Comprehensive Evaluation and Transition of Non-Chromate Containing Paint Primers

EXECUTIVE SUMMARY

Project #: WP-201132

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INTRODUCTION

Hexavalent chromium (chromate) is the key component for high-performance corrosion-inhibiting primers used on many DoD weapon systems, especially for aviation and aerospace applications. Hexavalent chromium is a known carcinogen and is targeted by DoD for minimization. The U. S. Environmental Protection Agency (EPA) limits air emissions and regulates solid waste disposal from operations using hexavalent chromium. The U. S. Occupational Safety and Health Administration (OSHA) regulates the amount of hexavalent chromium to which workers can be exposed, and reduced the Permissible Exposure Limit (PEL) for hexavalent chromium from the current 50 micrograms per cubic meter (µg/m3) to 5 µg/m3, with allowance for using PPE to meet the PEL for aircraft painting. The need is to identify, test, validate and implement non-chromate primers and surface preparations which are as broad in capabilities and performance as current chromated primers and surface preparations. These alternative materials must perform in conjunction with both chromated and authorized non-chromated metal finishes and substrates, across the breadth of corrosive environments and protecting both surfaces and interfaces.

Recent research and development of non-chromate primers has largely been driven by "bottoms up" ideas and improvements generated by universities, private companies and DoD organizations, often focused on a single technology "solution". Many efforts have focused on meeting the minimum corrosion requirements in the primer specifications in the belief that this level of performance would be good enough to enable non-chromate primers to replace chromate primers.

The bottoms-up approach has led to the development of multiple competing alternatives without a clear understanding of the overall need or value of each alternative. In many cases there has been little high-level guidance on applicability, potential for authorization and implementation, and impact to overall DoD and service chromate minimization goals. This project will provide high-level implementation strategies, assist in the understanding of the risk associated with non-chromate materials at all levels of maintenance, provide guidance to acquisition programs on the potential impact of alternatives on aircraft life-cycle, and provide a unified position among all affected sites with regard to strategies for implementing non-chromate materials for aircraft maintenance.

OBJECTIVES

ESTCP Project # WP-201132 focused on the demonstration and validation of mature non-chromate primers on Department of Defense aviation assets. The overarching objective of this project was a comprehensive evaluation of applications and requirements for chromate inhibited primers, characterization of the performance and maturity of available or proposed alternative primer technology, and recommendations and actions for development, optimization, and demonstration/validation of non-chromate inhibited primers. Due to the challenge associated with transitioning from legacy technology to a new technology within the DoD, the outer mold line (OML) became the primary focus of demonstration and transition to non-chromate primers from legacy chromate paints.

TECHNOLOGY DESCRIPTION

For the purpose of this report, per MIL-PRF-23377K & MIL-PRF-85582D, a non-chromate primer is a corrosion inhibiting, chemical and solvent resistant epoxy primer coating that have a maximum volatile organic compound (VOC) content of 340 grams per liter (g/L), contains non-chromium corrosion inhibitors, along with extenders and other pigments, and where the incidental hexavalent chromium content shall be not greater than 5 parts per million.

Tremendous improvements have been made to the ultimate corrosion performance of non-chromated primers in the past 10 years. However, in testing to date, even the best, state-of-the-art products do not perform equivalently to chromated primers when tested to failure in all the applications in which primers are used. Applications include:

- With and without topcoats;
- Within galvanic couples;
- On aluminum, composites, titanium, magnesium, and steel;
- Over anodized aluminum and magnesium;
- Over sacrificial coatings like ion-vapor deposited (IVD), sputtered or electroplated aluminum; zinc and zinc alloys; and cadmium;
- “Wet installed” for fasteners, bushings, faying surfaces, and other interfaces;
- In conjunction with specialty coatings, such as conductive paints, sealants and low observable coatings; and
- Applied by various users in different environments for newly built weapons and components, depot repaired items, and field repaired items.

