Electroless Nickel:

A Functional Solution for Industry's Problems

by
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Abstract

Electroless nickel plating is one of the fastest growing segments of the metal finishing industry. The superior properties and many applications of the process are attracting more attention from both end users and metal finishers. Electroless nickel coatings are commonly used by most industries for many different reasons.

This paper will describe how electroless nickel coatings are applied and the unique structure and properties of the deposits. It will also describe some important and interesting applications of the coating.

Introduction

Electroless nickel coatings are not a new product for most industries. They have been used for many different applications since their introduction in 1953. Today, with the development of different types of electroless nickel with different functional properties, and with the increased importance being shown equipment cost and reliability, these coatings are being considered for more uses. Electroless nickel coatings are now one of the fastest growing segments of the metal finishing industry.

For most applications, electroless nickel is commonly used for many different, but often complimentary reasons. For instance, in different applications, electroless nickel coatings can:

- Reduce corrosion,
- Reduce friction and wear,
- Avoid product contamination,
- Improve equipment operation and reliability, and
- Reduce investment and maintenance cost.

Because of this unique combination of properties, electroless nickel has been valuable to industry, and is frequently used to replace more expensive alloys. Typical properties of electroless nickel coatings are compared in Table 1 to those of electrolytic nickel and chromium.

A Different Type of Plating

Unlike most conventional plating, electroless nickel coatings are applied without the use of an electric current. Instead, the coating is deposited by the chemical reduction of nickel ions by a reducing agent, usually sodium hypophosphite. Thus, anodes are also not required and racking and positioning the part is much less important than with electroplating. Because it is applied without a current, the coating's thickness is uniform on all areas in contact with fresh solution.

Electroless nickel coatings can only be applied directly to a catalytic surface, such as iron, steel and aluminum. Metals like copper, stainless steel, zinc and titanium are not catalytic and must first be electroplated with nickel before they can be plated with electroless nickel. Since the deposit is also catalytic to reduction, the plating reaction continues as long as the surface remains in contact with the electroless nickel solution. Consequently, the process is also called autocatalytic nickel or chemical nickel.

Electroless nickel solutions are blends of different chemicals, each performing an important function to control the chemical reaction. Electroless nickel solutions typically contain the following:

- A source of nickel ions, usually nickel sulfate,
- A reducing agent, usually sodium hypophosphite,
- Energy as heat,
- Complexing agents to control the free nickel available for the reaction,
- Buffering agents to resist the pH changes produced by the hydrogen ions released during plating,
- Accelerators to help increase the speed of the reaction,
- Inhibitors or stabilizers to help control the reduction reaction, and
- Reaction by-products.

The characteristics of an electroless nickel bath and its deposit are determined by the composition of these components. There are three basic types of hypophosphite reduced electroless nickel plating solutions. They are characterized by the phosphorus content of the deposits that they produce.

Low Phosphorus Baths. Low phosphorus type baths typically produce deposits containing 2 to 4 percent phosphorus. The coating offers improved hardness and wear characteristics, higher temperature resistance, improved solderability and increased corrosion resistance in alkaline environments. The share of the market filled by low phosphorus coatings is growing, with considerable interest from aerospace and automotive manufacturers.

These plating solutions typically are operated at lower temperature and higher pH than other baths. Their optimum operating conditions are 180°F (82°C) and 6.2 pH. At these conditions, this type of bath will produce a plating rate of 0.6 to 0.8 mil/h (15 to 20 µm/h).

Bright Mid Phosphorus Baths. Mid phosphorus type baths are the most commonly used baths for the general electroless nickel market. These baths are stable, long lived, tolerant of contaminants, and have a high plating rate. The deposits usually contain 7 to 9 percent phosphorus and are bright and aesthetically pleasing. These coatings, however, are usually porous and stressed, and are only moderately corrosion resistant.

These baths typically are run at 192°F (89°C) and 5.0 pH. Their plating rate is usually 0.6 to 0.8 mil/h (15 to 20 µm/h), although plating rates of one mil/h (25 µm/h) or more are possible with some formulations. Mid phosphorus baths are the workhorse of the industry.

High Phosphorus Baths. High phosphorus type baths are used to apply coatings containing 11 to 12 percent phosphorus. These deposits have two separate and distinct uses. Because of their nonmagnetic characteristics, large volumes of these solutions are used as an undercoat on aluminum computer memory disks. This application accounts for more than one third of the electroless nickel coatings applied by industry. The remaining high phosphorus coatings are used for functional applications, where their high corrosion resistance, ductility and resistance to impact can provide significantly improved parts.

