# New Electroless Nickel Technology as an Alternative to Hard Chromium Plating

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Metal finishing has continued to service a diversity of industries with functional coatings to solve problems of wear and corrosion at a competitive cost. Two principal processes which serve these type of applications are hard chromium and electroless nickel. The traditional differences in deposit characteristics and processing capabilities between these two technologies has been one factor that has limited crossover use of one coating for the other. Improper understanding of the EN process (comfort level) to the traditional hard chromium user has added to the reluctance of engineers to shift current applications to electroless nickel. In fact, this attitude has helped spawn activity in the use of a hard chrome overlay on electroless nickel to take advantage of the individual performance features of each deposit.

Today, however, advances in electroless nickel plating processes have set forth new products and technology which challenges existing preconceptions about its use as an alternative to hard chromium. The availability of such improvements is of interest to job shops now involved in hard chromium plating that may be able to more effectively use electroless nickel as a companion finish depending on the particulars of a given job. These new processes are of special interest, however, to captive plating operations which have an increasing concern over retaining chrome processes in-house. Most recently, the announced regulations on chrome containing waste in selected states have added corporate liability concerns and worries about future compliance and the cost of compliance. In this case, consideration for the use of electroless nickel as an alternative takes on added importance to the captive metal finisher in today's marketplace. This includes greater emphasis on jobbing out existing hard chromium work and/or employing electroless nickel as an in-house replacement.

This article takes a current view of the relationship between these two coatings and provides a general comparison between these processes and the deposit characteristics achievable with present state of the art technology.

At the outset, let's identify the key areas of importance to production when considering electroless nickel as an alternative to hard chromium.

## IMPORTANT ISSUES FROM THE MANUFACTURING PERSPECTIVE

- General coating cost
- Requirements for process control when plating
- Surface preparation/reactivation for plating added thickness
- Set-up for plating (i.e., fixturing, thiefing, etc.)
- Post-plate finishing needs (grinding, machining)
- Masking
- Stripping
- Heavy deposit build-up (over 5 mils)
- Dimensional tolerance (retention/uniformity)
- Waste treatment

## COST OF COATING:

Often the first question that is asked when two different coatings are being considered as alternatives is "What is the cost going to be?" In the case of these two engineering finishes, the answer varies from one application to the next; there is no single answer. The chemical cost of a hard chromium deposit (mil for mil) is substantially cheaper (perhaps 60 to 80% less) than an equal deposit thickness of electroless nickel. In general, however, this difference is often of limited significance compared to the total cost for plating a given part. The following segments on differences in processing characteristics between electroless nickel and hard chromium helps paint the picture in more depth.

## REQUIREMENTS FOR EQUIPMENT AND PROCESS CONTROL:

The cost for equipment to plate electroless nickel or hard chromium is similar. Normally, electroless nickel requires a dual tank set-up for plating due to the finite life of the plating bath and the need for periodic passivation of the tank. Hard chromium plating necessitates the use of a rectifier and fume scrubber. Both processes need adequate ventilation and exhaust. Electroless nickel plating requires adequate filtration, solution circulation, and agitation. Typically a 5-$\mu$ bag filter and a flow rate that allows the tank volume to be passed through the filter 8 to 10+ times per hour is adequate and recommended.

Process control required for electroless nickel is more involved and labor intensive than for hard chromium plating. The focus is on regular analysis and replenishment of the plating solution to maintain both plating rate and deposit quality. pH, temperature, nickel concentration and hypophosphite concentration are the parameters of importance. This normally requires a laboratory technician or chemist who can periodically perform these simple tests. In today's production environment, however, automatic electroless nickel controllers add to the ease with which solution analysis and replenishment can be made (Fig. 1). Controllers, such as the one shown, do analysis, replenishment, allow upper and lower control limits to be set, provide statistical data, and interface with a computer for data gathering and remote station control. In the case of hard chromium, today's improved technology high speed processes require minimal chem-

