday Technologies and currently being tested under the Toxic Metals Reduction Program with Corpus Christi Army Depot (CCAD). The FARADAYIC® Process uses a trivalent chromium plating bath as a replacement for hexavalent chromium for functional applications. The patented FARADAYIC® Process is an electrochemical process that utilizes a controlled pulsed electric field to electrodeposit a material of interest. The material deposition rate is determined by the applied electric field. This provides the means for precise control of the process length, the total material deposited and the deposit properties.

Related Efforts

Table 29 is a list of efforts related to the research, development, testing, and evaluation of trivalent hard chrome plating. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 29. Trivalent Chromium Electroplating Related Efforts

Effort	Systems	Technology	Points of Contact
Validation of Functional Trivalent Chrome Plating Process – Phase II[23]	All aircraft All helicopters All vehicles	Trivalent chrome plate	Bill Chenevert National Center for Manufacturing Sciences billc@ncms.org (734) 995-798
EPA Small Business Innovation Research - Eliminating Hexavalent Chrome from High Performance Chrome Coatings	All aircraft All helicopters All vehicles	Trivalent chrome plate	Dr. E. Jennings Taylor Faraday Technologies (937) 836-7749

Applicability

Assuming the technology can be successfully scaled-up and it can meet the necessary materials standards, it should be applicable to FRCSE requirements.

Barriers

Technical

The trivalent hard chrome plating technology has two major obstacles to overcome technically: 1) scale-up and 2) meeting the materials standards of various applications. Early testing by Faraday Technologies has been promising, but there is still considerable development to accomplish.

Financial

There are significant capital costs associated with trivalent hard chrome plating as the purchase of a pulsed rectifier and other electroplating equipment are necessary. In earlier development, the cost of a trivalent plating bath cost $5.53 per pound of chromium applied (versus $4.81 for hexavalent chromium). However, lower life cycle costs based on exposure and disposal should more than cancel this out.

Acceptance

Acceptance of trivalent hard chrome plating as an alternative for traditional hard chrome plating hinges on the technology's ability to meet the material standards of various applications. Once the material standards are met, the process is very similar to hard chrome plating and should have little trouble finding acceptance.

Logistics

Once trivalent hard chrome plating is qualified and accepted on weapon systems, the Technical Orders and drawings may still need to be changed to reflect adoption of the new technology.

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[23] https://www.ncms.org/wp-content/NCMS_files/CTMA/Symposium2011/presentations/WedTrack3PM/1-00%20Faraday%20-%20CTMA%20Meeting%20Presentation%20040511%20-%20Final.pdf

3.2.4 *Alternative:* Other

HVOF, nCoP, and trivalent chromium plating are probably the most mature and applicable technologies for DoD depot applicaions. However, several other technologies have been developed, tested, and demonstrated as potential alternatives to hard chrome plating for particular applications. These include physical vapor deposition, sputtering, explosive cladding, electrospark deposition, cold spray, cold spray plus Tagnite, and various other thermal spraying processes. Of these, an FRCSE application for cold spray might be the magnesium gearboxes and electrospark deposition shows some promise, particularly for non-aircraft applications such as ground support equipment. A more detailed description of the electrospark technology is provide in the following paragraphs.

Electrospark deposition (ESD) is essentially a pulsed micro-welding process that is used for small scale repair of high value components. Electrospark deposition is also known as spark hardening, electrospark toughening, electrospark alloying, pulsed fusion surfacing and pulsed electrode surfacing. Electrospark deposition systems contain a capacitor-based power supply that produce short duration high current pulses through a rotating wire consumable electrode. The consumable electrode material is deposited onto the work piece by means of electric sparks. In the electrospark deposition process, the electrode is the anode and the work piece is the cathode.

When the energy is released, the direct current generates a plasma arc between the tip of the electrode and the work piece. The plasma arc ionizes the consumable and a small quantity of molten electrode material is transferred onto the work piece. The transfer is rapid and the self-quenching is extremely fast. Based on short duration, high current pulses, the process imparts a low heat input to the substrate material, resulting in little or no modification of the substrate microstructure. Components can be restored to their original dimensions, because with such low heat input the bulk substrate material remains near to ambient temperature with thermal distortion, shrinkage and high residual stresses avoided. Moreover, the process generates a good metallurgical bond between the coating and the substrate. Electrospark deposition can also be considered as a process to increase the wear and the erosion resistance of small surface areas such as repair of small and shallow defects, but it is not appropriate for large defects. We are not aware that it is currently or has been used for aircraft repair.

Related Efforts

Table 30 is a list of efforts related to the research, development, testing, and evaluation of electrospark deposition. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

noblis

Table 30. Electrospark Deposition Related Efforts

Effort	Systems	Technology	Point of Contact
Electrospark Deposition for the Repair of Army Main Battle Tank Components[24]	M1A1	ESD	Victor Champagne US Army Research Laboratory vchampag@arl.army.mil (410) 306-0822
Electrospark Deposition for Depot and Field-Level Component Repair and Replacement of Hard Chromium Plating[25]	All aircraft All helicopters All ships All vehicles TF33 turbine engine M1A1	ESD	Dr. Robin Nissan SERDP-ESTCP Nissan, Robin A CIV OSD OUSD ATL (US) robin.a.nissan.civ@mail.mil (571) 372-6399

Applicability

Electrospark deposition is applicable to repair and small area applications. It is not intended to replace a hard chrome plating bath. For the appropriate application, electrospark deposition is applicable to FRCSE.

Barriers

Technical

Electrospark deposition is a proven technology for repair and small area applications, excluding aircraft where the quality of the coating is not adequate in most cases. The primary technical challenge to meeting materials standards (e.g., hardness, wear resistance, fatigue) for individual applications. For repairs, there is also the question of what material to apply to existing hard chrome plating. Can a non-chrome coating (meeting reduction goals) be applied effectively to existing chrome plating?

Financial

Capital costs associated with the implementation of electrospark deposition technology are not too intensive as the power supply is relatively inexpensive. However, it is a slow process and does not demonstrate the “throw-rate” of hard chrome plating, making application of the technology very selective.

Acceptance

Acceptance of electrospark deposition as an alternative for traditional hard chrome plating hinges identification of small surface or repair applications and the technology’s ability to meet the material standards of these applications. Once the material standards are met, the process is very different from hard chrome plating and will require extensive training and certifications.

Logistics

Once electrospark deposition is qualified and accepted on weapon systems, the Technical Manuals and drawings may still need to be changed to reflect adoption of the new technology.

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24 www.dtic.mil/cgi-bin/GetTRDoc?AD=ada453366

25 https://www.serdp-estcp.org/content/download/5776/79338/file/WP-0202-FR.pdf

3.3 Cadmium Plating – Process Improvements and Alternatives

3.3.1 *Alternative:* Zn-Ni Plating

Zn-Ni electroplating is a composite plating process typically consisting of a bath with a concentration of 11-16 Ni components and the remainder Zn. The Ni helps to offset the rapid corrosion of Zn to form an engineering coating that is an accepted replacement for Cd plating in many applications. There are multiple forms of Zn-Ni electroplating, including both acidic and alkaline low hydrogen embrittlement (LHE) processes.

Zinc alloy electroplating can be regarded as an electrogalvanization process for corrosion protection of metal surfaces and increasing their wear resistance. Modern development started during the 1980s with the first alkaline Zn/Ni (94%/6%) deposits. The reinforcement of the corrosion specifications and regulations banishing the use of Cr^{6+} required greater use of alkaline Zn/Ni containing between 12 and 15% Ni (Zn/Ni 86/14).

Corrosion protection is primarily due to anodic potential dissolution of zinc versus steel. Zinc acts as a sacrificial anode for protecting iron (steel). Steel is preserved from corrosion by cathodic protection. Alloying zinc with nickel at levels less than 1% has minimal effect on the potential; but both alloys improve the capacity of the zinc layer to develop a chromate film by conversion coating. This further enhances corrosion protection. Zn/Ni between 12% and 15% Ni (Zn/Ni 86/14) has a potential around -680 mV, which is closer to cadmium -640 mV. Thanks to this mechanism of corrosion, this alloy offers much greater protection than other alloys.

Several different Zn-Ni alloys have been tested by the DoD, aerospace industry, academia, and other related entities. These include Zn-Ni electroplate (acid), Dipsol IZ-C17 (alkaline LHE), Zn14-16Ni electroplate (alkaline LHE), and Zn-12Ni electroplate (alkaline LHE).

Related Efforts

Table 31 is a list of efforts related to the research, development, testing, and evaluation of Zi-Ni plating as an alternative to Cd plating. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 31. Zn-Ni Plating Related Efforts

Effort	Systems	Technology	Point of Contact
Cadmium (Tank) Electroplating Alternative (NESDI project	All	IZ C-17+ ZnNi electroplating	Luzmarie Youngers, FRCSE
Validation of Alternatives to Electrodeposited Cadmium for Corrosion Protection and Threaded Part Lubricity Applications	All	IVD Al Sn-Zn electroplate Zn-Ni electroplate (acid) IZ-C17 (LHE ZnNi)	Concurrent Technologies Corporation 814-266-2874
Surface Finishing and Repair Issues for Sustaining New Aircraft	All aircraft C-17 AH-64 Apache	AlumiPlate IZ-C17 (LHE ZnNi)	Keith Legg Rowan Technology Group klegg@rowantechnology.com 847-680-9420

Effort	Systems	Technology	Point of Contact
Cadmium Alternative Coating Corrosion Performance on 4340 Steel	All	AlumiPlate IVD Al IZ-C17	Eun U. Lee NAVAIR Patuxent River Aircraft Division
Field Repair of Chrome and Cadmium Replacements	F-35 JSF	AlumiPlate Al-Mn Electroplate Electroless Ni-P (acid) Electroless Ni-B (alkaline) IVD Al Sn-Zn electroplate Zn-Ni electroplate (acid)	Keith Legg Rowan Technology Group klegg@rowantechnology.com 847-680-9420
High Strength Steel Joint Test Protocol for Validation of Alternatives to Low Hydrogen Embrittlement Cadmium for High Strength Steel Landing Gear and Component Application	All aircraft	AlumiPlate Electroless Ni-P (acid) IVD Al Sn-Zn electroplate Iz-C17 (LHE ZnNi) Al-ceramic (chrome free)	Erin Beck NAVAIR Patuxent River Aircraft Division Erin.beck@navy.mil 301-342-6183
The Nuts and Bolts of Cadmium Plating Alternatives – A Study on the Long-Term Performance Characteristics Conducted by the US Army	All vehicles BFV	Sn-Zn electroplate Zn-Ni electroplate (acid) Metal-flake (chrome free) Zn electroplate	George Shaw US Army – Tank Automotive and Armament Command 586-282-5000
Cadmium Replacement Alternatives for Corrosion and Hydrogen Embrittlement Protection of High Strength Steels	All aircraft All helicopters All ships	IZ-C17 (LHE ZnNi)	Denise Aylor, NSWC Carderock
Fluid Corrosion Compatibility Study of Electroplated Cadmium Alternatives on 4130 Steel	All aircraft All helicopters All ships All vehicles	AlumiPlate IVD Al IZ-C17 (LHE ZnNi)	Army Research Laboratory
Cadmium Replacement for Propellant Actuated Devices (PADS)	All aircraft All helicopters	Zn-12Ni electroplate (alkaline LHE)	Harry L. Archer Naval Surface Warfare Centers
Low Hydrogen Embrittlement (LHE) Zinc-Nickel SBIR Phase II	All aircraft	IZ-C17 (LHE ZnNi) Zn14-16Ni electroplate (alkaline LHE)	Dave Frederick OO-ALC Hill AFB David.frederick@hill.af.mil 801-774-6250
Evaluation of Alternatives to Electrodeposited Cadmium for Threaded Fasteners Applications	All Aircraft All helicopters	AlumiPlate Zn14-16Ni electroplate (alkaline LHE)	Jerry Brown Lockheed Martin c-jerry.brown@lmco.com 817-655-6404

Effort	Systems	Technology	Point of Contact
Validation of Alternatives to Electrodeposited Cadmium for Corrosion Protection and Threaded Part Lubricity Applications	All aircraft All helicopters V-22 B-1 B-2 B-52 E-3 F-22 KC-135 Missiles CH-46 CH-47 E-6	IVD Al Sn-Zn electroplate Zn-Ni electroplate (acid) IZ-C17 (LHE ZnNi) Zn14-16Ni electroplate (alkaline LHE)	Vernon L. Holmes The Boeing Company
Rotating Bending Beam (RR Moore) Fatigue Testing and Corrosion Testing of Various Potential Alternatives to Cadmium Plating	All aircraft All helicopters	IVD Al Sn-Zn electroplate Zn-Ni electroplate (acid) IZ-C17 (LHE ZnNi) Zn14-16Ni electroplate (alkaline LHE)	Daniel Ferry Boeing Military Aircraft, Philadelphia daniel.ferry@boeing.com 610-591-5931/5930
A Study of Zinc-Nickel as an Alternate Coating to Cadmium for Electrical Connector Shells Used in Aerospace Applications	All aircraft All helicopters All ships All vehicles	Electroless Ni-P (acid) Zn-12Ni electroplate (alkaline LHE)	Odunayo Ogundiran Rensselaer Polytechnic Institute
Ultra-High Efficiency/Low Hydrogen Embrittlement Nanostructured Zn-Based Electrodeposits as Environmentally Benign Cd-Replacement Coatings for High Strength Steel Fasteners (SERDP project WP-1616)	All aircraft All helicopters All ships All vehicles	Zn-Ni electroplate (acid) Zn14-16Ni electroplate (alkaline LHE) Zn-12Ni electroplate (alkaline LHE)	Jonathan McCrea Integran Technologies mccrea@integran.com 416-675-6266
Characterization of a Zinc/Nickel Plating Bath		Zn14-16Ni electroplate (alkaline LHE)	Paulo Veira Elsyca Inc. 770-683-2929
Hydrogen Re-embrittlement Susceptibility of Ultra High Strength Steels	All aircraft	Al-ceramic (high chrome): Sermatel Zn14-16Ni electroplate (alkaline LHE)	Douglas J. Figueroa Gordon Cranfield University +44 1234 750111
Replacement Coatings for Aircraft Electronic Connectors	All aircraft	AlumiPlate Electroless Ni-B (alkaline) IVD Al Sn-Zn electroplate Metal-flake (chrome free) Zn electroplate Electroless Ni-P composite: PTFE Ni Watts	AFRL – Materials and Manufacturing

Effort	Systems	Technology	Point of Contact
		Zn14-Ni16 electroplate (alkaline LHE)	

Applicability

Zn-Ni electroplating is applicable to many Cd plating applications including some fasteners and landing gear. In addition, it has been tested and proven on other substrates in use at FRCSE. If the technology is shown to meet corrosion protection and other requirements, it is an applicable Cd alternative at FRCSE.

Barriers

Technical

Zn-Ni electroplating has been shown to meet the corrosion requirements of commercial aircraft and many DoD weapon systems, including all Air Force landing gear plated at Hill AFB. High strength steel applications use one of the alkaline LHE formulations and processes. Navy weapon systems can have more stringent corrosion protection requirements than Air Force systems, so additional testing might be necessary to ensure that system requirements are met.

Financial

Much of the same infrastructure can be used for Zn-Ni electroplating as is used for Cd plating, so up front capital costs are minimal. In addition, the process cost per part is very close and is easily offset by the elimination of medical monitoring and other ESOH measures currently necessary for processing with Cd.

Acceptance

Acceptance of Zn-Ni electroplating as an alternative to Cd plating at FRCSE hinges on its ability to meet the material and corrosion protection requirements of FRCSE weapon systems. Once it meets these requirements, implementation is not complex and training to use the new electroplating process is minimal.

Logistics

The primary logistical challenge with the implementation of Zn-Ni electroplating is infrastructure requirements in Building 101. The plating shop really has no additional space for tankage, so the Cd plating line would have to be reused for the process. Extensive planning would be necessary to ensure that the entire line is not shut down and that production is not impacted through implementation. Once Zn-Ni electroplating is qualified and accepted on weapon systems, the Technical Manuals and drawings may still need to be changed to reflect adoption of the new technology.

3.3.2 *Alternative:* AlumiPlate

Aluminum electroplating is done using a toluene-based organic solution based on technology patented by Siemens. The solvent introduces no free protons into solution and, therefore, little or no propensity for hydrogen embrittlement in the Al plating process itself. Unlike standard aqueous electroplating, the organic plating solution must be kept free of oxygen and water, which necessitates the use of a completely enclosed plating line. This line is completely sealed in a steel tank that contains an inert atmosphere. Items to be plated are inserted into the system through a load-lock at one end and are then picked up and carried by a traveling crane. Each bath (activation, plating, rinsing, etc.) is isolated by a gate valve, which is opened to admit the workpiece, then closed for the duration of the operation. All of these movements and process are computer controlled.

Prior to plating items are cleaned in a standard aqueous cleaning line and given either an electroplated Ni strike or a grit blast for adhesion. In the past a Ni strike was always used. However, working with Goodrich AlumiPlate has developed a grit blast surface preparation method that works well. Electroless Cu has also been used instead of a Ni strike on aluminum and composite connectors. A preparation method for direct plating of Alumiplate on aluminum connectors has also been developed.