High phosphorus type baths are normally operated at 190°F (88°C) and 4.8 pH. Their plating rate is only 0.4 to 0.5 mil/h (10 to 12 µm/h). Disadvantages of these baths are that they have short lives compared with other baths and are somewhat intolerant of impurities.

An Unique Engineering Material

The structure of electroless nickel coatings makes them a unique engineering material. In the as-deposited condition, most electroless nickel coatings are completely or partially amorphous. However, the amount of amorphous material that a coating contains depends on its phosphorus content.[1]

Electroless nickel coatings containing up to 4½ percent phosphorus consist of a microcrystalline, solid solution of phosphorus in nickel.[1] The size of these crystals is between 20 and 60 Å as compared with 100 to 1000 Å for electrolytic nickel plating.[2] When their phosphorus content exceeds 11 percent, electroless nickel coatings become totally amorphous, without any crystal structure. Amorphous alloys are also sometimes called metallic glasses. The lack of structure of high phosphorus deposits has been confirmed by electron diffraction at 150,000 magnifications.[3] Both crystalline and amorphous phases are metastable, non-equilibrium phases.

Between 4½ and 11 percent phosphorus, electroless nickel coatings consist of a mixture of amorphous and crystalline phases.[1] The change in structure with changing phosphorus content, and especially the transitions between phases, produces significant changes in the properties of these coatings.

The continuity of electroless nickel coatings also depends upon their composition. Amorphous coatings containing more than 11 percent phosphorus are typically continuous. A cross sectional view of one of these coatings is shown in Figure 1. Lower phosphorus coatings, and especially those applied from baths stabilized or brightened with heavy metals or sulfur compounds, are often porous. These deposits consist of columns separated by cracks and holes. The presence of such discontinuities affects the deposit's properties, especially its ductility and corrosion resistance.

When electroless nickel coatings are heated to high temperatures, nickel phosphide (Ni_3P) begins to precipitate and any amorphous material begins to crystallize. The formation of intermetallic phosphide particles in the deposit causes the coating's hardness and wear resistance to increase, while its ductility and corrosion resistance declines.

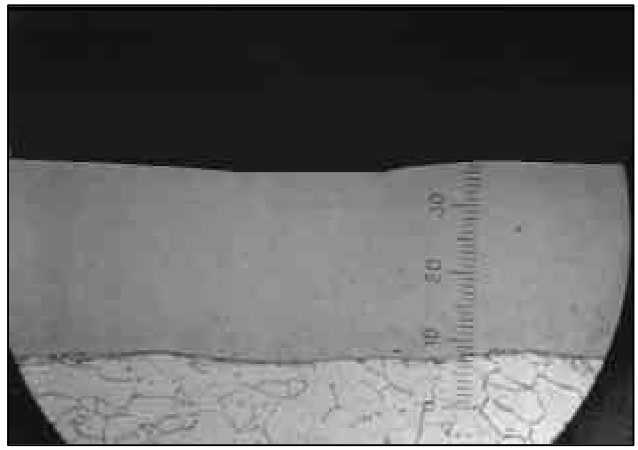

Figure 1
Cross sectional view of a 3 mil thick electroless nickel deposit containing 11 percent phosphorus at 400 magnifications

Appearance. Usually, the appearance of electroless nickel coatings is similar to that of metallic nickel, but with a slight yellow hue caused by oxidation. The appearance or brightness of deposits can vary significantly, depending on the plating solution's formulation, the presence of brightening agents, and the surface finish of the part. Typically, low and high phosphorus coatings have a duller finish than the medium phosphorus deposits. Brightened medium phosphorus coatings can be very reflective and shinny.

The surface finish of the substrate can also affect the appearance of the coating. Rough or abraded surfaces produce dull coatings, while polished surfaces allow bright coatings to be applied. Typically, electroless nickel coatings will reproduce the surface finish of the substrate within ±3 µin RMS.

Uniformity Provides Many Benefits. One especially beneficial property of electroless nickel is its uniform coating thickness. Electroless nickel coatings follow the contours of the base metal very closely. This is accomplished on both small and large parts and on components with complex shapes or recessed areas. Electroplating such parts would produce non-uniform deposition on ridges or edges and reduced thickness or even voids on interior surfaces. Not only can these variations affect the ultimate performance of the coating, but they can also cause additional finishing to be required after plating.

