WHAT IS ELECTROLESS NICKEL?

EN plating is a chemical process that involves several simultaneous reactions in an aqueous solution which occur without the use of external electrical power. The reaction is accomplished when hydrogen is released by the reducing agent (sodium hypophosphite), and oxidized thus producing a negative charge on the surface of the part. The charge causes a layer of nickel and phosphorus to form and this continues until the part is removed from the solution. Since the plating process requires no electrical current, the coating produced is very uniform and has a dense amorphous structure that can be applied over various metals and substrates to provide corrosion and wear resistance.

One of problems with EN is its generic name. "Electroless Nickel" is the term used to describe the deposition of an alloy on a substrate, however, there are many different types of EN coatings and processes available to meet a wide range of unique applications. Physical and mechanical properties vary considerably from one EN process to another depending on the phosphorus content, the formulation of the bath and both the preplate and postplate treatments, yet all the EN coatings offer excellent deposit uniformity and superior corrosion protection.

FEATURES OF EN COATINGS

- Corrosion resistance
- Precise thickness control
- Uniformity of deposit
- Increased hardness
- Abrasion resistance
- Inherent lubricity
- Anti-galling and fretting wear protection
- Quick release properties
- Non-magnetic properties
- Conductivity
- Solderability/Weldability/Brazeability

TWIN CITY PLATING CO.
Roger W. Plath, President

SPECIALIZING IN QUALITY
- Electroless Nickel Plating
- Industrial Hard Chrome Plating
- Passivation
- Cryogenics
- Anodizing

Precious Metals

641 Hoover Street N.E.
Minneapolis, MN 55413-2996
Phone: (612) 331-8895
Fax: (612) 331-3926
UNIFORM COATING: Because it is an electroless process, the plating rate and coating thickness are the same on any section of the part exposed to fresh plating solution. Even on the most complex and irregular surfaces, close tolerances can be held without any additional machining or finishing. Unlike electroplating, no complicated fixturing or positioning of anodes is required. Shafts, rollers, gears, nuts and bolts, bearing journals, servo valves and oil nozzles all benefit from EN plating. See fig. 1 for the effects of plating on thread dimensions.

THICKNESS: EN can be accurately and uniformly deposited in a wide range of coating thicknesses. The majority of commercial applications utilize a thickness between 0.1 - 1.0 mils while holding a tolerance of ±0.00005. Thicknesses of 1.0 - 3.0 mils are common for corrosive service, while deposit thicknesses above 3.0 mils are typical of repair and rework. Deposition of heavier coatings requires careful process control to avoid roughness and pitting.

CORROSION RESISTANCE: EN is a barrier coating, protecting the substrate by sealing it off from the environment, rather than using sacrificial action. EN is an amorphous alloy; it has no crystal or phase structure and is, therefore, more resistant to attack than equivalent polycrystalline materials. Incapsulation is the principal method of protection and corrosion control of the substrate. The EN plating solution generally penetrates into small voids and surface imperfections as well as on the surface providing excellent corrosion resistance that, in many environments, is superior to pure nickel or chromium alloys. The better the surface finish prior to coating the better the corrosion resistance. Coating thickness, substrate condition and surface preparation are important factors that determine both coating porosity and the ultimate resistance to corrosive attack. Fig. 2.

The Effect of Electroplating on Thread Dimension

Figure 1

Copyright 1966, Superior Plating, Inc., Minneapolis, Minn.
HARD FINISH: EN coatings offer outstanding protection against wear and abrasion. Additional heat treatment of the EN coating causes the alloy to age harden and, under lubricated conditions, produce hardness values and wear resistance levels equal to most commercial hard chromium coatings. For some applications high temperature treatments cannot be tolerated because parts may warp, the strength of the substrate may be reduced or maximum corrosion protection may be effected. For these applications, longer times and lower temperatures are used to obtain the desired hardness.

HARDNESS OF EN - ROCKWELL C HARDNESS*

<table>
<thead>
<tr>
<th>Phos level</th>
<th>As Plated</th>
<th>Heat treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 3%</td>
<td>58 - 62</td>
<td>68 - 70</td>
</tr>
<tr>
<td>6 - 8%</td>
<td>46 - 50</td>
<td>65 - 68</td>
</tr>
<tr>
<td>10 -12%</td>
<td>44 - 48</td>
<td>65 - 67</td>
</tr>
</tbody>
</table>

* Approximate values based on Vickers hardness.

