Non-Line-of-Sight Hard Chromium Alternatives

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Abstract

CTC has been working with the U.S. AFRL through the National Defense Center for Environmental Excellence (NDCEE) contract to evaluate alternatives to hexavalent chromium electroplating for non-line-of-sight applications (NLOS). These include parts with complex geometries, such as internal diameters, blind holes and other features that are not amenable to line-of-sight surfacing techniques. Environmentally acceptable electrochemical alternatives to hard chromium plating were identified for such applications based on the needs of Air Force Air Logistics Centers (ALCs). All available alternatives were compared to hard chromium plating, each other, and criteria that was identified by the ALCs as being high priority. A decision tool was developed to assist in the selection of alternatives. All selected alternatives are being tested during demonstrated activities. Screening tests include relatively simple and somewhat inexpensive tests that can adequately discriminate between alternatives, and subsequent tests that are increasingly more complex and expensive, but that will enable further discrimination. This paper describes the demonstration activities performed to date and the test data that have been generated as a result.

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Introduction

The U.S. Air Force Research Laboratory and Concurrent Technologies Corporation (*CTC*), through the National Defense Center for Environmental Excellence (NDCEE), have been investigating potential alternatives to hexavalent chromium electroplating. Hexavalent chromium has been used extensively to finish surfaces due to its physical properties and decorative appeal. However, the use and disposal of hexavalent chromium is strictly controlled by federal and state regulatory agencies, making the search for viable alternatives to hexavalent chromium electroplating a high priority.

The task has targeted non-line-of-sight (NLOS) components that are not amenable to high velocity oxygen fuel (HVOF) technology, which is being implemented for simple geometry components. NLOS components are those parts that have complex geometries, such as blind holes, crevices, and internal diameters. The goal of the project is to implement the most viable alternative at the Air Force Air Logistic Centers (ALCs), where large amounts of hexavalent chromium compounds are used for hard chromium electroplating operations.

Project Overview

The scope of this project is to identify, demonstrate, validate, and implement alternatives to hexavalent hard chromium plating processes for NLOS applications at the ALCs. The following goals must be met:

- Reduce worker health and safety risks by reducing, eliminating, or improving the control of hazardous materials
- Reduce or eliminate the generation of hazardous waste
- Reduce or eliminate the release of hazardous materials into the environment
- Maintain production rate and part quality while minimizing maintenance requirements
- Maintain or minimize life cycle costs as compared to current plating operations.

This task is being completed in four (4) phases with each phase consisting of a series of tasks. The first phase of the project, which was comprised of two tasks, has been completed. The first task of Phase I involved the identification of NLOS components that are hard chromium plated by the Air Force ALCs. Included in the identification was an analysis of the part requirements and/or process constraints related to treating the NLOS components. Upon identifying the requirements, data was collected to characterize the size and quantity of components that currently are being hard chromium plated at the ALCs.

Concurrently with the identification of requirements task, an investigation of potential alternatives was conducted. The search was limited to electrochemical processes and/or processes that are readily available and relatively simple to implement at the ALCs. ALC preferences were solicited during the site surveys and were incorporated into the identification of alternatives efforts. Preliminary assessments considered performance characteristics, production capabilities, quality factors, capital costs, economic impacts, and environmental, health, safety factors associated with each of the alternative technologies identified. Based on the findings, Air Force personnel selected the most appropriate processes. These processes will be further investigated through screening and validation testing in subsequent phases of the project.

The second phase of the project involves screening and validation testing, technology justification, and process implementation planning. Testing activities will be conducted according to test plans developed by the NLOS team members. This includes review by technical representatives from the ALCs, original equipment manufacturers (OEMs), representatives from other organizations studying alternatives to hard chromium plating such as the Propulsion Environmental Working Group (PEWG), HCAT, and other members of the engineering community. The test plan(s) will identify specific process conditions that must be controlled, as well as delineate (1) test concepts, objectives, and requirements to be satisfied; (2) testing methods and procedures; (3) activities associated with the testing; (4) required test measures; and (5) recording procedures that will be used. Test matrices also will be included to ensure sufficient data are collected to characterize the alternatives identified in previous phases of the project. At the conclusion of testing, a report documenting the test results, recommendations, and rationale will be prepared.

