Minimization of EPA 17 Hazardous Chemicals in Plating Shop
at Tinker AFB
Glenn Graham, Mike Patry & Patti Shreve
Tinker AFB, OK

The electroplating shop in the Oklahoma City Air Logistics Center uses a variety of hazardous materials to restore worn dimensions and provide corrosion protection to engine and aircraft parts. In the past many coatings were specified automatically for certain applications. Today, the environmental impact is also taken into account. We consider source reduction preferable to recovery or treatment. The specific requirements for each application are identified and alternative processes or substitute products chosen to meet those needs. Secondarily, recovery and treatment techniques are employed. Our policy has been to implement established technology before research and development work is undertaken.

The following is a prioritized list of the hazardous materials that have been targeted for source reduction or elimination:

(1) Cadmium
(2) Chromium
(3) Cyanide
(4) Perchloroethylene
(5) Nickel
(6) Toluene
(7) Xylene

This paper will address each of these hazardous materials delineating the reasons for their use as well as the work currently underway to reduce or eliminate them. Potential problem areas will also be identified in order to help focus future R&D efforts.

Many of the hazardous chemicals have already been reduced or eliminated. Cadmium plating has been virtually eliminated by product substitution of zinc-nickel alloys. Chromium plating has been reduced by several process substitutions. The use of cyanide has been reduced by the substitution of non-cyanide alkaline cleaners and nickel stripper solutions. Spray washers are currently being investigated to replace the perchloroethylene vapor degreasers. A plasma spray process has replaced some of the nickel plating applications. Even though nickel is on our hazardous chemical list, our plans call for its use as a substitute for cadmium and chromium until a less hazardous chemical and/or process is found. We plan to steadily move down our targeted list until none of these chemicals are used.
MINIMIZATION OF EPA-17 HAZARDOUS CHEMICALS IN PLATING SHOP
AT TINKER AFB

Glenn Graham  OC-ALC/LPPNP  Tinker AFB, OK  405-736-2635
Mike Patry  OC-ALC/LPPNP  Tinker AFB, OK  405-736-5185
Patti Shreve  OC-ALC/EMV  Tinker AFB, OK  405-736-7698

The Oklahoma City Air Logistics Center (OC-ALC) is responsible for the repair or
overhaul of many of the Air Force's aircraft and weapons systems. The Propulsion
Directorate at the Oklahoma City ALC operates one of the largest surface finishing
facilities in the United States. The electroplating shop uses a variety of hazardous materials
to restore worn dimensions and provide corrosion protection to engine and aircraft parts.
Over the past several years, many changes have occurred that impact its operation. Air
emission standards have tightened. Allowable exposure limits have decreased. Water
quality standards have increased. Solution and sludge disposal costs have skyrocketed.
And hazardous waste disposal sites have closed. All these changes point to only tougher
restrictions in the future. To meet these tougher restrictions, we must reduce or eliminate
the toxic materials.

At the OC-ALC, the Process Engineering Group in the Propulsion Directorate has been
working in partnership with the Environmental Management Pollution Prevention Group.
The process group has identified and implemented projects that target hazardous waste
minimization. The environmental group has supplied funds and support to manage these
important projects. Together we have been effective in reducing hazardous materials.

Our first step toward developing a hazardous waste minimization program was to identify
the hazardous chemicals. By examining the EPA's top 17 toxic chemicals, we developed
the following prioritized "hit" list:

1. Cadmium
2. Chromium
3. Cyanide
4. Perchloroethylene
5. Nickel
6. Toluene
7. Xylene

Our next step was to define an overall plan. We are working toward meeting our
hazardous waste minimization goals using the following approaches: Source Reduction,
Recycle, Material Recovery, Process Control, and Waste Treatment.

We consider source reduction or elimination of the chemical preferable to all other
approaches as it is the only long-term solution to the hazardous waste problem.
We first identify waste streams that contain toxic chemicals. Second, we identify the
specific requirements for each application that uses the toxic chemicals. Next, we identify
and evaluate alternative processes or substitute products to meet those needs. And finally, we implement the best alternative. We use the following guidelines when planning our source reduction strategy:

1. Source reduction is preferable to recovery or treatment.
2. More than one alternative process could be required.
3. Implement established technology where possible.
4. Proposed substitutes must meet or exceed all functional requirements.
5. Improve production efficiency.
7. Conserve production floor space.