Once in the plating line the surface is chemically activated in a semiaqueous bath and any water rinsed off prior to plating. Simple components can be plated using a standard anode arrangement. However, complex components requiring an even plate on all surfaces must be plated using conformal anodes or multiple anodes, as in any other electroplating process. Unlike IVD Al, electroplated Al requires no post-processing since the material is dense and adherent as-deposited. In many applications it does require a chromate treatment, just as with any other Cd alternative. For threaded sections of fasteners and connectors a solid lubricant is required because of the tendency of Al to gall.

Related Efforts

Table 32 is a list of efforts related to the research, development, testing, and evaluation of Alumiplate. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 32. Alumiplate Related Efforts

Effort	Systems	Technology	Point of Contact
Cadmium Alternative Coating Corrosion Performance on 4340 Steel	All	AlumiPlate IVD Al IZ-C17	Eun U. Lee NAVAIR Patuxent River Aircraft Division
Surface Finishing and Repair Issues for Sustaining New Aircraft	All aircraft C-17 AH-64 Apache	AlumiPlate IZ-C17 (LHE ZnNi)	Keith Legg Rowan Technology Group klegg@rowantechnology.com 847-680-9420

Effort	Systems	Technology	Point of Contact
Field Repair of Chrome and Cadmium Replacements	F-35 JSF	AlumiPlate Al-Mn Electroplate Electroless Ni-P (acid) Electroless Ni-B (alkaline) IVD Al Sn-Zn electroplate Zn-Ni electroplate (acid)	Keith Legg Rowan Technology Group klegg@rowantechnology.com 847-680-9420
Cadmium Replacement Alternatives for the Joint Strike Fighter	F-35 JSF	AlumiPlate Al-Mn electroplate IVD Al Al-ceramic (chrome free) Sn-Zn electroplate Zn-Ni electroplate (acid) Al-ceramic (low chrome)	Keith Legg Rowan Technology Group klegg@rowantechnology.com 847-680-9420
High Strength Steel Joint Test Protocol for Validation of Alternatives to Low Hydrogen Embrittlement Cadmium for High Strength Steel Landing Gear and Component Application	All aircraft	AlumiPlate Electroless Ni-P (acid) IVD Al Sn-Zn electroplate Iz-C17 (LHE ZnNi) Al-ceramic (chrome free)	Erin Beck NAVAIR Patuxent River Aircraft Division Erin.beck@navy.mil 301-342-6183
AlumiPlate as a Cadmium Alternative	All aircraft All helicopters F-35 JSF	AlumiPlate	Keith Legg Rowan Technology Group klegg@rowantechnology.com 847-680-9420
Surface Treatment Implementation F-16 AlumiPlate	F-16	AlumiPlate	Jerry Brown Lockheed Martin c-jerry.brown@lmco.com 817-655-6404
Surface Treatment Implementation F-35 LG AlumiPlate	F-35	AlumiPlate	Neil Harris Goodrich Corporation Neil.Harris@Goodrich.com 216-429-4202
Surface Treatment Implementation Sikorsky CH-53K AlumiPlate	CH-53K	AlumiPlate	Robert Guillemette Sikorsky (United Technologies) rguillemette@sikorsky.com 203-386-7559
Fluid Corrosion Compatibility Study of Electroplated Cadmium Alternatives on 4130 Steel	All aircraft All helicopters All ships All vehicles	AlumiPlate IVD Al IZ-C17 (LHE ZnNi)	Army Research Laboratory
Testing Cadmium Alternatives for High Strength Steel Phase 2	All aircraft	AlumiPlate IVD Al Sn-Zn electroplate	Concurrent Technologies Corporation

Effort	Systems	Technology	Point of Contact
Evaluation of Alternatives to Electrodeposited Cadmium for Threaded Fasteners Applications	All Aircraft All helicopters	AlumiPlate Zn14-16Ni electroplate (alkaline LHE)	Jerry Brown Lockheed Martin c-jerry.brown@lmco.com 817-655-6404
Corrosion Immersion Testing of 13 mm-Diameter Grad-10.9 Bolts for Bolt-on Armor	All vehicles	AlumiPlate Zn electroplate	Thomas A Considine US Army Research Laboratory
Cadmium Alternatives for High Strength Steel (JCAT)	All aircraft	AlumiPlate IVD Al Sn-Zn Electroplate Zn-Ni electroplate (acid) Zn14-Ni16 electroplate (alkaline LHE) Sputtered Al Sermetel 249/273	Steven A Brown NAVAIR Patuxent River Aircraft Division Steven.a.brown@navy.mil 301-342-8101
Replacement Coatings for Aircraft Electronic Connectors	All aircraft	AlumiPlate Electroless Ni-B (alkaline) IVD Al Sn-Zn electroplate Metal-flake (chrome free) Zn electroplate Electroless Ni-P composite: PTFE Ni Watts Zn14-Ni16 electroplate (alkaline LHE)	AFRL – Materials and Manufacturing

Applicability

AlumiPlate is applicable to many Cd plating applications at FRCSE including many fasteners and electrical connectors. In addition, it has been tested and proven on other substrates in use at FRCSE. If the technology is shown to meet corrosion protection and other requirements, it is an applicable Cd alternative at FRCSE.

Barriers

Technical

AlumiPlate has been shown to meet the corrosion and lubricity requirements of many DoD weapon systems, especially for Army applications and on the F-35 Joint Strike Fighter.   Other Navy weapon systems, however, might have more stringent corrosion protection requirements than Air Force systems, so additional testing might be necessary to ensure that system requirements are met. AlumiPlate has the same issue as IVD Al that it is attacked by alkaline cleaners that are often used for sustainment.

Financial

There are significant financial impacts associated with the implementation of AlumiPlate. The technology can be implemented either by licensing the process or by outsourcing the plating to the technology owner. Licensing is very expensive and requires the purchase and installation a specialized, sealed plating line. None of the existing Cd plating infrastructure could be reused. Outsourcing is also expensive as the process cost per part is several times that of Cd.

Acceptance

Licensing and installation of an AlumiPlate plating line at FRCSE would have trouble finding acceptance on several fronts, including cost and ESOH concerns with the large solvent (toluene) bath necessary for the Al electroplating. Outsourcing would be a much easier "sell," if the cost issues can be overcome.

Logistics

Implementation of AlumiPlate at FRCSE has several logistical hurdles to overcome. The first is the placement of the infrastructure in Building 101. There is no more room in the plating shop. The second is the fact that none of the Cd plating infrastructure can be reused. Finally, given the nature of the technology and the process, there is extensive training associated with the use of AlumiPlate. Outsourcing causes many fewer logistical challenge, primarily relying on contracts to right a tight agreement with the technology provider. In addition, there are logistical challenges associated with the transportation of components as well as Quality Control of the coatings once they have been shipped back to FRCSE. Once AlumiPlate is qualified and accepted on weapon systems, the Technical Manuals and drawings may still need to be changed to reflect adoption of the new technology.

3.3.3 *Alternative:* Other

In addition to Zn-Ni electroplating and AlumiPlate, a number of other technologies have been evaluated and demonstrated as potential alternatives to Cd plating. There are too many technologies to sufficiently cover all of them, so this implementation plan will focus on: IVD Al, Cold Spray, Sn-Zn electroplate, and Al-Mn electroplate.

IVD Al

Ion Vapor Deposition (IVD) of aluminum is a vapor deposition plating process which deposits pure aluminum on nearly any substrate to prevent corrosion. The process was originally developed by McDonnell Douglas Corp. as a replacement for cadmium plating on steel. In this process, the substrate, or component being aluminum coated, is the cathode of a high-voltage system. A negative potential of 500 to 1,500 volts DC is applied to the part. Aluminum is evaporated from resistively heated elements or from an aluminum slug by electron beam. Specifically, aluminum alloy wire is fed into a resistively heated source called about in the IVD aluminum coater. The boat is made from a special composite material that has the proper electrical characteristics to get sufficiently hot with current flowing through it, yet not erode rapidly or create hot spots. Also, the boat has sufficient strength to withstand stresses imposed on it at operating temperature. The vaporized aluminum, a gas, spreads out into the vacuum vessel coating the part and the shell of the vacuum vessel in the vicinity of the boat. A part placed above the evaporating aluminum becomes hot. Heating of the part is primarily due to the heat of condensation that develops whenever the aluminum changes its state from vapor (gas) to liquid to solid. In a rack-type coater with a moving evaporator system, the radiant heating of the part is smaller and less significant than the heat of condensation of aluminum onto the part.

Cold Spray

Cold spray imparts supersonic velocities to metal particles by placing them in a heated nitrogen or helium gas stream that is expanded through a nozzle. The powder feed is inserted at high pressure at the nozzle entrance. High pressures and temperatures yield supersonic gas velocities and high particle acceleration within the gas stream. The particles are directed towards the surface, where they embed on impact, forming a strong bond with the surface. Subsequent spray passes increase the coating thickness. The adhesion of the metal powder to the substrate, as well as the cohesion of the deposited material, is accomplished in the solid state.

Sprayed particles must reach a "critical velocity" before impact will result in consolidation with the surface. This required minimum velocity varies among metal types and is typically between 500 and 800 m/s. The gas used for particle acceleration is generally nitrogen, helium, or a mixture of the two. The gas expands and accelerates through the nozzle as its temperature decreases. Very rapid changes take place at the nozzle throat, where gas sonic velocity is reached.

Upon impact with the substrate surface, the particle flattens while the substrate crater depth and width increase. At the same time, a jet composed of both the particle material and the substrate material is formed at the particle/substrate contact surface and there is a temperature rise, concentrated at the particle/surface interface. This temperature rise is an indication of shear instability, which causes extensive flow of material at the corresponding surfaces, and the estimated impact velocity to induce shear instability compares fairly well with the experimentally determined critical velocity of copper. This means that, as in the case of explosive welding of materials, bonding in cold spray is a result of the shear instability at the interacting surfaces.

The attributes of cold spray include low temperature deposition, dense structures, and minimal or compressive residual stress. In addition to these characteristics, the deposited material possesses strength close to or above that of wrought material. In the as-deposited state, cold spray deposits can exhibit higher strengths than wrought alloys. When annealed, cold spray deposit strength decreases, but elongation and ductility increase. Such characteristics allow cold spray repairs to closely mimic or surpass in strength the material that is repaired. In addition to good strength characteristics, the repairs can be easily accomplished and cosmetically acceptable.

Sn-Zn Electroplate

The tin zinc alloy plating process provides a 70/30 Tin/Zinc ratio and offers an environmentally friendly and RoHS compliant alternative when applied. Sn-Zn electroplate is a viable replacement for cadmium in many applications. Commercially, this process is approved by General Motors, DaimlerChrysler, Mitsubishi, and Toyota for this Tin Zinc Plating Alloy process.

Advantages of Sn-Zn plating include: high corrosion resistance, especially against salt water and sulfur dioxide; excellent solderability; excellent performance in secondary processing due to superior ductility; and excellent throwing and covering power resulting in relatively uniform thicknesses even in recesses.

Applications using Sn-Zn electroplating include: providing corrosion resistance to salt water for aircraft, ships, machinery and equipment used at sea, railway equipment and automobiles; providing corrosion resistance to sulfurous chemicals; and providing solderability for electrical appliances and electronic components

Al-Mn electroplate

There has been considerable effort to minimize the use of cadmium by Department of Defense activities because of its toxicity. While no single coating has been found to replace cadmium in all aircraft applications, aluminum has been found to be a good alternative coating material in many applications requiring good corrosion resistance and minimal effect on fatigue properties. Only two commercial aluminum coating processes, vacuum deposition and ion vapor deposition, have been developed to the point of being widely employed: IVD Al and CVD Al.

Efforts have been initiative to attempt to scale-up an aluminum-manganese plating bath that could produce an alternative to aluminum coating by vacuum processes. The Al-Mn bath technology was originally developed by the National Steel Corporation and consists of a mixture of anhydrous aluminum chloride, manganese chloride, potassium chloride, and sodium chloride. This salt mixture is melted in a suitable vessel and operated at a temperature of 166-177*C (330-350'F). Plating is performed in the normal manner used for aqueous baths, the major difference being that the bath and the surrounding atmosphere must be kept as dry as possible. If the bath comes into contact with water or moist air, there is the potential to create hydrochloric acid fumes.

The Al–Mn alloy coatings are electrodeposited onto substrates in $AlCl_3$–NaCl–KCl–$MnCl_2$ molten salts at 170 °C to improve the corrosion resistance. Substrates are often pre-plated (striked) with a thin zinc layer as intermediate layer. The corrosion resistance of the coatings have been evaluated and confirmed that the Al–Mn alloy coatings exhibited good corrosion resistance with a clear passive region and significantly reduced corrosion current density at anodic potentiodynamic polarization. The corrosion resistance of the alloy coatings is also related with the microstructure and Mn content of the coatings.

Related Efforts

Table 33 is a list of efforts related to the research, development, testing, and evaluation of Other technologies for the replacement of Cd plating. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 33. Other Technology Related Efforts

Effort	Systems	Technology	Point of Contact
Validation of Alternatives to Electrodeposited Cadmium for Corrosion Protection and Threaded Part Lubricity Applications	All	IVD Al Sn-Zn electroplate Zn-Ni electroplate (acid) IZ-C17 (LHE ZnNi)	Concurrent Technologies Corporation 814-266-2874
Cadmium Alternative Coating Corrosion Performance on 4340 Steel	All	AlumiPlate IVD Al IZ-C17	Eun U. Lee NAVAIR Patuxent River Aircraft Division
Field Repair of Chrome and Cadmium Replacements	F-35 JSF	AlumiPlate Al-Mn Electroplate Electroless Ni-P (acid) Electroless Ni-B (alkaline) IVD Al Sn-Zn electroplate Zn-Ni electroplate (acid)	Keith Legg Rowan Technology Group klegg@rowantechnology.com 847-680-9420
High Strength Steel Joint Test Protocol for Validation of Alternatives to Low Hydrogen Embrittlement Cadmium for High Strength Steel Landing Gear and Component Application	All aircraft	AlumiPlate Electroless Ni-P (acid) IVD Al Sn-Zn electroplate Iz-C17 (LHE ZnNi) Al-ceramic (chrome free)	Erin Beck NAVAIR Patuxent River Aircraft Division Erin.beck@navy.mil 301-342-6183
Evaluation of Aluminum Ion Vapor Deposition as a Replacement for Cadmium Electroplating at Anniston Army Depot	All vehicles All aircraft	IVD Al	
Magnesium Repair by Cold Spray	All aircraft All helicopters	Cold spray Al	Dennis Helfritch US Army Research Laboratory 410-306-1928
The Nuts and Bolts of Cadmium Plating Alternatives – A Study on the Long-Term Performance Characteristics Conducted by the US Army	All vehicles BFV	Sn-Zn electroplate Zn-Ni electroplate (acid) Metal-flake (chrome free) Zn electroplate	George Shaw US Army – Tank Automotive and Armament Command 586-282-5000
Fluid Corrosion Compatibility Study of Electroplated Cadmium Alternatives on 4130 Steel	All aircraft All helicopters All ships All vehicles	AlumiPlate IVD Al IZ-C17 (LHE ZnNi)	Army Research Laboratory

Effort	Systems	Technology	Point of Contact
Testing Cadmium Alternatives for High Strength Steel Phase 2	All aircraft	AlumiPlate IVD Al Sn-Zn electroplate	Concurrent Technologies Corporation
Cold Spray Phase I AFMC06PV12	All aircraft	AlumiPlate IVD Al MOCVD Al Cold spray Al PVD sputtered Al	Peter Lurker Wright Patterson Air Force Base Peter.lurker@wpafb.af.mil 937-255-3567
Aluminum Manganese Molten Salt Plating WP9903		Al-Mn electroplate	Erin Beck NAVAIR Patuxent River Aircraft Division Erin.beck@navy.mil 301-342-6183
Development of Advanced Aerospace Materials: Aluminum Manganese Plating from a Molten-Salt Bath		Al-Mn Electroplate	
Rotating Bending Beam (RR Moore) Fatigue Testing and Corrosion Testing of Various Potential Alternatives to Cadmium Plating	All aircraft All helicopters	IVD Al Sn-Zn electroplate Zn-Ni electroplate (acid) IZ-C17 (LHE ZnNi) Zn14-16Ni electroplate (alkaline LHE)	Daniel Ferry Boeing Military Aircraft, Philadelphia daniel.ferry@boeing.com 610-591-5931/5930
Replacement Coatings for Aircraft Electronic Connectors	All aircraft	AlumiPlate Electroless Ni-B (alkaline) IVD Al Sn-Zn electroplate Metal-flake (chrome free) Zn electroplate Electroless Ni-P composite: PTFE Ni Watts Zn14-Ni16 electroplate (alkaline LHE)	AFRL – Materials and Manufacturing

Applicability

IVD Al is currently in use at FRCSE and has replaced Cd in many applications. To further judge applicability for IVD Al as an alternative to remaining Cd applications, substantial evaluation would be necessary. It is possible that IVD Al is being used for all of the applications for which it is applicable. Cold spray technology has not been tested or qualified to any FRCSE processes or operations, so significant testing, evaluation, and demonstration would be necessary. Assuming cold spray can meet the material and corrosion protection requirements, it should be an applicable technology. Both Sn-Ni and Al-Mn electroplating are applicable for some Cd plating processes, so a comprehensive evaluation of requirements would be necessary to determine their applicability at FRCSE.