T-45 Primed with
MIL-PRF-23377, Class N

H-60 primed with
MIL-PRF-23377, Class N

H-60 primed with
Al-Rich Primer

PERFORMANCE ASSESSMENT

This report documents all laboratory testing, demonstration and validation efforts across all participants.

Laboratory testing included flat panel and galvanic assemblies treated with various coating stack-ups were exposed to accelerated corrosion testing, as well as outdoor beach exposure at NASA Kennedy Space Center. An example of this testing is captured in the next two paragraphs.

NAVAIR and USAF CTIO galvanic assemblies were assembled in accordance with the JTP. Another interest of the joint USAF/USN effort was to compare and study two different galvanic test procedures: one developed by NAVAIR and one developed by USAF CTIO. NAVAIR's galvanic procedure uses one panel for each coating system and tests dry installed titanium and stainless steel fasteners, scribed and unscribed. The CTIO galvanic procedure used a triplicate test of one painted system scribed or unscribed. This method also uses titanium screws, cadmium-plated screws, and aluminum rivets. The interest of this project was to analyze and compare the data received from each.

NAVAIR and USAF CTIO chambers appear to have similar corrosion rates, although the NAVAIR evaluator in this project was a little harsher judge than the USAF CTIO evaluator. As with the flat panels that had been exposed to ASTM B 117 neutral salt spray, the chromate pretreatments and primers outperformed chromate-free coatings. The results with the USAF CTIO galvanic panels correlated well with the flat panel with the data obtained with NAVAIR galvanic panels.

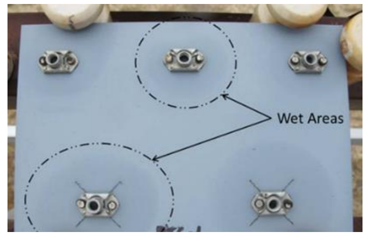
All three departments executed demonstration of various non-chromate primers and associated coating stack-ups, based on internal corrosion technical warrant holder guidance.

- NAVAIR: H-46, E-2C, F/A-18A-D, MV-22B, CH-53E, P-3C, T-6, T-34, T-44, and T-45.
- USAF: A-10, B-1, B-52, C-5, C-17, C-130, E-8, F-15, F-16, F-22, F-35, KC-135, KC-46, RQ-4, and T-38.
- AMCOM: UH-60 components.

Demonstration results included in this report are from NAVAIR, AMCOM & USAF only. Prior plans to include USCG, NASA and OEMs did not materialize during the later stages of this effort. For non-DOD government organizations, this can be attributed to change TPOCs, local organizational priorities and resourcing limitation. Acquiring non-chromate primer demonstration data from OEMs was dependent on approval from the OEM themselves. If deemed proprietary, the OEM will not share data. In the future, principal investigators should aim to coordinate with Program Offices to assist in data acquisition, by leveraging existing DOD/OEM contracts to acquire the test data and reporting. Working with depot engineers is not sufficient to garner OEM engagement / support.

Prior to the start of this effort, Army Aviation implemented non-chromate primer, specifically Deft (now PPG Industries, Inc.) 02-GN-084, on the outer mold line of their helicopters. Through this project, AMCOM initiated demonstrations of the lower TRL commercialized aluminum-rich primer on UH-60 components starting in February 2017. AMCOM identified cargo doors and stabilators as low risk components for this demonstration, to allow for paint application in a climate controlled paint booth at TASM-G in Groton, Connecticut.