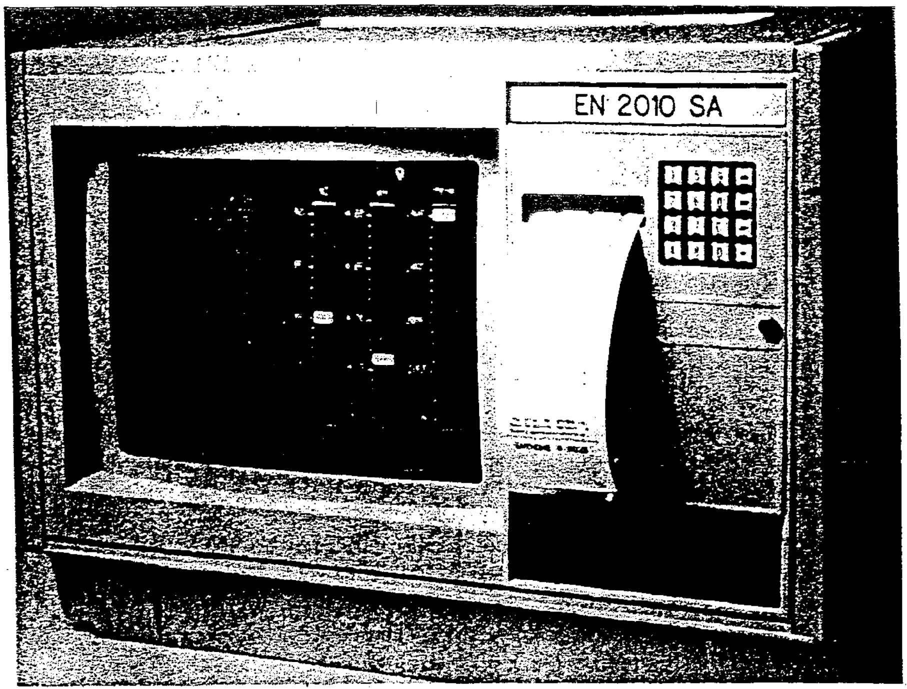

*Fig. 1. Automatic electroless nickel controller.*

ical analysis and attention as do the standard hard chromium processes on the market.

SURFACE PREPARATION:

The methods of surface preparation for hard chromium and electroless nickel plating are similar when considering the most commonly plated substrates. Careful cleaning and activation methods are generally more critical for electroless nickel than for hard chromium plating due to the beneficial effects of a reverse chromic acid etch (for final surface activation) before deposition begins.

SET-UP FOR PLATING:

With the exception of rack design, no special set-up is required for electroless nickel plating since no current is required to drive the deposition process. As long as the plating solution is in contact with the part, and the solution is adequately replenished and agitated, deposition will continue with excellent uniformity. This fact also means barrel or basket plating and high volume, high work load rack plating are readily accomplished, bringing down the cost per unit to process.

Hard chromium plating has involved set-up procedures that can vary significantly with each application. Some typical fixtures, anodes, thiefs, etc. required to provide proper current distribution are shown in Fig. 2. The part illustrated in Fig. 3 is a typical example of components fixtured for hard chromium plating. The complex mold displayed in Fig. 4 shows the very complex anode fixturing that can be involved when hard chromium plating some parts. Figure 5 shows the wider rack spacing required to minimize part to part thiefing and maximize distribution of plating thickness. In general, parts can be racked much more closely with electroless nickel and complex parts require none of the accommodations needed for hard chromium to achieve good plate distribution.

POST PLATE FINISHING NEEDS:

A major potential cost associated with hard chromium plating occurs when grinding, machining or honing of the plated surface is necessary to achieve specified dimensional tolerances. Shafts that are plated for rebuilding of dimensions (sometimes 10 to 20 mils or more) require overplating to insure the minimum is applied and then grinding back due to normal variations in the plated thickness. Hydraulic or pneumatic cylinders plated with hard chromium have very precise tolerances which cannot be realized without overplating and then machining the deposit back to the correct deposit thickness.

High efficiency hard chromium deposits reduce the amount of thickness variation which has been a trademark of hard chromium electroplating. This also reduces the amount of overplate in certain high current density areas. It does not, however, necessarily eliminate the need for grinding or machining. Because these new deposits have a different deposit structure, they also can be more difficult to grind or machine. Electroless nickel maintains the advantages of not requiring these post finishing operations, thereby significantly shifting the overall cost differential between the two processes. In the case of hard chromium, these procedures, when required, can cost two to four times the value of the plating. It should also be noted that because more hard chromium plate is required to insure all areas are at or above minimum dimension, more cost is absorbed in the plate than is indicated by the final deposit thickness. Increased rejects can also result from chipping or spalling of the hard chromium plate due to machining.

MASKING:

Maskants used in conjunction with hard chromium solutions include PVC and lead tapes, lacquers, polymer coatings, copper and aluminum foils and waxes. These materials are readily available, relatively easy to apply and inexpensive. The effectiveness of these

*Fig. 2. Typical fixtures required to provide proper current distribution in hard chromium plating.*

