Improving Aluminum Ion Vapor Deposition

Lisa Cato, Concurrent Technologies Corporation, Edgefield, SC, USA
Melissa Klingenberg, Concurrent Technologies Corporation, Johnstown, PA, USA

Many Department of Defense (DoD) repair facilities use IVD aluminum to replace cadmium electrodeposits. Chromate conversion coatings, which contain carcinogenic hexavalent chromium, are applied to the IVD coating to impart the necessary corrosion protection and lubricity. Elimination of the chromate conversion coating is desirable. *CTC* has incorporated a pulsed, high voltage power supply into conventional IVD equipment for the purpose of improving coating structure. This may allow a less corrosion resistant, non-chromate pretreatment to be applied, while maintaining or improving the overall corrosion resistance of the coating system. This paper will discuss a National Defense Center for Environmental Excellence (NDCEE) project that is investigating the use of such equipment, the test results to date, and the plan for validating its use and subsequent implementation into DoD facilities.

For more information, contact:
Lisa Cato
Concurrent Technologies Corporation (*CTC*)
100 *CTC* Drive
Edgefield, SC 29824
Phone (803) 637-2516
FAX (803) 637-2510

Introduction

Ion vapor deposition (IVD) of aluminum is a suitable cadmium replacement for many applications, but it does not provide the lubricity of cadmium, nor does it always provide sufficient corrosion protection due to coating porosity. To densify the aluminum coating and improve its adhesion to the substrate material, glass bead peening is often used. Subsequently, a chromate conversion coating is applied to impart greater corrosion resistance, lubricity, and provide a surface amenable to painting.

Conventional chromate conversion coatings use hexavalent chromium, a class one carcinogen. To ensure that mists containing hexavalent chromium are not released into the environment or pose a significant health risk to workers, regulations have been imposed by the Occupational Safety and Health Administration (OSHA) and Environmental Protection Agency (EPA). The cost associated with maintaining compliance with these regulations is escalating. Many alternative non-chromate pretreatments have been investigated by private industry and the military, but with limited success.

An improved IVD aluminum process was demonstrated by ISM Technologies, a division of Cutting Edge Products, Inc., in conjunction with the former McDonnell Douglas Aerospace (now part of the Boeing Company). The coating, when combined with conventional chromating processes, showed significant improvement in corrosion resistance over conventional chromated IVD deposits. To implement the improved IVD aluminum process, existing IVD aluminum chambers are retrofitted with a pulsed high voltage power supply. The pulsed high voltage bias is applied to parts during deposition. The negative bias attracts any ionized coating material as well as gaseous ions from the surrounding plasma. Because the bias is a greater negative voltage than that used in conventional IVD processes, the ions experience a greater attraction to the parts and are accelerated at greater velocities. In theory, more momentum is transferred to the depositing coating, resulting in the collapsing of coating voids, which leads to a denser aluminum coating. The improved IVD process combined with a non-chromate conversion coating has the potential to achieve the same product quality as conventional IVD with a chromate conversion coating.

Project Overview

The scope of this project is to demonstrate the pulsed high voltage IVD system, and justify it as a cost effective, environmentally benign process that can eliminate glass bead peening and/or chromate conversion coatings on IVD aluminum. The new process must meet or exceed existing performance and operational requirements. Information obtained in the execution of this project is directly transferable to DoD repair depots using IVD aluminum coatings. It is anticipated that successful completion of this project will enable depots to

- Reduce the use of hexavalent chromium, leading to reductions in environmental, health, and safety costs
- Reduce labor costs, as associated with glass bead peening
- Reduce the generation of solid waste and its associated disposal costs
- Meet the corrosion requirements of the military
- Maintain or improve the component life cycle.

This project is being completed in four activities. The first activity of the project involved the identification of candidate components that are currently treated using conventional IVD. Environmental, health, and safety (EHS) costs and baseline process operations and costs for these components were captured. Specification and testing requirements based on military specifications MIL-DTL-83488, MIL-C-5541 and MIL-C-81706 were identified as well as additional tests necessary for *CTC* to establish a technical performance baseline. These tests include adhesion, corrosion, metallography, and thickness.

The second activity of the project involved identification of alternatives. Because there are many IVD aluminum systems used throughout DoD repair depots, improved IVD aluminum was identified as an alternative coating system through which large capital investments for new systems could be avoided while reducing environmental impact and production costs. To complement the improvements in corrosion protection, use of a non-chromate pretreatment is desired to obtain environmental improvements. Based on previous studies conducted at *CTC* as well as input from the Stakeholders, non-chromate pretreatments were selected for use in this project. Only those non-chromate pretreatments having shown some success will be tested on the improved IVD aluminum coating. *CTC* also performed a preliminary assessment of the production, quality, environmental, health, safety, and economic factors associated with implementing the non-chromate pretreatment alternatives identified. This information will be used for justifying the use of successful alternatives.