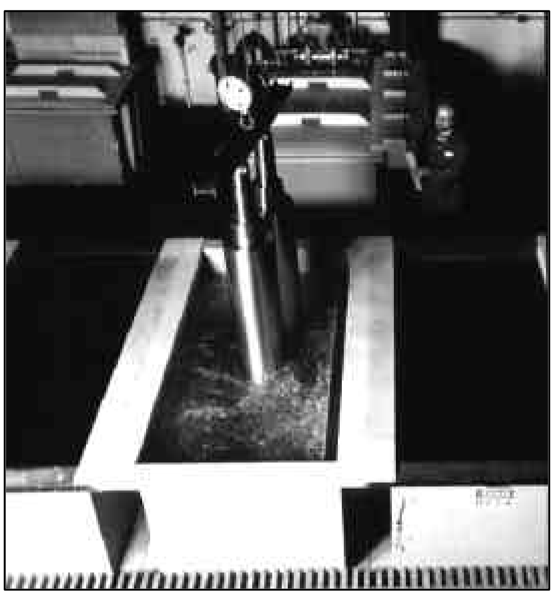

Figure 2
Two printing press cylinders plated with 1.5 mils of high phosphorus electroless nickel

Because electroless nickel is applied by chemical reduction, the plating rate and coating thickness are the same on any section of the part exposed to fresh plating solution. Grooves, slots, blind holes, and even the inside of tubing will have the same amount of coating as the outside of a part.

The benefits of the coating's uniformity are illustrated by the conversion of many cylinders and rolls used in the printing and textile industries from hard chrome to high phosphorus electroless nickel. Previously these cylinders had to be ground, plated and ground a second time, before they could be balanced and installed. With electroless nickel they are now ground only once, balanced, plated to the desired diameter and installed. This change has not only reduced handling and the overall cost of finishing, but also allows the manufacturer to use his grinding machines to produce more new parts, thus increasing his productivity.[4] Two of these cylinders are shown in Figure 2.

The range of thickness of electroless nickel plating for most commercial applications is 0.1 to 10 mils (2½ to 250 µm). The primary limitation to thickness is the operator's ability to keep the plating process chemically balanced and free of contaminants and solids. Coatings with a thickness greater than 25 mils (625 µm) have been achieved. Deposition of these heavier coatings, however, requires more careful attention to process control to avoid roughness and pitting.

Most commercial applications, except those involving severe corrosive service or heavy buildup on worn parts, have a thickness between 0.1 and 1 mil (2½ and 25 µm). A thickness of 1 to 3 mils (25 to 75 µm) are common for corrosive services, while a deposit thickness above 3 mils (75 µm) is typical of repair and rework. The accuracy of thickness control can be as good as ±0.05 mil (±1 µm).

Adhesion Strength is Outstanding. The adhesion of electroless nickel coatings to most metals is excellent. A replacement reaction occurs when catalytic metals such as steel and aluminum are placed into the electroless nickel bath. This reaction helps remove submicroscopic contaminants and allows the deposit to establish metallic plus mechanical bonds with the substrate. Adhesion, however, is dependent on proper cleaning of the substrate.

The bond strength of electroless nickel coatings to copper alloys and mild steel has typically been found to be 30,000 to 60,000 psi (200 to 420 MPa).[5] Bond strengths of 55,000 to 68,000 psi (380 to 470 MPa) have been reported on AISI 4340 steel after proper surface preparation.[6] The bond strength on light metals such as aluminum is usually lower and depends on the alloy and its surface preparation. However, it is usually between 9,000 and 36,000 psi (60 and 250 MPa).[5]

With non-catalytic metals, such as stainless steel, an initial replacement reaction does not occur and adhesion is reduced. With proper pretreatment and activation, however, the bond strength of the coating is usually between 23,000 and 29,000 psi (160 and 200 MPa).[5]

A Strong and Tough Alloy. The mechanical properties of electroless nickel coatings are like those of other glasses; they have high strength, limited ductility and a reduced modulus of elasticity. Except for low phosphorus deposits, the ultimate tensile strength of most coatings exceeds 100,000 psi (700 MPa). This strength is equal to that of many hardened steels and allows the coating to withstand a considerable amount of abuse without damage. The strength of low phosphorus coatings is only about one third of that of nickel metal.[7]