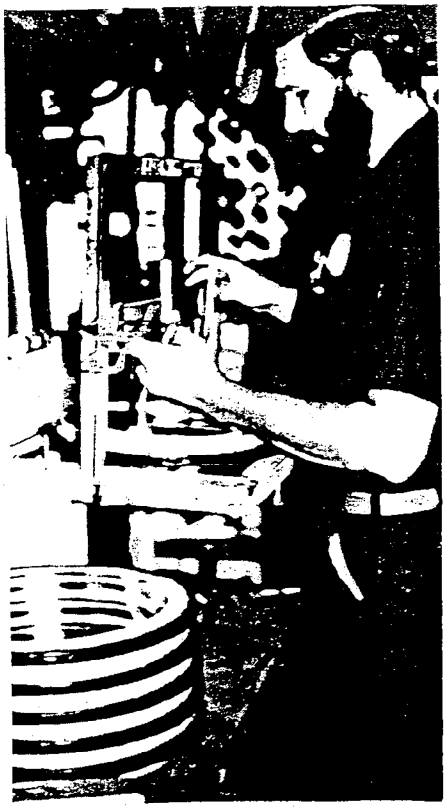

Fig. 3. *Typical component being fixtured for hard chromium plating.*

maskants is also good when they are properly applied. This is due both to the low operating temperature of hard chromum baths and also to the reduced tendency of these solutions to plate onto unwanted areas. Fine pin holes in the wax, for example, may not plate if no anode is located nearby to supply current.

Masking materials required for electroless nickel normally necessitate more careful selection and application due to the elevated temperature (180-195°F) involved in the plating process which can result in unwanted lifting, peeling, etc. Typical maskants include polymeric materials which can be sprayed, dipped or brushed onto the part. They must be free from porosity (before plating) since the autocatalytic nature of the electroless process will cause deposition in voided areas. Thus, a second coat may be needed along with sufficient curing time for each layer of maskant. Special tapes are also frequently used with electroless nickel. These tapes must be temperature resistant and normally require more time to apply (compared to hard chromium) in order to insure that all edges are tight and firmly in place. When heavy deposit build-ups (over 5 mils) of electroless nickel are applied, the long immersion times in the hot solution can increase the chance for deterioration of the masking material.

Electroless nickel masking materials can also be more difficult to remove after plating (due to their greater chemical resistance). This is particularly true when they are placed into internal areas, on threads, in blind holes, etc., all of which can retain residual amounts of these materials. Prolonged plating times further harden certain maskants in the electroless nickel tank that can add to removal problems.

Interestingly, an important element of cost with hard chromium is the need to mask key areas of critical dimensional tolerance due to limitations in plate distribution (i.e, recessed areas, moting surfaces, etc.). With electroless nickel preengineering of the part design to match plated thickness to final tolerances in these areas can significantly reduce labor cost and time in process.

## STRIPPING:

Stripping electroless nickel is generally a more time consuming and costly process than with hard chromium. This is particularly true of high phosphorus deposits at thicknesses above approximately one mil which are essentially amorphous and nonporous, and therefore, difficult for the stripping solution to attack the coating substrate interface. More complex stripping solutions containing inhibitors are required to remove electroless nickel deposits without attacking the substrate in localized areas where the electroless nickel coating is preferentially removed during the stripping process.

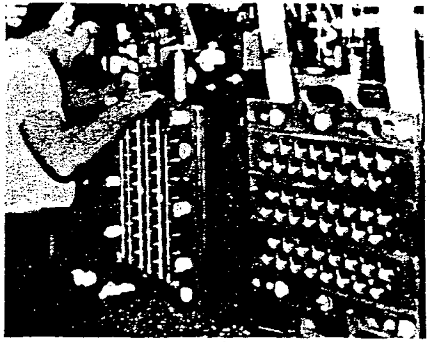

Fig. 4. *Complex anode fixturing for hard chromium plating.*

Hard chromium is readily stripped in HCl (over 60%) or in reverse current alkaline solutions. In this case, the uniform crack structure of hard chromium aids in the stripping process.

## HEAVY DEPOSIT BUILD-UP:

Hard chromium is a very cost effective process for applications where heavy deposit build-ups above five mils, are required. This is due in part to the faster processing times which can be achieved with hard chromium compared to electroless nickel (when bath chemistry and operating procedures are modified). This is especially true for situations which require 10 to 20 mils or more for dimensional repair (over 100 mils have been done commercially). Today's high efficiency, high speed, hard chromium processes, have made significant advances in this area. These new processes plate at approximately two mils/hr at 3 to 6 A/in$^2$. Previous technology would only give 0.8 to 1 mil at 2 to 3 A/in$^2$.

