MAINTENANCE

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COMPOSITE ELECTROLESS NICKEL COATINGS FOR THE WIND ENERGY INDUSTRY VARIETIES AND PERFORMANCE ADVANTAGES

This paper presents information on composite electroless nickel (CEN) coatings — a class of coatings with a wide variety of performance and economic advantages to the diverse and demanding components used in the wind energy industry.

By Michael Feldstein

Coatings can be advantageous, and, in many applications, they are essential for proper performance, protection, lifetime, and many other factors. Therefore, selecting the proper coating for each application is vital. But choosing the right coating for components used in the wind energy industry is especially challenging because parts used in the wind industry come in a tremendous array of shapes, sizes, and base metals and are utilized in an equally exceptional range of climates, requirements, and usage conditions.

One category of coatings that can enhance many applications in the wind industry is composite electroless nickel plating. Electroless nickel (EN) is a sophisticated and reliable chemical process with many inherent features well-suited to applications in the wind industry including hardness, corrosion resistance, and perfect conformity to even the most complex geometries. Composites are formed with the addition of super fine particles into the EN. These particles can provide hardness, wear resistance, low friction, release, heat transfer, high friction, and/or even identification and authentication properties.

This paper discusses all varieties of composite EN (CEN) that take advantage of the synergies between EN and particles to dramatically enhance existing characteristics and even add entirely new properties. This makes CEN coatings especially advantageous for applications in the wind industry to:

1. Meet ever more demanding usage conditions requiring less wear, lower friction, and heat transfer.
2. Facilitate the use of new substrate materials such as titanium, aluminum, lower cost steel alloys, ceramics, and plastics.
3. Allow higher productivity of equipment with greater speeds, less wear, and less maintenance efforts and downtime.
4. Replace environmentally problematic coatings such as electroplated chromium.

As shown in Image 1, CEN coatings will naturally maintain their properties and performance even as some portions of the coating may be worn or 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 (0.001 inch) in thickness. The particles can comprise approximately 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 be the most widely utilized CEN coatings in the wind industry to date. Particles of many hard materials such as diamond, silicon carbide, aluminum oxide, tungsten carbide, and boron carbide can be used. But the unsurpassed hardness of diamond has made this material the most common composite. Despite the expensive-sounding name, CEN with diamond is actually comparable to the cost of similar coatings, yet the performance advantages are far greater. These coatings are also inherently beneficial to the environment as they make parts last longer, reducing scrap, and often save energy.

The Taber Wear Test is the most common test method 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 highly superior wear resistance of a composite diamond-EN coating versus other surface treatments and a hardened tool steel.

More practical and relevant than standardized test results are, of course, actual performance benefits experienced in real-life wind industry applications. In that regard, CEN coatings have the ability to make high-wear components last significantly longer and thereby reduce the need or frequency for maintenance or replacement. For a bearing, rotor, gear, housing, and many other wind system components installed in very inconvenient locations in all sorts of environments on- and offshore, the ability to extend their life is of exemplary value.

Coating or Base Material	Taber Wear Index per 1,000 cycles (10^4 mils^3) [a]	Wear Rate versus Composite Diamond Coating®
Composite Diamond Coating® [b]	1.159	1.00
Cemented tungsten carbide [c]	2.746	2.37
Electroplated hard chromium	4.699	4.05
Tool steel, hardened Rc 62	12.815	13.25

Table 1: Taber Wear Test Results of Various Materials

[a] Weight loss in mg/1,000 cycles (average of 5,000 cycles with CS 100 wheels and 1,000g load.
[b] Composite Diamond Coating® is a registered trademark of Surface Technology, Inc., Trenton, NJ, USA
[c] Grace C-9 (88WC, 12 Co)

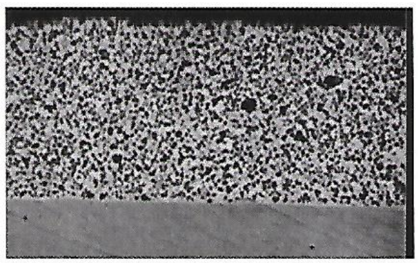


Image 1: Example of a CEN coating that is a cross sectional photomicrograph at 1,000x showing a uniform dispersion of fine diamond within EN

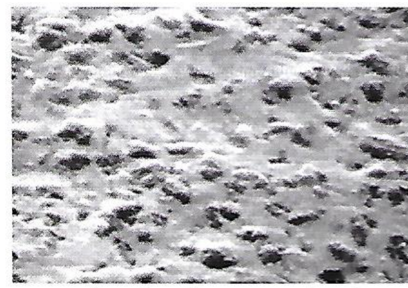


Image 2: The surface of a composite electroless nickel coating at 3,000x magnification

HEAT TRANSFER

Diamond is not only the hardest material known, it is also the best conductor of heat. Fortunately for wind energy components where it is advantageous to draw heat away from the component, the incorporation of diamond in a CEN coating can provide this benefit as well. Prime examples are electrical components, heat sinks, and any component operating in thinner atmospheres where heat transfer is compromised. In testing comparing aluminum to EN and CEN with diamond and CEN with carbide particles, the CEN with diamond yielded a 20-percent heat transfer increase over aluminum.

LOW FRICTION

Certain particles can be incorporated into EN to produce a coating with all the properties of EN as well as a low coefficient of friction. Although these composite coatings also provide wear resistance benefits, they are considered in a separate category based on the unique characteristics they embody — dry lubrication, improved release properties, and repellency of contaminants such as water and oil.

Composite coatings with lubricating particles are generally in thicknesses of 6-25 microns (0.00025" to 0.001"), which is thinner than coatings typically designed for wear resistance. Most commercial interest in composite lubricating coatings has focused on the incorporation of sub-micron Teflon® (PTFE) particles into EN deposits. The properties of PTFE are widely recognized from industrial applications to frying pans.