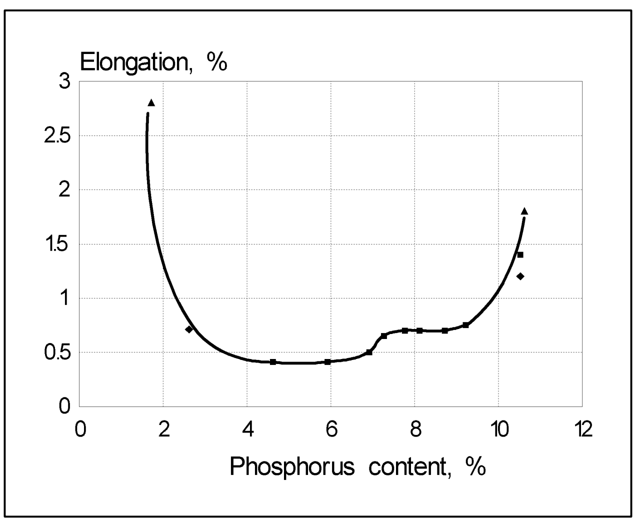

Figure 3
The effect of phosphorus content on the ductility of electroless nickel coatings

The ductility of electroless nickel coatings is limited when compared with most other types of plating or with conventional materials of construction. As shown in Figure 3, the ductility of high and low phosphorus coatings is generally between 1 and 2 percent. However, the elongation of medium and most low phosphorus coatings is typically less than 1 percent.[1 7 8 9] While this level of ductility is low, it is adequate for most coating applications. Thin films of the deposit can be bent completely around themselves without fracture, and the coating has been used successfully for springs and bellows. Electroless nickel, however, cannot be applied successfully to articles that subsequently will be bent or drawn. Severe deformation will crack the deposit, reducing its performance.

The physical properties of electroless nickel coatings are similar to those of the austenitic stainless steels. As deposited, their electrical and thermal conductivity are much less than that of conventional conductors like copper. Coatings containing more than about 11 percent phosphorus are completely nonmagnetic. Heat treatment precipitates nickel phosphide from the deposit and significantly increases its conductivity and magnetic susceptibility. However, electroless nickel's consistent electrical, thermal and magnetic properties, combined with its uniformity, excellent solderability and corrosion protection, make electroless nickel an ideal coating for electronic and computer applications. An example of its uses for electronic components is the connectors shown in Figure 4.

Figure 4
Aluminum coaxial connector bodies plated with 1 mil of high phosphorus electroless nickel

Provides Excellent Resistance to Wear.
Hardness and the resulting wear resistance of electroless nickel coatings are very important properties for many applications. Before heat treatment, the microhardness of medium and high phosphorus coatings is between 500 and 600 HV_{100}. Low phosphorus coatings can have hardness values as high as 650 to 700 HV_{100}. This is very approximately equal to 50 and 56 HRC respectively and is equivalent to the hardness of many hardened alloy steels.

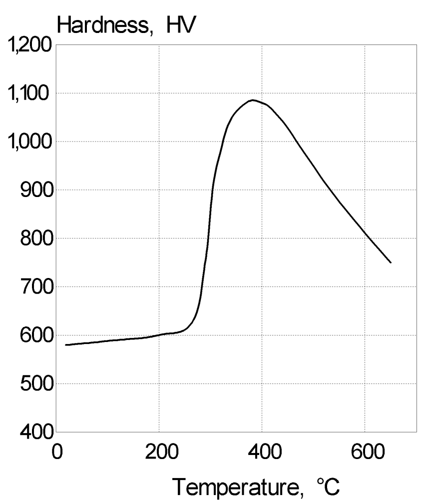

Figure 5
Effect of temperature on one hour heat treatments of electroless nickel containing 11 percent phosphorus

Heat treatment will cause electroless nickel coatings to precipitation harden and can produce hardness values as high as 1100 HV_{100}. This is equal to the hardness of most commercial hard chromium coatings. Figure 5 shows the effect of different one-hour heat treatments on the hardness of an electroless nickel coating containing 11 percent phosphorus.[10 11]

Hardening of electroless nickel coatings is due primarily to the precipitation of nickel phosphide particles within the alloy. At temperatures above 500°F (260°C), coherent and then distinct Ni_3P particles begin to form, and at temperatures of 650°F to 680°F (340°C to 360°C) the amorphous phase begins to crystallize. This causes the coating's hardness to increase rapidly. Maximum hardening is typically obtained with treatments at 750°F (400°C).

When electroless nickel coatings are heat treated at temperatures over about 550°F (290°C) in air, an oxide film is produced which discolors its surface. Depending upon the temperature and duration of the treatment and the humidity of the air, the color may range from a yellow tan to blue to green. The oxide film does not affect the performance of the coating, but it may be cosmetically objectionable. However, discoloration can be prevented by heat treating the coating in an inert atmosphere or vacuum.

The coating's high hardness also promotes outstanding wear resistance. The adhesive wear resistance of hardened electroless nickel, as measured by the Falex Wear Test under lubricated conditions, is equal to hard chromium. In addition, electroless nickel coatings produce less damage to the mating surface than does hard chromium.