Kennedy Space Center
Beachfront Facility



Galvanic Corrosion Test
Article for exposure

COST ASSESSMENT

The cost analysis for this effort was focused on U.S. Navy (USN) and U.S. Marine Corps (USMC) aviation only. Capturing comprehensive cost data was challenging as corrosion prevention & control costs are rarely tracked with enough granularity to facilitate cost savings or cost benefit analysis. The overall cost analysis strategy was as follows:

- **Facilities Cost:** In FY21, the cost to strip and repaint one aircraft at a Navy or USMC depot installation was approximately $190,000. Each installation processed 70 or more aircraft, totaling an estimated cost of $14M per site. Depaint/repaint operation costs are not housed in a singular location, and gathering this information required personal requests from each Fleet Readiness Center (FRC). It costs a depot approximately $10-15M annually to operate the paint and depaint facilities, with waste disposal costs ranging from 1% to 30% of the total operating cost.
- **Product Cost:** The cost of non-chromate primers is roughly comparable to chromate primers ($80/gal vs. $100/gal). Implementation did not require additional equipment or start-up costs, and minimal training (1 day per TMS) was needed for depot artisans.
- **Environmental Compliance:** Navy Aviation FRCs incur approximately $1M per year per depot site in fines due to non-compliance with environmental regulations. Continued use of chromate primers for touch-ups and spot repairs poses risks of contaminating non-chromate paint schemes. All chromium waste, regardless of its form is disposed of in the same manner (e.g., cost per pound), hindering cost savings from waste management.
- **Mortality Risk Valuation:** A health benefit valuation was conducted to quantify the economic benefits of reducing health risks associated with hexavalent chromium (Cr(VI)) exposure. Using the EPA's Value of Statistical Life (VSL) adjusted for inflation, the estimated cost avoidance is $7,700 per worker per year. For 400 painters at DoD Aviation Depot Facilities, this translates to a health cost avoidance benefit of approximately $3M per year. For the population U.S. Navy FLEET certified aircraft painters, the benefit is approximately $14M per year.

IMPLEMENTATION ISSUES

Transitioning from legacy technology to new technology continues to challenge the DoD. The implementation of non-chromate primers is dependent on service-specific priorities and readiness to minimize hexavalent chromium use. Key implementation issues include:

- **Conservative Approach by NAVAIR:** NAVAIR has exhibited reservations about the technology switch due to concerns over increased corrosion risk. Their approach relies on chromium-containing conversion coating chemistries for aluminum skin surface preparation.
- **Regulatory Challenges:** Potential implementation of 2018 ACGIH recommendations could limit the use of aerosolized chromate or trivalent chromium compounds, hindering current application methods.
- **Technology Maturation:** Further work is needed to develop robust chromium-free alternatives for conversion coatings and anodize processes. NAVAIR is focusing on alternative conversion coating application processes and corrosion-resistant adhesion promoter technologies.
- **Coordination and Approval Processes:** Implementation requires coordination among multiple technical areas, including Fleet Support Team engineering, PMA Configuration Management, Class Desk, and Chief Engineering approval. Engineering change proposals (ECPs) must be approved by all stakeholders and supported by FRC capabilities.
- **Broad Implementation:** Full implementation across FRC facilities and the Fleet requires amendments to local process specifications to include non-chromate primers as an option. Engineers are tasked with bridging knowledge gaps between engineering and logistics to ensure thorough evaluation and implementation of new technologies.

CONCLUSION

This project demonstrated significant progress in developing non-chromate primers that approach the performance of traditional chromated primers. Continued efforts are needed to optimize these alternatives and ensure their widespread adoption within the DoD. The report provides a comprehensive evaluation of current technologies, performance assessments, and strategic recommendations for future implementation.

Despite these challenges, several NAVAIR PMAs are implementing non-chromate primers based on data generated by this program and other initiatives. Continued efforts are required to mature the technology and achieve widespread adoption within the DoD aviation community.

NAVAIR Addendum: Since the completion of this effort NAVAIR has continued testing and demonstration of non-chromate primers. This additional work has resulted in formal NAVAIR authorization for MIL-PRF-23377, Class N (Type I and Type II) epoxy primer for aircraft OML applications. The process has also transitioned to FRCSE, FRCE and FRCSW when performing aircraft repaint operations.