United States
Environmental Protection
Agency

Research and Development

Risk Reduction
Engineering Laboratory
Cincinnati, OH 45268

EPA/600/SR-94/074 May 1994

EPA

Project Summary

Substituting Cadmium Cyanide Electroplating with Zinc Chloride Electroplating

B.C. Kim, P.R. Webb, J.A. Gurklis, and R.K. Smith

The environmental and economic implications of substituting zinc chloride electroplating for cadmium cyanide electroplating were evaluated. The process substitution successfully achieved product quality to satisfy the customer requirements for corrosion resistance. Corrosion resistance was determined by salt-spray tests in accordance with the ASTM Method B117-90. Not only did the process substitution eliminate cadmium and cyanide from the wastes and chlorine from the wastewater treatment process, thereby greatly reducing hazards to plant personnel and pollution of the environment, the process substitution also reduced oil and grease waste. On the negative side, however, the process change increased the generation of wastewater, wastewater treatment sludge, and chromium. For a new installation, the zinc-plating process offers an economic advantage of slightly lower operation cost over the cadmium-plating process.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

This study, performed under the U.S. Environmental Protection Agency's (EPA's) Waste Reduction Innovative Technology Evaluation (WRITE) Program, was a cooperative effort between EPA's Risk Reduction Engineering Laboratory (RREL) and Aeroquip Corporation. The objective of the WRITE program is to evaluate, in a typical workplace environment, examples of prototype technologies that have potential for reducing wastes. Substitution of zinc chloride electroplating for cadmium cyanide electroplating was evaluated at Aeroquip's Industrial Connectors Division* in Van Wert, OH. The goal of this project was to evaluate (1) the effects of the process substitution on product quality, (2) the waste reduction/pollutant reduction effects of the process substitution, and (3) the economics of the process substitution.

The Processes

The cadmium cyanide and the zinc chloride plating processes for the rack plating line at Aeroquip are compared in Table 1. Hydrochloric acid is used to condition parts (shown as step 12 in Table 1) before plating in the zinc chloride process whereas sodium cyanide is used in the cadmium cyanide process. The cadmium cyanide plating line had separate tanks to apply either clear chromate or yellow chromate coatings (steps 18 and 20 in Table 1). Previously, Aeroquip used clear chromate coating on most (90% to 95%) of the cadmium-plated parts. Currently, Aeroquip uses yellow chromate coating on all zinc-plated parts because (1) Aeroquip has adopted a worldwide standardization of yellow as the color for their fittings and (2) yellow chromate coating vastly improves the corrosion protection

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Table 1. Comparison of Zinc Chloride and Cadmium Cyanide Rack Plating Processes

Process Step	Tank No.	Operation: Zinc Chloride Plating Line	Operation: Cadmium Cyanide Plating Line
1	1	Soak clean	Soak clean
2	2	Rinse	Rinse
3	3	Electroclean	Electroclean
4	4	Rinse	Rinse
5	5	Rinse	Rinse
6	6	Hydrochloric acid pickle	Hydrochloric acid pickle
7	7	Rinse	Rinse
8	8	Rinse	Rinse
9	9	Electroclean	Electroclean
10	10	Rinse	Rinse
11	11	Rinse	Rinse
12	12	Hydrochloric acid pre-dip	Sodium cyanide pre-dip
13	13	Zinc plating	Cadmium plating
14	14	Rinse	Rinse
15	15	Rinse	Rinse
16	16	Nitric acid dip	Rinse
17	17	Yellow chromate dip	Nitric acid dip
18	18	Rinse	Clear chromate dip
19	19	Chromate seal	Rinse
20	20	Rinse	Yellow chromate dip
21	21	Drip tank dip	Rinse
22	22	Water-soluble oil dip	Water-soluble oil dip

of the zinc-plated fittings. The yellow chromate solution used by Aeroquip contained approximately a five times greater chromium concentration than did the clear chromate solution. In the water-soluble oil application step (step 22 in Table 1), the concentration of the oil was reduced by a factor of approximately ten in the zinc chloride plating process from the level used in the cadmium cyanide plating process. The change was necessary to obtain improved adhesion of chromate coating during the subsequent heat-curing step.