The third activity of the project involves demonstrations of the (1) improved IVD aluminum process and (2) the technology(ies) selected for the non-chromate pretreatments. Demonstration activities have been designed to confirm that the technology(ies) selected can meet depots' repair needs and requirements. Several sets of samples are being produced using conventional IVD aluminum and the improved IVD aluminum, with some panels being glass bead peened. Subsequently, these panels will undergo either a chromate or non-chromate pretreatment. The treatment matrix has been designed as follows:

Conventional IVD aluminum, glass bead peened, chromated
Conventional IVD aluminum, unpeened, chromated
Conventional IVD aluminum, glass bead peened, unchromated
Conventional IVD aluminum, unpeened, unchromated
Conventional IVD aluminum, glass bead peened, non-chromate
Conventional IVD aluminum, unpeened, non-chromate
Improved IVD aluminum, glass bead peened, chromated
Improved IVD aluminum, unpeened, chromated
Improved IVD aluminum, glass bead peened, unchromated
Improved IVD aluminum, unpeened, unchromated
Improved IVD aluminum, glass bead peened, non-chromate
Improved IVD aluminum, unpeened, non-chromate.

The conventional coatings will serve as baseline panels against which all other treatments will be compared.

Standard salt fog tests are being used to evaluate corrosion resistance, and a standard bend test is being used for measuring adhesion. Thickness, coating density, defects, and microstructure are being evaluated using a Scanning Electron Microscopy (SEM). The primary criterion for success is that the improved IVD coating combined with a non-chromate pretreatment must provide equal or greater performance than the chromated conventional IVD coating.

The fourth activity involves technology justification. Tools, such as cost-benefit analysis*, return on investment calculations, estimates of the potential reduction in the use and emission of hazardous materials, and estimates of product quality improvements will be used to obtain necessary cost justification data. This activity will be completed upon successful completion of the technical activities and will be captured in a Justification Report.

*Environmental Cost Analysis Methodology (ECAM^{SM}), Concurrent Technologies Corporation, Johnstown, PA.

Upon completing the four activities, *CTC* expects to continue its efforts through follow-on work, which may include component testing and/or additional testing such as fatigue, hydrogen embrittlement, torque tension, or other specialty testing.

Work Completed

Requirements Analysis Task

CTC personnel performed site surveys at Anniston Army Depot (ANAD), Jacksonville Naval Aviation Depot (NADEP JAX), and Oklahoma City Air Logistics Center (OC-ALC). The surveys were conducted to identify the parts being treated using IVD, the current IVD processing methods, including post-treatments (i.e., glass bead peening and chromate conversion coating), and the associated costs for treating the parts. It was determined that most parts at these facilities are constructed of 4340 steel and are engine parts. Specifically, the parts belong to the M48, M60, M80, F-15, F-18, B-52H, C141 and C18 weapon systems. The treatments applied to the parts typically follow Type I or Type II, Class 3 (0.001" thickness) IVD coating application specifications. Type I treatment involves IVD aluminum coating only, and Type II treatment involves a subsequent glass bead peening and chromate conversion coating. The costs obtained during the site survey will be used in the economic justification activity of this task. All information obtained during the site surveys was compiled into a Requirements Report.

Identify Alternatives

CTC procured a pulsed, high voltage power supply from ISM Technologies, Inc., a division of Cutting Edge Products. ISM fabricated and, working with *CTC* personnel, installed the power supply into the IVD system located in the NDCEE Demonstration Factory in Johnstown, PA. To accommodate the new ancillary equipment, software upgrades were performed to ensure that the system functioned properly with the new, as well as the old, IVD process. ISM provided *CTC* with training on the pulsed, high voltage power supply and the associated control system.

Concurrent with equipment procurement, *CTC* identified and evaluated non-chromate conversion coatings for use with the improved IVD system. Non-chromate pretreatment evaluation was based on past projects conducted by *CTC* and the DOD stakeholders. Once candidate treatments were selected, pretreatment vendors were contacted to obtain information related to their respective processes. Vendor-supplied data were organized into an Alternatives Report that provided a technical description of the process, material properties that can be obtained using the alternative, and advantages and limitations associated with each process. Three proprietary alternative conversion coatings** were selected for this project, in addition to a trivalent chromium pretreatment selected by Navy stakeholders.

Technology Demonstration

The test panels being used for this project are fabricated from 4340 steel to ensure that the coating/substrate interface is representative of that expected for components treated at the DOD facilities. Demonstration activities were designed according to a formal Demonstration Plan. This demonstration plan delineated (1) the activities necessary in demonstrating the conventional improved IVD process and each of the selected non-chromate conversion coating alternatives, (2) the activities necessary for developing the baseline, and (3) testing methods and procedures. Test matrices were created to ensure sufficient data was collected to qualify or disqualify the alternatives.