## DEPOSIT UNIFORMITY:

The uniformity and precision of electroless nickel plating to thickness is a key reason it is selected instead of hard chromium for many applications. The autocatalytic or chemical plating of electroless deposits (using no current) produces a very uniform and controllable coating thickness, even on complex part configurations, due to the lack of

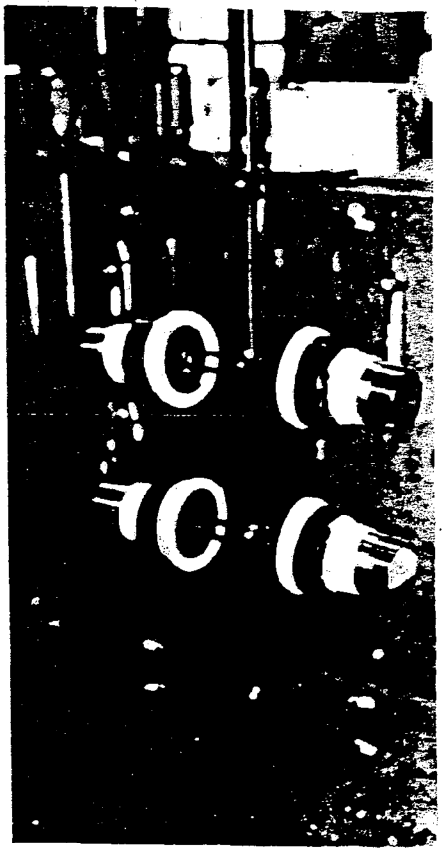

Fig. 5. *Wider rack spacing is required to minimize part to part current thieving.*

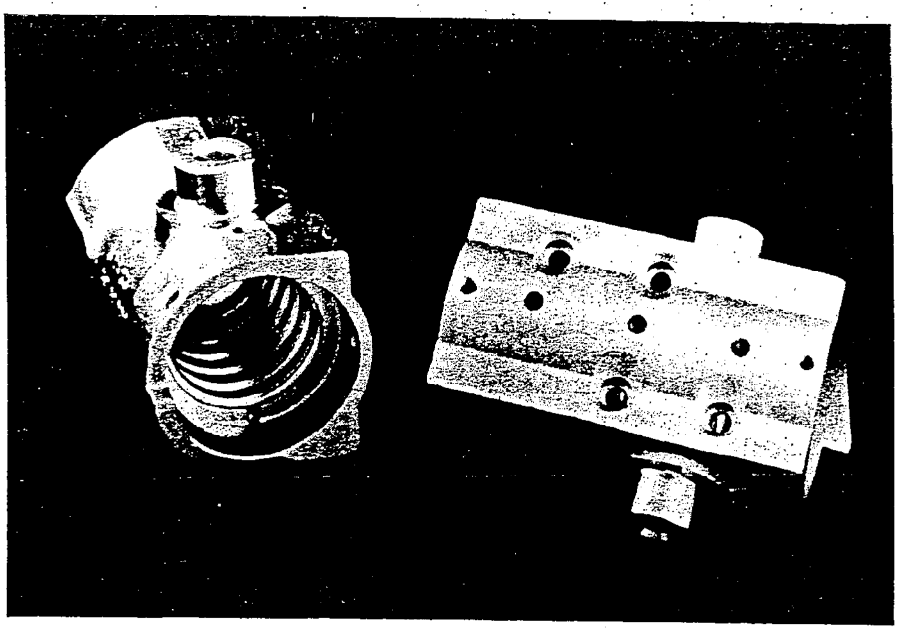

*Fig. 6. Typical parts easily plated uniformly with electroless nickel.*

high or low current areas. In general, recesses, internal areas, threads, edges, complex shapes, etc., are evenly coated as long as the plating solution is properly replenished, well agitated and not stagnant in these areas. Figure 6 provides an example of parts that are easily plated directly to the required thickness with electroless nickel. It is possible to maintain deposit thickness variations to within 50 to 100 micro-inches on even complex parts with electroless nickel.

Hard chromium deposits are not uniform by nature and require a careful fixturing of anodes and proper thiefing or shielding to improve their uniformity in high and low current density areas. A typical cross section of a part, where good anode placement practices were used, can show some coverage in all areas, but the hard chromium coating is still not normally uniform in all areas. In most cases, when a uniform hard chromium deposit is required, the part is plated over thickness and then post grinding or machining steps are employed. For example, to achieve a minimum 10 mil build-up of hard chromium, thicknesses of 60 to 70 mils may be deposited in the high current density areas of complex shapes or on large parts such as cylinders.

Current high efficiency, high speed hard chromium processes have made noticeable improvement in their ability to provide complete coverage and good uniformity on more complex parts. A 50% or better improvement in deposit uniformity can be realized with this new technology.

## KEY ENGINEERING AND PERFORMANCE ISSUES

### HARDNESS:

A convenient point of departure for initiating a comparison of the engineering properties of hard chromium to electroless nickel is coating hardness. Traditional hard chromium plating has always maintained an advantage in as-plated hardness over conventional electroless nickel. As indicated in Fig. 7, hard chromium is normally 950 to 1000 $\text{VHN}_{100}$ as plated, this varies primarily as a result of changes in bath chemistry. Certain adjustments in bath chemistry (i.e., the addition of fluorides) can increase the hardness to 1000 to 1100 $\text{VHN}_{100}$. Under post baking procedures (above 250 to 300°F) the hardness of hard chromium actually falls off due to stress relief occurring in the deposit. Current high efficiency, high speed hard chromium processes have similar hardness properties but tend to have less stress.

