Composite Electroless Nickel Coatings for the Gear Industry

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Electroless Nickel (EN) plating, a process dating back to the 1940s, is one of the predominant metal finishing methods today. It is especially suitable for the gear industry, whose end uses span innumerable other industries, providing an endless assortment of requirements, environments, materials and specifications. EN plating has a broad array of functional features, which include:

1. Corrosion resistance,
2. Exceptional hardness,
3. Outstanding wear resistance,
4. Perfect uniformity of coating thicknesses on all geometries,
5. Lubricity,
6. Nonmagnetic properties,
7. Solderability,
8. Applicability to nearly all metals and alloys.

Since EN can be produced with a bright and reflective finish similar to chrome, it is also widely used in applications where cosmetics are critical.

Composite Electroless Nickel

The incorporation, or codeposition, of specific finely sized particles within EN coatings can greatly enhance their existing characteristics and, in some cases, add an entirely new feature to the coating.

In typical composite coatings, the fine particulate matter can range in size from 0.1μm to about 10μm and can be loaded up to about 40% by volume within the coating. The ratio of codeposited particles to the metal matrix in composite electroless plating can be adjusted to a fixed and constant ratio. Most commercial practices, however, focus on 18–25% by volume of the particle within the matrix.

Because of the uniform manner in which the particulate matter is codeposited, these coatings are known as regenerative, maintaining their properties even when portions of the coating are removed by prolonged use (See Fig. 1).

Though it is possible to generate thicker coatings, deposits of 0.5–1.0 mil are adequate for most commercial applications. Composite EN coatings on gears are generally 0.8–1.0 mil in thickness.

While a wide variety of particulate matter can be codeposited, commercial composite electroless plating is limited to just a few types of particulate matter for three general purposes. For increased wear resistance and hardness, diamond or other hard particles are commonly codeposited within EN. Enhanced lubricity is achieved with the incorporation of polytetrafluoroethylene (PTFE)

Fig. 1 — Composite EN coating with diamond particles (1000x mag.).

and certain inorganic particles that reduce the coefficient of friction. In addition, a new generation of composite coatings containing light-emitting particles has recently been developed. All three primary categories of composite coatings and their applicability to the gear industry will be discussed in the remainder of this article.

Wear Resistance

Composite EN coatings are most commonly used to improve the wear resistance of machinery parts. Wear to gears and many other machinery parts causes undesirable replacement costs, downtime, mechanical malfunction and inconsistent output or product.

Various test procedures have been employed to evaluate the degree of wear resistance achieved. The Taber wear test is the most common. It evaluates the resistance of surfaces to abrasive rubbing produced by the sliding rotation of two unlubricated, abrading wheels against a rotating sample. This test measures the worn volume.

The merits of composite EN coatings in comparison to conventional EN coatings as shown by Taber wear testing were illustrated by Parker (Refs. 1,2) in Table 1. Parker measured the wear resistance of miscellaneous composites containing diamond, carbides, borides and aluminum oxide. The composites he tested, however, employed particulate matter of

Table 1 — Abrasive Wear Data For Electroless Nickel With Particle Inclusions

		Taber Wear Index[a]	
Particle	Particle Hardness, Knoop	No Heat Treatment	Heat Treated[b]
None	—	18	8
Chromium carbide	1735	8	2
Aluminum oxide	2100	10	5
Titanium carbide	2470	3	2
Silicon carbide	2500	3	2
Boron carbide	2800	2	1
Diamond	7000	2	2
Hard chromium, 1000 KHN		3	—
Aluminum hardcoat		2	—

[a]Weight loss in mg/1000 cycles (average of 5000 cycles) with CS 10 wheels and a 1000 g load.
[b]Heated 10 to 16 hr at 290°C.

Table 2 — Taber Wear Test Data		
	Wear Rate	
Wear Resistant Coating or Material	per 1000 cycles (10^4 mils^3)	vs. diamond
Polycrystalline diamond*	1.159	1.00
Cemented tungsten carbide Grace C-9 (88WC, 12 Co)	2.746	2.37
Electroplated hard chromium	4.699	4.05
Tool steel, hardened R_c 62	12.815	13.25

*Composite coating containing 20–30% of a 3µm grade diamond in an electroless nickel matrix.