Concurrent with screening and validation testing, a technology justification will be performed. The technology justification will determine the economic and environmental impact of implementing the alternative process(es). This information will determine if implementation of the alternative process(es) can be justified. The Environmental Cost Analysis Methodology (ECAM^{SM}) tool will be used to determine the impact of implementing the alternatives that pass screening and validation tests.

Upon completing Phase II, *CTC* will proceed to Phase III. During this phase of the task, *CTC* will develop implementation plans for each selected, screened, validated, and justified technology. *CTC* anticipates that Phase III activities will include process design, coordinating process design and implementation plans with ALCs, and identifying logistics and resource requirements.

Following Phase III, *CTC* intends to complete Phase IV through follow-on work. Phase IV is the implementation stage, which will include the procurement and installation of the chosen technology(ies), as well as training and post-implementation consulting services.

Work Completed

CTC has completed the first phase of the project. Both the Requirements Report and Alternatives Report have been completed, and seven (7) viable technologies have been selected for further consideration. The following describes the activities performed and results obtained during Phase I.

<u>*Requirements Task*</u>

CTC personnel performed two site surveys at Oklahoma City Air Logistics Center (OC-ALC), Ogden Air Logistics Center (OO-ALC), and Warner Robins Air Logistics Center (WR-ALC) to identify NLOS chromium plated parts, the coating requirements for those parts, and relevant processing methods for each part. Through these investigations, it was determined that 20-40% of the chromium-plated parts are NLOS components. All identified NLOS candidates were catalogued and the processing methods were defined for each component. The individual components ranged in size, geometry, and substrate composition.

In addition to obtaining NLOS part information, current ALC processing methods and part characteristics were identified. In general, it was found that most current rework processes follow similar sequences, and that part characteristics were a combination of the requirements identified in the Federal Specification for Chromium (Electrodeposited) (QQ-C-320B) and the functional, production, and environmental needs and concerns, as identified by ALC production engineers and equipment operators.

Federal Specification QQ-C-320B is referenced by most process instructions for the components identified at the ALCs. Therefore, the criteria outlined in this specification were used to evaluate each of the alternative processes. Other characteristics and considerations that were deemed to be important by ALC personnel and the NLOS team, included anti-galling characteristics, removal and processing times, coating properties (i.e., quality, rms finishes), hazardous/toxic nature of the coating, processing and capital costs related to the coating, hydrogen embrittlement elimination, and compatibility with existing plating equipment.

Additional requirements identified by the NLOS team included 1) the ability to remove or grind the coating, 2) the reproducibility of the process, and 3) property data such as wear and corrosion resistance, coefficient of friction, and fatigue life of the coating. The baseline data used for comparison is listed in Table 1.

Table 1. Performance Characteristics

Characteristic	Value
Microhardness (per ASTM B-578)	950-1050 VHN 68-74 RCH 900 KHN [1]
Corrosion Resistance (per ASTM B117)	24 hours (per ASTM B-117 salt spray testing) *
Wear resistance (per ASTM D 4060)	0.004 g loss/1,000 cycles [1]
Coefficient of Friction	0.5 [2]

Alternatives Task

A market survey, including a literature search and discussion with vendors and researchers, was conducted to identify available alternatives to hard chromium plating. Vendors were contacted to obtain information related to their respective processes. Information also was obtained through material safety data sheets, technical data sheets, and a survey requesting specific process and product data. In addition, articles that focused on hard chromium alternatives were reviewed for their applicability to NLOS issues. Those articles that offered pertinent information were summarized and efforts to retrieve additional information from the authors were made.

After reviewing the potential alternatives, the alternative processes were separated into three categories: (1) commercially available alternatives, (2) alternatives approaching commercialization, but require some development, and (3) alternatives in the research phase. Alternatives were categorized based on information obtained from the vendor/researcher of the process/coating. Information was gathered about each process/coating, the physical and mechanical properties of the coating, the environmental impacts of the process, ability of the coating to be reworked, the ability of the coating to restore dimensions, and the process limitations and/or advantages. Capital and operating cost information also was gathered when available.

