ELECTROLESS NICKEL COMPOSITE COATINGS

Electroless nickel coatings reinforced with diamond, silicon carbide, boron nitride, or PTFE particles can impart specific wear and lubricity properties to complex surfaces.

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Electroless nickel is an alloy of nickel and phosphorus. It is an autocatalytic coating, which simply means it will deposit from solution on certain substrates without any external source of electricity. Electroless nickel coatings are produced by the controlled chemical reduction of nickel ions onto a catalytic surface. The reaction continues as long as the surface remains in contact with the electroless nickel solution. Because the deposit is applied without an electric current, its thickness is uniform on all areas in contact with fresh solution.

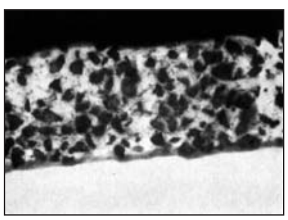

Fig. 1 — 1000X cross section photomicrograph of a EN/diamond coating with 2 μm diamond particles.

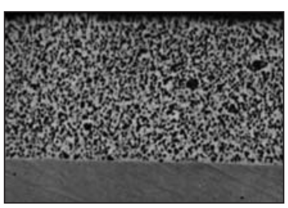

Fig. 2 — Cross section of EN/PTFE deposit.

All electroless nickel coatings have the distinct advantage of being able to evenly coat the substrate, both inside and out, as long as the solution flows uniformly. Electrolytic coatings, vapor coatings, and thermal-spray coatings typically cannot achieve uniform coating thicknesses across a broad range of part geometry. With some of these methods, a final 0.0005 inch thickness on a part interior may require depositing 0.001 inch or more on the exterior. Others cannot deposit on the interior of parts at all. This can be a major cost advantage for electroless nickel coatings, and also makes it the only real choice in certain applications.

Electroless nickel plating can be divided into three main types: low phosphorus (1 to 4 wt.% P), mid phosphorus (4 to 10 wt% P), and high phosphorus (>10.5 wt% P). Without the composite element, each subset has distinct uses and properties. Some properties of non-composite electroless nickels are presented in Table 1.

This article will examine the performance and cost advantages possible with electroless nickel composite coatings. It will focus on four specific types of composite electroless nickels: diamond, silicon carbide, boron nitride, and polytetrafluoroethylene (PTFE).

Composite electroless nickel

Composite electroless nickels are defined as those that incorporate distinct particles into the deposit to impart a specific property. Figure 1 is a photomicrograph of a typical EN/Diamond composite coating that displays the incorporated diamond particles. Figure 2 is a photomicrograph of an EN/PTFE deposit. As you can see, the functional particles are evenly and thoroughly distributed in the EN matrix, which is firmly bonded to the substrate. This unique combination of distribution and bond strength makes composite EN coatings extremely long lasting and durable compared with many other wear and lubrication alternatives.

Theoretically, almost any type of particle could be co-deposited, as long as it could withstand the conditions within an EN bath, and if it were of the appropriate size. Since this article is concerned with wear and lubricity, only the four most widely used EN composites will be considered.

Improvements in wear resistance

Generally speaking, diamond and silicon carbide electroless nickel composite coatings are chosen for wear resistance. Boron nitride and PTFE composite coatings are selected for lubricity. However, depending on the application, any of these coatings might improve wear resistance or lubricity, as the mechanisms for failure or success can be similar in both cases, depending on the type of wear. Wear resistance

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Table 1 — Properties of non-composite electroless nickels

Plating type	Phosphorus, wt%	Corrosion resistance, neutral salt spray	Taber wear*, as plated	Type of stress	Hardness as plated, Rc	Hardness after 1 hr bake at 725°F, Rc	Structure
Low phosphorus	1-4	Moderate	6-15	Tensile or Compressive	53-63	60-70	Crystalline
Mid phosphorus	4-10	Moderate	14-19	Tensile	44-49	59-67	Crystalline
High phosphorus	10.5-14	Very good	20-35	Compressive	42-48	60-69	Amorphous

**milligrams loss per 1000 cycles, load of 10N, CS-10 wheel* can be improved in three general ways:

• **Modify the substrate to improve wear.** This can be achieved by changing alloys and carbon content in ferrous-based alloys, and applying a subsequent thermal treatment to increase hardness (although increases in hardness do not always increase wear). Shortfalls of this method are the much higher costs for changing the entire substrate when the wear resistance is only needed at the surface; and usually reduced corrosion resistance of the substrate due to grain structure and alloy changes necessary for hardening. Hardening options are extremely limited or non-existent with substrates such as copper, aluminum, magnesium, and plastics. These types of materials require coatings to achieve good wear resistance.

• **Apply a lubricant that retards the mechanisms of wear.** While lubricants are and will continue to provide wear resistance in many applications, their standalone use is mostly limited to areas of light-to-moderate loading. Most are not durable and need to be continually re-applied on a fairly frequent basis to be functional. Wet lubricants also tend to trap wear particles and dirt that contribute to further wear. In areas of critical wear applications, lubricants are seldom applied without a wear-resistant coating or substrate hardening.