Barriers

Technical

IVD Al and Cold Spray are both line of sight technologies and, therefore, not able to coat some complex or inside diameter components. This basic limitation of the technologies will determine what components might be able to be transferred to these processes. In addition, cold spray has not been tested against FRCSE weapon system requirements, so significant evaluation is necessary to surpass these technical hurdles. Both Sn-Zn and Al-Mn electroplating are non-line of sight technologies, but both have limited material characteristics and are applicable to only a subset of applications. Regardless, significant testing, evaluation, and demonstration would be necessary to qualify either process as an alternative to Cd plating.

Financial

IVD Al equipment is very expensive, however, FRCSE already has the equipment, so the cost comparison is really based on process costs and operations and maintenance. IVD Al is more expensive per part and the equipment requires significant upkeep compared to Cd plating. However, total lifecycle costs are likely to be a wash. Implementation of cold spray would require significant investment in new infrastructure and equipment. Process costs (cost per component) are not available for comparison. Sn-Zn plating could make use of existing Cd plating infrastructure, minimizing upfront capital expenditures. The process costs of Cd plating and Sn-Zn electroplating are very close as well. Al-Mn electroplating requires the use of molten salt baths to perform the process and would not be able to utilize the existing Cd plating infrastructure. The capital costs would be significant and the process costs are higher. In addition, safety concerns regarding the use of Cd are just traded off for safety concerns surrounding use of a 170C molten salt bath.

Acceptance

Acceptance of any of these alternative technologies hinges on their ability to meet the material and corrosion protection requirements of FRCSE weapon systems. IVD Al is in use at FRCSE, so acceptance would not be an issue. Cold spray is similar in principle and application to HVOF and plasma spray, which is in use at FRCSE, so acceptance following training would not be an issue. Sn-Zn electroplating is essentially a drop-in replacement for Cd plating, so acceptance should be easy to gain. Al-Mn electroplating is very process intensive, requires new infrastructure, and extensive training. That coupled with the fact that it uses a 170C molten salt bath, acceptance would be harder to gain prior to and after implementation.

Logistics

There are no logistical barriers associated with the implementation of IVD Al. Logistical barriers associated with cold spray revolve around the purchase and placement of the infrastructure necessary to implement the process. Cold spray would require an enclosed booth for application of the coating and placement would be an issue in Building 101. The primary logistical challenge with the implementation of Sn-Zn electroplating is infrastructure requirements in Building 101. The plating shop really has no additional space for tankage, so the Cd plating line would have to reused for the process. Extensive planning would be necessary to ensure that the entire line is not shut down and that production is not impacted through implementation. Implementation of Al-Mn electroplating would face significant logistical challenges. There is no additional space in the plating shop for additional tankage, so tanks from the Cd plating line would have to be removed to install the molten-salt bath and ancillary tanks. Like with Sn-Zn electroplating, extensive planning would be necessary to ensure that the entire line is not shut down and that production is not impacted through implementation. Once any new technology is qualified and accepted on weapon systems, the Technical Manuals and drawings may still need to be changed to reflect adoption of the new technology.

3.4 Chromate Conversion Coatings – Process Improvements and Alternatives

Chromate conversion coatings are unique in the way they work, in that they react chemically with the surface to produce a converted layer of substrate. When wet, the chromate dissolves in water and precipitates out at corrosion locations. Conversion coatings are based on Cr^{6+}, while passivation coatings may be based on either Cr^{6+}, Cr^{3+} or other chemistries that are non-chrome.

Unlike chromates, non-chromate passivates are not hydrated, which allows them to act as an electrically insulating film and offers greater stability at higher temperatures. Electrical conductivity becomes an issue for applications calling for aluminum enclosures for electronics and aluminum electrical connectors. If chromates (Cr^{6+}) are heated above 212°F (100°C) they dehydrate and become ineffective. Most of the chromate-free passivates can be heated at least to 375°F (190°C), which is the temperature required to bake the hydrogen out of steels. If a steel product needs to be heated, chemical conversion has to be applied after the heat treat, which often requires that the surface be re-activated. Chromate-free passivates avoid this problem by making it possible to heat treat after passivation.

While there may be products that perform exceptionally well for specific materials and applications, overall the chromate-free passivates are not as effective as chromates for inhibiting corrosion, or as robust, requiring more care in processing and application conditions. The probability of corrosion failure is increased unless the processing is done with strict specifications and process controls.

3.4.1 Process Improvements

Alodine 600 solutions are normally unheated but can be operated between 70F and 110F. The process cycle time and coating thickness are dependent upon both concentration and temperature and the process can be optimized to run at a higher temperature and lower concentration to reduce drag out and facilitate evaporative recovery of rinse water. As much as 75% drag out reduction is possible with best management practices. Drag out recovery efficiency is dependent upon the evaporation to drag out ratio. The tank evaporation rate at these temperatures is relatively small, however the concentration of the solution is also low, and upwards of 85% drag out recovery is possible with two countercurrent recovery rinses followed by a third open rinse discharging to wastewater treatment.

Chromate conversion processes (and all other conversion coatings) require some bleed as substrate (Al, Zn, Ni, Cd) metal builds up as a contaminant in the solution. Drag out is a natural bleed and the bleed rate is inherently a function of workload. Effective solution control and waste reduction can be optimized by calibrating drag out reduction and recovery to maintain solution contaminants within a specified range.

3.4.2 *Alternative:* Trivalent Chromium Process (TCP) Conversion Coatings

Non-chromate passivates do not function in the same way as chromate conversion. The most successful passivates are based on trivalent chrome (Cr_2O_3) with a passivate species. For aluminum, one of the most successful passivates is a hexafluorozirconate (i.e. based on Zr), which was developed as a trivalent chromium process (TCP) by the Naval Air Systems Command (NAVAIR). This is the basis for Alodine 5900, Aluminescent, MacDermid TCP, METALAST, SurTec and other coatings. There are also non-chrome passivates based on titanates, vanadates, permanganates and other inhibitors. NASA has implemented a non-chromate coating system for use on aluminum alloy Solid Rocket Boosters (SRB) that recommends Alodine 5700 for implementation as a pretreatment alternative.

Related Efforts

Table 34 is a list of efforts related to the research, development, testing, and evaluation of tri-chrome conversion coatings. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 34. TCP Related Efforts

Effort	Systems	Technology	Points of Contact
Non-Chromate Aluminum Pretreatments [26]	Solid rocket booster F-16 LCAC S-3 F-18 C-46 AAAV BFV MLRS Commercial aircraft	PreKote Alodine 5200/5700 AC-130/131 (Boegel) TCP (NAVAIR)	Craig Matzdorf NAVAIR Patuxent River Aircraft Division craig.matzdorf@navy.mil (301) 342-89372
Validation of Non-Chromate Aluminum Pretreatments	All aircraft All helicopters	PreKote Alodine 5200/5700 AC-130/131 (Boegel) Aklimate Chemidize 727ND Oxsilan AL-500 Sanchem 7000 Alodine 1200S TCP (NAVAIR)	Craig Matzdorf NAVAIR Patuxent River Aircraft Division craig.matzdorf@navy.mil (301) 342-9372

[26] www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA582070

Effort	Systems	Technology	Points of Contact
Evaluation of Modified Zirconium/Trivalent Chromium Conversion Coatings by Accelerated Corrosion and Electrochemical Techniques	All aircraft All helicopters	Conversion: Hexavalent Cr Conversion: TCP-license (Trivalent Chrome Pretreat) Conversion: Adhesion promoter TCP (NAVAIR)	Craig Matzdorf NAVAIR Patuxent River Aircraft Division craig.matzdorf@navy.mil (301) 342-9372
Qualification of Trivalent Chromate as a Hexavalent Chromate Alternative for Propellant and Cartridge Actuated Devices[27]	Propellant and Cartridge Actuated Devices	TCP (NAVAIR)	Harry L. Archer Naval Surface Warfare Center Indian Head, MD (301) 744-4284
Non-Chromate/No VOC Coating System for DoD Applications (ESTCP Project WP-1521)[28]	All	Alodine 5200/5700 Alodine 1200S TCP (NAVAIR)	John J. La Scala US Army Research Laboratory jlascala@arl.army.mil (410) 306-0687
NDCEE Demonstration Projects: Task No. 000-01 Subtask 4 - Nonchromated Conversion Coatings for Weapon Systems Rework and Repair	All aircraft All vehicles	Alodine 5200/5700 AC-130/131 (Boegel) Chemidize 727ND Oxsilan AL-500 TCP (NAVAIR)	US Army Research Laboratory Fred Lafferman Fred.lafferman.civ@mail.mil 410-306-1520
Data for Test 3.1 Neutral Salt Fog Exposure to Unpainted, Pretreated Coupons	Solid rocket booster F-16 LCAC S-3 F-18 C-46 AAAV	Alodine 5200/5700 Sanchem 7000 Alodine 1200S TCP (NAVAIR)	Brian Placzankis US Army Research Laboratory, Aberdeen Proving Ground, MD plaz@arl.army.mil (410) 306-0841
Nonchromate Aluminum Pretreatments Project Number: S-00-OC-016	Solid rocket booster F-16 LCAC S-3 F-18 C-46 AAAV C-130 H-46 Missiles	PreKote Alodine 5200/5700 AC-130/131 (Boegel) Aklimate Chemidize 727ND Oxsilan AL-500 Sanchem 7000 Alodine 1200S TCP (NAVAIR)	NAVAIR Patuxent River Aircraft Division 1-800-787-9804
TCP Application and Field Validation on AAAV P1	AAAV	TCP (NAVAIR)	Craig Matzdorf NAVAIR Patuxent River Aircraft Division craig.matzdorf@navy.mil (301) 342-9372

[27] www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA48640
[28] https://www.serdp-estcp.org/content/download/7542/95669/file/WP-1521-FR.pdf

noblis

Effort	Systems	Technology	Points of Contact
Hexavalent Chromium (Cr^{6+}) Reduction at U.S. Air Force Plant 44 in Tucson, Arizona		TCP (NAVAIR)	Paul Fecsik Raytheon Missile Systems (520) 794-3000
Accelerated Corrosion and Adhesion Assessments of CARC Prepared Aluminum Alloy 2139-T* Using Three Various Pretreatment Methods and Two Different Primer Coatings	M113 EFV	Alodine 5200/5700 TCP (NAVAIR) Metalast TCP-HF	Brian Placzankis Elizabeth A. Charleton Amy L. Fowler Army Research Lab Aberdeen Proving Ground plaz@arl.army.mil (410) 306-0841
Implementation Summary: Metalast TCP-HF, Red River Army Depot	BFV MLRS M800 M900 HEMTT HMMWV	Metalast TCP-HF	Mike Starks Red River Army Depot mike.starks@redriver-ex.army.mil (903) 334-3103
METALAST TCP-HF® - Hexavalent Free Trivalent Chromium Post-treatment Compositions and Processes	All aircraft All vehicles	Metalast TCP-HF	David Semas METALAST International Inc (775) 782-8324
Non-Chromated Post Treatments (trivalent Cr post treatment or TCP)		TCP (NAVAIR)	Ken Kaempffe NAVFAC EXWC, EV NESDI PM ken.kaempffe@navy.mil 805-982-4893
Scientific Understanding of Non-Chromated Corrosion Inhibitors Function (SERDP Project WP-1620)	All aircraft All helicopters All ships All vehicles	Conversion: Trivalent Cr - not TCP	Gerald Frankel Ohio State University frankel.10@osu.edu (614) 688-4128
Determination of Hexavalent Chromium in NAVAIR Trivalent Chromium Process (TCP) Coatings and Process Solutions	All aircraft All helicopters	Alodine T5900 Alodine 1200S Surtec 650 - ChromitAl TCP	Steven L. Suib University of Connecticut steven.suib@uconn.edu (860) 486-2797
Characterization of NAVAIR Trivalent Chromium Process (TCP) Coatings and Solutions	All aircraft All helicopters	Alodine T5900 Alodine 1200S Surtec 650 - ChromitAl TCP	Aparna Lyer University of Connecticut
Demonstration and Validation of Trivalent Aluminum Pretreatment on U.S. Navy S-3 Aircraft	S-3	TCP (NAVAIR)	Craig Matzdorf NAVAIR Patuxent River Aircraft Division craig.matzdorf@navy.mil (301) 342-9372

Effort	Systems	Technology	Points of Contact
Non-Chromate Aluminum Pretreatments – (ESTCP Project WP-200025)	All aircraft All helicopters All vehicles C-130 CH-46 CH-47 F-16 F-18 S-3 BFV EFV LCAC Solid rocket booster	PreKote Alodine 5200/5700 AC-130/131 (Boegel) Aklimate Chemidize 727ND Oxsilan AL-500 Sanchem 7000 Alodine 1200S	NAVAIR Patuxent River Aircraft Division 1-800-787-9804
ASTM B 117 Screening of Nonchromate Conversion Coatings on Aluminum Alloys 2024, 2219, 5083, and 7075 Using DOD Paint Systems	All aircraft All helicopters All ships All vehicles	PreKote Alodine 5200/5700 AC-130/131 (Boegel) Aklimate Chemidize 727ND Oxsilan AL-500 Sanchem 7000 Alodine 1200S	Brian Placzankis US Army Research Laboratory plaz@arl.army.mil (410) 306-0841
Enhanced trivalent Chromium Pretreatment for Improved Coloration and Corrosion Performance of Aluminum Substrates (NESDI Project 514)	All aircraft	Enhanced TCP	Ken Kaempffe NAVFAC EXWC, EV NESDI PM ken.kaempffe@navy.mil 805-982-4893

Applicability

Given the wide range of testing, evaluation, demonstration, and validation on an array of weapon systems, TCP should be applicable to FRCSE processes and systems. Some testing will remain on specific components and/or substrates, but most will have already been tested.

Barriers

Technical

Widespread use of trivalent chromium processes have been hampered due to insufficient color change following conversion coating with trivalent chromium. This visual change in color is preferred to ensure process quality control. An enhanced trivalent chromium process (eTCP) is being developed with the addition of a color additive to the approved TCP formulation.[29] In general, the non-chrome systems do not perform as well as the trichrome.

[29] "Enhanced trivalent Chromium Pretreatment for Improved Coloration and Corrosion Performance of Aluminum Substrates". NESDI Project 514.

Financial

Capital costs associated with alternative chromate conversion coatings should be minimal as most are implemented as drop-in replacements. There may be cost impacts based on chemical prices, but these should be offset by the decrease in medical monitoring, training, and protective equipment. Another major cost reduction is that most trivalent treatments are done at room temperature rather than high-temperature. A cost analysis will indicated that the cost of running a bath 24/7 at a high temperature is very expensive, and a room temperature bath far outweighs the additional cost of the trivalent chemicals. This was demonstrated for trivalent sealant for phosphate coatings in an ESTCP project.

Acceptance

TCP alternatives are primarily drop-in replacements for chromate conversion coatings. FRCSE (and NAVAIR) have not approved tri-chrome conversion coatings with non-chrome primers or total chrome-free systems. However, if the technologies prove to meet corrosion protection requirements, there should be little reluctance to accept the alternative and implement.

Logistics

Once a non-chromate conversion coating is qualified and accepted on weapon systems, the Technical Manuals and drawings may still need to be changed to reflect adoption of the new technology.

3.4.3 *Alternative:* Boegel/Sol-Gel

The adhesion promoters represent an entirely different way of protecting the surface of aluminum. The earlier formulations of sol-gels do not contain any inhibitors, but instead work by ensuring excellent adhesion between the surface and the overlying primer, preventing water from entering and disbonding the primer from the metal surface. Boeing developed the original silane-based sol-gel (Boegel), which is now sold by 3M under the trade name AC 131. This product was originally designed as a cure for “rivet rash” (Figure 6), which is a condition often seen on passenger aircraft where the paint comes off the rivets even though it adheres well to the aluminum skin (you will often see this as you board a plane if you look along the fuselage). It is used on all new Boeing commercial aircraft fuselages. There are various versions of these sol-gel coatings available in the market, and they are a good way to ensure paint adhesion over surfaces that contain different materials. A new sol-gel chemistry containing zirconium inhibitors is now available from Socomore in France, and has been approved by Airbus. Because most sol-gels do not contain corrosion inhibitors they are not usually permitted on unpainted surfaces.

Figure 6. Paint Loss from Rivet Head – "Rivet Rash" (Source: Boeing)[30].