Conventional medium phosphorus and high phosphorus electroless nickel deposits typically provide an as-plated hardness between 500 and 550 $\text{VHN}_{100}$. Heat treatment will increase this hardness to values of 900 to 950 $\text{VHN}_{100}$, approximating the hardness of hard chromium (as plated). Increased hardness in electroless nickel deposits results from the fact that they are alloyed deposits of nickel and phosphorus. Nickel phosphides begin to develop at temperatures of 225 to 300°C (depending on phosphorus content) and as temperature and time increase, varying levels of hardness can be achieved in electroless nickel coatings. Optimum hardness is achieved at temperatures of 650 to 750°F (350 to 400°C) depending again on phosphorus content. In general, the flexibility of electroless nickel in being able to adjust its hardness has proven to be an engineering advantage in certain applications. On the other hand, the noticeable differential between the two coatings in as-plated hardness has been one factor that has affected the acceptance of electroless nickel as an alternative coating to hard chromium.

The more recent availability of commercially viable, low phosphorus electroless nickel processes has altered this as-plated hardness differential considerably while retaining the flexibility of being able to adjust hardness upward

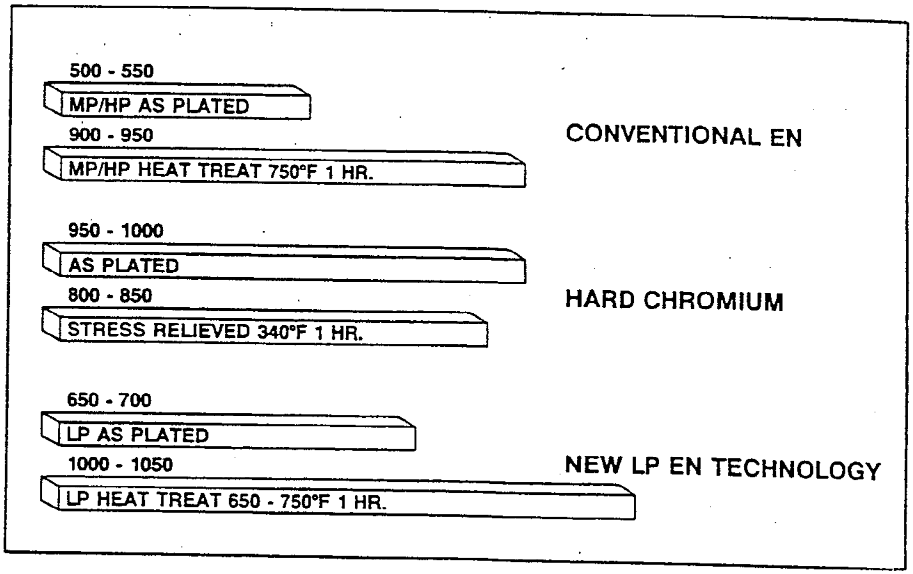

*Fig. 7. Hardness comparison of electroless nickel and hard chromium, $\text{VHN}_{100}$.*

## DEFINITIONS OF WEAR

***Fretting Wear:***
Fretting wear is developed as a consequence of oscillatory motion between two mating surfaces. Normally no lubrication is present under such conditions. The constant vibration during operation generates heat, breaks loose particles and causes a localized abrasive action or polishing action to occur between two surfaces.

***Fatigue Wear:***
Fatigue wear is normally associated with bearing applications where load is applied to a rotating or rolling cylidrical surface under lubricated conditions. During continued operation with load shifts, the cyclical applied stress can develop fatigue cracks which propagate until failure. The fatigue failure can be fast once the crack propagation mechanism starts.

***Erosive Wear:***
Erosion is directly related to impinging particles which impact a surface at a given velocity. Impingement angle, temperature conditions, and particles of differing shapes and sizes, all influence the erosion rate. The mechanism of failure varies since, at low impingement angles (i.e., 20°), the metal coating is removed by a cutting action. Thus compressively stressed coatings that "give-a-little" under impact are more desirable. At a high angle of attack (i.e., 90°), hardness is an important criteria since chipping and spalling are a key mechanism of failure along with crack propagation toward the substrate. These are not the only issues, however. Another aspect to erosion resistance is the ability to dispel thermal energy generated at the point of contact.

***Adhesive Wear:***
The mechanism in adhesive wear is the generation of heat and formation of adhesive bonds between the two moving surfaces. These bonds fracture during continued motion causing metal particles to be pulled from one surface and then cause wear or eventually galling. The potential for adhesive wear is influenced by several factors including load, lubricant type, coating type and hardness differential between the two mating surfaces. In the case of load, there may be low loads, high loads, point loads and or cyclical loads. In general, the higher the load and/or the wider and more frequent the shift in the load during operation, the greater the chance that the lubricant film will be breached and adhesive wear will occur.