![Chart A](image1)

![Fig. 2](image2)

![Fig. 3](image3)
WEAR RESISTANCE: Wear is the mechanical loss of material on a surface. There are many types of wear and nearly 200 specific wear tests, making for a complex evaluation of many applications. Wear can be combined into four categories which define most situations.

1. **Fretting Wear** is produced when the surface is mechanically deformed, causing material to be fractured and removed. Fretting wear generally occurs when there is small movement at high loads. An example of a fretting situation involved diesel valve spring retainers on locomotive engines. As the springs and valve stems moved, the retainer clips, made of hardened RC 35 steel, exhibited fretting, causing movement and wear debris on the valve stem. An EN coating of .0003" was applied and the retainers did not show any sign of fretting at overhaul.

2. **Adhesion Wear** is the most common in metal-to-metal wear situations. It is produced when microwelds cause the material interface to join, and the adhesive failure of the coating or wearing material occurs below the weld. Any metals of similar hardness will gall and eventually cold weld to each other. EN provides the lubricity and hardness at the interface to significantly reduce adhesion wear and improve the service of the plated article.

3. **Abrasion Wear** is the result of solids being cut from the surface. It is produced when paper, textiles, debris, etc. pass over the wearing surface and cut into the substrate, removing material. Again, the lubricity and hardness of EN reduces abrasion wear and improves the service of the substrate.

4. **Erosion Wear** is the most complex of the four. It involves the movement of liquids, solids, and gasses near or on the surface producing micro failure and abrasion. It eventually causes macro amounts of material to be removed. EN deposits have been used in several environments with good success. These include: alkalies, salts and brine solutions, petroleum, sweet and sour applications, solvents and hydrocarbons.

BRIGHTNESS: The brightness or reflectivity of EN varies significantly, depending upon the specific formulation, the presence of brightening agents, and the surface finish. An EN solution which is producing a bright deposit on smooth surfaces may provide a much duller deposit on a surface that is rough from machining, sand blasting, etching etc.
POROSITY: The porosity of EN varies with deposit type, thickness of plate, pretreatment, post-treatment and surface condition. EN baths with a high phos content are preferred for applications where minimal or no porosity is critical. Deposit thickness should be a min of .7 -1 mil on smooth surfaces - up to 50 RMS and 2-3 mils on rougher surfaces >100 RMS. Improper cleaning of the metal surface will increase coating porosity as well as produce poor adhesion. Heat treatment of EN deposits above 300 degrees C. will tend to create microcracking, significantly increasing coating porosity. Rough surfaces or coarsely machined or milled areas, produce sites where some porosity of the final plate may be unavoidable without the introduction of special processing techniques.

LUBRICITY: The phosphorus in EN coatings provides natural lubricity and release properties which can be very useful for applications such as plastic molding. The coefficient of friction for EN is 0.6 for un lubricated conditions and up to .13 for lubricated conditions. Heat treatment or the level of phosphorus does not significantly affect the frictional properties of the EN. EN/PTFE composite coatings (PEN-TUF/EN) greatly enhances the inherent lubricity of EN. Coefficient of friction values range from 0.17 in a dry condition to 0.07 in a lubricated condition.

SOLDERABILITY/WELDABILITY: EN alloys are easily soldered with a highly active acid flux. Soldering to EN will not be consistent if the there is EN oxidation due to heat treatment, steam aging, improper handling, or long storage times prior to soldering. Successful welding to EN can be correlated to the substrate and type of EN. Lower carbon steels (1008-1018) provide a good basis for subsequent welding operations whereas substrates with high levels of phosphorus, carbon and sulfur tend to yield inconsistent and unsatisfactory results.
ELECTROLESS NICKEL COATINGS

PRE-TREATMENTS

Proper pretreatment can be as important to the successful application of EN as the actual deposit. Part design, manufacturing processes and surface contamination must be evaluated before determining the pretreatment required to produce a quality EN coating.