Because source reduction is not always possible, other methods have also been used. Recycling decreases the quantity of toxic chemicals both disposed and purchased. Both purification and rejuvenation and closed loop material recovery are examples of recycling. Process control measures include conductivity-controlled rinses, computerized chemical tracking, dedicated solution-maintenance crews and chemists, and training. The plating shop wastewater pretreatment plant is an example of waste treatment.

We have questioned and re-evaluated past decisions. Many coatings were specified almost automatically for certain applications simply because that is the way it was always done. The specific requirements such as hardness, degree of corrosion protection, wear resistance, etc., must first be identified. Then new processes can be implemented which produce coatings that meet those requirements. A prime example of this philosophy at work is the case of chromium. In the past, chromium was always selected as a build-up material of choice for any high wear, high temperature application. We are now looking at plating nickel alloys as an alternative.

In some cases, we have substituted a one toxic chemical in place of another toxic chemical because either the process is less hazardous or the wastes are more easily controlled. For example, nickel is being used in place of cadmium and chromium for some applications. Our strategy is to incorporate new, less hazardous processes and chemicals into our shops as they become approved. In this way, we plan to steadily move down on our toxic enemies hit list.

Waste minimization is a continuous process. We have made great strides in eliminating or reducing our hazardous chemicals by attacking each chemical one-by-one using the above guidelines as a directive. The on-going refurbishment of our plating shop is proof of our accomplishments. As a result of some of the process substitutions, the total number of plating tanks has been significantly reduced. We are planning for only one chrome plating line instead of two. Likewise, the nickel plating lines have been reduced from four to one and one-half. The cadmium and nickel-cadmium line has been eliminated. The total cost of the refurbishment has been significantly reduced. This reduction has been accomplished without loss of production capability, efficiency, part quality, or surge capacity.
Cadmium

Cadmium was the most toxic metal used in the plating shop and was, therefore, number one on our hit list. It is used to provide sacrificial corrosion protection to steel and high strength steel. Since cadmium is less noble than steel, the cadmium layer corrodes first, protecting the underlying part. Cadmium is a very soft coating and is also limited to low temperature applications. Nickel-cadmium is used where increased erosion resistance and higher temperature limits are required. We eliminated cadmium tank electroplating at Tinker in 1991. Only a small workload of Cadmium brush plating is still being used. We have been successful in substituting several processes for Cadmium and Nickel-Cadmium electroplating.

Cadmium Brush Plating
We presently brush plate low hydrogen embrittlement (LHE) cadmium on aircraft parts such as engine supports. Although this process still uses cadmium, it does have the advantage of using very small quantities of solution (less than 5 gallons). Other corrosion resistant coatings such as zinc-nickel can also be applied with brush plating. The Navy has approved the use of LHE zinc-nickel brush plating. We have requested the Aircraft Material Management engineers to authorize the use of LHE zinc-nickel in place of cadmium brush plating.

Ion Vapor Deposition of Aluminum (IVDAI) Substitution
Ion Vapor Deposition of Aluminum (IVDAI) process is already in widespread use in both civilian and military shops to replace Cadmium and Nickel-Cadmium plating. IVDAI is performed in a vacuum. Aluminum wire is fed into a chamber and vaporized. The positively charged aluminum vapor is attracted to the negatively charged parts thus depositing a very uniform coating of aluminum.

IVDAI coated parts show superior sacrificial corrosion protection with no hydrogen embrittlement. They also have a higher maximum service temperature over cadmium (925 F vs. 450 F). They are good electrical conductors and are compatible with aircraft fuels.

One of the concerns with IVDAI coated parts are with threaded components. Because aluminum has a higher coefficient of friction than cadmium, a higher torque must be applied to achieve the same axial loading. Testing has shown that using an IVDAI-coated bolt with a Cd-Plated nut requires 12% more torque than that required for Cd-plated nuts and bolts. Application of dry film lubricants further reduces this difference to only 8%. Most of our threaded components are approved for either Cd or Ni-Cd and the torque values with IVDAI fall between these. Torque is not critical for compressor tie rods since these parts are tightened to a specified stretch.