***Abrasive Wear:***
Abrasive wear can be characterized more commonly as nonlubricated adhesive wear. In this instance, sharp metal or other abrasive particles cut into a mating metal surface.

through heat treatment. Interestingly, the temperature required to reach optimum hardness is about 50 to 100°F lower than for other electroless nickel deposits.

## WEAR:

The wear resistance of electroless nickel and its comparison to hard chromium is perhaps one of the more qualitative issues involved in a comparison of these two processes. The notion that wear is a simple well defined phenomena to which simple, straightforward tests can be applied to determine a "best solution", is not necessarily the case. The reality is that wear is an involved science which includes various categories (types) of wear (see Box). These types of wear are distinguished by the mechanism(s) with which wear is initiated, the forces and conditions under which wear proceeds, and finally the mode of failure.

While avoiding the detailed technical issues, Table I summarizes the major types of wear and the characteristics which help identify it. The following description offers added information on these different types of wear. Overall, it can be said that both hard chromium and electroless nickel are excellent wear resistant coatings. In most cases, hardness by itself is not a sole indication of wear resistance and the suitability of one coating to be used interchangeably with another requires further information. With the advent of improved electroless nickel coatings, however, the interchangeability of these two technologies has increased. Figure 8, for example, gives data relating to abrasive wear as determined by the Taber Abraser.

## CORROSION PROTECTION:

The corrosion protection of electroless nickel is generally considered to be superior to that of hard chromium, when compared at equal thicknesses. This is, to a large extent, related to the differences in deposit structure. The normal microcracked structure of hard chromium deposits, especially at thicknesses below 2 to 3 mils, tends to provide direct access to the basis metal. This situation can also be aggravated when complex part geometries and/or ineffective anode placement produce areas of thin or nondeposition. As heavier thicknesses are deposited, individual cracks do not propagate directly through to the substrate. Porosity may still exist in the deposit, however, due to the interconnections which exist between the many cracks in the coating. Newer, high efficiency, high speed hard chromium processes have a smaller, more finely distributed crack structure which is less pronounced. Still, sufficient porosity exists to retain the general properties of hard chromium in standard accelerated corrosion tests.

Porosity in hard chromium deposits can be reduced in several ways. First, increased deposit thicknesses (2 to 3

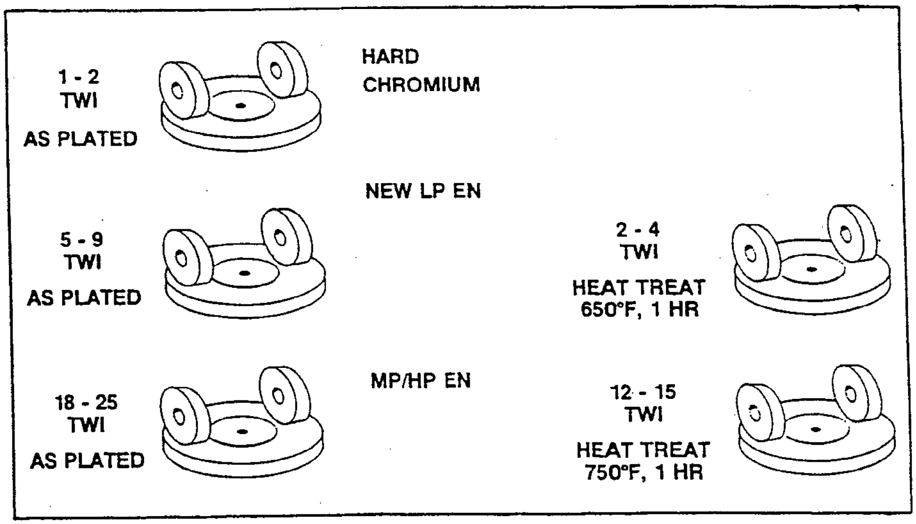

*Fig. 8. Taber abraser wear test results, Taber Wear Index (TWI) milligrams weight loss/1000 cycles.*