• **Apply a wear-resistant coating to the substrate**. Applying a coating to the substrate accurately deposits the correct amount of wear resistant material to the surface. This may allow for the following advantages:

• Choice of a base material that could be much more cost effective or corrosion resistant.

• Vastly increased wear resistance over that attainable with the base material.

• Lower overall production costs.

As far as wear-resistant coatings are concerned, chrome electroplating has been a standard for many years. It is fairly inexpensive and has excellent wear capabilities. However, it does not provide good corrosion protection, and it often requires a post-plate grinding operation because of gross thickness distribution variances. Furthermore, because it exists as hexavalent chromium in the plating bath, it is heavily regulated. Although this regulatory impact may not directly affect the end user today, it may limit chromium's availability in the future.

Table 2 shows a comparison of wear resistance for several common coatings and tool steel versus EN/diamond and EN/SiC. Note that composite electroless nickels can be orders of magnitude more wear-resistant than some other options.

EN/SiC and EN/diamond incorporate particles of various sizes within the EN deposit, anywhere from nanoparticles up to several microns in size. Because of the differences in hardness, size, shape, and cost of particle, each has its own advantages and disadvantages in specific applications. But each generally has outstanding wear resistance performance over most other coatings.

Table 2 — Wear resistance of various coatings vs. tool steel

Coating type	Taber wear index	Yarnline abrasive wear rate
EN/Diamond	0.0115	3.2
EN/SiC	0.0170	349.8
Electroplated hard chrome	0.0469	966.6
Cemented tungsten carbide	0.0274	43.7
Tool steel, Rc 63	0.1281	3478.6
Flame-sprayed aluminum oxide	Not tested	173.6
Flame-sprayed chromium oxide	Not tested	106.9

Wet film and dry film

Lubrication is defined as the reduction of frictional resistance and wear, or other forms of surface deterioration, between two load bearing surfaces by the application of a lubricant. By this definition, lubricious surfaces can and should reduce wear to some extent.

Lubricants can be a wet film (liquids) or dry film (solids). With liquid film lubricants, two opposing surfaces are separated by pressures within the lubricating film, thereby minimizing wear and fretting, and reducing frictional forces. These include the oils and greases, among others.

Dry film, or solid lubricants, work by the same mechanisms as liquid lubricants, that is, by separation of the two opposing surfaces. Solid film lubricants are of special interest in harsh environments in which liquid lubricants would congeal or evaporate.

EN/PTFE or EN/boron nitride are technically in the class of dry film lubricants. However, they are a very special subset of this class. They provide very low coefficient of friction numbers while maintaining abrasive wear resistance superior to many other liquid or dry film lubricants. When these coatings are applied on top of a base layer of high phosphorus electroless nickel, the combination also provides outstanding service in corrosive environments.

PTFE and boron nitride

EN/PTFE deposits can typically contain 10 to 25% by volume PTFE in the deposit. The deposit is self lubricating and has very good coefficient of friction and wear rate numbers. This lubricating effect is greatly enhanced when both opposing surfaces are coated with it, as seen in Tables 3 and 4. It is fairly inexpensive to coat, and is readily available across the United States.

Howver, PTFE does decompose at temperatures above 300°C, which limits its service in high temperature applications. It is also a softer coating

Table 3 — Friction coefficients

Material	Load, kg/cm^2	Friction coefficient
EN (No particles)	0.1	0.12
EN/PTFE	0.1	0.13
EN/BN	0.1	0.18
Chromium	0.1	0.25
EN (no particles)	0.3	0.09
EN/PTFE	0.3	0.13
EN/BN	0.3	0.16
Chromium	0.3	0.40
EN (no particles)	0.5	0.08
EN/PTFE	0.5	0.13
EN/BN	0.5	0.15
Chromium	0.5	150.00

Table 4 — Falex testing results

Block coating	Steel ring volume loss
EN/BN	0.43
EN/PTFE	3.44
Chromium	16.35
Plasma	45.60

than the inorganic EN composites mentioned previously. Because of these temperature and softness limitations, it is best suited for lower-temperature, light-loading applications.

EN/boron nitride incorporates 6 to 8% by weight of hexagonal boron nitride particles of a mean size of 0.7 μm in a medium to low phosphorus EN matrix. This coating has lower coefficient of friction numbers under higher loads than the EN/PTFE exhibits.

Boron nitride particles are ceramic and can withstand temperatures up to 3000°C. Therefore, this coating can be utilized in higher temperature applications (up to the solidus point of the EN matrix, which is approximately 880°C). This coating has also been successful in mold release applications, where its uniform thickness in complex cavities, moderate wear resistance, excellent lubricity, and release properties outperform most other coatings. Performance data for EN/BN coatings is shown in Tables 3 and 4.

Electroless nickel composite coatings can have both a performance and a cost savings benefit in many applications. They can be tailored for the specific application, coated at any thickness from 0.00001 to more than 0.010 inch, provide uniform thickness across variations of geometries, and provide excellent lubricity as well as resistance to corrosion and wear. Because they are truly a "family" of coatings, their versatility makes them appropriate as a solution to many tribological problems.

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