** Alodine 2000, Henkel Surface Technologies, Madison Heights MI
Rainseal™, Natural Coating Systems, LLC, Martinsville, Indiana
Sanchem's Full Process, Sanchem Inc., Chicago, IL

Although *CTC* has not completed the deposition trials for completion of the test matrix, *CTC* has performed many depositions in an effort to select processing parameters that provide the greatest improvements in coating structure, and, hence, corrosion resistance. The pulse frequency and voltage applied to the parts was varied during these trials. Coatings were deposited to a target coating thickness of 0.3 mils, and no glass bead peening or chromate or non-chromate pretreatments were applied.

Depositions were performed using 2.0, 5.0, 7.5, and 10.0 kV with pulse frequencies ranging from 1.6 to 15.0 kHz, using many combinations of voltage, frequency, and operating pressure. Operating pressures ranged from 1 to 8 mTorr.

Some technical obstacles were encountered and addressed during preliminary trials. Firstly, it was determined that a 15.0 kHz pulse frequency causes the amplitude of the control voltage to be reduced to a point where it can no longer switch the tube, causing uncontrolled pulsing. There are no plans to modify the electronics to provide for a reliable pulsing at 15 kHz. Because the equipment is very reliable up to 10 kHz and the preliminary coating structure and corrosion tests indicate higher pulse rates are not necessary, no further trials will be performed under these conditions. It also should be noted that researchers found that conventional, stainless steel, support bolts used on the parts rack cannot be used during the pulsed, high voltage process. Researchers found that the breakdown voltage of the insulators surrounding the bolts was exceeded at the higher voltages used during processing. Nylon support bolts provided a sufficient insulation path to ensure against short-circuiting during processing.

Samples produced during deposition trials were subjected to corrosion testing per ASTM B 117, where a 5% NaCl salt fog was used. Testing was conducted for 168 hours on the panels, and a standard IVD specimen was used as a baseline. Evaluations were conducted periodically throughout testing to determine the intervals during which white and red corrosion products appeared. Six specimens, representing 5 different processing conditions, performed better than the current IVD process, with varying degrees of improvement. However, in many instances another specimen from the same run performed worse than the conventional IVD process, indicating that the location where the panel is placed in the IVD chamber may have some influence on the coating structure and/or thickness. SEM analysis of the coating topography was performed, with significant differences being noted between conventional IVD coatings and all coatings produced using the pulsed, high voltage method (See Figures 1 and 2). Fracture analysis of the coatings is planned, and is expected to permit further discrimination between the coating trials performed. X-ray diffraction (XRD) was performed on a specimen from each trial. Although detailed analysis of the spectra has not been performed yet, it was noted that some of the coatings deposited by the pulsed, high voltage method displayed slightly broader peaks than conventional IVD, indicating increased disorder and/or smaller grain size. In addition, the different combinations of voltage and frequency produced differences in preferred orientation.

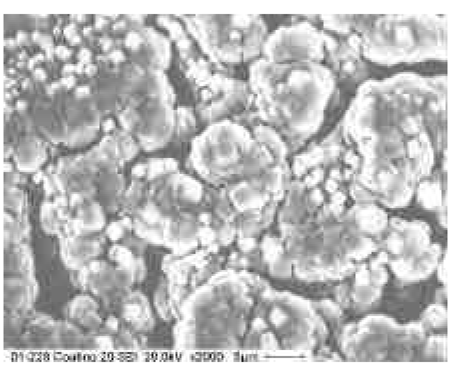

Figure 1. Conventional IVD Coating

Figure 2. Pulsed, High Voltage IVD Coating

Coating thickness was assessed using magnetic means. All of the coatings that demonstrated improved corrosion protection were thinner than the standard IVD coating, as measured using magnetic means. Because all specimens were produced using the same relative deposition rate and duration, it is assumed that the higher voltages and pulse frequencies lead to increased sputter removal of the coating, as is expected. Scanning electron microscopy (SEM) evaluation of the thickness of cross-sections will be used to confirm or disprove this theory and enable researchers to account for sputter removal in the process.

The preliminary proof-of-concept trials provided data that seems to support the original research that showed that the process has the ability to improve the corrosion protection of IVD coatings. Process optimization and subsequent testing will provide the technical justification to proceed or discontinue pursuit of this improved IVD aluminum process. It is anticipated that all demonstration activities will be completed by the time this paper is presented and the results will be compiled in a Demonstration Report.

Summary

Identification of the processing requirements were crucial in establishing a baseline, against which the improved IVD process and non-chromate conversion coating alternatives could be compared. Test results shown previously indicated that the life of the component could be improved, in terms of corrosion resistance, from nearly two-fold to more than three-fold, using the improved IVD process with conventional chromating processes. It is hypothesized that this improvement also can be gained through the use of non-chromate conversion coatings as top coatings. A decreased use of hexavalent chromium also will result in substantial reductions in EHS costs.