Air Force Efforts to Identify and Evaluate Emerging Technologies

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The U.S. Air Force has implemented a variety of environmentally acceptable materials and processes that have greatly increased pollution prevention and reduced compliance burdens. However, regardless of these advances, there remain a number of maintenance and sustainment activities that use hazardous chemicals and/or involve polluting processes for which more environmentally friendly alternatives have not been identified. To remain aware of the wide range of emerging technologies and evaluate their applicability for Air Force operations, the Air Force Research Laboratory (AFRL) and Concurrent Technologies Corporation (*CTC*) established an effort to evaluate specific technologies through small-scale testing and analysis efforts. The analyses assess the technologies' viability as potential solutions that can reduce or eliminate the Air Force's compliance burden and its reliance on hazardous materials and processes. Typically, the work that is conducted includes laboratory-scale testing to confirm manufacturers' performance claims and to determine if the product is worthy of further demonstration/validation and/or technology transition activities.

Over the past three years, this task has investigated alternatives to chromium and cadmium electroplating, cadmium brush plating, and "cold" thermal spray processing compared to high velocity oxygen fuel thermal spray technology. There are a number of new technologies that are planned for evaluation.

This paper will focus on the general investigative approach, as well as explain the status of each investigative effort. Information related to the approaches employed, baseline and alternative information found, and test results obtained will be discussed, depending on the progress made on each effort at the time of presentation.

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BACKGROUND AND OBJECTIVE

The U.S. Air Force operates Air Logistics Centers (ALCs) to maintain and refurbish military equipment and components. The ALCs conduct a wide variety of activities, such as routine maintenance, resurfacing, part refurbishment, and dimensional rebuilding, among others. Some of the activities completed at the ALCs are ones that use hazardous materials and/or have various compliance, performance, cost, and/or environmental, health and safety issues associated with their use. While the Air Force has made significant progress in the area of implementing environmentally advantaged materials and processes for a variety of applications, there are a number of maintenance and sustainment activities that currently use hazardous chemicals and polluting processes. For these activities, there are needs to identify and evaluate potential alternatives and then recommend those that are found to be viable for validation and implementation into ALC operations.

Remaining cognizant of the wide range of emerging, innovative technologies and determining their applicability for Air Force needs is an ongoing task that requires significant effort. The Air Force has been actively involved with the search for viable process and material alternatives to replace hazardous materials, and a number of possible technologies have been identified. However, in order to determine the potential advantages of implementing these technologies, testing and evaluation activities are needed to determine if the technologies are applicable for Air Force operations. To support the Air Force with its investigative efforts, the Air Force Research Laboratory (AFRL) tasked Concurrent Technologies Corporation (*CTC*) to establish the "Alternative Technology Identification and Evaluation Screening" task (informally referred to as Task 56) to evaluate several, potential technologies that may have the ability to reduce or eliminate the Air Force's compliance burden and reliance on hazardous materials and processes.

PURPOSE OF WORK

Task 56 was established to conduct short-term, minimal cost evaluations of potential alternative processes for specific technology areas, as identified by the Air Force. The types of analyses completed under Task 56 include investigative studies to assess the availability and maturity of the technology under investigation; screening testing to confirm manufacturers' performance claims and to determine if the technology would be worthy of further demonstration/validation and/or technology transition activities; and reporting efforts to document the activities and results that were completed for each technology that was evaluated.

To date, Task 56 has focused on conducting efforts for six types of interest areas, which include:

- Electroplated hard chromium (EHC) alternatives and enhancement process
- Cadmium plating alternatives
- Cadmium brush plating alternatives
- Cold spray technology

- Establishment of EHC Taber Wear Resistance Baseline
- Joint Group on Pollution Prevention (JG-PP) support.

In all instances (excluding the last area), Task 56 has assessed potential alternative capabilities and used the results to determine if the processes under investigation are applicable for Air Force operations. This paper discusses the efforts that have been completed under Task 56, presents the status of current work, and briefly outlines planned activities.