## Table I. A General Comparison of the Wear Performance of Electroless Nickel and Hard Chromium

| *Type of Wear* | *Basic Wear Mechanism* | *Comments on Electroless Nickel vs Hard Chromium* |
|---|---|---|
| Adhesive Wear/ Galling | Reduced wear by minimizing metal to metal contact. This is aided by providing a uniform deposit thickness; by retaining a lubricating film which can support the external load; by reducing friction; and avoiding a wide hardness differential between wear surfaces. | EN better in its uniformity and ability to match hardness of wearing surfaces correctly; better in its ability to wet with lubricant across surface; LP EN an improvement for supportin higher loads, avoiding heat treatment to get increased hardne EN avoids galling when mated to aluminum, stainless steel, o titanium.<br>HC unacceptable for mating against stainless steel, titanium, aluminum; produces high counter face wear on softer metals. |
| Abrasive Wear | Low wear results from increased coating hardness and resistance to the cutting action of metal surfaces; avoidance of a highly stressed coating. | LP is a major improvement for EN in abrasive wear. Low stres high hardness make it more comparable to hard chromium.<br>HC better than conventional EN in abrasive wear. |
| Erosive Wear | Erosion resistance at low angles of particle impingement is achieved by coating toughness, dissipation of thermal energy, and the coating's ability to "give-a-little" under impact. Erosion at high angles of attack is more directly affected by coating hardness. | EN is better overall since it combines high hardness with low stress and good thermal dissipation properties; LP EN an improvement for 90° attack<br>HC good for high angles of attack except for edge areas where excess thickness and stress may affect chipping. |
| Fatigue Wear | Fatigue wear resulting from cyclical stress that produces crack propagation and eventual failure. | LP EN is an improvement for higher load situations.<br>HC, with its ability to retain lubricant, is very good; HC also handles highly loaded bearings very well. |
| Fretting Wear | Reduction of wear due to fretting is accomplished by reducing friction and heat as well as resistance to abrasion. | EN is better when the mating metal surface is softer (i.e. SS) or light metals are involved (i.e., Ti, Al)<br>HC and EN are generally very good for reducing fretting wear on steel. |

mils) help stagger the microcracked structure sufficiently to minimize (or eliminate) easy access of corrosive materials to the basis metal. Second, underlays of sulfamate nickel, hard nickel, duplex nickel, copper/nickel, or electroless nickel are very effective in eliminating coating porosity and improving corrosion resistance. These methods represent the most common means used commercially to improve the corrosion protection of hard chromium. In addition, crack-free chromium deposits can be produced. Unfortunately, when they are subjected to minor stresses, these deposits will develop cracks and a resultant porosity. Crack-free chromium deposits also tend to be softer than most normal hard chromium deposits due to the modifications in bath chemistry which are necessary to produce them. Therefore, they are not that desirable for many commercial applications.

The corrosion protection of electroless nickel-phosphorus coatings is excellent due, in part, to the minimal, or lack of porosity which results from their very dense, essentially amorphous deposit structure. It is also due to the adherent, passive oxide films which can form on the deposit surface which enhance the overall corrosion protection of electroless nickel in these tests. The porosity of electroless nickel deposits, however, can vary significantly with deposit thickness. It can also vary with bath chemistry, surface condition, surface preparation, and heat treatment. Thus, some care must be tak when attempting to draw broad concl sions regarding the relative corrosi protection of electroless nickel and ha chromium deposits.

The porosity of electroless nickel a hard chromium has been evaluated i accelerated corrosion test methods i cluding the ASTM B-117 5% neutr

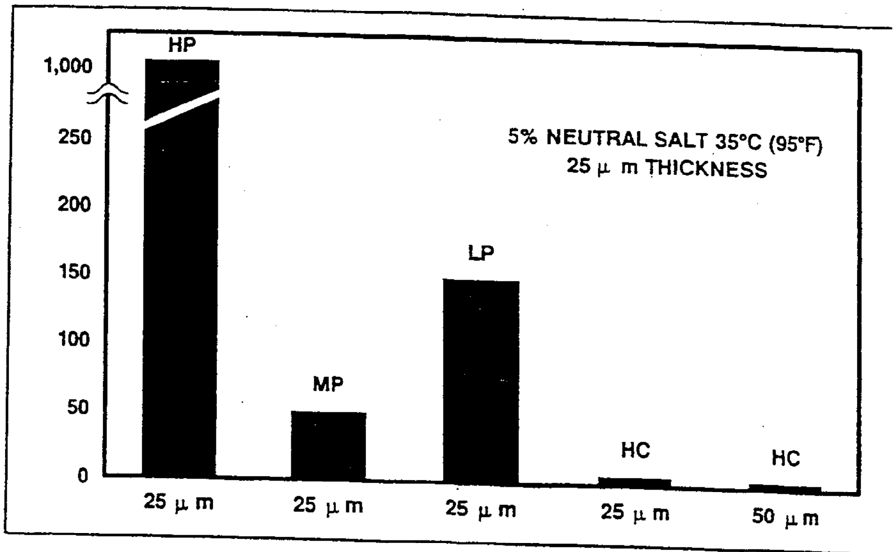

*Fig. 9. Typical ASTM B117 salt spray performance of electroless nickel vs. hard chromiu on steel.*