Rinse water and various cleaning and plating solutions are discharged continuously or periodically dumped from the tanks and treated in an on-site wastewater treatment plant. All wastes from the plating operations eventually are in three waste streams — treated wastewater, dewatered sludge, and waste oil — that are discharged or disposed from the wastewater treatment plant. The treated wastewater is discharged to a sanitary sewer. The dewatered sludge is collected in a 20-yd^3 hopper and sent to an off-site hazardous landfill once a month. The waste oil is collected in drums and sent to an off-site hazardous waste incinerator every 3 mo.

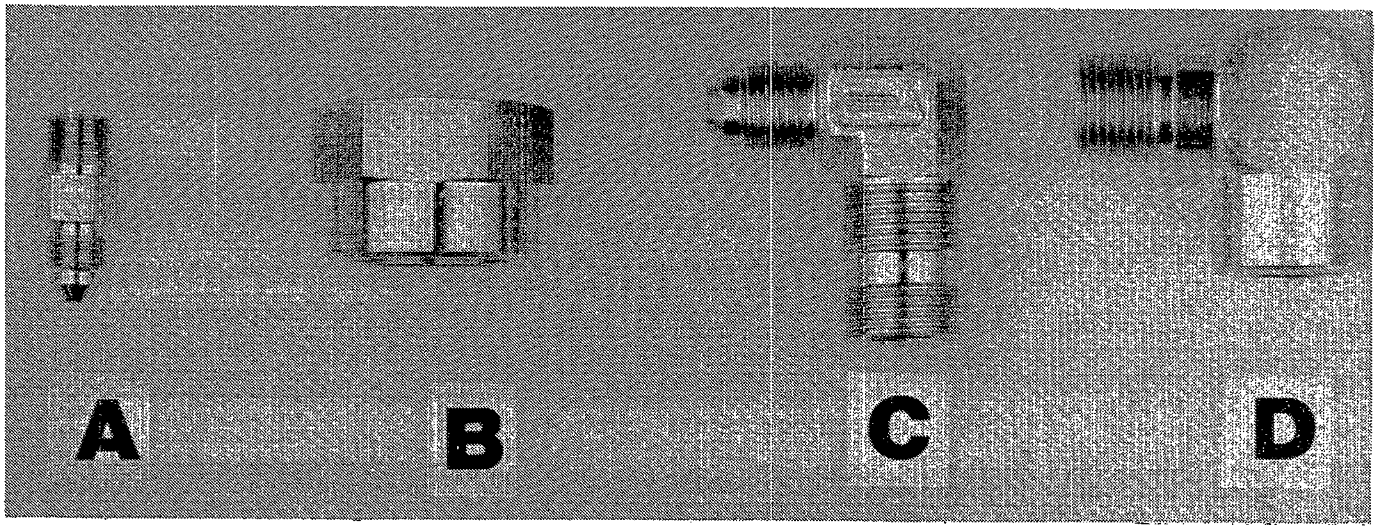
Product Quality Evaluation

Product quality was measured by the corrosion resistance of plated parts determined by salt-spray (fog) tests carried out in accordance with the ASTM Method B117-90 (Standard Test Method of Salt Spray [Fog] Testing). As part of their quality acceptance criteria for zinc-plated parts, Aeroquip's engineering process specification has adopted the ASTM Method B633-85 (Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel) requirement of 96 hr of freedom from white corrosion products in salt-spray testing. Most Aeroquip customers require 96 hr before the first appearance of white corrosion on zinc-plated parts. The process specification for some of Aeroquip's products has an additional internal acceptance criterion (not required by customers) of 360 hr of exposure to salt spray before the first appearance of red rust.