1. Design: The design of the part may require special handling and surface treatments. A very large part may require external, manual finishing. Parts with deep recesses or blind holes require special handling and draining techniques to avoid cross contamination during the plating process. They also determine whether a soak or electrolytic surface treatment should be used.

2. Select Plating: When plating must be applied to only certain areas of parts, the areas not to be plated must be stopped off or masked, which means they must be covered with a material that will not let the EN plating solution come in contact with the surface of the substrate. Masking materials must adhere well to the metal surface, withstand the temperatures of the plating solutions, be resistant to chemicals used for cleaning, etching and plating, and easy to remove after plating. A sharp, uniform demarcation between plated and nonplated areas is sometimes difficult to produce and a transition area is helpful to bridge the gap. Plugs, waxes and rubber coatings are some of the different masks available but they all require extensive hand operations that contribute significantly to the cost of plating. One of the alternatives to masking is to machine the coating off the desired surface or to drill and tap holes after plating.

3. Substrate: Different base metals require different treatments. An aluminum part cannot be processed through a typical steel cleaning cycle without damage to the part. Alloy types of the same base metal require different preparations prior to plating, for example a 1100 series aluminum part will be processed differently than a 380 cast aluminum part.

4. Metallurgy: EN is sensitive to the metallurgical state of the substrate. Localized strains and stresses caused by poor machining or other mechanical handling practices will alter the surface energy of the material. This in turn will cause localized differences in the electrochemical potentials of the substrate surface and result in an EN deposit with pits,
poor adhesion and low corrosion resistance.

5. **Surface Contamination:** It is often difficult to achieve 100% effectiveness in cleaning the surface of the substrate especially in recessed areas, deep blind holes, rough surfaces and coarsely machined areas because of contaminants on the surface. The contaminants can be divided into two basic categories:

5.1. **Organic soils** - Mineral oils, animal fats and vegetable oils used as lubricants in manufacturing. Usually, little or no attention is paid to the type or formulation of lubricants used during forming, stamping, machining and similar processes. Yet, many of the lubricants are formulated with active chemicals to inhibit corrosion by adhering or chemically bonding to the substrate surface. In some cases, a pre-plate bake in a reducing atmosphere may be necessary to remove theses soils from the surface.

5.2. **Inorganic films** - Rust, oxidation and scale from heat treatment operations. Heavily scaled parts or those that have been in service generally require mechanical or abrasive cleaning, especially on the ID of tubular parts. Chemical cleaning alone is not generally effective in removing scale or rust from the substrate.
ELECTROLESS NICKEL COATINGS

POST-TREATMENTS

STRESS RELIEF/ HYDROGEN EMBRITTLEMENT RELIEF: During processes such as EN plating, hydrogen can be absorbed into the metal substrate especially if the metal is a high strength steel. This penetration causes cracking and failure of the metal and is known as hydrogen embrittlement. To prevent hydrogen embrittlement, components are baked to diffuse the absorbed hydrogen out of the steel. This restores the mechanical properties of the steel almost completely, helping to ensure against failure. The time required to remove hydrogen from a steel depends on the strength of the steel. Longer periods or higher temperatures are needed as the strength of a steel increases.

Stress Relief Recommendations

<table>
<thead>
<tr>
<th>Tensile strength of steel (mpa)</th>
<th>Recommended HT time in hrs</th>
<th>Allowable Delay for embrittlement relief in hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 1050</td>
<td>190-230 degrees C</td>
<td>-</td>
</tr>
<tr>
<td>1051-1450</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>1451-1800</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>&gt;1800</td>
<td>24</td>
<td>immediate.</td>
</tr>
</tbody>
</table>