COMPLETED WORK

As mentioned above, Task 56 has focused on six areas. Five of these areas are considered technical efforts and the sixth area support services. The sixth area was added to the scope of Task 56 to provide *CTC* with a means of supporting JG-PP efforts focused on the application and analyses of powder coating alternatives and the completion of a Joint Test Report for oxygen line cleaning. These JG-PP efforts were completed in 2002 and will not be discussed at any further length in this paper. For additional information related to these topics, visit the JG-PP website at www.jgpp.com.

The technical efforts that *CTC* has completed for the EHC, cadmium plating, cadmium bush plating, and cold spray technology areas, to date, are summarized in the following tables (Tables 1 – 4, grouped by technical area focus). The information presented for each technical area shows the types of alternatives that were investigated and summaries of results. It is important to point out that in all cases, testing and analyses were conducted on vendor-coated specimens. This is a key aspect of Task 56. The task was purposely established to confirm vendor claims and assess the products' applicability for Air Force applications; therefore, vendors were engaged from the start of each investigative effort. *CTC* arranged processing dates, supplied the test specimens to the vendors, and paid all vendor-related processing fees all in efforts to obtain the "best[1]" coating for evaluation.

Alternatives to EHC plating were investigated under Task 56 as a complimentary effort to the Air Force's "Non-Line-of-Sight (NLOS) Hard Chromium Alternatives[2]" initiative that was started in 1998. The AFRL and *CTC* received information indicating commercial advances had been made in the arena of EHC alternatives since the start of the NLOS effort. Because the NLOS task's alternative identification efforts were closed, the Air Force directed *CTC* to evaluate some of these new processes under Task 56. These newly identified EHC alternatives were being investigated for possible inclusion in the NLOS project; therefore, they were subjected to the same testing that had already been completed for the originally selected alternatives. This approach was taken to

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[1] It is believed that because the vendor is intimately familiar with their process, the "best" coating would be obtained by having them deposit it. This approach also eliminated any processing discrepancies that may have occurred in the event that a third party deposited the coatings.

[2] For more information related to the NLOS Initiative, please contact either Mr. Joseph Kolek, AFRL/MLSC, at 937-656-5700 or Ms. Milissa Pavlik, *CTC*, at 814-269-2545.

ensure that all of the data were comparable. To date, *CTC* has evaluated three EHC plating alternative processes via Task 56. The results of these evaluations are shown in Table 1. Based upon the test results obtained and coordination with the various vendors, *CTC* recommended that all three of the processes (electroless nickel-boron [ENB] and two electrolytic nickel-cobalt [EN-Co] processes) be considered as candidates for NLOS project. The ENB process is currently considered viable for inclusion in the NLOS project, and the EN-Co processes are still under investigation. The EN-Co processes are interesting because of their electrolytic nature; however, per vendor feedback these processes may still require further optimization to provide the best coating for steel substrates. As noted in Table 1, *CTC* does intend to subject the EN-Co (2) process to hardness, composition and profile testing.

Table 1. EHC Technical Area – Work Completed

Evaluation Criteria	Alternative Processes		
	Electroless, Ni-B	Electrolytic, Ni-Co (1)	Electrolytic, Ni-Co (2)
Thickness	PASS	PASS	N/A
Quality	PASS	PASS	PASS
Composition	PASS	PASS	TBD
Hardness (KHN)	842 - 959	828 - 846	
Profile	PASS	PASS	
Adhesion	PASS	FAIL	PASS
Taber Wear Resistance	13.1	10.8	15.4
Grinding	PASS	N/A	

Per Air Force input, the ALCs conduct cadmium electroplating in accordance with Federal Specification QQ-P-416F, *Plating, Cadmium (Electrodeposited)*. Therefore, a viable alternative must be one that meets the requirements outlined within this specification, as well as not negatively impacting the processing workload. The alternatives that *CTC* investigated for the cadmium plating technical area include an aqueous-based coating that is extensively used in the automotive industry and an innovative dry process that was recently designed by an original equipment manufacturer (OEM). These processes and their respective test data that was obtained during Task 56 are shown in the following table. Based on the data, *CTC* did not recommend that the Air Force further consider these processes, at the present time. The dry process developed by an OEM was found to still be in stages of research and development (R&D) and not ready for commercial use. The water-based process was eliminated from consideration based on the data collected; however, the vendor claims that the testing results obtained are not typical of the performance expected of this coating.

