Ion Beam and Plasma Based Alternatives to Chrome Plating of Gas Turbine Engine Parts

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

At virtually every DOD facility, the current refurbishment processes for gas turbine engines (GTEs) involves electrolytic hard chromium (EHC) plating. EHC involves the use and release of hexavalent chromium, a human carcinogen. Because of the environmental and health issues associated with hexavalent chromium, the DOD has been searching for alternative methods and/or coatings for repairing worn surfaces. This presentation will discuss a National Defense Center for Environmental Excellence (NDCEE) project that is investigating ion beam and plasma-based deposition and surface modification techniques that can reduce or eliminate EHC operations. Ideally, a repair process/material combination may only need to be applied once during the life of the repaired part.

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

Virtually every military gas turbine engine (GTE) system in service utilizes electrolytic hard chromium (EHC) plating in engine overhaul operations. The Navy, Army, and Air Force repair facilities use EHC in GTE maintenance operations to restore the dimensions of worn or corroded parts and to provide a wear and corrosion resistant surface. This process involves the use and release of hexavalent chromium, a known human carcinogen. During plating, acid mists, which contain hexavalent chromium, are released to the atmosphere. These mists pose a health risk to nearby workers. Therefore, the Occupational Safety and Health Act (OSHA) has imposed a permissible exposure limit (PEL) on hexavalent chromium at 0.1 mg/m^3 and is considering reducing that PEL to 0.0005 mg/m^3. Chromium compounds are also targeted by the United States Environmental Protection Agency (EPA). The EPA is striving to have their own health standard in which guidelines on training and reporting will be required. Complying with regulations has become more difficult, and the trend is expected to continue, thereby increasing the total operational costs of EHC plating.

In addition to environmental concerns with EHC, issues related to long-term maintainability and reliability of DOD systems must be considered. Reductions in funding for national defense has necessitated continued operation of aging propulsion systems in aircraft, ships, and certain military vehicles. Although EHC has been an accepted practice for GTE repair for many years, chromium is not necessarily the best material/process in terms of cost and mission effectiveness. The civil aircraft industry and the DOD have initiated a number of efforts to qualify thermal spray processes that apply superior coatings, such as tungsten carbide, in aircraft and engine manufacture and rework. However, thermal spray processes are limited to line-of-sight applications (simple geometries) and can input a significant amount of heat into small components. It is estimated that these processes cannot accommodate 25-30 percent of the engine parts being refurbished. In addition, processes that are capable of providing surfaces that will perform better than conventional hard chromium are needed. Ideally, a repair process/material combination that only needs to be applied once during the life of the repaired part, is environmentally friendly, and complies with green engine initiative guidelines will be sought. Such a process also may be implemented at the original equipment manufacturer (OEM) level for initial improvements in service life.

The Propulsion Environmental Working Group (PEWG) and Concurrent Technologies Corporation (*CTC)* are collaborating on a project to identify, demonstrate, validate, optimize, and justify alternatives to hard chromium plating. The selected alternative must meet all military requirements. This paper discusses the current status of the project and results obtained to date.

Project Overview

The scope of this project is to demonstrate ion beam and plasma-based deposition and surface modification techniques, and justify them as cost effective, environmentally benign processes that can reduce or eliminate EHC operations. The new process must meet or exceed performance and operational requirements. Information obtained in the execution of this project is transferable to DOD repair depots and OEMs. Successful completion of this project will:

- Reduce the use of hexavalent chromium, leading to reductions in environmental, health, and safety costs
- Reduce the operational costs and labor requirements as a result of eliminating hazardous materials and the associated compliance procedures/processes
- Reduce operator exposure to hexavalent chromium
- Reduce waste generation.

Phase I of this project is being completed in four tasks. The first task of the project involved the identification of the classes of GTE components that are currently EHC plated. Specification and testing requirements based on Federal Specification QQ-C-320B were identified as well as additional tests necessary for *CTC* to establish a technical performance baseline. These tests include adhesion, hardness, thickness, wear, corrosion, profilometry, and metallography. *CTC* and representatives of the PEWG concur that each test must be performed and the results compared to traditional EHC (excluding thickness, composition, coefficient of friction, melting point, and microstructure). Such a comparison is required to determine whether the alternate process is capable of providing a surface of equal or better quality than the EHC coating.

After identifying the requirements, the investigation of alternatives was conducted. Alternatives focused on dry processing methods, including physical vapor deposition, ion beam and laser technologies. Performance criteria of the alternatives were evaluated during the selection process. PEWG preferences were solicited and incorporated into the identification of alternatives, where appropriate.

Based on the findings, PEWG and *CTC* personnel selected the most promising of the technologies evaluated. These technologies will be further investigated through demonstration and validation activities in subsequent tasks.

The third task of the project involves demonstration of the selected alternative processes. Specimens will be treated using the selected technologies. Where possible, the specimens will be treated using the equipment located in the National Defense Center for Environmental Excellence (NDCEE) Demonstration Factory. Otherwise, subcontractors will be used to perform the required services. *CTC* will monitor the progress of each subcontractor and will ensure that quality specimens are delivered. EHC coatings will be obtained and will serve as baseline specimens against which all other treatments will be compared.