In the first series of tests, four representative types of parts plated with zinc in the rack plating line were tested in parallel by Aeroquip and an independent testing laboratory (Detroit Testing Laboratory, Inc. [DTL], Warren, MI). These parts, shown in Figure 1, included swivel nut (Group B) and three types of adapter (Groups A, C, and D). In the DTL tests, all of the Group A, B, and D specimens were free of white corrosion products at 120 hr, so that the 96-hr requirement of no white corrosion for zinc-plated parts was met. Very slight white corrosion was noted on some Group C specimens at 120 hr. In the DTL tests, all specimens in Groups A, B, and D were free of red rust at the end of the 360-hr observation period; two of the six specimens in Group C showed red rust at the 336-hr and 360-hr observation periods. In the Aeroquip tests, there was no sign of white corrosion products on any of the specimens in any of the groups at the 96-hr observation period. Further, the extended-exposure tests showed that only one of six specimens in Group D exhibited red rust at 264 hr. Thus, of a total 24 specimens tested by Aeroquip, only one specimen definitely would not have met Aeroquip's internal requirement of freedom from red rust at 360 hr. One specimen in Group B exhibited red rust at 408 hr; at 336 hr, no specimens in this group showed red rust. In general, very good agreement and full compliance with the requirement for absence of white corrosion products for 96 hr was noted for the groups of specimens tested at both laboratories. Further, there was generally good agreement in results with respect to the appearance of red rust. At both laboratories, only 3 of 48 specimens did not meet the Aeroquip's internal requirement of freedom from red rust for 360 hr of exposure to salt-spray.

Aeroquip also tested four groups of parts plated with zinc in the barrel plating lines. The parts included nipple (Group A), crimp socket (Group B), and two other types of socket (Groups C and D). All specimens in all four groups met the requirement of freedom from white corrosion products at 96 hr. White corrosion started to appear on most of the specimens at the 168-hr observation point. All parts also met the requirement of no red rust at 360 hr. One specimen in Group A exhibited red rust at 432 hr. At 504 hr, red rust was present on Group A and Group C parts, but Group B and Group D specimens showed no red rust.

From October 15 to November 5, 1991, Aeroquip carried out corrosion tests to compare the salt-spray corrosion resistance of zinc-plated parts with cadmium-plated parts. Seven groups of representative parts plated with zinc and seven groups of identical parts plated with cadmium were tested. The parts included two types of barrel-plated reusable sockets (Groups A and B), two types of barrel-plated reusable nipples (Groups C and D), two types of rack plated nuts (Groups E and F), and a rack-plated crimp fitting (Group G). The results of the salt-spray tests on the zinc-plated parts were as follows: (1) all specimens in the seven groups of parts passed the requirement of 96 hr before the first appearance of white corrosion products; (2) no red rust appeared on any of the specimens in the seven groups at the 360-hr observation time; (3) all specimens in Groups A, B, D, and G were still free of red rust after 504 hr of salt-spray exposure; red rust was



Group A: Part No. 2021-2-35; Pipe to 37 ° male flare adapter
Group B: Part No. 210204-12s; swivel nut (crimp type)
Group C: Part No. 206204-8-6s; SAE male to 37 ° male flare adapter
Group D: Part No. 2089-6-6s; 90 ° male to female pipe adapter

Figure 1. *Zinc-plated parts salt-spray tested by Detroit Testing Laboratory and Aeroquip (rack plated).*

beginning to develop on specimens in Groups C, E, and F at 504 hr. The results of the salt-spray tests on cadmium-plated parts were as follows: (1) all specimens in the seven groups passed the requirement of 96 hr before the first appearance of white corrosion products, and the appearance of white corrosion products in any of the seven groups was delayed to 336 hr and beyond and (2) no red rust was observed on any of the cadmium-plated specimens after 504 hr of exposure, at which point the tests were ended. These results demonstrated that the cadmium-plated parts exhibit superior corrosion resistance to zinc-plated parts with regard to the appearance of white corrosion products and red rust in salt-spray tests.