Table 2. Cadmium Plating Technical Area – Work Completed

Evaluation Criteria	Alternative Processes	
	Aqueous-based Coating	Dry Process
Thickness	PASS	FAIL
Adhesion	FAIL	FAIL
Corrosion Resistance	FAIL	FAIL
Hydrogen Embrittlement	PASS	N/A
Quality	PASS	PASS
Organic Paint Adhesion	N/A	FAIL

For cadmium brush plating operations, the ALCs follow Federal Specification QQ-P-416F, *Plating, Cadmium (Electrodeposited)* for general guidance in addition to Military Standard 865C, *Selective (Brush Plating), Electrodeposition*. The Air Force permits brush plating operations to be conducted at their repair depots as well as within the field. Therefore, potential alternatives must be ones that can be applied either at the ALCs or in the field. Under Task 56 and per the direction of AFRL personnel, *CTC* investigated two types of possible cadmium brush plating alternatives – zinc-nickel (Zn-Ni) and tin-zinc (Sn-Zn), as outlined in Table 3. These technologies were found to be available from two vendors. One is commercially available and other, a nano-composite based formulation, which is still in the research phase. Based on the findings of this evaluation, *CTC* did not recommend any further analyses or consideration be given these products by the Air Force.

Table 3. Cadmium Brush Plating Technical Areas – Work Completed

	Process Type --------- Post Treatment			
Evaluation Criteria	Zn-<20%Ni ---- Chromate No HE relief	Sn-20%Zn ---- Chromate No HE relief	Zn-<20%Ni ---- None	Sn-20%Zn ---- None
Corrosion Resistance	FAIL	FAIL	MIXED (4 fail, 2 pass)	FAIL
Hydrogen Embrittlement	FAIL	FAIL	MIXED (2 fail, 4 pass)	FAIL
Adhesion	FAIL	MIXED (3 fail, 1 pass)	MIXED (1 fail, 5 pass)	FAIL
Thickness (average mil)	0.6	0.4	1.0	0.4
Hardness (KHN)	291.9	N/A	167.7	N/A

The primary coating that is currently being considered as an alternative to EHC plating for line of sight applications is tungsten carbide cobalt (WC-Co), applied via the high velocity oxygen fuel (HVOF) thermal spray process. The HVOF process has been investigated for more than eight years by the DOD's Hard Chrome Alternatives Team (HCAT) and has started to be implemented at a variety of DOD locations. Evaluations of HVOF-applied WC-Co coatings have shown that these the coatings will crack, spall, and delaminate when the substrate is subjected to stresses in its higher operating range. It is possible that the high temperatures that the coating experiences as a result of the HVOF process may be a primary cause for the poor coating integrity. In attempt to address the coating integrity issue associated with HVOF technology, AFRL/MLSC became interested in the capabilities of cold spray processing. The cold spray process, in general, is similar to HVOF except it does not require high temperatures for application. To compare the technologies, AFRL personnel requested that *CTC* investigate the coating integrity and other performance characteristics of cold spray processes, as compared to HVOF-applied WC-Co. As part of this effort, *CTC* identified five cold spray processes for analysis. The coatings were applied by the vendors and subjected to a series of screening tests, as presented in Table 4. Coating integrity results are shown by photographs of coatings evaluated by AFRL/MLSC. These pictures are shown in Figure 1.