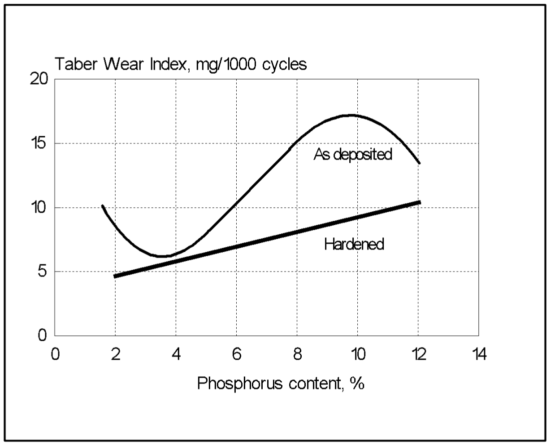

Figure 6
Effect of phosphorus content on the Taber Abraser Wear resistance of electroless nickel coatings

Electroless nickel coatings have good resistance to abrasion and erosion, although not equal to that of hard chromium. The Taber Wear Index of as deposited mid and high phosphorus coatings is about 18 to 20 mg/1000 cycles. The Index of low phosphorus coatings is as low as 7 mg/1000 cycles, as shown in Figure 6.[1] All three types provide a significant improvement over conventional metals like steel or aluminum. After heat treatments to produce maximum hardness, abrasive wear can be reduced to between 5 and 10 mg/1000 cycles, while that of hard chromium is only about 1.5 mg/1000 cycles. However, both heat treated and non heat treated coatings are commonly used to reduce the effects of erosion and abrasion, especially if corrosion is also a factor.

Polyethylene pelletizer bowls are an excellent example of the superior abrasive wear resistance of electroless nickel. Bowls, with a 3 mil thick coating, have been in service for one year with no measurable loss or attack. Precious bare aluminum bowls failed in three weeks after 40 percent of their original weight was worn away. A plated pelletizer is shown in Figure 7. Other typical wear applications of electroless nickel coatings include feed screws and extruders, hydraulic cylinders, computer drive mechanisms, textile machinery, molds and dies, and packaging equipment.

Another property related to wear is lubricity. Under wearing conditions, heat up of low friction surfaces is reduced and they are less subject to scoring, galling, or scuffing. Because of its phosphorus content, electroless nickel deposits have a low coefficient of friction, typically 0.38 to 0.45 under non lubricated conditions.[5] This is much better than steel, aluminum or stainless steel. The frictional properties of electroless nickel coatings do not vary with either phosphorus content or with heat treatment. Lubricity can be useful for applications such as molds, hydraulic systems, valve seats, rollers, and textile guides.

Figure 7
Aluminum polyethylene pelletizer body coated with 3 mils of high phosphorus electroless nickel after five months of service

Corrosion Resistance is Also Excellent. The corrosion resistance of high phosphorus electroless nickel deposits is also excellent and in many environments superior to that of pure nickel and chromium alloys. Electroless nickel is a barrier coating. It protects the underlying metal by sealing it off from the environment, rather than by galvanic or sacrificial action. Their superiority is illustrated by Figure 8.[12] Because they are not completely amorphous, the corrosion resistance of mid and low phosphorus coatings is greatly reduced in many environments.

When properly applied, high phosphorus nickel alloy coatings have superior resistance in most environments. They are almost totally resistant to alkalis, like caustic and potash; to salt solutions and brines, like seawater; to acid gas environments like those found in the petroleum industry; and to all types of hydrocarbons and solvents. High phosphorus deposits also have good resistance to ammonia solutions; to organic acids like lactic or acetic; and to reducing acids, like hydrochloric or sulfuric. Electroless nickel coatings are only significantly attacked by strongly oxidizing media like nitric or concentrated sulfuric acid.

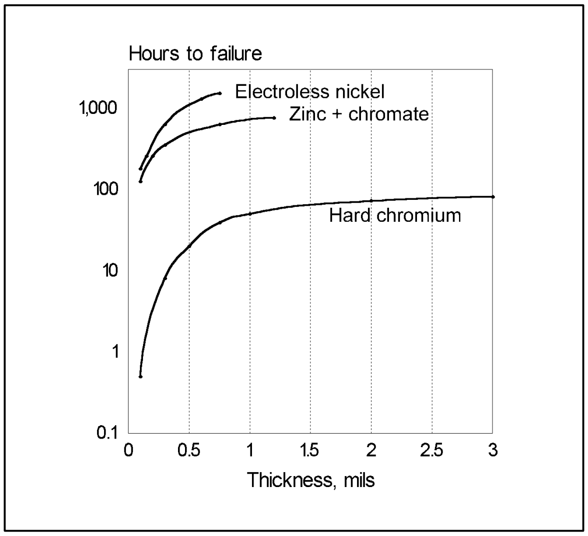

Figure 8
Effect of coating thickness on the corrosion protection of electroless nickel deposits compared to zinc and hard chromium