Waste Reduction Potential

Waste reduction potential of the process substitution was determined on the basis of waste volume reduction and pollutant reduction. Waste volume reduction was estimated for the treated wastewater and the dewatered sludge, which, respectively, affect conservation of water and landfill space. Pollutant generation focused mainly on toxic pollutants such as cadmium, cyanide, chromium, and chlorine. Tables 2 and 3 show the changes in the total waste and pollutant generation, respectively.

The increases in wastewater and sludge were due to an increase in plating bath concentration from approximately 3 oz/gal of cadmium in the cadmium-plating baths to approximately 3.5 oz/gal zinc in the zinc-plating baths. The decrease in oil and grease was due to an approximately tenfold decrease in the concentration of oil

Table 2. *Annual Generation of Treated Wastewater and Sludge from Cadmium- and Zinc-Plating Processes (Aeroquip Data)*

Year	*Plating Process*	*Treated Wastewater, gal*	*Sludge, lb*
1989	*Cd*	*40,000,000*	*282,000*
1991[(a)]	*Zn*	*44,900,000*	*383,000*

(a) Adjusted to the 1989 production rate of the electroplating process.

Table 3. *Pollutant Generation from Cadmium- and Zinc-Plating Processes (lb/yr based on production rate of 3.29 million ft ^{2})*

Pollutant	*Cadmium Plating*	*Zinc Plating*
Cd	*12,100*	*0*
Total CN	*835*	*0*
Total Cr	*677*	*4,420*
Zn	*0*	*22,300*
Oil & grease	*14,600*	*5,120*

used in the water-soluble oil dip tank. The increase in chromium was due to an approximately fivefold increase in the chromate bath concentration. The chromium, which also is a priority pollutant, was effectively converted from the toxic hexavalent form to a much less toxic trivalent form in the wastewater treatment plant; therefore, it does not pose as great a health risk as does the cadmium. Thus, the overall hazard level of the waste was substantially reduced by eliminating cadmium and cyanide. The process substitution also eliminated the use of chlorine (95,900 lb in 1989) for cyanide destruction in the wastewater treatment plant. Personnel health risks were reduced significantly by eliminating the handling of hazardous materials such as cadmium, cyanide, and chlorine. Consequently, the process substitution has reduced the company's potential liability for accidental worker exposure to and environmental release of these hazardous materials.

Economic Evaluation

Economic evaluation of the process substitution was based on a simple payback period analysis with the use of the cost data provided by Aeroquip. The evaluation included estimation of capital costs for the process conversion and operating costs of both processes. Table 4 shows the capital cost (in 1992 dollars) for converting the plating lines at Aeroquip from cadmium plating to zinc plating.

Approximately 72% of the total cost was for expenses related to cleaning up the cadmium process equipment and for disposal of the waste generated from the cleanup operation; the remaining 28% was for installing new equipment. Table 5 shows the annual operating cost (in 1992 dollars) for the two plating processes. The operating cost for the zinc-plating process was slightly lower than that for the cadmium-plating process. For a new installation, therefore, the lower operating cost of the zinc chloride plating process results in an economic advantage over that of the cadmium cyanide plating process. The payback period for the capital investment required for converting an existing cadmium-plating process to a zinc-plating process was estimated at 115 yr. The process conversion, therefore, cannot be justified solely on economic grounds. It should be based on worker safety and environmental pollution, as well as on greater acceptance of the zinc-plated components in domestic and foreign industrial and consumer markets.