Another concern is with internal surface coverage of IVDAI-coated parts. Although not strictly limited to line-of-sight applications. IVDAI is unable to coat the inside of a bore to a depth greater than half its diameter. This problem can be addressed by using paint coatings, zinc alloy, or electroless nickel plating to coat ID’s and recessed areas.
And finally, IVDAI (pure aluminum) and cadmium are relatively soft coatings and are not typically used where erosion is a concern. Nickel-cadmium (Ni-Cd) is much more erosion-resistant. Tests have shown that IVDAI wears about four times faster than Ni-Cd. However, in many applications, the IVDAI coating may be applied thicker, thus minimizing the difference. Testing of alloys of aluminum has not significantly improved hardness or erosion resistance.

**ZINC ALLOY PLATING SUBSTITUTION**

Zinc alloy baths are known to produce coatings with up to 3 times the corrosion resistance of cadmium. The automotive industry uses zinc alloys extensively, particularly zinc-cobalt and zinc-nickel. Boeing has a patented nickel-zinc coating for aerospace applications that meets the specifications of AMS 2417. The Army Material Command has completed a study that shows unchromated zinc-nickel plating (12% nickel) to be superior to cadmium plating. The Material Management Engineers for Propulsion and Aircraft both have taken the above data as sufficient to approve AMS 2417 as a substitute for cadmium plating.

Tinker has been using the nickel-zinc alloy AMS 2417 as an authorized replacement for Cadmium plating since February 1992. Our corrosion tests confirm that the nickel-zinc alloy with 10-12% nickel is superior to cadmium, nickel-cadmium, and IVDAI coatings in salt fog spray corrosion resistance. We also have an on-going research project with a contractor to both validate our practice and to see if our nickel-zinc use could be expanded to cover some of the former nickel-cadmium coated parts. Results are pending.

Chemical conversion coatings, such as chromate, are currently being used, but do not provide any benefit on an operating jet engine. We are using it mainly for quality control and for room temperature storage enhancement. We are actively looking for a non-chromate chemical conversion coating.

**HIGH PHOSPHOROUS ELECTROLESS NICKEL (EN) PLATING SUBSTITUTION**

High phosphorous (10.5 - 12 %) EN plating produces a very uniform coating with almost no porosity. Although it does not provide sacrificial corrosion protection like cadmium or zinc alloys, it does produce a tough barrier that protects the underlying surface. The advantages of EN include:

1. Extremely uniform coverage of complicated geometries.
2. Surface finish of the as-plated coating mirrors that of the base material.
3. Ability to plate to near-final size.
4. Barrier-type corrosion protection.
5. Available technology to plate out remaining nickel from spent baths.
6. Excellent wear/erosion resistance.

The main area of concern with EN is the relatively short bath life. The baths only produce acceptable coatings for about 4 to 5 nickel metal turnovers. The short bath life is due primarily to the buildup of orthophosphate in the solution. This buildup causes rough plating and pitting and causes the deposit to cross over from being compressively stressed to tensilely stressed. Tinker has a research project with a contractor to investigate the
rejuvenation of EN baths. The Stapleton-Infinity Process has been identified and prototype equipment is planned for installation in late 1994. The technology consists of treating a slip stream with a calcium hydroxide to precipitate the orthophosphite, filtering, then sending the filtrate back to the bath.

High Phosphorous (10.5 - 12%) EN coatings are now specified by the Original Equipment Manufacturer (OEM) of aerospace equipment such as Pratt & Whitney for corrosion and erosion protection. Tinker not only uses EN as specified by OEM but also as one of the coatings being used to make up for some of the shortcomings of IVDAI. Since IVDAI does not provide uniform coating of complex geometries and deep narrow inner diameters, EN plating is being used to meet the corrosion requirements for these parts. The other requirement of erosion resistance provided by nickel-cadmium plating can easily be met by EN plating. Corrosion tests at OC-ALC's Material Management Laboratory have shown chromate treated EN plating to be superior to cadmium plating, nickel-cadmium plating, IVDAI coating, and slightly better than regular EN plating. This test data has further expanded the use of EN plating as a cadmium and nickel-cadmium plating substitute.

