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COMPOSITE ELECTROLESS NICKEL COATINGS FOR THE MICRO MANUFACTURING INDUSTRY — VARIETIES AND PERFORMANCE ADVANTAGES

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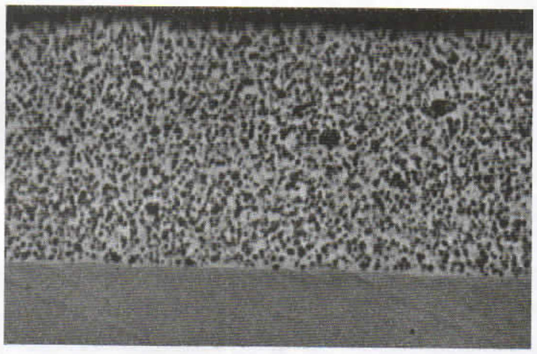
Coatings can be advantageous and in many applications are even essential for proper performance, protection, longevity and many other factors. Selecting the proper coating for each application, therefore, is vital. But choosing the right coating can be a challenge for two main reasons. First, there are many coatings available to the micro manufacturing industry. Second, parts used in micro manufacturing come in a tremendous array of shapes, sizes, base metals, etc. and are utilised in an equally exceptional range of climates, requirements and usage conditions.



One category of coatings that can enhance many applications in micro manufacturing is based on electroless nickel plating. Electroless nickel (EN) is a sophisticated yet reliable chemical process, with many inherent features well-suited to applications in the micro manufacturing industry, including hardness, corrosion resistance, and perfect conformity to even the most complex geometries.

In addition, EN is an exciting coating method as it is possible to add super fine particles into the EN to form composite EN coatings. These particles can provide hardness, wear resistance, low-friction, release, heat transfer, friction, and/or even phosphorescent properties.

This paper will discuss all varieties, but first a brief background on composite EN coatings.

EN has grown to be a mature segment of the metal finishing industry since its discovery in the 1940's. EN is generally an alloy of 88–99% nickel and the balance with phosphorous, boron, or a few other possible elements, depending on the specific requirements of an application. It can be applied to numerous substrates — including metals, alloys and nonconductors — with outstanding uniformity of coating thickness to complex geometries. It is this last point that most commonly distinguishes electroless from electrolytic coatings like chrome plating.

Composite EN is exciting given the synergies possible between the EN and particles that can dramatically enhance existing characteristics and even add

TABLE 1 — TABER WEAR TEST DATA	
Coating or Material	Wear Rate - 104 mils³ / 1000 cycles
Composite Diamond Coating*	1.159
Composite EN-Silicon Carbide	1.738
Cemented tungsten carbide, Grace C-9 (88WC, 12 Co)	2.746
Electroplated hard chromium	4.699
Tool steel, hardened, Rc 62	12.815

*Composite EN containing 25–30% of 3 μm grade diamond

TABLE 2 — FRICTION COEFFICIENT AND WEAR DATA FOR ELECTROLESS NICKEL-PTFE COMPOSITE

Coating on Pin	Coating on Ring	Coefficient Friction Relative	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	Cr steel	0.2–0.5	20

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entirely new properties. This makes composite EN coatings especially advantageous for applications in the micro manufacturing industry as they:

- Meet ever more demanding usage conditions requiring less wear, lower friction, etc.
- Facilitate the use of new substrate materials such as titanium, aluminium, lower cost steel alloys, ceramics and plastics.
- Allow higher productivity of equipment with greater speeds, less wear and less maintenance related downtime.
- Replace environmentally problematic coatings such as electroplated chromium.

Image 1 is one example of a composite EN coating. It is a cross-sectional photomicrograph showing a uniform dispersion of fine diamond within EN. As you can see from this photograph, composite EN coatings are regenerative, meaning that their properties are maintained even as portions of the coating are removed during use. This feature results from the uniform manner with which the particles are dispersed throughout the entire plated layer. Particles from a few nanometers up to about 50 microns in size can be incorporated into coatings from a few microns up to many mils in thickness. The particles can comprise about 10% to over 40% percent by volume of the coating, depending on the particle size and application.

WEAR RESISTANCE

Coatings designed for increased wear resistance have proven to date to be the most widely utilised composite EN coatings in the micro manufacturing industry. Particles of many hard materials can be used, such as diamond, silicon carbide, aluminum oxide, tungsten carbide, boron carbide and others. Although the unsurpassed hardness of diamond has made this material the most common composite. Despite the expensive sounding name, composite EN with diamond is actually comparable with the cost of similar coatings, yet the performance advantages are far greater.

The Taber wear test is the most common test method and has been employed to evaluate wear resistance of different materials and coatings. 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 weight or volume. The Taber results in **Table 1** demonstrate the wear resistance of various materials, including two different composite EN coatings, as well as a conventional EN coating.