The findings of the alternatives search was assembled into the Identification of Alternatives Report. It discussed each alternative process and provided comparisons of each alternative to that of hexavalent chromium plating.

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* The corrosion resistance of hard chromium, with an underlayer of nickel, is 96 hours, per QQ-C- 320B.

To evaluate and compare the alternatives, a matrix of the characteristics of the alternatives was developed. The matrix highlighted data voids. Where no data were present for a particular alternative, the vendor(s) were contacted again to attempt obtain the missing data. The matrix provided a searchable database of the alternatives and their engineering characteristics.

Four primary requirements were identified that each alternative process must meet to be considered for ALC use. They were:

1. The alternative must be readily available and easily implemented at the ALCs.
2. The alternative must adhere to steel substrates.
3. The alternative cannot contain any form of chromium (e.g. trivalent chromium).
4. The alternative must be able to plate to a thickness of two mils or greater.

Any alternative that did not meet any one of these four requirements was eliminated from further consideration.

Based on the remaining information in the matrix, a tool was developed to analyze the remaining alternatives and determine the most viable alternative(s) for this task. The engineering data were given ratings of 3, 2, or 1, where 3 equated to "exceeds requirements," 2 equated to "meets requirements," and 1 equated to "does not meet requirements." For example, an alternative that displayed a hardness value that was lower than hard chromium would receive a rating of 1.

The characteristics being evaluated were then weighted to reflect the importance of each criterion; i.e., a multiplier was assigned according to the importance of the criterion. The importance of each criterion was established by input, quantified by surveys, from key personnel involved with this project, which included members of the HCAT and the PEWG, and representatives from the ALCs, OEMs, and AFRL.

A final score for each alternative was determined by multiplying the rating of each characteristic by the ranking of that characteristic. The alternative processes were then ranked from high to low. The findings were submitted to AFRL to select those processes that will be evaluated during the demonstration activities.

Selection

The coatings identified were primarily nickel-based processes, and specifically electroless nickel (EN) coatings. The majority of the non-nickel alternatives that were identified are in the research and development stage. The nickel-based alternatives included conventional, electroless nickel phosphorous and electroless nickel boron coatings as well as composite and alloy coatings. Many of the composite or alloy coatings involved the codeposition of polytetrafluorethylene (PTFE), tungsten, silicon, silicon carbide, diamond, boron nitride, inorganic powders, boron and phosphorous, CF_x (a product formed by reacting coke with fluorine), and combinations thereof. In addition, two commercially available non-nickel alternatives were identified, which included a polymer-based product and a cobalt-tungsten alloy.

The NLOS team met in January 2000 to select the technology (ies) that would be evaluated in Phases II and III of the NLOS Project. The Air Force set minimum requirements that each alternative needed to demonstrate to be considered a viable alternative for NLOS applications. The technologies that were selected for Phase II evaluation include two (2) electroless nickel phosphorous processes, one (1) electroless nickel boron process, one (1) electrolytic nickel-tungsten technology, one (1) electroless nickel silicon carbide composite, one (1) electroless nickel composite diamond coating, and one(1) nickel-based nanoparticle electrodeposition process.

Summary

The identification of the part and processing requirements was crucial in establishing a baseline against which the alternative coatings could be compared. The interaction with the HCAT, PEWG, AFRL, and the ALCs was extremely helpful in establishing the method and prioritizing the criteria used to evaluate each of the alternatives and compare them to hard chromium plating. In Phase II of this project, which will have commenced by the time of publishing this paper, screening and validation tests will be accomplished to further evaluate the selected processes.

By the time this paper is presented, *CTC* expects to be in process of conducting testing and evaluation activities.

References

[1] Personal communication with Dr. Donald Snyder of Atotech U.S.A. in October, 1999.
[2] Walter, K.C., et.al, “Increased Wear Resistance of Electrodeposited Chromium Through Applications of Plasma Source Ion Implantation Techniques”, Surface Coatings Technology (preprint), p. 14.