Table 3 — Friction Coefficient and Wear Data for Electroless Nickel-PTFE Composite

Coating on Pin	Coating on Ring	Coefficient of Friction	Relative Wear Rate
EN	Cr steel	0.6–0.7	35
EN + PTFE	Cr steel	0.2–0.3	40
EN + PTFE	EN + PTFE	0.1–0.2	1
EN + PTFE[a]	Cr steel	0.2–0.5	20
EN + PTFE[b]	EN + PTFE	0.1–0.7	2

a Wear determined in a test machine consisting of a pin and a rotating ring.
b Heated 4 hrs. at 400°C.

Table 4 — Friction Coefficients For Various Composites and Materials

Coating	Load kg/cm^2	Friction Coefficient
PTFE	0.1	0.12
EN-BN	0.1	0.13
EN-SiC	0.1	0.15
EN (No particles)	0.1	0.18
Chrome	0.1	0.25
EN-BN	0.3	0.09
PTFE	0.3	0.13
EN-SiC	0.3	0.14
EN (No particles)	0.3	0.16
Chrome	0.3	0.40
EN-BN	0.5	0.08
PTFE	0.5	0.13
EN-SiC	0.5	0.14
EN (No particles)	0.5	0.15
Chrome	0.5	150.00

different sizes, and neither the concentration of particles within the matrix nor the surface roughness for the coating prior to testing was revealed. Accordingly, based on the data published, no definitive conclusion can be drawn about the performance of one particle versus another.

What is clear, however, is that all of the composites, regardless of the particulate matter incorporated, performed substantially better than the EN without any particulate matter.

In Table 2, additional results employing the Taber test (Ref. 3) demonstrate the unsurpassed performance of diamond in a composite EN coating compared with more commonly used materials.

Lubricity

It has been observed (Ref. 4) that electroless composites with certain particles can yield a lower friction coefficient than identical coatings without such particulate matter. In recent years, most commercial interest has focused on the incorporation of PTFE into electroless nickel deposits.

The incorporation of PTFE and other lubricating particles into the EN composite provides several benefits:

- Dry lubrication,
- Improved wear resistance,
- Improved release properties,
- Repellency of contaminants such as water and oil.

Most applications employ composite coating thicknesses ranging from approximately 0.25 to 1.0 mil, sometimes with an un-derlayer of electroless nickel. The presence of the underlying electroless nickel is believed to provide improved corrosion resistance when necessary. Typical electroless nickel-PTFE composite coatings incorporate PTFE in the range of 18–25% by volume. Unlike coatings with wear-resistant particles like diamond, electroless nickel-PTFE composite coatings utilize particles *of 1µm or smaller.*

Using a rotating ring apparatus, Tulsi (Ref. 5) investigated the friction coefficients for electroless nickel and for composites with PTFE. Table 3 summarizes these observations, which suggest that the lowest coefficient of friction is attained when both the pin and the ring are coated with an electroless nickel-PTFE composite coating. These results have particular relevance in gear applications where metal gears contact each other. To achieve maximum lubricity and wear resistance, therefore, all mating gears are typically coated.

Table 4 (Ref. 6) documents the friction coefficients for a variety of lubricating composite EN coatings, of which boron nitride yields the lowest coefficient of friction, especially with increased loads employed on the friction machine.

Composite EN coatings with boron nitride and other types of inorganic particles have recently been investigated and commercially developed. These inorganic particles, compared to PTFE, have certain significant advantages that fulfill the demands of the gear industry and other industries, including

1. Temperature resistance to above 600°C.
2. Exceptional hardnesses to about 1,000 Hv.
3. Greater abilities to take direct loads,
4. Lower costs than composite PTFE coatings.

Light Emission

Light-emitting composite EN coatings are a recent and exciting development in the field. These coatings have all the inherent benefits of EN, but, when viewed under UV light, emit a distinct, brightly colored light. This novel property has two main uses. First, the presence of light can be valuable in authenticating OEM machinery parts (for example, in the aircraft industry). Second, the light can serve as an "indicator" layer, warning when the coating has worn off and replacement or recoating is necessary before the part itself is worn and/or produces inconsistent product. This indicator layer can even be applied between the part and another coating to indicate when the first coating has worn through to the light-emitting layer.

Hand-held, battery operated UV lights are readily available and make inspection of the indicator layer fast and convenient at the operating site. In the gear industry, this coating is particularly advantageous for applications employing very expensive gears; it avoids wear into the base metal and provides the opportunity to recoat the gear with a wear resistant coating. It is also beneficial in situations where operating with worn components must be avoided to insure consistent performance or product. ○

References:

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