Demonstration activities will be designed according to a formal Demonstration Plan. This demonstration plan will delineate: (1) the activities necessary in demonstrating each of the selected alternatives; (2) testing methods and procedures; and (3) responsible activities associated with the demonstrating and testing. Test matrices also will be included to ensure sufficient data are collected to qualify or disqualify the alternatives. At the conclusion of demonstration and testing, a report documenting the results, recommendations, and rationale will be prepared.

Concurrently with demonstration and testing, a technology justification will be performed. *CTC* will use component data to establish an economical and environmental baseline. PEWG will support *CTC* in gathering all such data. The baseline information will include the following:

- Total cost-of-ownership
- Environmental, health, and safety (EHS) costs
- Labor costs associated with chromium rework operations
- Waste generation/disposal costs.

Tools, such as environmentally-based costing*, 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 information will be captured in the Justification Report.

Upon completing the four tasks, *CTC* expects to continue its efforts through follow-on work, which will include Phase II. Implementation plans for each selected, justified technology will be prepared

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

in Phase III. *CTC* anticipates that these plans will include process design, coordinating process design and implementation plans with Army Navy, and Air Force facilities, and identifying logistics and resource requirements. Phase IV will be the acquisition reform stage, which will include the procurement and installation of the chosen technology, as well as training and post-implementation consulting services.

Work Completed

By the time this paper is presented, *CTC* expects to have completed the demonstration activities of the project and a portion of the testing requirements. The Requirements Report and Alternatives Report have been completed, and the most viable technologies have been selected for further consideration. The following describes the activities performed thus far.

Requirements Analysis Task

To acquire all of the pertinent requirements information, many discussions were held with members of the PEWG. Additionally, some requirements information was obtained from the Joint Test Protocol (JTP) entitled "Validation of Advanced Thermal Spray Coatings as a Replacement for Hard Chrome Plating on Gas Turbine Engines." The information gathered through discussions with PEWG members and the JTP was assembled into a Requirements Report. This report contains information concerning the classes of parts in a GTE, the materials of fabrication, and the required performance characteristics for EHC plating.

Many parts are used in a gas turbine engine; however, these parts generally can be categorized into five families of components. Those families are as follows:

- Shafts
- Hubs
- Gears
- Bearing housings
- Accessory gearbox components.

Although a variety of materials are used in the fabrication of GTEs, the most prevalent substrate materials are Inconel 718 (IN718) and 4340 steel. As a result, these materials were selected for test coupons to be used for screening tests. Subsequent treatment and testing of the materials will determine the applicability of the technologies for components fabricated from these materials.

To measure the ability of an alternative to meet the performance requirements of GTEs, the general characteristics of EHC were used as guidelines. Table 1 lists those characteristics.

Table 1. Performance Characteristics

Characteristic	Value
Adhesion (per ASTM D4541)	No flaking, peeling, or blistering when examined after test.
Hardness (ASTM B578)	950-1,050 VHN 68-74 RCH 900 KHN
Wear Resistance (ASTM D4060)	0.004 g loss/1,000 cycles [1]
Corrosion Resistance (per ASTM B117)	24 hours [2]

VHN = Vickers hardness number
RCH = Rockwell C hardness
KHN = Knoop hardness number
[1] Note that Atotech, a major manufacturer of EHC, suggests a common weight loss of 4 mg in the first 1,000 cycles.
[2] Note that the corrosion resistance of hard chromium, with an underlay of nickel, is 96 hours, per QQ-C-320B.

Identify Alternatives

Vendors were contacted to obtain information related to their respective processes. Vendor-supplied data obtained for each of the alternative processes were organized into a Potential Alternatives Report (PAR) 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. Where possible, performance comparisons to EHC plating were made. Eleven alternative processes were analyzed and six were selected for demonstration. Based on the analysis results, the following technologies were selected for investigation.

- Ion beam assisted deposition (IBAD)
  - Plasma Immersion Ion Processing (PIIP)
- Beamline ion implantation, gaseous and metal
- Cathodic arc deposition
- Electron beam evaporation (E-beam evaporation)
- Sputtering
- Surface modifications using lasers*

Technology Demonstration

After submission of the PAR and selection of the alternatives, *CTC* contacted primary vendors of each of the selected technologies to determine an appropriate treatment for obtaining the desired performance characteristics. The coatings include niobium nitride, chromium nitride, chromium oxycarbide, a few varieties of diamond-like carbon, and various metal-bearing carbon coatings. The implants include chromium, titanium/nickel, and titanium into 4340 steel and tantalum, phosphorous, titanium/nickel, and aluminum into IN718.

Summary

Identification of families of components and processing requirements were crucial in establishing a baseline against which the alternative technologies could be compared. The technologies being examined in this sub-task are technologies that are capable of offering next generation coatings. These next generation coatings and surface modifications are being sought to reduce the use of chromium through life extension at the OEM level. In addition, if the next generation coating becomes worn or in disrepair in only a very shallow layer, then that same coating technology may be considered for use in the repair process at the depot level as well.

*Laser Induced Surface Improvements (LISI^{SM}), Surface Treatment Technologies, Tullahoma, TN.