Based on these results, AFRL and *CTC* personnel believe that the processes applied by Vendors B an E offer the most promise to apply a WC-Co coating to high strength steel that will provide acceptable performance at higher stress levels. Vendors B and E were the only vendors evaluated that were able to apply a WC-Co coating that might be acceptable for to Air Force depot maintenance activities. Vendor B's process preheats the sprayed particles to temperatures below their melting point so it is not a true cold spray process; however, this process provided a coating that exhibited coating integrity similar to EHC and passed all testing criteria. Vendor E's process is of interest to the Air Force because it applies the coating at room temperature and it is believed that, with some optimization, coating performance can be enhanced. As a result of this effort, the AFRL intends to conduct a comprehensive evaluation of these two cold spray processes.

Table 4. Cold Spray Technical Area – Completed Work

Test	Vendor A	Vendor B	Vendor C	Vendor D	Vendor E
Coating Composition	WC 35Co	WC 17Co	Cr3C2-25NiCr	Zn/Al/Cu/Al_2O_3 (layered)	WC 15Co
Spray Particle Temp (F)	300-575	2,300-2,375	200-490	70-125	< 1,000
Thickness	PASS	PASS	PASS	PASS	PASS
Microhardness	FAIL	PASS	FAIL	FAIL	FAIL
Metallographic Characteristics	FAIL	PASS	FAIL	FAIL	PASS
Coating Integrity	FAIL	PASS	FAIL	FAIL	FAIL