Related Efforts

Table 35 is a list of efforts related to the research, development, testing, and evaluation of Beogel/ Sol-Gel type conversion coatings. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 35. Beogel/Sol-Gel Related Efforts

Effort	Systems	Technology	Points of Contact
Non-Chromate Aluminum Pretreatments	Solid rocket booster F-16 LCAC S-3 F-18 C-46 AAAV BFV MLRS Commercial aircraft	PreKote Alodine 5200/5700 AC-130/131 (Boegel) TCP (NAVAIR)	NAVAIR Patuxent River Aircraft Division 1-800-787-9804

30 http://www.asetsdefense.org/documents/Workshops/SustainableSurfaceEngineering2011/19-Osborne%20-%20LessonsLearned_ASETSDefense2011_v3_osborne.pdf

Effort	Systems	Technology	Points of Contact
Validation of Non-Chromate Aluminum Pretreatments	All aircraft All helicopters	PreKote Alodine 5200/5700 AC-130/131 (Boegel) Aklimate Chemidize 727ND Oxsilan AL-500 Sanchem 7000 Alodine 1200S TCP (NAVAIR)	Craig Matzdorf NAVAIR Patuxent River Aircraft Division craig.matzdorf@navy.mil (301) 342-9372
NDCEE Demonstration Projects: Task No. 000-01 Subtask 4 - Nonchromated Conversion Coatings for Weapon Systems Rework and Repair	All aircraft All vehicles	Alodine 5200/5700 AC-130/131 (Boegel) Chemidize 727ND Oxsilan AL-500 TCP (NAVAIR)	US Army Research Laboratory Fred Lafferman Fred.lafferman.civ@mail.mil 410-306-1520
Nonchromate Aluminum Pretreatments Project Number: S-00-OC-016	Solid rocket booster F-16 LCAC S-3 F-18 C-46 AAAV C-130 H-46 Missiles	PreKote Alodine 5200/5700 AC-130/131 (Boegel) Aklimate Chemidize 727ND Oxsilan AL-500 Sanchem 7000 Alodine 1200S TCP (NAVAIR)	NAVAIR Patuxent River Aircraft Division 1-800-787-9804
Non-Chromate Aluminum Pretreatments – (ESTCP Project WP-200025)	All aircraft All helicopters All vehicles C-130 CH-46 CH-47 F-16 F-18 S-3 BFV EFV LCAC Solid rocket booster	PreKote Alodine 5200/5700 AC-130/131 (Boegel) Aklimate Chemidize 727ND Oxsilan AL-500 Sanchem 7000 Alodine 1200S	NAVAIR Patuxent River Aircraft Division 1-800-787-9804
ASTM B 117 Screening of Nonchromate Conversion Coatings on Aluminum Alloys 2024, 2219, 5083, and 7075 Using DOD Paint Systems	All aircraft All helicopters All ships All vehicles	PreKote Alodine 5200/5700 AC-130/131 (Boegel) Aklimate Chemidize 727ND Oxsilan AL-500 Sanchem 7000 Alodine 1200S	Brian Placzankis US Army Research Laboratory plaz@arl.army.mil (410) 306-0841

Effort	Systems	Technology	Points of Contact
Commercial Aircraft non-Cr Finish	Boeing 737 Boeing 747 Boeing 767 Boeing 777	AC-130/131 (Boegel)	Joe Osborne Boeing Commercial Aircraft joseph.h.osborne@boeing.com (206) 544-4651
Non-Chromated Coating Systems for Corrosion Protection of Aircraft Aluminum Alloys	All aircraft All helicopters	AC-130/131 (Boegel)	N. Voevodin University of Dayton Research Institute 937-229-2113
Surface Treatment Implementation	Commercial Aircraft F-22 B-2 AH-66 C-46 CH-47 F-18 Delta-IV Rocket B-1 CH-64 CH-47 C-5 V-22 F-16 C-130	AC-130/131 (Boegel)	Joe Osborne The Boeing Company Joseph.h.osbourne@boeing.com 562-797-2020
Dissimilar Metals Corrosion Testing of Non-Chrome Coating Systems	All aircraft	PreKote Alodine 5200/5700 AC-130/131 (Boegel) XP417	John D. Patterson The Boeing Company 562-797-2020

Applicability

Given the wide range of testing, evaluation, demonstration, and validation on an array of weapon systems, Boegel/Sol-Gel/3M AC 131 alternatives should be applicable to FRCSE processes and systems. Some testing will remain on specific components and/or substrates, but most will have already been tested.

Barriers

Technical

Technical challenges still remain with the Boegel/Sol-Gel alternatives. They are primarily adhesion promoters and, therefore, do not offer the same level of corrosion protection as hexavalent chromium conversion coatings or even trichrome conversion coatings. They are not applicable to non-painted surfaces. However, on painted surfaces, the adhesion promoters help ensure a bond with the total system to inhibit corrosion. Significant testing remains to determine how effective Boegel/Sol-Gel alternatives are on FRCSE applications.

Financial

Capital costs associated with alternative chromate conversion coatings should be minimal as most are implemented as drop-in replacements. There may be cost impacts based on chemical prices, but these should be offset by the decrease in medical monitoring, training, and protective equipment.

Acceptance

Boegel/Sol-Gel alternatives are primarily drop-in replacements for spray-on chromate conversion coating applications. FRCSE (and NAVAIR) have not approved non-chrome conversion coatings with non-chrome primers or total chrome-free systems. However, if the technologies prove to meet corrosion protection requirements, there should be little reluctance to accept the alternative and implement.

Logistics

Once a non-chrome conversion coating is qualified and accepted on weapon systems, the Technical Manuals and drawings may still need to be changed to reflect adoption of the new technology.

3.5 Stainless Steel Passivation – Process Improvements and Alternatives

3.5.1 *Alternative:* Citric Acid Passivation

Citric acid passivation is the only identified alternative to the passivation of stainless steels with chromic acid. Starting in 2000, Boeing conducted a series of tests to develop a citric acid passivation process that could replace nitric acid and nitric acid - dichromate passivation processes. Boeing was successful in this endeavor, and in 2005 issued Boeing specifications PS 13001 and BAC 5625 that allowed citric acid as an alternative passivation process. At the same time, based partially on work done by Boeing, AMS-QQ-P-35 was cancelled and replaced with AMS 2700, which also allowed citric acid as an alternative passivation process.

Boeing performed passivation testing on citric acid using several wrought stainless steel alloys. The optimized citric acid solution was compared with Boeing BAC 5625 – Solution 14C (22% nitric acid at 130oF for 30 minutes), QQ-P-35 Ty II (nitric acid + sodium dichromate), a proprietary citric acid solution, and a DoE optimized nitric acid solution (20% nitric acid, room temperature, 30 minutes). Tests showed that all of the passivation solutions performed very well except for the QQ-P-35, Type II solution. The QQ-P-35 nitric-dichromate passivation solution was not capable of passivating the heavily contaminated stainless steel test panels. It appeared the testing revealed that the dichromate not only inhibits attack of the stainless steel in nitric acid but also removal of the steel particles embedded on the stainless steel.

The testing conducted by Boeing showed that citric acid was capable of passivating a wide range of stainless steel alloys that were heavily contaminated with steel particles. Citric acid did not cause IGA and pitting attack and had no measurable etch rate on the stainless steel alloys tested, including 303 stainless steel.

Aviation and Missile Command (AMCOM) and Corpus Christi Army Depot (CCAD) is currently considering a project to test, demonstrate, and implement citric acid passivation for stainless steel components.

Applicability

Citric acid passivation of stainless or corrosion resistant steels has been thoroughly tested on a number of substrates, including those in use at FRCSE. Testing has shown that citric acid passivation works at least as well as nitric acid or nitric acid/dichromate passivation on all of the stainless steels tested. Based on Boeing's results, the technology should be applicable to FRCSE applications.

Barriers

Technical

Citric acid passivation has been shown to work well on austenitic (e.g. 300 series stainless steels) and precipitation hardening (e.g., A-286, 17-4PH) stainless steels. It does not passivate martensitic (e.g. 400 series) stainless steels as well, however, it does perform better then nitric acid or nitric acid/dichromate on the martensitic steels. Some technical challenges will have to be overcome in passivating 400-series steels as well as optimization of the bath properties and dwell times.

Financial

The COTS citric acid solutions are only slightly more expensive than nitric acid or nitric acid/ dichromate solutions, but this should be offset by lower overall lifecycle costs.

Acceptance

Citric acid passivation is a drop-in alternative with a very similar process to nitric acid or nitric acid/dichromate passivation. Acceptance should not be an issue.

Logistics

The citric acid passivation can use the same tankage as the existing passivation process. Planning will have to be done to ensure that the passivation process is not unavailable and that production is not impacted. Once the COTS citric acid passivation is qualified and accepted on weapon systems, the Technical Manuals and drawings must still be changed to reflect adoption of the new technology.

3.6 Adhesives and Sealants – Process Improvements and Alternatives

Much of the work performed in identifying alternatives to polymeric adhesives and sealants has been for the purpose of reducing or eliminating HAPs and VOCs. However, there has been some work focused on reformulating adhesive and sealant products to reduce or eliminate hexavalent chromium. Other work in the area has focused on the bonding primer, using alternative chemistries to strengthen the bond between the substrate and adhesive/sealant to reduce the potential for corrosion. The efforts identified below focus on the understanding of non-hexavalent chromium corrosion inhibiters and on alternative adhesive and sealant chemistries. However, given the broad range of adhesive and sealant products in use at FRCSE and their differing applications, there are no true drop-in replacements currently identified. Each product/application combination will have to be addressed separately.

3.6.1 *Alternatives:* No Single Drop In Replacement Identified at this time

Related Efforts

The following is a list of efforts related to the research, development, testing, and evaluation of non-chromated adhesive and sealant chemistries. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 36. Adhesives/Sealants Related Efforts

Morphology and Mechanism of Benign Inhibitors (WP-1619)	All aircraft All helicopters All ships All vehicles	Technology	Dale Schaefer University of Cincinnati dale.schaefer@uc.edu (513) 556-5431
Scientific Understanding of Non-Chromated Corrosion Inhibitors Function (WP-1620)[31]	All aircraft All helicopters All ships All vehicles		Gerald Frankel Ohio State University frankel.10@osu.edu (614) 688-4128
Scientific Understanding of the Mechanisms of Non-Chromate Corrosion Inhibitors (WP-1621)[32]	All aircraft All helicopters All ships All vehicles		Marta Jakab Southwest Research Institute marta.jakab@swri.org (210) 522-5240
Chrome sealer/bond primer alternative - ACFJ08PV10	F-16 F-22 Raptor F-35 JSF	Sealant - non-chrome	Gene McKinley Wright Patterson AFB gene.mckinley@wpafb.af.mil (937) 255-3596
Structural Technology and Analysis Program (STAP) Delivery Order 0010: Sol-Gel Technology for Surface Preparation of Metal Alloys for Adhesive Bonding and Sealing Operations. SERDP WP-1113, Task 2[33]	All aircraft All helicopters	AC-130/131 (Boegel) Sealant - non-chrome	Kay Blohowiak The Boeing Company (Phantom Works) kay.y.blohowiak@boeing.com (562) 797-2020

Boeing was able to eliminate almost all of their chromated sealants for OMLs, faying surfaces, butt joints, etc., because they performed testing that showed that the only mechanism for the chromate in the sealant to exhibit corrosion inhibiting characteristics was if the sealant did not seal. If there was a good quality sealant then water did not penetrate the sealant itself and the chromate was not used. After that testing, Boeing abandoned the chromates on the grounds that they were completely irrelevant.[34]

31 https://www.serdp-estcp.org/content/download/17737/196952/file/WP-1620-FR.pdf
32 https://www.serdp-estcp.org/content/download/24985/256876/file/WP-1621-FR.pdf
33 https://www.serdp-estcp.org/Program-Areas/.../WP-1113/WP-1113
34 Personal communications with Keith Legg 15 November 2015

Applicability

While all of the work that has been performed to date is applicable to OC-ALC requirements, there are no commercial off-the-shelf (COTS) alternatives identified for drop-in replacement. Each of the FRCSE applications will need to be addressed separately and adhesive or sealant alternatives identified for testing, demonstration, and eventual implementation.

Barriers

Technical

There are significant technical barriers to overcome before alternative non-chrome adhesives and sealants can be implemented. There are a number of adhesives and sealants used at FRCSE, many with very different formulations and in very different applications. Each of these applications have requirements associated with them. Alternatives to non-chrome adhesives and sealants will have to be identified, tested, demonstrated, and implemented for each application and, sometimes, for each individual product. The overall usage of Cr^{6+} will have to be attacked in small increments.

Financial

Capital costs associated with alternative, non-chrome adhesives and sealants should be minimal as most would be implemented as drop-in replacements. There may be cost impacts based on chemical or product prices, but these should be offset by the decrease in medical monitoring, training, and protective equipment.

Acceptance

Alternative non-chrome adhesives and sealants should be drop-in replacements for existing products and should face no resistance assuming they meet all necessary materials requirements.

Logistics

Once a non-chrome adhesive or sealant is qualified and accepted on weapon systems, the Technical Manuals and drawings may still need to be changed to reflect adoption of the new technology.

3.7 Cadmium Brush Plating – Process Improvements and Alternatives

Zinc-nickel brush plating is the alternative to cadmium brush plating and there are COTs products available. Two products include one developed by Dalistick® and one by SIFCO. Both of these are known as no-bake ZnNi applications. Both products including solutions and plating equipment do work; reportedly the advantage of the Dalistick is better process control and recirculated electrolyte to prevent dripping and contamination of adjacent areas.

In the following paragraphs, the technology is described in greater detail, the applicability to OC-ALC weapon systems is addressed, and known barriers to implementation are documented.

3.7.1 Process Improvements

Brush plating specifications typically limit the total surface area and/or amp-hrs plated per liter of solution. Cadmium waste can be minimized by monitoring amp-hrs and fully utilizing brush plating solution within the specification. This requires segregation of solution collection and rinsing to avoid dilution and premature disposal of unspent cadmium plating solution.

3.7.2 *Alternative:* Zn-Ni Brush Plating

Ongoing Zn-Ni efforts focus on elimination of Cd for brush plating repair operations, and reduction of solid waste associated with adsorbents used to contain solution leakage attributed with traditional brush plating repair processes. The technical objectives are to:

1. Demonstrate the commercial off-the-shelf (COTS) brush plating tool Dalistick® Station for selective plating, ensuring its safety and cost effectiveness for Department of Defense (DoD) maintenance, repair, and overhaul operations.
2. Test and evaluate the COTS Zinidal Aero (code 11040) zinc-nickel (Zn-Ni) brush plated coating as a Cd replacement on high strength steels (HSS) for repair applications on weapon systems parts and components (landing gear, terminal assemblies, landing gear doors, bushings, etc.

These efforts evaluate the ability of a novel brush plating tool Dalistick® Station to plate the COTS product Zinidal Zn-Ni coating on HSS. The Dalistick® Station is a mobile electroplating system that enables selective electrochemical treatments without generating any leakage of electrolyte during the plating process. The Dalistick® Station recovers residual brush plating solution and recycles it for reuse in a closed-loop process at the point of contact with the part. It is designed to perform plating and surface finishing operations on steels or light alloys on site, at depots, or in the field. It performs these treatments on curved, horizontal, and/or vertical surfaces and edges without any leakage of electrolyte and minimal generation of waste (spent solution and pads). The Zinidal coating is a promising candidate to replace Cd plating. The Zinidal Aero Zn-Ni solution deposits a coating with 10-16 weight% Ni and 84-90 weight% Zn at varying thicknesses. The coating provides sacrificial corrosion protection to steels, and the process does not require the hydrogen embrittlement relief baking when plated on HSS.

Related Efforts

Table 37 is a list of efforts related to the research, development, testing, and evaluation of Dalistick® and Zinidal Zn-Ni as alternatives to Cd brush plating. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 37. Zn-Ni Related Efforts

Effort	Systems	Technology	Points of Contact
Cadmium-Free Alternatives for Brush Plating Repair Operations (ESTCP WP201412)	High strength steel applications	Zinidal Zn-Ni using the Dalistick	Mr. Richard Slife Air Force Materiel Command Phone: 478-926-0209 Richard.slife@robins.af.mil
Cadmium Brush Plating Alternative on the Minuteman	Low strength steel applications on the Minuteman	Zinidal Zn-Ni using the Dalistick	Dr. Elizabeth Berman Air Force Research Laboratory elizabeth.berman@wpafb.af.mil (937) 656-5700

Applicability

Based on observation of the process and knowledge of the substrates, the Zinidal Zn-Ni solution applied with the Dalistick is an applicable technology that will not cause embrittlement in high strength steels.

Based on observation of the process and knowledge of the substrates, the Zinidal Zn-Ni solution applied with the Dalistick is an applicable technology that will not cause embrittlement in high strength steels.

Barriers

Technical

Brush plating with substituted alloys for cadmium is basically the same; however, attention must be paid to proper surface cleaning and activation. It is more critical to control this process to maintain proper performance of the brush plated alloys. Substrates will have to investigated, but should not pose any issues. Corrosion requirements and criticality of the components are not beyond what has already been tested, so the Zn-Ni solution should have no problem passing additional USAF testing.

Financial

Initial capital costs associated with the Dalistick station are approximately $160,000 not including spares, parts, or solutions so the equipment will require programming and planning in the budgeting process. Solution costs are decreasing and there is a drastic reduction in solid waste associated with the Dalistick station, so operating costs should not be a barrier. Reliability costs to determine maintenance costs are not yet available for use in DoD production environment.

Acceptance

Brush ZnNi using SIFCO solutions is a Boeing-qualified process under BAC5664. Zinidal and the Dalistick station are currently being tested on several systems and have been evaluated against common substrates in use at FRCSE. Significant testing will still have to take place to qualify the technology on FRCSE-maintained weapon systems.

Logistics

Once Zinidal Zn-Ni and the Dalistick station are qualified and accepted on weapon systems, the Technical Manuals and drawings must still be changed to reflect adoption of the new technology.

3.8 Chromate Sealers – Process Improvements and Alternatives

Some of the same technologies identified as alternatives to chromate conversion coatings are applicable for use as non-chromate sealers for anodized components. This primarily pertains to the trivalent chromium technologies and some permanganate alternatives. The following paragraphs discuss ongoing research and related efforts, the applicability to FRCSE processes, and the barriers to be overcome to implementation..

3.8.1 Process Improvements

Seal solutions are typically batch dumped on an arbitrary calendar schedule resulting in unsteady state process control and excessive waste generation. Seal solution waste streams can be reduced, and process control improved by controlling solution bleeds and feeds with automated conductivity and pH control of the solutions. Chemical feeds can be controlled by monitoring solution pH and bleeds controlled by monitoring solution conductivity.