**CADMIUM STRIP REJUVENATION (CLOSED LOOP - RECYCLE)**

Even though cadmium plating is no longer used by the Air Force, the overhaul of previously processed parts includes the removal of old cadmium coatings. The stripping process generates a concentrated bath and large volumes of rinse waters. Before we closed looped our cadmium stripping operation, we were generating a concentrated stripping bath that had to be periodically hauled off-site for disposal. We were also generating large volumes of weak cadmium rinse water that had to be treated on site. The cadmium would end up in the wastewater treatment sludge that could have limited future disposal options. By close looping the operation, we are recovering the cadmium as a metal that can be sold to refiners. The technology was installed in May 1994 and consists of cadmium removal from strip solutions by ion exchange followed by electrowinning of the ion exchange regenerate solution to recover cadmium metal.

**CHROMIUM**

Chromium plating has survived as a common coating since its beginning in the early 1920's due to its exceptional hardness (up to 68 Rc) and high temperature resistance (up to 1700 F). It is used extensively despite its disadvantages such as poor plating efficiency, undesirable build-up on high current density areas, and slow deposition rate.

We are actively pursuing a multiple approach to the elimination of chromium plating even though our newly refurbished chrome plating line includes a chrome recovery system consisting of a climbing film evaporator and an ion exchange column. This system takes water from the rinse tanks and the scrubbers, concentrates it, removes the impurities, and puts it back into the plating tanks (i.e., recycle - closed loop). Once this system is optimized, we expect it to not only reduce the amount of chromic trioxide purchased each
year but also to eliminate the majority of the chromium that must be removed by the wastewater pretreatment system.

Due to substitutions already in place, we are currently operating our chrome line at 50% of the capacity that we were using in 1988 and we hope to reduce it further. To do so will require a part-by-part re-evaluation of what coating properties are really needed.

**BRUSH PLATING SUBSTITUTION**

Brush plating has been used for many years to apply industrial coatings. Brush plating is already approved to apply nickel coatings on some gas turbine engine parts. We had anticipated using semi-automated brush plating equipment to apply nickel and nickel alloy (such as nickel tungsten) coatings as a substitute for chrome plating. The benefits of brush plating include:

1. Very fast deposition rates due to the close proximity of the anode to the part's surface.
2. Little masking required. Plating occurs only where the anode makes contact with the part. Waxing of the entire part is not required.
3. Capability to plate parts to size. Post machining could be minimized or eliminated due to the extreme precision inherent in the process.
4. A brush plating system can be used to plate a variety of coatings.

Initially contractor tests were positive. Unfortunately, later contractor tests designed to evaluate the suitability of “only commercially available” brush plated coatings as chrome plating substitutes were unsuccessful so efforts were abandoned. This technology may be investigated again if additional brush plating solutions are developed.

**ION VAPOR DEPOSITED ALUMINUM AND HIGH TEMP ALUMINUM PAINTING**

Ion vapor deposited aluminum and high temperature aluminum painting are being used for their corrosion protection on some parts.

**HIGH VELOCITY OXY-FUEL FLAME SPRAY (HVOF) SUBSTITUTION**

HVOF is the newest generation high energy thermal spraying process. Thermal spray refers to any process in which metallic powders are melted and projected against a surface. HVOF uses hydrogen and oxygen as carrier gases traveling at gas velocities up to 1500 cubic feet/hr. This high impact speed produces very dense, hard coatings. HVOF is already approved for the application of wear/erosion resistant coatings and thermal barriers on exhaust nozzles, combustion chambers and compressor blades.

The primary advantages of HVOF over chromium plating are:

1. Much faster coating times. Typical processing time for HVOF is 45 minutes compared to 48+ hours for chrome plating.
2. Greater coating flexibility. Approximately 23 different coatings can be sprayed with one HVOF system. Production floor space is conserved.
3. Much smaller quantities of waste are generated. The overspray can be captured in a wet or dry booth.
4. Coating quality and worker safety are enhanced due to robotics.
5. Masking is greatly simplified. Reusable, bolt-on sheet metal masks are used instead of labor intensive tape and wax.

One drawback to the HVOF process is its restriction to line-of-sight applications. Special nozzles are available that allow coating IDs as small as four inches, but the use of these nozzles creates turbulence that results in lower-density coatings. Since the majority of our chrome plating workload involves OD's, we do not see this as a serious impediment.

As a result of an Air Force Component Improvement Program (CIP) and a contractor engineering study, we recently installed a robotic HVOF system. The engineering study was designed to identify and test HVOF spray powders as potential substitutes for hard chrome plating. The results from the powders tested indicated that HVOF was superior to chrome plating in about 75% of the metallurgical tests. The results also led to the purchase and installation of a robotic HVOF system. Tinker is now in the process of evaluating the requirements on a part-by-part basis to determine when substitution is in order.