The petroleum and chemical process industries are probably the largest users of functional electroless nickel coatings for corrosion protection. The resistance of these deposits to corrosion in petroleum environments is superior to that of most other metals. Electroless nickel coatings not only ensure easy and reliable operation of equipment, but also can extend their life. For example, since the 1980's, more than 27,000 feet (8000 m) of electroless nickel coated production tubing was installed in about 250 wells in the Permian Basin area of West Texas. These are primarily API-J55 and N80 tubulars and collars, and typically have been coated with a 2 mil (50 µm) thick deposit. Many are protected on both the inside and outside surfaces. They are exposed to temperatures as high as 400°F (200°C) and to brines containing large amounts of H_2S, $C0_2$, and sand. Most of these installations have been successful and have greatly extended the lives of the production strings. In one well, tubing life was increased from 30 days for plain steel to more than 16 months with electroless nickel. Other applications include valves, blow out preventors, chokes, heat exchange equipment, pumps and all types of downhole equipment.

Conclusion

Functional electroless nickel deposits have many unique properties that make them a superior engineering material. These coatings offer high strength, excellent abrasion and wear resistance, superior corrosion resistance, with ease of application and uniform thickness. They have been useful in improving equipment life and reliability and in reducing investment and operating costs. Some typical applications of these coatings are listed in Table 2.[10]

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Table 1
Typical Properties of Electroless Nickel, Nickel and Chromium Coatings

Property	**Ni-3P**	**Ni-8P**	**Ni-11P**	**Nickel**	**Chromium**
Composition	3-4%P, balance Ni	6-9%P, balance Ni	11-12%P, balance Ni	100% Ni	100% Cr
Structure	Micro crystalline	Mixed crystalline and amorphous	Amorphous	Crystalline	Crystalline
Internal stress	-10 MPa	+40 MPa	-20 MPa	+140 MPa	+200 MPa
Final Melting Point	1275°C	1000°C	880°C	1450°C	1890°C
Density	8.6 g/cm^3	8.1 g/cm^3	7.8 g/cm^3	8.9 g/cm^3	7.1 g/cm^3
Coefficient of Thermal Expansion	12.4 µm/m°C	13 µm/m°C	12 µm/m°C	14 µm/m°C	8.4 µm/m°C
Electrical Resistivity	30 µS-cm	75 µS-cm	100 µS-cm	8 µS-cm	40 µS-cm
Thermal Conductivity	0.6 W/cm°K	0.05 W/cm°K	0.08 W/cm°K	0.95 W/cm°K	0.67 W/cm°K
Specific Heat	0.25 cal/g°K	ND	0.11 cal/g°K	0.11 cal/g°K	0.11 cal/g°K
Magnetic Coercivity	130 Oe	1.4 Oe	0	70 Oe	ND
Tensile Strength	300 MPa	900 MPa	800 MPa	400 MPa	120 Mpa
Ductility	0.7 %	0.7 %	1.5 %	28 %	0.1 %
Modulus of Elasticity	130 GPa	110 GPa	170 GPa	180 GPa	120 Gpa
Hardness, as deposited	700 HV_{100}	600 HV_{100}	530 HV_{100}	170 HV_{100}	1000 HV_{100}
Hardness, heat treated	960 HV_{100}	1000 HV_{100}	1050 HV_{100}	NA	NA
Coefficient of Friction	ND	0.38	0.45	ND	0.43
Taber Wear Index, as deposited	11 mg/ 1000 cycles	16 mg/ 1000 cycles	19 mg/ 1000 cycles	25 mg/ 1000 cycles	2 mg/ 1000 cycles
Taber Wear Index, heat treated	9 mg/ 1000 cycles	12 mg/ 1000 cycles	12 mg/ 1000 cycles	NA	NA
Corrosion Protection, salt fog resistance	24 hours	96 hours	1000 hours	24 hours	<24 hours