HEAT TREAT FOR HARDNESS: As plated, EN is one of the harder coatings available and its hardness may be increased by heat treatment. EN deposits have a maximum achievable hardness and once that level has been reached any further treatment will lower the hardness factor. Heat treating is generally done in an air circulating oven, but nickel oxides may form causing undesirable cosmetics or interference with subsequent soldering and bonding operations. An alternative would be to heat treat in an inert atmosphere to avoid this type of oxide formation. Polishing should be done prior to heat treatment when the deposit is softer. Improved corrosion resistance as a result of heat treatment is only partially true. Corrosion resistance improves up to a certain temperature because of oxide formation; once that temperature is exceeded crazing in the coating occurs and avenues for substrate corrosion are opened.
EFFECTS OF HEAT TREATMENT: As EN deposits are heated to temperatures above 430 degrees F, nickel phosphide particles begin to form, reducing the phosphorus content of the remaining material. This reduces the corrosion resistance of the coating. The particles also create small active/passive corrosion cells, further contributing to the destruction of the deposit. The deposit shrinks as it hardens, which can crack the coating and expose the substrate to attack. Baking treatments used for hydrogen embrittlement relief, cause no significant increase in corrosion. Hardening however, has caused the corrosion rate of the deposit to increase from 0.6 mil/yr to more than 35 mils/yr. Where maximum corrosion resistance is required, hardened coatings should not be used.

Table 5: The effect of heat treatment on the corrosion of a 10.7% phosphorus electroless nickel in 10% hydrochloric acid

<table>
<thead>
<tr>
<th>Heat treatment</th>
<th>Deposit hardness, HV</th>
<th>Corrosion rate, μm/yr/mil/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>None . . . . . .</td>
<td>480</td>
<td>15</td>
</tr>
<tr>
<td>190 °C (375 °F)</td>
<td>1.4 h . . . . . . .</td>
<td>20</td>
</tr>
<tr>
<td>290 °C (550 °F)</td>
<td>. . . . . . . . . . 900</td>
<td>1900</td>
</tr>
<tr>
<td>340 °C (650 °F)</td>
<td>10 h . . . . . . .</td>
<td>1400</td>
</tr>
<tr>
<td>400 °C (750 °F)</td>
<td>4 h . . . . . . . . 970</td>
<td>900</td>
</tr>
<tr>
<td>1050</td>
<td>1200</td>
<td>47</td>
</tr>
</tbody>
</table>
# SUMMARY OF ELECTROLESS NICKEL DEPOSIT PROPERTIES

<table>
<thead>
<tr>
<th>Property</th>
<th>Low</th>
<th>Mid</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition</td>
<td>LOW</td>
<td>MID</td>
<td>HIGH</td>
</tr>
<tr>
<td>Nickel</td>
<td>98%</td>
<td>92%</td>
<td>88%</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>2%</td>
<td>8%</td>
<td>11%</td>
</tr>
<tr>
<td>trace</td>
<td>.02%</td>
<td>.05%</td>
<td>.5%</td>
</tr>
<tr>
<td>Elongation %</td>
<td>.1%</td>
<td>0.1 - 0.4%</td>
<td>0.5 - 1.5%</td>
</tr>
<tr>
<td>Density g/cm³</td>
<td>8.28</td>
<td>8.12 - 7.95</td>
<td>7.85</td>
</tr>
<tr>
<td>Thermal Expansion (10^-6 m/m/C)</td>
<td>9</td>
<td>9 - 13</td>
<td>14</td>
</tr>
<tr>
<td>Resistivity microohm-cm</td>
<td>20 - 30</td>
<td>40 - 70</td>
<td>120</td>
</tr>
<tr>
<td>Magnetic</td>
<td>30 oersteads</td>
<td>1.4 oersteads</td>
<td>0.2 oersteads</td>
</tr>
<tr>
<td>Tensil Strength</td>
<td>40 Kp/mm²</td>
<td>70 Kp/mm²</td>
<td>as plated</td>
</tr>
<tr>
<td></td>
<td>80 Kp/mm²</td>
<td>25 Kp/mm²</td>
<td>2 hr 750°C</td>
</tr>
<tr>
<td>Elasticity</td>
<td>1.2 to 2 x 10^-4 Kp/mm²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Stress</td>
<td>-3 to +30 MPa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melting Point</td>
<td></td>
<td></td>
<td>881 (C)</td>
</tr>
<tr>
<td>Hardness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vickers 100 gram load</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>As plated</td>
<td>550 - 700</td>
<td>500 - 550</td>
<td>450 - 500</td>
</tr>
<tr>
<td>200 (C)</td>
<td>600 - 800</td>
<td>550 - 650</td>
<td>550 - 600</td>
</tr>
<tr>
<td>400 (C)</td>
<td>750 - 1000</td>
<td>900 - 1000</td>
<td>900 - 950</td>
</tr>
<tr>
<td>600 (C)</td>
<td>900 - 1000</td>
<td>800 - 850</td>
<td>850 - 900</td>
</tr>
<tr>
<td>Taber Abrader Index Resistance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mg/1000 cyc</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>As Plated</td>
<td>12 - 16</td>
<td>18 - 28</td>
<td>20 - 25</td>
</tr>
<tr>
<td>400 (C)</td>
<td>8 - 12</td>
<td>12 - 16</td>
<td>12 - 18</td>
</tr>
</tbody>
</table>
Electroless Nickel vs Other Materials