**NICKEL ALLOY PLATING SUBSTITUTION**

Electroless Nickel (EN) plated coatings offer very uniform coverage, the capability of plating to near-final size, good abrasion/erosion resistance, and high hardness. We are currently substituting high phosphorus EN (nickel alloy) for chromium on gears and gear shafts. Lower phosphorus EN deposits, with hardness values similar to chromium may be used for additional chrome substitution. We plan to investigate this possibility further. The main drawback with EN plating is the relatively short bath life. As described earlier, we are planning installation of a prototype EN bath rejuvenation system.

We recently received the results of a research project addressing the issue of substituting nickel alloys for hard chrome plating. Three technologies were studied -- Enplate Ni-426 (low-phosphorous EN), AMPLATE (Ni-W-B electroplating process), and TAKADA (Ni-W, SiC composite electroplating process). Overall, the coatings produced by the TAKADA process performed better than the other alternatives. This process produced a coating with good anti-galling effects and improved fatigue debit characteristics over chromium. Also the process deposited thick coatings (>15 mils) at relatively fast rates. The drawbacks of the Takada process were its relatively low hardness and poor wear resistance; but improvement of these characteristics might be possible through process optimization. We plan to follow the work on the Takada process being done at McClellan AFB.

**CYANIDE**

The use of cyanide in the plating shop has been cut by over 95% since 1989 by the introduction of non-cyanide alkaline cleaners and nickel stripper solutions. Non-cyanide cleaners and nickel strippers that we now use cannot be treated in our waste treatment system. The ozone oxidation process that we use to destroy cyanide has no effect on these
solutions so they have to be drummed and hauled off for disposal. We are looking at ways to extend the life of these solutions. We are currently awaiting installation of a microfiltration system to rejuvenate our caustic solutions in our chemical cleaning shop. Once this process is installed and proven, a similar filtration process will be looked at for the plating shop for the alkaline cleaners. The stripping solutions cannot be handled by filtration so we are looking at replacing the stripping process with a high-pressure water jet cleaner-stripper. This is an example of having to implement more than one process to accomplish the goal of source reduction.

The remaining cyanide is used in silver plating and silver stripping solutions. Non-cyanide silver plating solutions are commercially available, but they have not yet been approved by the engine manufacturers. We are currently prototyping one of the silver plating solutions in the Tinker plating shop. A non-cyanide silver stripping solution that allows for recovery of the silver metal is also needed. We currently recover approximately 50 pounds of silver metal per year as silver cyanide. In the event we cannot find a suitable substitute, it would be possible to close-loop the silver plating and stripping operation.

**PERCHLOROETHYLENE**

The plating shop operates two state-of-the-art perchloroethylene vapor degreasers. They have extended, refrigerated freeboards, integrated solvent stills, low-velocity exhaust hoods and a carbon recovery system. These degreasers are used to remove masking wax after nickel and chrome plating. We plan to replace the degreaser wax removal operation with a spray washer (i.e., industrial dishwasher that uses a biodegradable soap). Preliminary vendor tests showed satisfactory wax removal capability. The equipment has been purchased and will be installed late 1994. At that time, prototyping will be done and we expect to be able to eliminate at least one of the perchloroethylene degreasers.

**NICKEL**

Nickel is number five on our hit list. As earlier stated, we plan to use nickel and nickel alloys in place of cadmium and chromium for some applications. We are currently using nickel-zinc as a replacement for cadmium and high-phosphorus EN as a replacement for chrome. We plan to continue investigating the use of other nickel alloys (EN, Takada, etc.) as additional substitutes for chrome.

Most of the major engine cases (including diffusers and intermediates) have been switched from nickel plating to twin-wire plasma spray. This substitution is a perfect example of the importance of questioning past practices and implementing new processes when the coating fits the requirement. Although the two coatings are not the same, the plasma coating met all performance requirements for the application. The result of this effort was a 50 per cent reduction in nickel plating waste and a significant decrease in production time.
TOLUENE & XYLENE

Toluene and xylene are used as solvents for the organisol maskant used in electroless nickel (EN) plating. We are currently looking for alternate water-based maskants. So far, a suitable replacement has not been found which will withstand the temperature of the EN plating bath.