Drag out is a natural bleed and the bleed rate is inherently a function of workload. Effective solution control and waste reduction can be optimized by calibrating drag out reduction and recovery to maintain solution contaminants within a specified range.

3.8.2 *Alternative:* TCP Anodize Sealers

The U.S. Navy has found their hydrofluorozirconate-inhibited trivalent passivate (TCP) process capable of sealing sulfuric acid anodizing layers. However the method has not yet been qualified for this application although it is moving that direction.

Related Efforts

Table 38 is a list of efforts related to the research, development, testing, and evaluation of TCP as an alternative to chromated sealers on anodizing or phosphate processes. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 38. TCP Anodize Sealers Related Efforts

Effort	Systems	Technology	Points of Contact
Non-chromate Sealers for Zinc Phosphate ESTCP Project WP-200906 [35]	Army and Navy Aircraft and Ground Vehicles:	Surtec 580 and Chemseal 100	Jack Kelley US Army Research Laboratory jkelley@arl.army.mil (410)306-0837
Chromate Alternatives for Metal Treatment and Sealing	All	PreKote TCP (NAVAIR) Tagnite-8200 Iridite NCP	Keith Legg Rowan Technology Group klegg@rowantechnology.com (847) 680-9420
Trivalent Chromium Process (TCP) as a Sealer for MIL- -A-8625F Type II, IIB, And IC Anodic Coatings	All aircraft	TCP (NAVAIR) Metalast TCP-HF	Craig Matzdorf NAVAIR Patuxent River Aircraft Division craig.matzdorf@navy.mil (301) 342-9372

Applicability

Testing to date on TCP as a non-chromated sealer has been conducted on anodized components with favorable results. However, additional testing would be required to qualify the technology, it is applicable to the processes at FRCSE.

Barriers

Technical

Further testing and evaluation would be necessary to determine if the technology can be used with these components and if it meets the corrosion, adhesion, and durability standards.

Financial

The TCP process is a drop-in replacement and would have little capital costs associated with its implementation. There are some differences in chemical costs, but these should be offset with

[35] https://serdp-estcp.org/content/download/35499/340712/file/WP-200906-FR%20Non-Chromate %20Sealers.pdf

reductions in medical monitoring and regulatory costs. There is some evidence that it will be significantly cheaper because it operates at room temperature.[36]

Acceptance

TCP has not been tested as a sealer for anodized components on any of the weapon systems at FRCSE. However, as a drop-in replacement, the technology should gain easy acceptance assuming it meets all of the corrosion, adhesion, and durability requirements.

Logistics

Once TCP is qualified and accepted on weapon systems, the Technical Manuals and drawings must still be changed to reflect adoption of the new technology.

3.8.3 *Alternative:* Sol-Gel Sealers

Some European organizations are reformulating the sol-gels used for aluminum passivation as anodize sealers, but have also not yet been fully tested.

Related Efforts

Table 39 is a list of efforts related to the research, development, testing, and evaluation of TCP as an alternative to chromated sealers on anodizing processes. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 39. Sol-Gel Sealers Related Efforts

Effort	Systems	Technology	Points of Contact
Chromate Alternatives for Metal Treatment and Sealing[37]	All	PreKote TCP (NAVAIR) Tagnite-8200 Iridite NCP	Keith Legg Rowan Technology Group klegg@rowantechnology.com (847) 680-9420
Structural Technology and Analysis Program (STAP) Delivery Order 0010: Sol-Gel Technology for Surface Preparation of Metal Alloys for Adhesive Bonding and Sealing Operations (SERDP Project WP-1113, Task 2)	All aircraft All helicopters	AC-130/131 (Boegel)	Kay Blohowiak The Boeing Company (Phantom Works) kay.y.blohowiak@boeing.com (562) 797-2020

Applicability

Testing to date on Boegel/Sol-gel as a non-chromated sealer has been conducted on anodized components with favorable results. However, additional testing would be required to qualify the technology, it is applicable to the processes at FRCSE.

36 https://serdp-estcp.org/content/download/32459/317176/file/WP-200906-CP.pdf
37 http://www.asetsdefense.org/docs/workshop%20report%20final-released.pdf

Barriers

Technical

To date, Boegel/Sol-Gel has not been tested or evaluated as an alternative sealer for anodized components at FRCSE. Testing and evaluation would be necessary to determine if the technology can be used with these components and if it meets the corrosion, adhesion, and durability standards.

Financial

Boegel/Sol-Gel is a drop-in replacement and would have little capital costs associated with its implementation. There are some differences in chemical costs, but these should be offset with reductions in medical monitoring, PPE, and regulatory costs.

Acceptance

Boegel/Sol-Gel has not been tested as a sealer for anodized components on any of the weapon systems at FRCSE. However, as a drop-in replacement, the technology should gain easy acceptance assuming it meets all of the corrosion, adhesion, and durability requirements.

Logistics

Once Boegel/Sol-Gel is qualified and accepted on weapon systems, the Technical Manuals and drawings must still be changed to reflect adoption of the new technology.

3.8.4 *Alternative: Other*

Testing and evaluation at Ogden Air Logistics Complex (OO-ALC) identified and validated a COTS permanganate seal as an alternative to dichromate sealers on anodized landing gear components. Additional studies have been undertaken by the Defense Logistics Agency (DLA) and Oklahoma City Air Logistics Complex (OC-ALC) on anodized components. Performance on anodized surfaces have been exceptional.

Related Efforts

Table 40 is a list of efforts related to the research, development, testing, and evaluation of permanganate sealers to chromated sealers on anodizing processes. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 40. Other Related Efforts

Effort	Systems	Technology	Points of Contact
AFRL/OC-ALC	All aircraft	Permanganate	Elizabeth S. Berman, Ph.D. USAF AFMC AFRL/RXSC Pollution Prevention Group Materials & Manufacturing Directorate Air Force Research Laboratory (937) 656-5700 Elizabeth.Berman@wpafb.af.mil

Effort	Systems	Technology	Points of Contact
OC-ALC/DLA project	All aircraft	Permanganate	Van Nguyen Air Force Sustainment Center (AFSC)/ENSP Thanhvan.nguyen.1@us.af.mil 405-739-9533

Applicability

Testing to date on permanganate sealers as a non-chromated sealer has been conducted on anodized components at OO-ALC and OC-ALC. However, it has not been tested on FRCSE anodized components. If the technology meets technical requirements, applicability should not be an issue.

Barriers

Technical

Testing on OC-ALC anodized components continues, but initial results have been promising. Final qualification remains, but most of the technical challenges have been met. Based on this, there has been testing on shared substrates, but not on any FRCSE anodized components. Testing in FRCSE specific applications would be necessary to technically qualify the technology.

Financial

The COTS permanganate sealer is a drop-in replacement and would have little capital costs associated with its implementation. There are some differences in chemical costs, but these should be offset with reductions in medical monitoring, PPE, and regulatory costs.

Acceptance

The permanganate sealer is a drop-in replacement, so the technology should gain easy acceptance assuming it meets all of the corrosion, adhesion, and durability requirements.

Logistics

Once the COTS permanganate sealer is qualified and accepted on weapon systems, the Technical Manuals and drawings must still be changed to reflect adoption of the new technology.

3.9 Topcoats and Specialty Coatings – Process Improvements and Alternatives

As identified in Section 2.9, two specialty coating processes have been identified as the major drivers for Cr^{6+} usage in this process category: Sermetel and Sanodal Deep Black MLW Dye.

3.9.1 *Sermetel Alternative:* Ceral 34

Ceral 34 is an inorganic ceramic aluminum coating consisting of very fine aluminum powder suspended in a chromate/phosphate binder (MIL-C-81751). It is used primarily as a corrosion and erosion-resistant coating on Ni-based alloys (e.g., turbine blades), and steel parts operating in environments up to 1100°F. Ceral 34 is a low-chrome coating that replaced the high-chrome coatings previously used on engines at OC-ALC (Sermetel). It is a low-chrome formulation, not non-chrome. It is normally applied by conventional spray techniques, although brushing and dipping are also possible. Coating components are dried and furnace-cured in order to fuse the binder and form a homogeneous coating. The coating provides a barrier between the substrate and the environment, and can be made conductive (usually by glass bead blasting) to provide galvanic and sacrificial protection. It is an overlay coating relying on physical and chemical bonding for adhesion. There is no metallurgical bond, allowing the coating to be easily stripped without degradation of the substrate. It is resistant to hydraulic fluids, fuel and hot water, and is highly resistant to thermal shock and impact damage. It is usually used in combination with a topcoat (Ceral 50); hence the coating is usually called out as Ceral 34. The topcoat provides additional protection as well as smoothing

Applicability

Ceral 34 is currently in use at OC-ALC and has replaced Sermetel in engine applications. The workload and substrates at FRCSE are very similar to those at OC-ALC. Based on past testing and implementation at another DoD depot, Ceral 34 should be applicable to FRCSE processes.

Barriers

Technical

Though Ceral 34 meets Air Force and OC-ALC requirements, it has not been tested on FRCSE components or weapon systems. Some NAVAIR corrosion requirements are more stringent, so additional testing on Navy engines would be required.

Financial

There are no capital costs associated with Ceral 34 and chemical costs of are comparable to Sermetel, so there are no financial barriers to implementation.

Acceptance

Ceral 34 is a drop-in replacement for Sermetel that can be applied using the same processes not in place at FRCSE. Once Ceral 34 meets performance requirements, there should be no issue with acceptance of the new process.

Logistics

Once the Ceral 34 is qualified and accepted on weapon systems, the Technical Manuals and drawings must still be changed to reflect adoption of the new technology.

3.9.2 *Sanodal Deep Black MLW Alternative:* Non-Chrome Anodize Dyes

Some non-chrome anodize dyes are commercially available, but none have been tested to FRCSE weapon system requirements to date.

Applicability

COTS non-chrome anodize dyes are on the market, but none have been tested against nor met FRCSE performance requirements. However, following the appropriate testing, non-chrome dyes should be applicable to FRCSE operations.

Barriers

Technical

Testing of COTS non-chrome anodize dyes on FRCSE weapon systems and components is necessary to validate any alternative. Testing would have to be performed to ensure the COTS alternatives provided acceptable color, did not damage the substrate, and provided comparable surface properties as the chromic acid dyes.

Financial

COTS non-chrome dyes are drop-in replacements with similar costs to chromated anodize dyes. There are no financial barriers to implementation.

Acceptance

COTS non-chrome dyes are drop-in replacements to chromated anodize dyes. Once the FRCSE performance specification are met, there should be no remaining barriers to acceptance.

Logistics

Once a COTS non-chrome anodize dye is qualified and accepted on weapon systems, the Technical Manuals and drawings must still be changed to reflect adoption of the new technology.

3.10 Coatings Removal – Process Improvements and Alternatives

Several alternatives have been identified with the potential to reduce the Cr^{6+} use and waste streams associated with chemical and physical coatings removal processes. These include laser coatings removal, Flashjet® coatings removal, and atmospheric plasma coatings removal. In the paragraphs that follow, there is a description of each alternative, the applicability of the technology to FRCSE, and known barriers to implementation.

3.10.1 *Process Improvement:* Blast Booth Segregation for Physical Removal

Blast booth segregation is applicable only to physical coatings removal using abrasive blast media. It involves the re-engineering of the blast booths and spent media collection systems to segregate parts and components that contain Cd or Cr^{6+} to only specific booths. By doing this, only media from the segregated booths is treated as hazardous waste. Waste media from non-Cd and Cr^{6+} booths can be disposed of as non-hazardous waste. This typically has the effect of dramatically reducing Cd and Cr^{6+} waste streams and reducing disposal costs.

Related Efforts

None identified.

Applicability

To determine the applicability of this methodology at FRCSE, a comprehensive study of their abrasive blasting operations needs to be initiated and completed. This study will reveal which components can be segregated into which blast booths and how the spent media collection systems can be modified. The study should also identify potential waste reductions and potential cost saving associated with implementation.

Barriers

Technical

There are no significant technical challenges associated with this approach.

Financial

If the study of the abrasive blasting systems suggests that implementation will result in a positive impact, significant financial investments may be required to modify the spent abrasive blast media associated with the segregated booths.

Acceptance

The challenge associated with blast booth segregation is making sure that components are processed in the appropriate booths and that components containing Cd and Cr^{6+} are not processed in non-hazardous booths. Acceptance of the methodology and training is critical to ensure success of the implementation.

Logistics

No new technology will have been introduced, so there should be no necessary changes to technical documentation. However, shop practices will have to be documented, workers trained, and processes monitored to ensure segregation of blast booths is being practiced. This could include changing the flow of components through the repair shops and possibly a system for marking components known to have Cd or Cr^{6+} containing coatings on them.

3.10.2 *Alternative:* Laser Coatings Removal

Laser Coating Removal Systems (LCRS), both robotic and operator controlled, (WP0526) and Portable hand held Nd:YAG laser systems (PLCRS) (WP0027) have been identified as a technology with the potential to supplement or replace existing coating removal operations. Laser coatings removal has shown to be non-intrusive, non-kinetic energy process that can be applied to multiple substrates, including composites, glass, metal, and plastic. Coating materials absorb high-level energy at the surface resulting in the decomposition and removal of the coating. Incorporated waste extraction systems further enhance the practicality of laser coating removal.

Related Efforts

Table 41 is a list of efforts related to the research, development, testing, and evaluation of laser coating removal technologies. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 41. Laser Coating Removal Technology Related Efforts

Effort	Systems	Technology	Points of Contact
Robotic Paint Stripping Cell (RPSC) at Hill AFB	F16	Laser	Debbie Naguy, AFLCMC/EZP Wright Patterson AFB, Dayton, OH debora.naguy@us.af.mil (937) 257-7505
Robotic Laser Coating Removal	KC-135	Lasers	Randel Bowman OC-ALC Oklahoma City randel.bowman@tinker.af.mil (405) 736-2736

Effort	Systems	Technology	Points of Contact
System (ESTCP Project WP-0526)[38]			
Laser Coating Removal from Helicopter Blades, Phase II[39]	All helicopters	Lasers	Lee Patch National Center for Manufacturing Sciences leep@ncms.org (734) 995-4930
NASA Portable Laser Coating Removal Systems Field Demonstrations and Testing[40]	M1A1 Abrams Ground support equipment Facilities, buildings	Lasers	Matthew J. Rothgeb NASA TEERM Principal Center Matthew.J.Rothgeb@nasa.gov (321) 867-8476
Naval Application of Laser Ablation Paint Removal Technology [41]	All ships	Lasers	Concurrent Technologies Corporation (CTC) (814) 269-2610
Integration of Laser Coating Removal For Helicopter Blade Refurbishment Phase I	All helicopters H-60 Blackhawk	Lasers	Edward Reutzel Applied Research Laboratory Penn State (814) 863-9891
Sealant Removal from an A-10 Thunderbolt Center Wing Fuel Tank Using a Portable Hand-Held Nd:YAG Laser System[42]	All aircraft A-10	Lasers	Norman J. Olson Pacific Northwest National Laboratory Richland, Washington 99352 Mitchell Wool General Lasertronics Corporation San Jose, California 95112
Portable Laser Coating Removal System (PLCRS) (ESTCP Project WP-200027)[43]	All aircraft	Lasers	Mr. Gerard Mongelli HQ AFMC/LGPE (CTC) Phone: 937-306-3310 Fax: 937-306-3305 mongellg@ctc.com

Applicability

To determine the applicability any coatings removal technologies at FRCSE, a comprehensive study of their abrasive blasting, hand sanding, and chemical stripping operations needs to be

38 www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA608206

39 http://db.materialoptions.com/ASETSDefense/SEDB/Related/Qual_Eng_Data/Laser%20stripping% 20Helicopter%20blades%20ARBSS%20report.pdf

40 http://hdl.handle.net/2060/20090005857

41 http://db.materialoptions.com/ASETSDefense/SEDB/Related/Qual_Eng_Data/CTC-%20Naval%20Application%20of%20Laser%20Ablation%20Paint%20Removal%20Technology%20-%20Final%20Project%20Report_Final.pdf

42 http://www.lasertronics.com/wp/wp-content/uploads/2011/11/A-10-PNNL-Study.pdf

43 https://www.serdp-estcp.org/content/download/8645/105479/file/WP%200027%20FR_Final_Complete%20-%20For%20Posting.pdf

initiated and completed. This study will reveal which components and/or systems can be stripped with alternative technologies and which are most applicable.

Barriers

Technical

The most significant technical challenge associated with coatings removal at FRCSE is ensuring that you don't get substrate damage and meeting current stripping rates. Laser coating removal systems have been proven to remove the coating systems in use at FRCSE, but questions remain regarding substrate damage and coating removal rates compared to abrasive blasting and chemical stripping.

Financial

Large scale, robotic, laser coating removal systems are expensive, costing in the millions of dollars. However, large scale PMB facilities are also expensive and the costs differential between robotic laser and PMB are not well documented at this time. Regardless of the cost differential, a significant investment will be necessary if FRCSE decided to implement. Hand-held systems are more affordable and may compare favorably with a reduction in chromated dust created by hand-sanding.

Acceptance

Laser coatings removal is a very different technology from anything currently in place at FRCSE, therefore, it will take significant training to fully implement. Robotic systems require much less labor and acceptance issues could arise from that fact.