Stainless Steel: The use on EN plating on carbon steel or cast-iron has key advantages when compared to stainless steel and other non-ferrous alloys.

* Lower cost.
* Ease of machining. Reduction of welding and fabrication problems because parts are plated after fabrication.
* Improved corrosion performance in many environments especially resistance to chloride attack.

Plastic Coatings: EN deposits offer advantages over phenolic or epoxy-type plastic coatings.

* EN will function over a broad temperature range.
* Better adhesion due to the metallurgical bond formed between the metals.
* Coating uniformity especially in recesses and on complex shapes.
* Electrical conductivity.
* Superior abrasion, wear resistance and durability. No cracking or tearing in threaded areas and better resistance to wire line damage.

Hard Chrome: EN coatings have several important advantages when compared to hard chromium.

* Coating uniformity holds critical tolerances even on complex geometries without subsequent machining.
* Superior corrosion resistance and lack of porosity. Hard chrome plating has a micro-cracked structure that is very porous and more susceptible to corrosion.
* Inherent lubricity offers galling resistance when mated against itself or stainless steel. Hard chromium tends to gall in these instances.
* Better total wear properties in many applications. The hardest part will not always provide the best wear.
* Increased pressure on chrome waste is causing corporate liability concerns about future compliance and cost of compliance.
WHY USE DIFFERENT EN FORMULATIONS?

The right nickel coating can eliminate the need for expensive high-alloy materials in corrosive environments, prolong the life of wear components by factors of four or more, improve release properties of molds, or improve the appearance of metal components.

Types of EN coatings include nickel-phosphorus, nickel-boron, poly alloys, and composite coatings. The variety of coatings available within these categories allows the design engineer to optimize an important property while retaining a good balance of all the properties common to EN.

Low Phos 1-4%

* Best for solderability.
* Magnetic.
* Corrosion resistance best in alkaline environments, poor in acidic environments.

Mid Phos 5-8%

* Faster deposition rate means lower costs.
* Generally suited for mild corrosive environments.
* Slightly magnetic.

High Phos 9-12%

* Corrosion resistance best in acid environments, fair to excellent in alkaline environments.
* Non-magnetic.
* Slow deposition rate results in higher cost.

Nickel boron

* Offers higher hardness and better solderability than conventional EN but has high tensile stresses that impair durability.
* Still very much in the developmental stages and under further evaluation.
Poly Alloys

* Copper-nickel-phosphorus poly alloys, offer the potential for better corrosion resistance, but currently are not durable enough for commercial use.
* This coating is also still under development and further evaluation.

Composite Coatings

* Silicon carbide particles incorporated in the deposit for enhanced abrasion/erosion resistance. Used in such applications as barrel tubes at bottoms of oil wells, where sand in the incoming slurry causes rapid abrasive wear. Also suitable for farm implements, machinery parts, sawblade tips, etc.
* PTFE particles are uniformly dispersed throughout the coating to offer reduced friction, improved lubricity and wear, and non-stick and anti-fouling properties. EN/PTFE coatings, such as PEN-TUF/EN are gaining widespread use in numerous applications such as mold plates and ejector pins for plastic injection molding, threaded parts for robotics, computer and other hardware applications, cylinders and rollers, and various parts for the printing, automotive and food industry.

TRY "PEN-TUF/EN"

FRONT RANGE PLATING'S ANSWER TO PTFE COMPOSITES
REFERENCES