ND = Not Determined   NA = Not Applicable

Table 2
Applications of Electroless Nickel Coatings

Application	Substrate	Thickness, µm	Reason for Use
Automotive			
Heat sinks	Aluminum	10	Corrosion resistance and solderability
Carburetor components	Zinc	15	Corrosion resistance
Fuel injectors	Steel	25	Corrosion and wear resistance
Ball studs	Steel	25 h	Wear resistance
Differential pinion ball shafts	Steel	25 h	Wear resistance
Disc brake pistons and pad holders	Steel	25 h	Wear resistance
Transmission thrust washers	Steel	25 h	Wear resistance
Synchromesh gears	Brass	30	Wear resistance
Knuckle pins	Steel	38 h	Wear resistance
Shock absorbers	Steel	10	Corrosion resistance and lubricity
Lock components	Steel	10	Wear and corrosion resistance and lubricity
Hose couplings	Steel	5	Wear and corrosion resistance
Gears and gear assemblies	Steel	25	Wear resistance
Aircraft			
Bearing journals	Aluminum	38 h	Wear resistance and uniformity
Servo valves	Steel	18	Corrosion resistance and lubricity
Compressor blades	Alloy steel	25	Corrosion resistance
Hot zone hardware	Alloy steel	25	Corrosion and wear resistance
Piston heads	Aluminum	25	Wear resistance
Engine main shafts and propellers	Steel	38	Wear resistance
Hydraulic actuator splines	Steel	25 h	Wear resistance
Seal snaps and spaces	Steel	20	Wear and corrosion resistance
Landing gear components	Aluminum	>125	Buildup of improperly machined surfaces
Pitot tubes	Brass/SS	12	Corrosion and wear resistance
Engine mounts	Alloy steel	25	Wear and corrosion resistance
Printing			
Printing rolls	Steel/CI	38	Corrosion and wear resistance
Press bed	Cast iron	38	Corrosion and wear resistance
Textiles			
Feeds and guides	Steel	50 h	Wear resistance
Fabric knives	Steel	12 h	Wear resistance
Spinnerets	SS	25	Corrosion and wear resistance
Loom ratchets	Aluminum	25	Wear resistance
Knitting needles	Steel	12	Wear resistance
Molds and dies			
Zinc die cast dies	Alloy steel	25	Wear resistance and part release
Glass molds	Steel	50	Wear resistance and part release
Plastic injection molds	Alloy steel	15	Corrosion and wear resistance and release
Plastic extrusion die	Alloy steel	25	Corrosion and wear resistance
Military			
Fuse assemblies	Steel	12	Corrosion resistance
Mortar detonators	Steel	10	Corrosion resistance
Tank turret bearings	Alloy steel	30	Wear and corrosion resistance
Radar wave guides	Aluminum	25	Corrosion resistance and uniformity
Mirrors	Aluminum	75	Uniformity and reflectivity

Table 2
Applications of Electroless Nickel Coatings

Application	Substrate	Thickness, µm	Reason for Use
Firearms			
Commercial and military	Steel	8	Corrosion and wear resistance and solderability
Marine			
Marine hardware	Brass	25	Corrosion resistance
Pumps and equipment	Steel / CI	50	Corrosion and wear resistance
Electronics			
Heat sinks	Aluminum	10	Corrosion resistance and solderability
Computer drive mechanisms	Aluminum	18	Corrosion and wear resistance
Memory discs	Aluminum	25	Wear resistance and lack of magnetism
Terminals and lead wires	Alloy steel	2	Solderability
Chassis	Aluminum	12	Corrosion resistance and solderability
Connectors	Aluminum	25	Corrosion resistance and solderability
Diode and transistor cans	Steel	5	Corrosion resistance and solderability
Interlocks	Steel / brass	12	Corrosion and wear resistance
Printed circuit boards	Plastic	5	Solderability and bondability
Railroad			
Tank cars	Steel	90	Corrosion resistance
Diesel engine shafts	Steel	>25	Wear and fretting resistance and buildup of worn surfaces
Electrical			
Motor shafts	Steel	12	Wear and corrosion resistance
Rotor blades	Steel / Al	25 h	Wear and corrosion resistance
Stator rings	Steel / Al	25	Wear and corrosion resistance
Chemical and petroleum			
Pressure vessels	Steel	100	Corrosion resistance and product purity
Chemical and petroleum			
Mixer shafts	Steel	38	Corrosion resistance
Pumps and impellers	Steel	75	Corrosion and erosion resistance
Heat exchangers	Steel	75	Corrosion resistance
Filters and components	Steel	25	Corrosion and erosion resistance
Turbine blades and rotors	Steel	75 h	Corrosion and erosion resistance
Compressor blades and impellers	Steel / Al	125 h	Corrosion and erosion resistance
Spray nozzles	Brass / steel	12	Corrosion and wear resistance
Valves	Steel	75	Corrosion resistance and lubricity
Valves	Stainless steel	25 h	Wear and galling resistance and protection against stress corrosion cracking
Chokes and control valves	Steel / SS	75	Corrosion and wear resistance
Oilfield tools	Steel	75	Corrosion and wear resistance
Oil well tubing and pumps	Steel	50	Corrosion and wear resistance
Drilling mud pumps	Alloy steel	75	Corrosion and fatigue resistance
Hydraulic systems and actuators	Steel	75	Corrosion and wear resistance and lubricity
Blowout preventors	Alloy steel	75	Corrosion and wear resistance
Medical and pharmaceutical			
Disposable surgical instruments	Steel / Al	12	Corrosion resistance and ease of operation
Sizing screens	Steel	20	Corrosion resistance and cleanliness
Pill sorters	Steel	20	Corrosion resistance and cleanliness
Feed screws and extruders	Steel	25	Corrosion resistance and cleanliness