Logistics

The biggest logistical challenge to implementation is the level of training necessary to operate the laser systems. Even the hand-held systems require a significant level of training to use appropriately and safely. Once laser coatings removal is qualified and accepted on weapon systems, the Technical Manuals and drawings may still need to be changed to reflect adoption of the new technology.

3.10.3 *Alternative:* Other

A number of coatings removal technologies have been investigated in the past years. One of the promising, albeit early in the R&D process, is atmospheric plasma. Atmospheric plasmas system uses a low pressure compressed air source and electricity to produce a special form of atmospheric pressure, air plasma, which is highly chemically activated and oxidizes the organic components of paints and other coatings. The system has been used to remove two major coating systems commonly found on Navy ships: (1) freeboard paint typically used above the waterline, and (2) antifouling paint typically used below the waterline. Initial results of this research project are promising, but significant scale-up is required before this technology is ready to use commercially.

Related Efforts

Table 42 is a list of efforts related to the research, development, testing, and evaluation of atmospheric plasma depainting technologies. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 42. Other Depainting Technology Related Efforts

Effort	Systems	Technology	Points of Contact
Atmospheric Plasma Depainting (SERDP Project WP-1762)[44]	All aircraft	Atmospheric Plasma	Jerome Cuomo North Carolina State University (919) 515-2011

Applicability

To determine the applicability any coatings removal technologies at FRCSE, a comprehensive study of their abrasive blasting, hand sanding, and chemical stripping operations needs to be initiated and completed. This study will reveal which components and/or systems can be stripped with alternative technologies and which are most applicable.

Barriers

Technical

Implementation of atmospheric plasma technology at FRCSE has several technical challenges. The technology, to date, has only been tested on two Navy coatings and has not been tested on the topcoat systems or any other paints used at FRCSE. It would have to first be demonstrated that the technology is capable of removing the coatings. In addition, the testing was done at the laboratory scale and significant scale-up would have to be accomplished to achieve commercially-acceptable stripping rates.

Financial

As the technology has not been scaled-up to commercial applications, cost data is not currently available.

Acceptance

Atmospheric plasma coatings removal is a very different technology from anything currently in place at FRCSE, therefore, it will take significant training to fully implement. Robotic systems require much less labor and acceptance issues could arise from that fact.

Logistics

The biggest logistical challenge to implementation is the level of training necessary to appropriate operate the atmospheric plasma systems. All of the systems require a significant level of training to use appropriately and safely. Once atmospheric plasma coatings removal is

[44] https://www.serdp-estcp.org/content/download/33697/327342/file/WP-1762-FR.pdf

qualified and accepted on weapon systems, the Technical Orders and drawings must still be changed to reflect adoption of the new technology.

3.11 Stainless Steel Welding – Process Improvements and Alternatives

Various approaches have been developed to reduce generation of or exposure to toxic fume from stainless steel welding. These include engineering controls such as changes in the welding parameters or shielding gas to limit the oxidation of metals, and compositional modification of the welding flux or electrode. For stainless steel welding, the most promising developments have been a new type of Cr-free consumable and the innovative use of silica precursor technology to modify the shielding gas. The chrome-free consumables technologies appear the most promising at this time but it is unclear if they are commercially available at this time.

Several projects are currently ongoing targeted at eliminating the release of Cr^{6+} during the welding process. Since most of the welding processes fume generated comes from the welding consumable, the filler metal employed during electric arc welding is the primary source. Chromium present in the consumables may be converted to hexavalent chromium during the welding process. The technologies below address chrome free consumables to reduce this source of fume. Some carbon steels contain recycled metals that include chromium. Even though most of the welding fume comes from the electrodes/filler wire, some of the fume does come from the metal being welded. Consequently, there is a potential for hexavalent chromium in the welding fume from these steels. This source of potential exposure is addressed through engineering controls. The best solutions are those using a combination of engineering controls and non-Cr consumables.

3.11.1 Process Improvements

Local exhaust ventilation (LEV) and personal PPE remain the most widely employed means of protecting welders' breathing zone, but they remain inconvenient and often cumbersome reducing the effectiveness of "in-the- field" welding. In a fixed facility where welding occurs in specific areas on the shop floor, local ventilation, exhaust fans, to an overhead collection systems can be effective.

3.11.2 *Alternative:* Non-Chrome Consumables

Conventional consumables for welding stainless steels have a chromium content of 16-20 percent by weight, which generates high levels of Cr^{6+} fume. New chromium free consumables have been developed as a possible replacement for standard 308 and 316 stainless steel electrodes.[45] Laboratory and field testing of an electrode alloyed with nickel (Ni), copper (Cu), and ruthenium (Ru) were found to provide almost a 100-fold reduction of Cr^{6+} in fume while producing welds with comparable corrosion resistance and mechanical properties relative to conventional methods.

[45] "Introduction and Validation of Chromium-free Consumables for Welding stainless Steels", Technical Report, Naval Facilities Engineering Command, TRNAVGAC-EXWC-EV-1508, Ver. 2, April 2015.

noblis

Related Efforts

Table 43 is a list of efforts related to the research, development, testing, and evaluation of non-chrome consumables. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 43. Non-Chrome Consumable Related Efforts

Effort	Systems	Technology	Points of Contact
Introduction and Validation of Chromium-free Consumables for Welding stainless Steels	Stainless steels	Non-Cr^{6+} consumables	Mr. Tom Torres Naval Facilities Engineering Command (NAVFAC) Phone: 805-982-1658 tom.torres@navy.mil
Innovative Welding Technologies to Control Hazardous Air Pollutant Emissions (WP-200903)[46] [47]	Stainless steels	Non-Cr^{6+} consumables – Nickel, Copper, Ruthenium	Mr. Tom Torres Naval Facilities Engineering Command (NAVFAC) Phone: 805-982-1658 tom.torres@navy.mil
Novel Approach for Welding Stainless Steel Using Chromium-Free Consumables (SEED Project) (WP-1346)[48]	Stainless steels	Non-Cr^{6+} consumables - Monel	Dr. Gerald Frankel The Ohio State University Phone: 614-688-4128 Fax: 614-292-9857 frankel.10@osu.edu
Development of Chrome-Free Welding Consumables for Stainless Steels (WP-1415)[49][50]	Stainless steels	Non-Cr^{6+} consumables - nickel, copper, and palladium (Ni-5Cu-1Pd); nickel, copper, ruthenium, and titanium (Ni-7.5Cu-1Ru-0.5Ti)	Dr. Gerald Frankel The Ohio State University Phone: 614-688-4128 Fax: 614-292-9857 frankel.10@osu.edu

Applicability

Non-Cr^{6+} consumable technology should be applicable to FRCSE processes, however, testing would be necessary to ensure weld strengths and other requirements are met by the novel materials.

[46] https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Surface-Engineering-and-Structural-Materials/Welding-and-Joining-Technologies/WP-200903/WP-200903/(language)/eng-US

[47] https://www.serdp-estcp.org/content/download/28598/281290/file/WP-200903-FR

[48] https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Surface-Engineering-and-Structural-Materials/Welding-and-Joining-Technologies/WP-1346/WP-1346/(language)/eng-US

[49] https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Surface-Engineering-and-Structural-Materials/Welding-and-Joining-Technologies/WP-1415/WP-1415/(language)/eng-US

[50] https://www.serdp-estcp.org/content/download/6556/86492/file/WP-1415-FR.pdf

Barriers

Technical

Laboratory and field testing of the non-Cr^{6+} consumables were found to provide almost a 100-fold reduction of Cr^{6+} in fume while producing welds with comparable corrosion resistance and mechanical properties relative to conventional methods. However, the consumables would have to be tested on FRCSE substrates and weapon system components to ensure requirements are met.

Financial

There are no capital costs associated with this technology as they are alternative consumables used in an existing process. However, the welding rods containing palladium, ruthenium, and titanium are considerably more expensive than traditional consumables. A cost benefit analysis or life cycle analysis would have to be performed to compare existing processes to the alternatives.

Acceptance

The non-Cr^{6+} consumables have not been tested on any FRCSE substrates or weapon systems, so additional testing and evaluation would be necessary to qualify the materials for use.

Logistics

Once non-Cr^{6+} consumables are qualified and accepted on weapon systems, the Technical Manuals and drawings must still be changed to reflect adoption of the new technology.

3.11.3 *Alterative:* Shield Gas Modification (Silica Precursor)

Another approach to reducing fume generation is to modify the shield gas used in the welding process. Silica precursor technology has been developed that can limit the oxidation of chromium by quenching oxygen species and coating metal particles in welding fumes with a thin, amorphous silica layer.

The laboratory used an insulated double-shroud torch (IDST) to inject vapor-phase silica precursor tetramethylsilane (TMS) into the welding operation. This reduced Cr^{6+} exposures by over 90% and increased fume particulate sizes to 180-300 nanometers from 20 nm. Field study results further confirmed the capability of using a silica precursor to reduce Cr^{6+} exposures and encapsulate other toxic metals, Mn and Ni.

Related Efforts

Table 44 is a list of efforts related to the research, development, testing, and evaluation of shield gas modification technologies. The name of the effort, the applicable systems, the actual technology tested/evaluated, and relevant points of contact are provided. Further details are available through the POCs, the responsible organization, or through the ASETSDefense Database.

Table 44. Shield Gas Modification Technology Related Efforts

Effort	Systems	Technology	Points of Contact
Innovative Welding Technologies to Control Hazardous Air Pollutant Emissions (WP-200903)	Stainless steels	Silica precursor	Mr. Tom Torres Naval Facilities Engineering Command (NAVFAC) Phone: 805-982-1658 Fax: 805-982-4832 tom.torres@navy.mil

Applicability

Shield gas modification technologies like silica precursors should be applicable to FRCSE welding operations based on the type of welding being performed. However, testing would be necessary to determine the impact (if any) of the technology on the quality of the welds and the logistics of the process. This technology is not commercially available.

Barriers

Technical

Laboratory and field testing has shown that the silica precursor technology reduced Cr^{6+} exposures by over 90% and increased the size of the fume particulates. However, testing would still need to occur with FRCSE operations, substrates, and weapon systems to qualify the process. There may also be testing necessary regarding crystalline silica exposure.

Financial

There are some capital costs associated with the technology and injection of the silica precursor into the shield gas. There is also the anticipated cost of the precursor itself. A cost benefit analysis or life cycle cost analysis would be required to determine if the technology is economically feasible.

Acceptance

The silica precursor technology has not been tested at FRCSE. There would have to be an evaluation of both the quality of the welds and the impact on current welding processes before acceptance could be expected.

Logistics

The base process is not changing, nor are the materials used in the welding operations. Technical Manuals and drawings should not require changes to reflect adoption of the new technology. However, this technology is not currently commercially available.

4 Fleet Readiness Center Southeast Roadmap

This section of the Implementation Plan prioritizes and time-phases Cr^{6+} and Cd-alternatives initiatives at FRCSE. These initiatives include ongoing projects, new starts, and research needs for those processes and materials relevant to FRCSE. The methodology used to prioritize initiatives is described first followed by a brief explanation for each initiative. The time-phased roadmap to achieve Cr^{6+} and Cd reduction goals follows the explanations.

4.1 Methodology

Cr^{6+} and Cd-reduction initiatives have been prioritized using a relative scoring methodology. Four metrics were selected for analysis in the prioritization process: 1) Impact to Readiness; 2) Likelihood of Implementation; 3) Return on Investment; and 4) Impact to Goals. Each metric was qualitatively analyzed.

Impact to Readiness: This reflects the relative impact to readiness if an alternative is not implemented for the Cr^{6+} or Cd-using process. Potential impact to readiness will take into account, but not be limited to, worker exposures, regulations impacting the supply chain such as REACH, more restrictive environmental and occupational health standards, number of weapon systems impacted by the process, criticality of the process and/or weapon system to the depot, Service and DoD, and impact to the weapon system(s) if Cr^{6+} and/or Cd were unavailable for use.

Likelihood of Implementation: This relative rating is a gauge on how likely or unlikely that an alternative will be implemented for a process or process/weapon system combination. Likelihood of implementation takes into account ongoing initiatives to replace or identify alternatives for the process, the technical risk of a implementing an alternative, the logistical issues associated with implementation, cost of implementation, and other potential barriers.

Return on Investment (ROI): This metric examines the relative financial return on investment of implementing an alternative to a Cr^{6+} or Cd-using process. The ROI calculation will take into account capital costs of implementation, yearly chemical or material costs, yearly maintenance costs, energy costs, and health and safety costs. The ROI analysis will be qualitative, assigning high, medium, and low values to each of the components to reach an overall ranking.

Impact to Goals: This metric examines the impact to Cr^{6+} and Cd reduction goals at the depot. Reduction goals are based on pounds of Cr^{6+} or Cd used in depot processes. Therefore, initiatives that target high-usage processes have a greater impact on reduction goals than those with relatively low usage. The Advanced Coatings 5-Year Strategy and Roadmap establishes goals for Cr^{6+} and Cd usage and emissions/exposures/waste streams reductions. In all cases, the reduction goals are >90% over the next 5 years. To achieve these reduction goals at FRCSE, several initiatives (both ongoing and new-start) are recommended and included here as part of the depot-specific implementation plan.

4.1.1 Tier 1 Priority Initiatives

Tier 1 priority initiatives are critical to achieving Cr^{6+} and Cd reduction goals. If these initiatives are not successfully implemented, the reduction goals cannot be achieved. These initiatives will typically have far reaching impact to other depots, addressing similar critical usages, emissions, exposures, and/or waste streams. Tier 1 priority processes typically have high impacts to readiness, though this is not always the case. Seven (7) of the recommended initiatives are considered Tier 1 priorities and, therefore, critical to achieving reduction goals at FRCSE. Each is described in greater detail below.

4.1.1.1 Chrome-Free Primer on OML

Qualitative Assessment

Chromated primers are currently used on every aircraft and commodity and most engine systems maintained at FRCSE. One of the primary usages is on the OML of aircraft, including the E-2C, E-3A, EA-6B, F/A-18, P-3 Orion, and P-8A. Based on this, impact to readiness is very high as the application is critical to the operation of these aircraft. The likelihood of implementation is high as there is ongoing work at FRCSE in this area. Non-chrome primers have been tested and approved for thhe E-2C and P-3C. Testing of non-chrome primers is also underway on the F/A-18-D and the H-46. If the non-chrome primer proves to be acceptable, it will be implemented. ROI is high based on reductions in PPE requirements, medical monitoring, and hazardous waste generation. Chrome primers represent, by far, the largest usage of Cr^{6+} at FRCSE and one of the largest subset usages is on the OML. FRCSE cannot reach its reduction goal of 90% without an alternative to chromated primers.

Description

NAVAIR has successfully demonstrated the PPG Deft 02-GN-084 non-chromated primer on the E-2C Hawkeye, P-3C Orion, T-6 Texan, T-34 Mentor, T-44 Pegasus, and T-45 Goshawk aircraft. Service inspections done post-deployment documented good corrosion and adhesion performance. As a result, in 2014 NAVAIR drafted an authorization letter[51] for the use of this primer over conversion coatings qualified to MIL-DTL-81706, Type I, Class 1A, on the outer-mold-line (OML) of all Navy gloss paint scheme aircraft.

In addition, OC-ALC is currently field testing the MIL-PRF-32239 non-chrome system on E-3 wings, a shared weapon system with FRCSE. This totally non-chrome system includes:

- Non-chromate Prekote pretreatment
- Aerodur 2100 Mg-rich non-chrome primer
- Epoxy surfacer (intermediate coating)
- MIL-PRF-85285 Type I topcoat

If the field testing is successful, the non-chrome system can be implemented on the entire OML of the E-3. Additional field testing simultaneous with the E-3 would accelerate implementation versus waiting for E-3 test results before deciding if additional validation is necessary. However, the data obtained from the E-3 testing might provide enough information to the other systems to initiate implementation.

NAVAIR is also currently evaluating Hentzen 17176KEP primer on V-22 Osprey Helicopter, H-46 Sea Knight Helicopter, H-53 Sea Stallion Helicopter, and F/A-18A-D Hornet aircraft. Unlike the gloss paint scheme aircraft, which are primarily aluminum on the OML, the OML tactical paint scheme of these aircraft is also incorporates composite substrates. Upon successful demonstration, NAVAIR anticipates authorizing the Type II primer for tactical aircraft as well. Once signed and released, each applicable Program will have the option to implement the primer at OEM and depot level.

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51 http://db2.asetsdefense.org/fmi/webd#Surface%20Engineering

FRCSE should continue with ongoing testing of the Hentzen 17176KEP primer on the F/A-18-D Hornet and H-46 Sea Knight as a replacement of the chromated primer on tactical aircraft as well as those with gloss schemes would eliminate chrome primers from the OML. Other primer options are also being tested under an ongoing ESTCP project led by NAVAIR and successfully tested primers from this program should also be flight tested. In addition, FRCSE should consider working with OC-ALC and others on total chrome-free systems, eliminating the chromate conversion coating as well.

4.1.1.2 Non-Chromate Conversion Coatings for Aluminum

Qualitative Assessment

Chromate conversion coatings on Al have a high impact to readiness as they are applied to almost every weapon system maintained at FRCSE. Inability to use a chromated conversion coating without identifying an alternative would compromise a number of aircraft. Likelihood of implementation at FRCSE is above average, assuming the adhesion and corrosion resistance requirements can be met. The current ARL effort identified above is a current effort to identify an alternative for both aircraft and ground support equipment, but technical challenges remain to be overcome before implementation of a new alternative. ROI is strong, with differences in product and material costs offset by savings on medical monitoring and protective equipment. The use of chromate conversion coatings is the fourth largest use of Cr^{6+} at FRCSE, documented at 145.6 lbs of Cr^{6+} according to 2014 hazardous materials usage data. However, it by far has the largest infrastructure footprint at 13,633 gallons While the usage reduction goal of >90% Cr^{6+} can be met without an alternative to chromate conversion coatings, waste and exposure reduction goals based on the infrastructure dedicated to the process cannot be met without an alternative.