Table 4. *Capital Cost to Convert (1992)*

Parameter	Barrel Plating Lines	Rack Plating Line	Subtotal
Expense (cleanup of old equipment and waste disposal)	$ 428,000	$ 999,000	$ 1,427,000
New equipment	$ 424,000	$ 122,000	$ 546,000
Subtotal	$ 852,000	$ 1,121,000	
Total			$ 1,973,000

Table 5. *Comparison of Operating Costs for Cadmium- and Zinc-Plating Processes (1992)*

Expenditure	Cadmium Plating	Zinc Plating
Electroplating chemicals		
Clear chromate	$ 3,840	
Brightener	3,180	$ 49,800
NaOH flakes	3,330	
Yellow chromate	16,900	28,900
Sodium cyanide	42,800	
Cadmium anode @ $0.99/lb	55,900	
Potassium chloride		6,680
Boric acid		18,200
Wetter		4,050
Zinc anode @ $0.78/lb		46,000
Wastewater treatment chemicals	$ 215,000	$ 190,000
Operating labor, 14 persons @ $25/hr	$ 728,000	$ 728,000
Electricity, @ $0.08/kwh	$8,920	$ 7,880
Miscellaneous		
Blood tests	$ 3,240	
Environmental monitoring	2,320	
Record keeping	463	
Washdown of plating dept.	6,370	
Treatment of washdown water	4,050	
Sludge disposal cost, @ $178.50/ton	$ 25,200	$ 34,200
Waste oil disposal, @ $600/drum	$15,600	$ 3,600
Total	$ 1,135,000	$ 1,118,000
Net cost reduction		$ 17,200

Conclusions

The results from the corrosion tests performed in this study and from historical data provided by Aeroquip indicate that zinc-plated parts meet customer requirements of 96 hr of exposure to salt spray (ASTM Method B117-90) before the appearance of white corrosion products. Further, the zinc-plated parts meet the Aeroquip process requirements of 360 hr of exposure to salt spray before the appearance of red rust. Although the corrosion resistance properties of cadmium-plated parts are superior to that of zinc-plated parts, the corrosion resistance of zinc-plated parts can be considered satisfactory to allow use of zinc as substitute for cadmium in many plating applications. The process substitution also satisfied the requirements of some domestic and foreign customers for cadmium-free products.

The changes in the waste generation from the process substitution were as follows:

- decrease of cadmium by 12,100 lb/yr,
- decrease of cyanide by 835 lb/yr,
- decrease of oil and grease waste, including waste oil, from 14,600 lb/yr to 5,120 lb/yr,
- increase of zinc by 22,300 lb/yr,
- increase of chromium from 677 lb/yr to 4,420 lb/yr,
- increase of treated wastewater from 40,000,000 gal/yr to 44,900,000 gal/yr, and
- increase of wastewater treatment sludge from 282,000 lb/yr to 383,000 lb/yr.

The use of chlorine for destruction of cyanide in the wastewater treatment plant was also eliminated.

The capital cost for the process change at Aeroquip was estimated to be $1,973,000. The annual operating cost reduction that resulted from the process change was estimated to be $17,200. Based on these costs, the estimated payback period is 115 yr. The process change, therefore, cannot be justified on economic grounds alone. Justification would be based on the improved worker safety and reduced environmental pollution plus the market's requirements for zinc-plated rather than cadmium-plated parts in many applications. In comparing the two processes for a new installation, the zinc chloride plating process offers obvious advantages over the cadmium cyanide plating process.

The full report was submitted in partial fulfillment of Contract Number 68-C0-0003, Work Assignment 3-36, under the Sponsorship of the U.S. Environmental Protection Agency.

☆U.S. GOVERNMENT PRINTING OFFICE: 1994 - 550-067/80247

B.C. Kim, P.R. Webb, J.A. Gurklis, and R.K. Smith are with Battelle, Columbus, OH 43201-2693.
***Teresa Harten** is the EPA Project Officer (see below).*
The complete report, entitled "Substituting Cadmium Cyanide Electroplating with Zinc Chloride Electroplating," (Order No. PB94-165321; Cost: $19.50 subject to change) will be available only from
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection Agency
Center for Environmental Research Information
Cincinnati, OH 45268

Official Business
Penalty for Private Use
$300

EPA/600/SR-94/074

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35