Table 2
Applications of Electroless Nickel Coatings

Application	Substrate	Thickness, µm	Reason for Use
Food			
Pneumatic canning machinery	Steel	25	Corrosion resistance and cleanliness
Baking pans	Steel	25	Temperature resistance, cleanliness, release
Molds	Steel	12	Cleanliness, corrosion resistance and release
Grills and fryers	Steel	12	Cleanliness, corrosion resistance and release
Mixing bowls	Steel	25	Cleanliness and corrosion and wear resistance
Bun warmers	Steel	12	Cleanliness and release
Feed screws and extruders	Steel	25	Cleanliness and corrosion resistance
Material handling			
Hydraulic cylinders and shafts	Steel	25	Corrosion and wear resistance and lubricity
Extruders	Alloy steel	75 h	Wear and corrosion resistance
Material handling			
Link drive belts	Steel	12	Wear and corrosion resistance and lubricity
Gears and clutches	Steel	>25	Wear resistance and buildup
Mining			
Hydraulic systems	Steel	60	Corrosion and abrasion resistance
Jetting pump heads	Steel	60	Corrosion and erosion resistance
Mine engine components	Steel/CI	30	Corrosion and wear resistance
Piping connections	Steel	60	Corrosion resistance
Framing hardware	Steel	30	Corrosion resistance
Wood and paper			
Knife holder corer plates	Steel	30	Corrosion and abrasion resistance
Abrading plates	Steel	30	Corrosion and abrasion resistance
Chopping machine parts	Steel	30	Corrosion and abrasion resistance
Miscellaneous			
Chain saw engines	Aluminum	25	Wear and corrosion resistance
Drill and taps	Alloy steel	12 h	Wear resistance and ease of use
Precision tools	Alloy steel	12	Wear resistance and cleanliness
Shaver blades and heads	Steel	8	Wear resistance and smoothness
Pen tips	Brass	5	Corrosion resistance

Ronald N. Duncan

BIOGRAPHICAL SKETCH

In Memory of Ron Duncan

Ron Duncan served as Vice President of Palm International, Inc., where he led the company's technical and educational initiatives. Prior to joining Palm, he was Director of Research at Elnic, Inc., focusing on electroless nickel formulation and materials research.

Before entering the metal finishing industry, Ron spent 12 years in the oil sector with Exxon and Caltex Petroleum Corporations, tackling materials and corrosion challenges. His work took him across the globe—including the United States, Middle East, Europe, South America, and Africa—where he developed a reputation for his deep expertise and practical problem-solving.

Ron held a BE in Mechanical and Metallurgical Engineering from Vanderbilt University. He was a Registered Professional Engineer and a certified Corrosion Specialist through NACE. A leader in technical standards, he chaired NACE task groups T-1G-19 and T-6A-53, contributing to authoritative reports on electroless nickel and other metallic coatings. He also served on the AESF's Electroless Committee.

Throughout his distinguished career, Ron authored more than fifty technical papers on corrosion, coatings, and electroless nickel. His work appeared in Materials Performance, Plating and Surface Finishing, Metals Progress, Products Finishing, and Finishers Management, as well as in numerous industry conferences. He was the principal author of the electroless nickel chapter in Volume 5 of the Metals Handbook and was honored with the AESF Gold Medal in 1996 for the best paper published in Plating and Surface Finishing.

Ron also directed the Electroless Nickel School, a comprehensive four-day seminar presented by Palm, which educated professionals in all aspects of electroless nickel technology.

Ron Duncan passed away on December 15, 2006. He is deeply missed by his family, colleagues, and the broader surface finishing community. His legacy of innovation, mentorship, and integrity continues to inspire all who had the privilege of working with him.