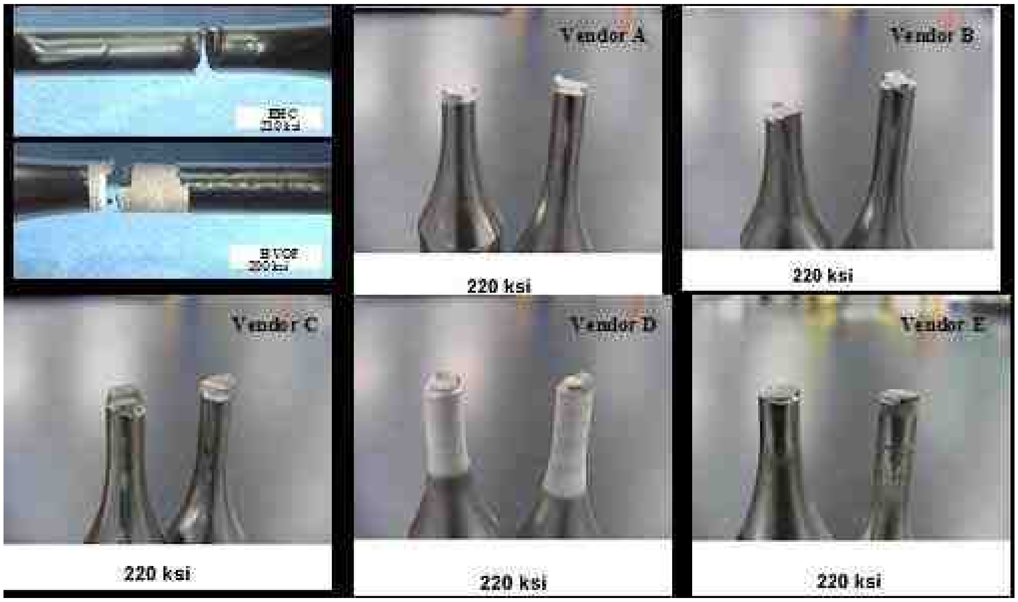

Figure 1. Cold Spray Coating Integrity Results

In addition to the technical alternative evaluations, *CTC* established a Taber wear resistance baseline for EHC, per the direction of AFRL personnel. To validate replacement technologies their performance capabilities must be evaluated. Because EHC plating is often used to provide a wear resistant coating, potential alternatives are commonly tested for their ability to provide protection in wear situations. The Federal specification for EHC (Federal Specification for Chromium (Electrodeposited) (QQ-C-320B)/Aerospace Material Specification (AMS-QQ-C-320)), does not provide a wear resistance requirement. Therefore, the wear resistance of potential alternatives must be compared to previously published data, expert input, and/or baseline test data. An initial Taber wear baseline of 4 milligrams (mg) loss per 1,000 cycles was provided by a commercial company in 1998, in support of the NLOS project. New figures from 2002, showed EHC losing approximately 24 mg per 1,000 cycles, about six times the initial estimate. It became apparent that a true baseline wear index fort EHC coatings needed to be established. During Task 56, *CTC* subjected EHC-coated (deposition performed by Oklahoma City ALC [OC-ALC]) to Taber wear resistance testing. Test results revealed that EHC wears at an average rate of 2.06 mg loss per 1,000 cycles, which equates to a 2.2 wear index. The work conducted in this effort was to establish a valid metric to which the wear performance of EHC plating alternatives could be compared. As major participants in the NLOS project, OC-ALC personnel informed AFRL and *CTC* personnel that as a general rule of thumb, a coating that exhibits a Taber wear index of 10 or less is considered a viable alternative.

WORK IN-PROGRESS

Currently, as a part of Task 56, three other potential EHC alternatives are under investigation. These processes include a nickel alloy and two nickel composite coatings (diamond and silicon carbide, respectively). At the time this paper was developed, the three processes were being applied by their respective vendors. Upon arrival of the vendor-coated panels, *CTC*, in cooperation with the University of Dayton Research Institute (UDRI) at AFRL, will subject the coatings to screening tests. Planned testing includes hardness, adhesion, thickness, composition, Taber wear resistance, and quality.

PLANNED EFFORTS

AFRL and Air Force Materiel Command (AFMC) personnel have requested that *CTC* investigate a laser-based process for its possible viability to act as an EHC enhancement process. At the time this paper was developed, *CTC* was in the midst of outlining activities to evaluate the process as well as working through vendor needs and involvement. The process is from an overseas company, thus logistic considerations also will play a major role in this evaluation. Currently, the focus of this planned activity will be on enhancing the performance of EHC alternatives that, as deposited, may not be able to meet performance requirements without heat treatments that are not acceptable for high strength steel. This evaluation will focus on the use of laser-based processing as the post treatment to enhance coating performance. It is proposed that the laser process will be able to modify the coating's properties without having any negative effect upon the high strength steel substrate. This activity is planned for a 2004 start.

Another effort that is currently planned for Task 56 work is the assessment of an Air Force aircraft topcoat paint additive that is expected to enhance the cleanability of the coating. This work is currently planned to prepare test panels using various primers and topcoats with the selected additive and subject them to cleanability assessments as outlined in Mil-PRF-85285 Cleanability Specification. Testing activities are expected to be completed by UDRI at the AFRL. This work also is planned to start in 2004.

SUMMARY

The Task 56 effort has allowed the Air Force to investigate a variety of innovative and emerging processes for numerous technical areas. The evaluations that have been completed and are planned under Task 56 are true screening activities that require minimal time and investment. Results from Task 56 efforts have provided the Air Force with justification to pursue some technologies, while determining that others are not worthy of further investigation.

To date, the Task 56 effort has proven to be successful and viable. A major component to the success of this effort includes the vendor participation that is integral to every evaluation. This approach ensures that the "best" alternative is tested and eliminates discrepancies that may occur if someone other than the vendor prepares test specimens. Further, vendors have provided useful feedback concerning testing results that has enhanced the Air Force's ability to make technically sound determinations. Yet, the likely greatest key to the success of Task 56 has been the regular communications between Air Force and *CTC* personnel. By discussing efforts regularly, the focus of testing efforts is always up to date and never misunderstood. By having direct Air Force support, *CTC* has been able to easily gain ALC feedback, freely work with MLSC/UDRI to increase the task's testing capabilities, and improve internal activities to better support the DOD's needs.