**Table II. Comparison of Weight Loss Corrosion Results of Electroless Nickel to Alternate Uncoated Materials**

| 60-Day, 40°C ± 2°C | Nickel 200 | Mild Steel | AISI 316 SS | Corrosion Rate EN Coated 1010-50µm | Suggested Deposited Type |
|---|---|---|---|---|---|
| Thionyl chloride | 7.0 | 200.0 | 5.1 | 1.8-2.5 | MP/HP |
| Orthochlorobenzyl chloride | 12.7 | NA | 25.0 | 3.8 | LP |
| Phosphoric acid | 10.0 | 1270.0 | 2.5 | 1.9-3 | None |
| Benzotrichloride | 5.1 | 9.0 | 5.1 | 2.5 | LP |
| Benzoyl chloride | 5.1 | 8.6 | 5.1 | 0.5-1.0 | LP/MP/HP |
| Phosphorus oxychloride | 10.1 | 100.0 | 18.8 | 1.5-2.5 | MP/HP |
| Sodium hydroxide | | | | | |
| 45% NaOH, 5% NaCl, 40°C | 2.5 | 35.6 | 6.4 | 0.3-0.5 | LP/MP/HP |
| 45% NaOH, 5% NaCl, 140°C | 80.0 | NA | 27.9 | 5.3 | LP |
| 35% NaOH, 93°C | 5.1 | 94.0 | 52.0 | 5.3 | LP |
| 50% NaOH, 93°C | 5.1 | 533.4 | 83.8 | 4.8-6.1 | LP/MP |
| 73% NaOH, 120°C | 5.1 | 1448.0 | 332.7 | 2.3 | LP |

**Table III. Materials Tested in Weight Loss Corrosion Test**

| Chemical | Typical Applications |
|---|---|
| Thionyl chloride | Chemical process intermediate |
| Orthochlorobenzyl chloride | Agricultural products, pharmaceuticals, plastics |
| Phosphoric acid | Food processing, pharmaceuticals, gelatins, glues, adhesives, metal processing, fabrics, plastics, chemical polishing |
| Benzotrichloride | Chemical intermediate, preparation of dye stuffs |
| Benzoyl chloride | Perfumes, chemical intermediate, resin manufacture, pharmaceuticals, pesticide intermediate |
| Phosphorus oxychloride | Organic phosphates, plasticizers, gasoline additives, preparation of dye stuffs, medicines, chemical intermediate |
| Sodium hydride | Food processing petroleum refining, pharmaceuticals, cosmetics, bleaching, dying, printing, textile manufacturing petroleum refining. |

salt spray test. The salt spray performance of different electroless nickel deposits, high phosphorus, medium phosphorus and low phosphorus are shown in Fig. 9 compared to a hard chromium deposit. These results indicate the significant differences in porosity that exist between two different electroless nickel deposits at an equal thickness of one mil. Low phosphorus and medium phosphorus electroless nickel are relatively porous and as a consequence have poorer results than for high phosphorus electroless nickel or hard chromium. In general, for a given electroless nickel deposit, plated onto a relatively smooth surface, the minimum or threshold thickness required to reduce coating porosity (due to deposit thickness) is about 0.7 to 1.0 mil.

## CORROSION RESISTANCE:

The corrosion resistance of electroless nickel is excellent in many process environments and normally far superior to hard chromium. This is partially due to the amorphorus nature of EN deposits and the ability to plate porosity-free. It is mainly due to the capability of nickel to form protective oxides and corrosion products that reduce the potential for accelerated galvanic corrosion to proceed. Some corrosion rate data on different phosphorus content EN processes is shown in Tables II and III. It is important to note that electroless nickel can provide superior cost/performance compared to stainless steel and nickel based alloy for many environments.

## SUMMARY

1. Increased pressure on chrome waste is causing captive hard chromium platers to work closer with outside plating vendors or consider electroless nickel as an in-house plating alternative.

2. Advances in electroless nickel technology, principally with the introduction of high hardness, LP electroless nickel, have narrowed the performance difference between electroless nickel and hard chromium plating.

3. The total cost of producing parts when comparing hard chromium and electroless nickel needs to be considered before determining the most cost effective technology for a given application.

4. There are applications for both hard chromium and electroless nickel that cannot employ a cross-over in technology. **MF**

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G.J. Shawhan

## Biographies

**Thomas W. Bleeks** holds the position of technical marketing specialist, plating chemicals division for Enthone. He is directly involved in the marketing of Enthone's electroless nickel product line. He is involved with Enthone's market development activities related to the aerospace industry.

**Gary J. Shawhan** is marketing manager, plating chemicals division for Enthone. He oversees the marketing activities of electroless nickel, electroplating and general metal finishing products. He is also responsible for the marketing of catalytic thick film products, aircraft/aerospace products and processes for plating on plastics for EMI shielding. Further information on this article may be obtained from him at: Enthone, Inc., Box 1900, New Haven, CT 06508. Telephone: 203/934-8611.