In addition to applications in the micro manufacturing industry, composite coatings with wear resistant particles are widely used in the textile, paper, plastics, automotive, moulding, petrochemical processing, dental/medical, glass and other manufacturing industries.

LUBRICITY

Certain particles can be incorporated into EN to produce a coating with all the properties of EN (such as hardness and wear resistance), as well as a low coefficient of friction and dry lubrication, and repellency of water, oil, and/or other liquids.

Most commercial use of such composite lubricating coatings in the micro manufacturing industry has been

TABLE 3 — FRICTION COEFFICIENTS FOR VARIOUS COMPOSITES AND MATERIALS		
Coating	Load kg/cm²	Friction Coefficient
EN-PTFE	0.1	0.12
EN-BN	0.1	0.13
EN (No particles)	0.1	0.18
Chrome	0.1	0.25
EN-BN	0.3	0.09
EN-PTFE	0.3	0.13
EN (No particles)	0.3	0.16
Chrome	0.3	0.40
EN-BN	0.5	0.08
EN-PTFE	0.5	0.13
EN (No particles)	0.5	0.15
Chrome	0.5	150.00

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with 20–25% by volume of sub-micron PTFE particles in EN deposits. The properties of PTFE are widely recognised, and its enhancement of EN clearly demonstrated in industry applications, as well as standardised testing, as is summarised in **Table 2**. These results further show that the lowest coefficient of friction is achievable when both mating parts are coated with composite EN-PTFE.

In addition to EN-PTFE coatings, newer low-friction coatings have been developed and are being increasingly adopted in the micro manufacturing industry. As beneficial as PTFE is, there are certain limitations that have been overcome by the incorporation of materials other than PTFE into EN. For example, composite EN-PTFE does not always provide optimal wear resistance and lubricity. This is often due to the fact that PTFE is relatively soft and cannot withstand high temperatures.

By contrast, particles of certain ceramics, such as boron nitride provide lubricity, are significantly harder than PTFE, and can withstand temperatures above 850°C. This tolerance for heat allows such coatings to be heat-treated after coating to achieve maximum hardness, which is a standard post treatment for most electroless nickel coatings.

Hardness of the composite is critical in applications, as is often the case in micro manufacturing — for greater wear resistance and in situations where there is a higher 'loading' or force between the coated part and the mating part or materials. When the coating is harder, it is less prone to 'give way' under pressure, and if the coating does not give, the friction will not increase as the loading increases. Think of the difference in friction between the point of a pencil and the eraser as they move across a piece of paper.

Table 3 demonstrates this effect in the coefficients of friction for a variety of coatings under different load conditions. As you can see, the coefficient of friction of EN-PTFE and chrome coatings increase as the load in increased, but the coefficient of friction of EN-BN and conventional EN actually decreases as the load in increased. This shows the incompatibility of the soft PTFE particles in higher load applications.

INDICATION

This category of composite EN coatings is a more recent and novel development in the field. These coatings have all the inherent features of EN and appear normal under typical lighting, but when these phosphorescent coatings are viewed under an ultraviolet (UV) light, they emit a constant lighted glow. This is a feature that can be used in two ways.

First, the presence of a coloured light emission from the coating can be valuable in authenticating parts from a distinct source. This is especially promising for the identification of genuine OEM parts, which otherwise can be routinely counterfeited. Its value also extends to the identification of specific manufacturing lots where conventional methods of marking are not sufficient or durable.

Second, the light can serve as an indicator layer, warning when the coating has worn off and replacement, or recoating, is necessary. This feature permits the avoidance of wear into the part itself that may cause irreparable damage to a potentially costly part, or the production of inconsistent product from a worn manufacturing device. Such a layer can be employed in one of two options to achieve this feature.

Option one is to have a light emitting indicator layer applied to a part prior to (or under) another functional coating to signal when the functional coating has worn through to expose the indicator layer. In this case, it is the appearance of light that signals wear to the functional layer and exposure of the indicator layer.

Option two is to use the light emitting coating by itself, whereby the disappearance of the light following periodic inspections indicates wear. Fortunately, hand-held, battery-operated UV lights are readily available and make inspection for the indicator layer at the operating site fast and convenient.

GENERAL FEATURES

All varieties of composite EN coatings share some additional general features that make them further suited for applications in the micro manufacturing industry.

For example, as with any conventional EN coating, these composite coatings can be chemically stripped, leaving the substrate ready for recoating. This can be a very cost-effective alternative to disposing of overly worn parts and replacing them with entirely new parts.

For certain applications, customised composite coatings have been developed to satisfy unique requirements:

- Coatings with particles of two or more materials into the same layer to provide multiple properties.
- Overcoating with a conventional EN layer for greater smoothness, i.e. in cosmetics, or other priorities.
- An underlayer of conventional (often high phosphorous) EN can be applied to insure maximum corrosion resistance.