Description

The US Army Research, Development, and Engineering Command (RDECOM) and Army Research Laboratory (ARL) have an ongoing initiative to address elimination of Cr^{6+} in military surface finishing processes. This initiative was prompted by and addresses AERTA requirement PP-2-02-04 by eliminating Cr^{6+} in pretreatments, Defense Federal Acquisition Regulation Supplement: Prohibition (223.7302), and OSHA Regulation 1910.1026. Primary benefits of the initiative include reduction of over 100K pounds of Cr^{6+} generated from aluminum conversion coatings each year. Success would eliminate at least 90% of Cr^{6+} from conversion coating operations, reduce corrosion costs to military for multi-services, manage risks of exposure by being accountable for material used, amount of emissions, and waste generated and disposed, and avoid fines, penalties and house-keeping costs for non-compliance with occupational regulation.

Current state of the art for pretreatment of metallic substrates is hexavalent or trivalent chromium containing materials for aluminum and zinc phosphate for ferrous substrates. Alternative technologies are currently at a TRL level of 7 and at project completion will be at an 8. The technology technologies being tested include:

- Aircraft assets/Aluminum/Spray and Immersion
    - 11-TGL-27 (Zirconium oxide)—PPG Industries
    - Bonderite 5700/5200 (Zirconium oxide)—Henkel Corp

- Iridite NCP (Aluminum fluoride)—MacDermid Industrial Solutions
- Recc 3021 (Rare earth/Cerium)—Deft/PPG
- Recc 3024 (Rare earth/Cerium)—Deft/PPG
- Prekoat (Solgel/Silanes)—Pantheon Enterprises, Inc
- AC-131(Zirconium/Silane)—3M Industries

- GSE assets/Multi-metal/Immersion only
  - X-Bond 4000 (Zirconium oxide)—PPG Industries
  - Recc 3012 (Rare earth/Cerium)—Deft/PPG
  - Bonderite/Oxsilan—Henkel/Chemetal

The intended end-product is a Cr^{6+} free pretreatment conversion coating for aviation and ground support equipment (GSE) with application for multi-metal. The goal is qualification and approval for transition to MIL-DTL-5541 and TT-C-490. The aviation demo sites will be CCAD, TASM-G, Ft. Campbell, Wheeler AAF and the GSE demo sites LEAD, RRAD, ANAD, and MDMC. The technical approach includes full scale demonstrations of commercially available products and verification of performance to baseline technologies for transition by PMs and PEOs in 3 years. Current state of the art for pretreatment of metallic substrates is hexavalent or trivalent chromium containing materials for aluminum and zinc phosphate for ferrous substrates. Alternative technologies are currently at a TRL level of 7 and at project completion will be at an 8.

FRCSE should consider involvement, joint testing, or at least monitoring the US Army RDECOM initiative. While the Navy does have some unique requirements, many of the material substrates and necessary testing will be addressed at the aviation sites listed above. Additional Navy specific testing would be minor in comparison with the overall initiative. Testing with painting systems used in the Navy would probably be one of the major additions and alterations. Involvement in this initiative and leveraging the Army's efforts could save months or even years of work in identifying an alternative.

4.1.1.3 Alternative to Cadmium Brush Plating

Qualitative Assessment

Cadmium brush plating has a high impact to readiness based on the number of weapon systems impacted by the process at FRCSE. Inability to use cadmium brush plating without an identified alternative would critically compromise several weapon systems maintained at FRCSE. Likelihood of implementation is high based on current efforts by ESTCP and AFRL to identify cadmium brush plating alternatives on mild and high strength steel. The technology is established and initial testing has been positive. The ROI is moderate based on the capital cost of the plating equipment, but alternative plating solutions costs are decreasing. Cadmium brush plating is the largest documented usage of Cd on FRCSE according to Calendar Year 2014 hazardous materials data. Based on this data, it is impossible to reach the cadmium reduction goals at FRCSE without implementing an alternative to cadmium brush plating.

Description

This project (ESTCP WP-201412) focuses on elimination of toxic and carcinogenic cadmium (Cd) material for brush plating repair operations, and reduction of solid waste associated with adsorbents used to contain solution leakage attributed with traditional brush plating repair processes. The technical objectives are to:

1. Demonstrate the commercial off-the-shelf (COTS) brush plating tool Dalistick® Station for selective plating, ensuring its safety and cost effectiveness for Department of Defense (DoD) maintenance, repair, and overhaul operations.
2. Test and evaluate the COTS Zinidal Aero (code 11040) zinc-nickel (Zn-Ni) brush plated coating as a Cd replacement on high strength steels (HSS) for repair applications on weapon systems parts and components (landing gear, terminal assemblies, landing gear doors, bushings, etc.

Low hydrogen embrittlement (LHE) Zn (14-16) Ni electroplates are now being used in the commercial aircraft industry to replace LHE Cd plating. Hill AFB is in the process of moving all of their LHE Cd plating production to this material. Brush plated ZnNi is an industry-recognized repair for this material. WP-201412 will evaluate the ability of a novel brush plating tool, the Dalistick® Station to plate the COTS product Zinidal Zn-Ni coating on HSS. The Dalistick® Station is a mobile electroplating system that enables selective electrochemical treatments without generating any leakage of electrolyte during the plating process. The Dalistick® Station recovers residual brush plating solution and recycles it for reuse in a closed-loop process at the point of contact with the part. It is designed to perform plating and surface finishing operations on steels or light alloys on site, at depots, or in the field. It performs these treatments on curved, horizontal, and/or vertical surfaces and edges without any leakage of electrolyte and minimal generation of solid waste. The Zinidal coating is a promising candidate to replace Cd plating. The Zinidal Aero Zn-Ni solution deposits a coating with 10-14% weight Ni and 86-90% weight Zn at varying thicknesses. The coating provides sacrificial corrosion protection to steels, and the process does not require hydrogen embrittlement relief baking when plated on HSS.

The elimination of Cd brush plating with the use of the Dalistick® Station and Zinidal solution will offer the following cost, regulatory, and environmental, health, and safety benefits:

- Avoidance of compliance issues in military repair operations.
- Environmental and operations impacts, such as the ability to perform selective electrochemical treatments (rust removal, coating removal, spot anodizing) and plating, using one unit-station without electrolyte/hazardous chemical solution leakage during processing on curved, horizontal, or vertical surfaces and edges either in the field or at the Air Logistic Complexes/Depots.
- Cost savings due to recycle and reuse of plating solution in the closed-loop process.
- Reduction of solid waste that is generated from using absorbents (estimated at 60-70%).
- Reduction of worker exposure to hazardous materials and to residual brush plating solutions.

- Reduction of monitoring, use of personal protective equipment, permitting, and record keeping.
- Reduction of transportation/energy costs due to in-field repair capability.
- Reduction of fielding time and flow time at the Air Logistic Complexes/Depots.
- Reduction of occupational and environmental hazards will benefit warfighter readiness

FRCSE should consider involvement, joint testing, or at least monitoring the ESTCP and Air Force initiative and should continue with their existing NESDI project. While the Navy does have some unique requirements, many of the material substrates and necessary testing will be addressed at the aviation sites listed above. Additional Navy specific testing would be minor in comparison with the overall initiative. Involvement in this initiative and leveraging ESTCP's and the Air Force's efforts could save months or even years of work in identifying an alternative.

4.1.1.4 Alternative to Coatings Removal Processes to Reduce Cr^{6+} Containing Waste Streams

Qualitative Assessment

Abrasive blasting has a moderate impact to readiness as there is little risk that the technology would become unavailable for any reason. However, almost every weapon system maintained FRCSE is impacted by this process. The likelihood of implementation is also considered moderate as there has, to date, been no studies of alternatives nor testing performed to qualify an alternative to abrasive media blasting. The return on investment is high as a large reduction in the amount of hazardous waste would save FRCSE significant amounts of money. Impact to goals is very high as this is the single largest Cr^{6+} and Cd waste stream on FRCSE. It is not possible to reach waste stream reduction goals for Cr^{6+} and Cd at FRCSE without addressing the spent blast media.

Description

This initiative should be implemented in phases. The first phase is an in-depth study of the abrasive media blasting processes at FRCSE. This study should identify, in great detail, the components being processed through the blast media cabinets and booths. This detail should include the components, substrate, coatings being removed, and the number of components. In addition, details on the blast media cabinets should be gathered including the type of media used, the purpose of the blasting, the type of cabinet, the recycle ratios, and the configuration of the cyclone systems, filters, and pressure systems.

Where possible, components containing Cr^{6+} or Cd should be segregated into specific cabinets connected to separate filters, cyclones, and pressure systems. Where this is not possible, investigation of coating removal technologies such as hand-held lasers, robotic lasers, Flashjet®, and atmospheric plasma can be considered. Each of these technologies result in a dramatic reduction in the amount of waste from the stripping operations.

4.1.1.5 Alternative to Hard Chrome Plating

Qualitative Assessment

Hard chrome plating has a high impact to readiness based on the number of weapon systems impacted by the process at FRCSE. Inability to use hard chrome plating without an identified alternative would critically compromise several weapon systems maintained at FRCSE. The likelihood of implementation is high based on current efforts at FRCSE, and CCAD to identify, develop, and demonstrate hard chrome plating alternatives. In addition, FRCSE has already transferred a portion of their plating workload (especially engine parts) to HVOF. However, the available alternative technologies for NLOS plating still require refinement and are not yet ready for implementation. The ROI is moderate based on the capital cost of the plating equipment, but alternative plating solutions costs are decreasing (lower overall life-cycle cost). Hard chrome plating required only minimal chemicals/materials according to Calendar Year 14 hazardous materials data, however, 8,662 gallons of tankage is dedicated to the process, making it the third largest user of infrastructure at FRCSE. While according to Calendar Year 2014 data, it is not critical to fulfillment of the 90% usage reduction goals at FRCSE, it is critical to meeting waste and exposure goals. Identifying an alternative to hard chrome plating for implementation across the DoD will be integral to meeting the larger-scale goals.

Description

There are two ongoing efforts to find NLOS alternatives to chrome plating, one ongoing at FRCSE and another that FRCSE should monitor and, if possible, become involved in as a testing and demonstration participant.

The initiative ongoing at FRCSE is Nanocrystalline cobalt-phosphorus plating (nCoP) testing and demonstration. nCoP is commercially available as an environmentally compliant alternative to hard chrome plating. As an electrodeposition process, nCoP is fully compatible with the existing hard chrome plating infrastructure, but exhibits higher cathodic efficiencies and deposition rates than hard chrome plating, thus yielding higher throughput, reduced facility footprint and reduced energy consumption. Further, nCoP offers significant performance enhancements over EHC including superior sliding wear, enhanced lubricity and corrosion resistance, and much improved fatigue properties. nCoP was developed in cooperation with SERDP and ESTCP. The ongoing ESTCP program (WP-0936) along with leveraged support from the Navy's Environmental Sustainability Development to Integration (NESDI) program (Project #348) aims at fully qualifying nCoP through performance testing and demonstration/validation on a number of components from NAVAIR (air vehicle and ground support equipment) and NAVSEA (shipboard machinery components and ground support equipment). It is recommended that FRCSE continue with validation and implementation of nCoP.

The other initiative is trivalent hard chrome plating at CCAD. The trivalent hard chrome plating technology is still in its development phase as an alternative to hard chrome plating with hexavalent chromium. CCAD is working with Faraday Technologies to test and scale-up the FARADAYIC® process under the Toxic Metals Reduction Program. The FARADAYIC® Process uses a trivalent chromium plating bath as a replacement for hexavalent chromium for functional applications. The patented FARADAYIC® Process is an electrochemical process that utilizes a controlled electric field to electrodeposit a material of interest. The material deposition rate is determined by the applied electric field. This provides the means for precise control of the process length, the total material deposited and the deposit properties.

Both technologies show promise for replacing some or all hard chrome plating applications. Involvement would allow FRCSE to leverage completed and ongoing work to more quickly and less expensively implement an alternative to hard chrome plating. However, both of these technologies produce coatings that do change with temperature, so coatings on engine parts may see relatively high temperatures would have to be qualified.

4.1.1.6 Alternative to Cadmium Plating

Qualitative Assessment

Cadmium plating has a high impact to readiness based on the number of weapon systems impacted by the process at FRCSE. Inability to use cadmium plating without an identified alternative would critically compromise several weapon systems maintained at FRCSE. The likelihood of implementation is high based on the fact that LOS applications have already been transitioned to IVD Al in many cases. Remaining NLOS applications will require more of a drop-in replacement that should find easy acceptance. However, the available alternative technologies for NLOS plating still require testing and refinement prior to implementation at FRCSE. The ROI is moderate based on the capital cost of the plating equipment, but alternative plating solutions costs are decreasing (lower overall life-cycle cost). Cadmium plating required no recharge chemicals/materials according to Calendar Year 14 hazardous materials data, however, 5,740 gallons of tankage is dedicated to the process. While according to Calendar Year 2014 data, it is not critical to fulfillment of the 90% usage reduction goals at FRCSE, it is critical to meeting waste and exposure goals for Cd. Identifying an alternative to cadmium plating for implementation across the DoD will be integral to meeting the larger-scale goals.

Description

Past cadmium plating alternatives projects have focused on a few application areas: 1) landing gear and other critical high strength steel applications; 2) low and high strength steel fasteners; and 3) electrical connectors. Most of FRCSE's workload for cadmium plating is landing gear and other critical components. Of the alternatives identified in Section 3.3, Zn-Ni electroplating probably has the best chance of meeting NAVAIR requirements and being implemented.

ESTCP Project WP-201107, "Demonstration/Validation of Zinc-Nickel as a Replacement for Cadmium/Cyanide Plating Process for Air Force Landing Gear" tested and validated LHE Zn-Ni, a cyanide-free plating process that demonstrates excellent throwing power and meets the requirements for a non-embrittling process per American Society for Testing and Materials (ASTM) Specification F519. The coating consists of a zinc alloy containing 12-20% nickel and demonstrates excellent sacrificial corrosion protection for steels. This project installed a production-ready LHE Zn-Ni plating line at Hill Air Force Base's landing gear overhaul facility for demonstration and validation of the plating process and provided landing gear components for field service evaluation. The technology has since been approved for use on all landing gear with the exception of the C-17, which is awaiting engineer approval and changes to the drawings.

FRCSE should continue to pursue the NESDI project investigating LHE Zn-Ni as an alternative to Cd tank plating. In addition, they should follow and participate in other DoD Cd tank plating replacement efforts (e.g., OO-ALC) to capture lessons-learned and leverage data on shared substrates and requirements.

4.1.1.7 Non-Chrome Primer on non-OML Applications

Qualitative Assessment

Chromated primers are currently used on every aircraft and commodity and most engine systems maintained at FRCSE. One of the usages is on the non-OML aircraft, interior, and flight control components, including on the E-2C, E-3A, EA-6B, F/A-18, P-3 Orion, and P-8A. Based on this, impact to readiness is very high as the application is critical to the operation of these aircraft. The likelihood of implementation is high as there is ongoing work at FRCSE in this area. Non-chrome primers have been tested and approved for the E-2C and P-3C. Testing of non-chrome primers is also underway on the F/A-18-D and the H-46. If the non-chrome primer proves to be acceptable, it will be implemented. ROI is high based on reductions in PPE requirements, medical monitoring, and hazardous waste generation. Chrome primers represent, by far, the largest usage of Cr^{6+} at FRCSE. FRCSE cannot reach its reduction goal of 90% without an alternative to chromated primers.

Description

NAVAIR has successfully demonstrated the PPG Deft 02-GN-084 non-chromated primer on the E-2C Hawkeye, P-3C Orion, T-6 Texan, T-34 Mentor, T-44 Pegasus, and T-45 Goshawk aircraft. Service inspections done post-deployment documented good corrosion and adhesion performance. As a result, in 2014 NAVAIR drafted an authorization letter[52] for the use of this primer over conversion coatings qualified to MIL-DTL-81706, Type I, Class 1A, on the outer-mold-line (OML) of all Navy gloss paint scheme aircraft. This testing should be extended to non-OML applications.

OC-ALC is currently field testing the MIL-PRF-32239 non-chrome system on E-3 flight controls, a shared weapon system with FRCSE. This totally non-chrome system includes:

- Non-chromate Prekote pretreatment
- Aerodur 2100 Mg-rich non-chrome primer
- Epoxy surfacer (intermediate coating)
- MIL-PRF-85285 Type I topcoat

If the field testing is successful, the non-chrome system can be implemented on flight controls and off-aircraft components of the E-3. Additional field testing simultaneous with the E-3 would accelerate implementation versus waiting for E-3 test results before deciding if additional validation is necessary. However, the data obtained from the E-3 testing might provide enough information to the other systems to initiate implementation.

NAVAIR is also currently evaluating Hentzen 17176KEP primer on V-22 Osprey Helicopter, H-46 Sea Knight Helicopter, H-53 Sea Stallion Helicopter, and F/A-18A-D Hornet aircraft. Unlike

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[52] http://db2.asetsdefense.org/fmi/webd#Surface%20Engineering

the gloss paint scheme aircraft, which are primarily aluminum on the OML, the OML tactical paint scheme of these aircraft is also incorporates composite substrates. Upon successful demonstration, NAVAIR anticipates authorizing the Type II primer for tactical aircraft as well. Once signed and released, each applicable Program will have the option to implement the primer at OEM and depot level. This testing should be extended to non-OML applications.

FRCSE should continue with ongoing testing of the Hentzen 17176KEP primer on the F/A-18-D Hornet and H-46 Sea Knight. Replacement of the chromated primer on tactical aircraft as well as those with gloss schemes would eliminate chrome primers from non-OML applications. In addition, FRCSE should consider working with OC-ALC and others on total chrome-free systems, eliminating the chromate conversion coating as well.

4.1.2 Tier 2 Priority Initiatives

Tier 2 Priority Initiatives are those not critical to achieving Cr^{6+} and Cd reduction goals at FRCSE, but address significant usages, emissions, exposures, and/or waste streams. These initiatives may impact similar processes at other depots, therefore, increasing the legitimacy of expending resources to identify and implement alternatives. These initiatives typically have moderate impact to readiness, but may exhibit strong ROIs. Four (4) initiatives are considered Tier 2 priorities at FRCSE. These are described in greater detail below.

4.1.2.1 Non-Chrome Al Deoxidizer

Qualitative Assessment

The impact to readiness of this process is high as it impacts most weapon systems at FRCSE and is a critical intermediary step prior to plating and conversion processes. Inability use chromic acid to deoxidize the aluminum components, without an alternative in place, would significantly impact the depot repair of these systems. The likelihood of implementing an alternative to the existing process is high, as there are non-chrome COTS oxidizers. The ROI is moderate as the cost of the products are very similar, but there will be some savings from eliminate medical monitoring and protective equipment. Impact to goals is moderate as identifying and implementing an alternative to the deoxider is not necessary for meeting Cr^{6+} usage reduction goals at FRCSE and fewer other depots are impacted. However, 3,710 gallons of tankage are dedicated to this process and implementation of a chrome-free alternative would help to reduce waste and exposure potential.

Description

The replacement of chromate-based deoxidizing/desmutting formulations in the aerospace industry has been difficult. This is primarily due to the nature of the aluminum alloys used for aerospace applications-specifically, alloying with copper. These alloys make the use of deoxidizing/desmutting formulations based on nitric or sulfuric acid infeasible. However, there has been some research in this area. Boeing and Parker-Amchen investigated the use of a two-step system for deoxidizing/desmutting. The first step is a fluoride-based chemistry that deoxidizes the aluminum alloy, but does relatively little to desmut the aluminum. The second step is a nitric acid-based chemistry that desmuts the aluminum, but does not attack the alloy as it is already in a deoxidized state. In addition, Henkel holds a patent on a non-chrome deoxidizer for aluminum that has been around since 1990. The Henkel technology is also a two step process, in which the aluminum is first cleaned in a dilute acidic or alkaline solution and then deoxidized in an acidic solution of hydrogen peroxide or heteropoly vanadic acids or their salts. Finally, Oakite has a non-chrome deoxidizer called Oakite Deoxidizer LNC that is approved to Boeing Process Specification BAC 5765, Cleaning and Deoxidizing Aluminum Alloys, and can be used to meet the requirements of SAE-AMS-W-6858, Welding, Resistance: Spot and Seam.

FRCSE should consider the investigation or one or more of these technologies as an alternative to the current chromate-based deoxidizer.

4.1.2.2 Reduction of Cr^{6+} Emissions from Stainless Steel Welding Operations

Qualitative Assessment

Stainless steel welding is performed on only a few FRCSE weapon systems, however, this process is critical to those weapon systems and the inability to use the appropriate welding materials would have a significant impact on the maintenance of these systems. The likelihood of implementation greatly depends on the alternative. Non-chrome consumables, as long as they meet the material requirements, are drop-in replacements. However, welders would have to have some training to become familiar and gain experience with the new consumables. Shield gas modification, such as precursors, can affect the process and might meet more resistance. Down-draft tables to help control emissions are easy “sells” and should be easily implementable. ROI is varied depending on the alternative, though none show short term ROI, instead only showing feasibility through the total life cycle. According to Calendar Year 2014 hazardous materials data, 291.29 pounds of Cr^{6+} can be attributed to stainless steel welding processes. This is the second largest usage on FRCSE as documented and is critical to meeting usage reduction goals.

Description

FRCSE should first conduct a comprehensive survey of their stainless steel welding operations. Where down-draft tables and other emissions controls are not being used, and are feasible, they should be put into place. In addition, FRCSE should investigate the use of non-chrome consumables, though this will require testing against material requirements of the weapon systems in question. The use of non-chrome consumables will eliminate Cr^{6+} usage and exposure, meeting both goals. If the use of a non-chrome consumable is not feasible, then the use of a precursor in the shield gas should be considered to reduce the Cr^{6+} emissions and exposure potential.

4.1.2.3 Non-Chrome Stainless Steel Passivation

Qualitative Analysis

Stainless steel passivation has a moderate impact to readiness of weapon systems as only a small subset of systems at FRCSE are impacted by the process. However, this process is critical to the corrosion protection of the passivated components and inability to use this technology would adversely impact the affected systems. In addition, only a few other depots have stainless steel passivation processes, including FRCE and CCAD. The likelihood of implementation of an alternative is high. The recommended alternative, citric acid passivation is a drop-in replacement with very similar processes protocols, so there are few issues with training and changes. The ROI is moderate as the higher cost in chemicals is offset by reductions to the overall life cycle. Impact to the Cr^{6+} usage reduction goal is moderate. Calendar Year 2014 hazardous materials data indicate that the tank was not dumped nor amended, so usage is low.

However, there are 1,480 gallons of tankage dedicated to the process, so waste and exposure potential is high.

Description

AMCOM and CCAD are currently considering a project to test, demonstrate, and implement citric acid passivation for stainless steel components. The project will most likely initiate in the third quarter of Fiscal Year 2016 and is scheduled to last for one year. The objective of the project is to qualify and implement citric acid passivation for stainless steels at CCAD. Ten different alloys will be tested including 300-series, precipitation hardening steels, and 400-series steels. FRCSE should consider leveraging this project and/or conducting joint testing to implement citric acid passivation.

4.1.2.4 Non-Chrome Sealer

Qualitative Assessment

Chromated sealers have a moderate to high impact to readiness as the systems processed are critical and the inability to effectively seal the anodized, phosphate, and cadmium plated components would compromise them. In addition, several other ALCs, FRCs, and Army depots have similar processes and can leverage the work done at FRCSE. The likelihood of implementing a solution is good. Ogden Air Logistics Complex (OO-ALC) has tested, validated and implemented a Permanganate Seal as an alternative to the chromate product. There is also existing work going on at for the Defense Logistics Agency (DLA) at OC-ALC focused on finding a non-chrome alternative to dichromate sealers on anodized aluminum components. OC-ALC is evaluating similar technologies as those implemented at OO-ALC. Finally, NAVAIR has tested and had good results with TCP as an anodize sealer. FRCSE should be able to leverage these efforts to demonstrate and adopt a similar process. The ROI is moderate, primarily driven by the decrease in medical monitoring, reduced protective equipment, and relaxed regulations. The impact to goals is moderate and it is not necessary to find an alternative to chromate sealers for FRCSE to reach their Cr^{6+} usage reduction goals. However, FRCSE has 9,996 gallons of tankage dedicated to this process, the second most on the depot. Implementation of a chrome-free alternative would greatly reduce their waste and exposure potentials.

Description

The objective of the projects at OO-ALC and OC-ALC are to identify, demonstrate/validate and transition alternatives to sodium dichromate sealer for anodized aluminum components. The technical approach included: determining OO-ALC and OC-ALC sealing requirements; Identifying alternatives to sodium dichromate seal; evaluating alternative sealers through screening and performance tests; conducting a cost-benefit analysis; conducting additional testing; and conducting technology transfer activities. Alternatives were expected to meet the following:

- Performance requirements in MIL-A-8625F
- Must be applicable to 2024-T3 and 7075-T6
- Reduce/eliminate environmental safety and occupational health (ESOH) concerns
- Easy to use process

- Prefer a "drop-in" replacement
- Must be cost-effective

Selected 2 of the most-promising COTS candidates for laboratory testing along with three baselines and one benchmark. Received OO-ALC Engineering Review Board approval to use the permanganate seal.

FRCSE should consider involvement, joint testing, or at least monitoring the ongoing DLA and Air Force initiative. While the Navy does have some unique requirements, many of the material substrates and necessary testing will be addressed by the Air Force. Additional Navy specific testing would be minor in comparison with the overall initiative. Involvement in this initiative and leveraging DLA's and the Air Force's efforts could save months or even years of work in identifying an alternative. In addition, FRCSE should leverage previous work on TCP as an anodize sealer to determine the best alternative for their applications.

4.1.3 Tier 3 Priority Initiatives

Tier 3 priority initiatives are not critical to achieving Cr^{6+} and Cd reduction goals and address usages, emissions, exposures, and/or waste streams minor enough to call into question the merit of expending resources to identify alternatives. These processes are typically localized, impacting only a single depot or shop and have little impact to readiness. Two (2) initiatives are considered Tier 3 priorities for FRCSE and is described in greater detail below.

4.1.3.1 Non-Chrome Anodize Dye

Qualitative Assessment

The use of anodize dyes has a low impact to readiness. The dyes are used to impart a color to the anodized aluminum and do not have a critical role in adhesion or corrosion protection. However, use of the dye impacts a number of FRCSE weapon systems, having broad applicability. The likelihood of implementation is high as an alternative would almost certainly be a drop-in replacement with little to no process changes. Testing would have to prove that the color requirements are met without negatively impacting the anodize coating or substrate. ROI is moderate as higher chemical costs are offset by lower life cycle costs. The impact to the Cr^{6+} usage goal is low and not critical to meeting the 90% reduction goal.

Description

The preferred approach would be to identify a commercially available non-chrome anodize dye that meets FRCSE color and material requirements. There are non-chrome anodize dyes commercially available, but none have been tested against FRCSE requirements. It is recommended that FRCSE research potential alternatives and test them against the requirements of the existing process.

4.1.3.2 Non/Low Chrome Sermetel Alternative

Qualitative Assessment

The application of Sermetel aluminized coatings to engine parts has a high impact to readiness. Though the process only impacts engines, it is critical to the components. Inability to use the technology would have an adverse impact on all of the engines maintained at FRCSE. The likelihood of implementation for a drop-in, similarly applied alternative is high, as operators would see little difference in the process. Acceptance by the engineering community would be dependent upon test results. ROI is a wash, as higher costs are cancelled out by lower life cycle costs. There is little impact to the Cr^{6+} reduction goals, making this process of low priority.

Description

FRCSE should consider the testing and eventual adoption of Ceral 34 as an intermediate alternative to Sermetl. Ceral 34 is an inorganic ceramic aluminum coating consisting of very fine aluminum powder suspended in a chromate/phosphate binder (MIL-C-81751). It is used primarily as a corrosion and erosion-resistant coating on Ni-based alloys (e.g., turbine blades), and steel parts operating in environments up to 1100°F. Ceral 34 is a low-chrome coating that replaced the high-chrome coatings previously used on engines at OC-ALC (Sermetel). It is a low-chrome formulation, not non-chrome. It is normally applied by conventional spray techniques, although brushing and dipping are also possible. Coating components are dried and furnace-cured in order to fuse the binder and form a homogeneous coating. The coating provides a barrier between the substrate and the environment, and can be made conductive (usually by glass bead blasting) to provide galvanic and sacrificial protection. It is an overlay coating relying on physical and chemical bonding for adhesion. There is no metallurgical bond, allowing the coating to be easily stripped without degradation of the substrate. It is resistant to hydraulic fluids, fuel and hot water, and is highly resistant to thermal shock and impact damage. It is usually used in combination with a topcoat (Ceral 50); hence the coating is usually called out as Ceral 34. The topcoat provides additional protection as well as smoothing

4.2 FRCSE Initiatives Timeline

As evidenced by the descriptions above, many of FRCSE's Cr^{6+} and Cd usage, emissions, exposure, and waste stream reduction goals can likely be met by leveraging ongoing or past initiatives. In fact, 90% Cr^{6+} and Cd usage reduction can be achieved by leveraging ongoing work either within the DoD. However, six new starts are recommended, though only two of those are Tier 1 priority initiatives, critical to achieving FRCSE reduction goals. Figure 7 illustrates the recommended timeline of initiatives to achieve reduction goals. Ongoing initiatives follow the timeline established by the organization leading the effort. For these initiatives, FRCSE involvement is indicated according to the priorities outlined in the paragraphs above. New start timelines are hypothetical projections intended to meet Cr^{6+} and Cd reduction goals. At the end of each initiative, a two-year implementation phase has been added to allow time for specification and technical manual changes, capital purchases, and full qualification of the alternative technology.

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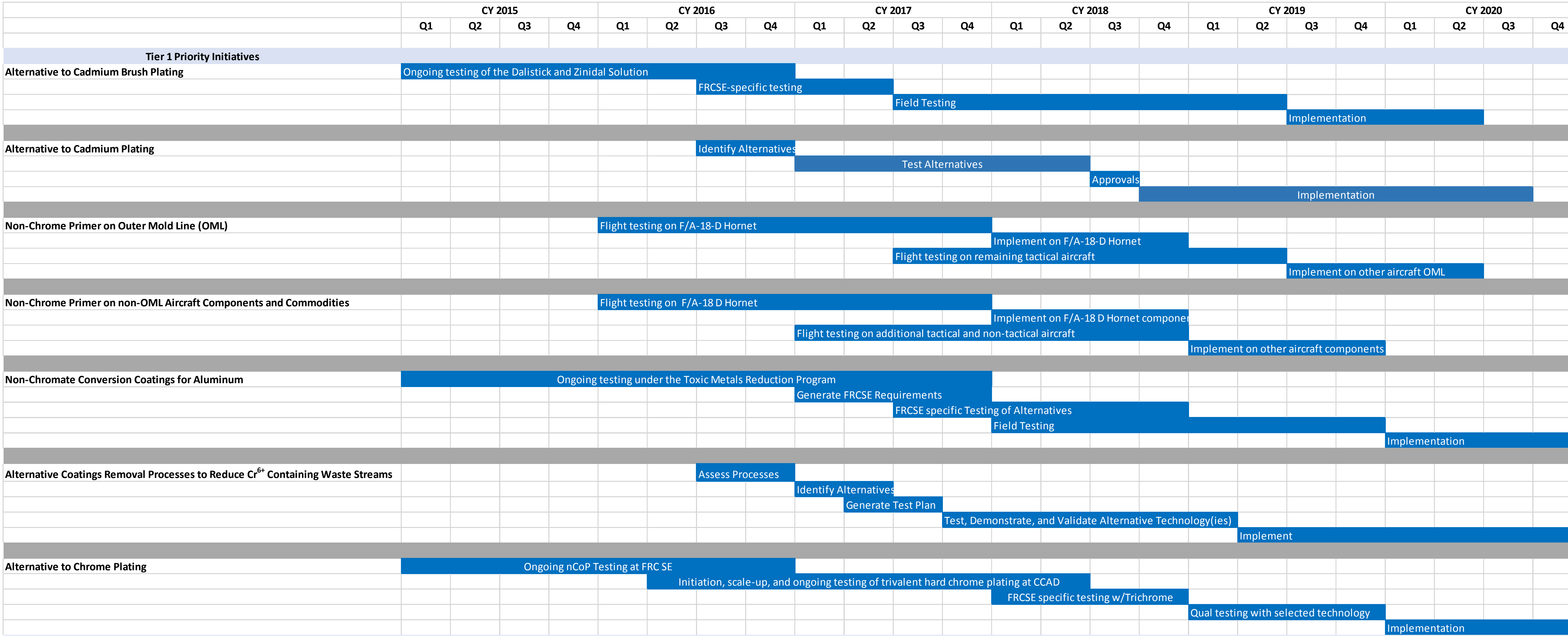
Figure 7. FRCSE Timeline



	CY 2015				CY 2016				CY 2017				CY 2018				CY 2019				CY 2020			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Tier 2 Priority Initiatives																								
Non-Chrome Sealers	Ongoing testing w/DLA and TCP																							
					FRCSE-specific testing																			
									Field Testing															
																	Implementation							
Non-Chrome Al Oxidizer											Identify Alternatives													
												Generate Test Plan												
														Demonstrate and Validate Alternatives										
																		Implementation						
Reduction of Cr^{6+} Emissions from Stainless Steel Welding Operations									Assess Processes															
											Research Alternatives													
												Install Emissions Controls (e.g., down-draft tables												
													Test non-Chrome Consumables and Shield Gas Precursors											
																			Implementation					
Non-Chrome Stainless Steel Passivation							CCAD Validation of Citric Acid Passivation																	
										FRCSE-specific testing														
													Field Testing											
																					Implementation			
Tier 3 Priority Initiatives																								
Non-Chrome Anodize Dye													Identify Alternatives											
														Generate Test Plan										
																Demonstrate/Validate Alternatives								
																				Implementation				
Non/Low Chrome Sermetel Alternative											Identify Alternatives													
												Generate Test Plan												
														Demonstrate/Validation Alternatives										
																		Implementation						