But, as with wear-resistant particles, there are a variety of low-friction particles that produce self-lubricating properties when co-deposited into EN. Materials other than PTFE have become increasingly popular in the plating field, especially certain specialty ceramics. PTFE is organic and decomposes at temperatures above 250°C. By contrast, many ceramic lubricating materials are harder and withstand higher temperatures than PTFE. As PTFE is a very soft material, its inclusion in EN makes the composite coating comparatively softer, especially as the percentage of PTFE increases. Higher temperature resistance permits higher post-plating heat treatment temperatures yielding greater hardness of the EN matrix. These factors make the composite ceramic lubricant coatings harder and more wear resistant than PTFE-EN in many conditions.

Table 2 shows the coefficients of friction for a variety of coatings under different load conditions. Boron nitride (BN) is one such inorganic material with lubricating properties. It has the ability to withstand temperatures up to 3,000°C depending on the atmosphere; and, as demonstrated in Table 2, composite EN with boron nitride has a lower coefficient of friction than composite EN-PTFE under higher load conditions. For the highly demanding components in the wind industry, the ability to apply thicker and harder CEN's with materials like BN are highly advantageous for both performance and service reliability.

HIGH FRICTION

While many moving components in wind energy equipment require low

[1] Teflon® is a registered trademark of E. I. du Pont de Nemours and Company or its affiliates.

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

Table 2: Coefficients of Friction for Various Coatings

friction, others benefit from deliberately textured surfaces to allow friction or grip between mating surfaces. One example is assemblies with adjacent components where one engages with the other and transfers motion or breaking to the other. In such applications, a lightly textured surface can enhance this engagement. CEN coatings with a variety of carbides, oxides, diamond, and other particles can provide this textured surface, as shown in Image 2 where such particles can be seen protruding from the surface of the CEN coating. For such applications, the particles are sized from 10 to about 75 microns, which is significantly larger than the smooth coatings used primarily for wear resistance that employ particles less than 10 microns in size.

INDICATION

The following four sections show a variety of synergistic coatings with valuable identification and authentication properties for unique benefits for wind industry applications.

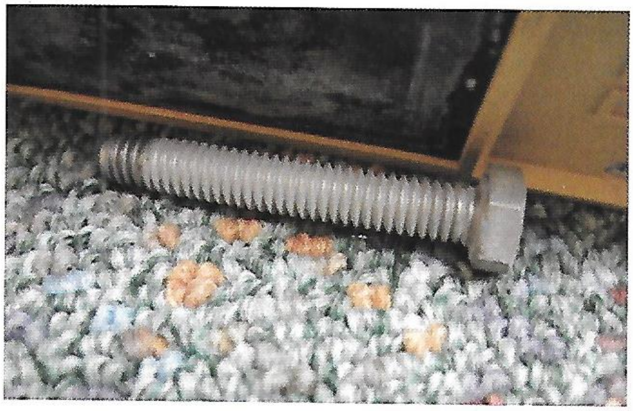
Phosphorescence

One method to create coatings for authentication is to incorporate particles with light-emitting properties into EN coatings. These novel coatings appear like normal EN under traditional lighting (sun, incandescent, fluorescent, etc.), but under an ultraviolet (UV) light, these coatings emit a distinct brightly colored glow. A person simply needs to shine a hand-held, battery-operated UV light on parts to display the light emission of a composite EN coating and thereby confirm the authenticity of the parts. As there are a number of materials that fluoresce under UV light, it is possible to produce a variety of EN coatings that each give off a different color glow when a UV light source is shined on the coating.

This coating variety can also be used under a functional coating such as CEN to demonstrate wear to avoid damage to the part itself. With a thin layer of a light-emitting coating between the substrate and the functional coating, an operator may then inspect the part periodically with a portable UV light, often while the part is still in use. Once colored light is observed, it is known that the functional coating has worn away. The part can then be recoated and reused before substrate damage to the part itself occurs and before inferior product is produced. In the wind energy industry, such a feature can be of tremendous value to allow inspection of a component without the cost of part removal and downtime.

Forensic Markers

While the composite phosphorescent-EN coatings are a useful technology for many applications, other applications



Images 3 and 4: A bolt coated with the Illumi-Layer™ CEN coating containing light-emitting particles and photographed under normal light (left) and ultraviolet light (right) to illuminate for authentication and indication require an even greater need for covert authentication. This can be accomplished by the use of certain forensic markers, which are a family of materials that have been developed using unique substances and can be detected by an electronic meter. The test is non-invasive, instantaneous, and infinitely repeatable. These materials are chemically inert, safe, and strong enough to persist in almost any conditions including an EN plating bath and heat treatment. Only small amounts of the ceramic-based materials need to be co-deposited into the EN coating to make their properties evident to the electronic meter. Therefore, the slight presence of the material in the coating is not readily visible and essentially does not affect the performance of the coating in other regards such as wear resistance, corrosion resistance, and friction.

There are dozens of such materials that can be used alone or in combination to create a unique marking or tracking system that can be embedded in almost any material or coating from paints and powder coating to CEN. This creates many new opportunities for product management, manufacturing process and logistics control, inventory management, quality assurance, and pollution control and authentication — all necessities in the global wind systems market.

Sound Activating

A further variety of authentication coating technology has been developed that actually allows the coating to activate a small detector to produce an audible report. This innovative technology is similar to that by using forensic markers since only a small quantity of specialized materials need to be incorporated into the coating to trigger the response of the detector. The test is instantaneous and generates a clear pass or fail indication. The detector is small and battery-operated for economy and convenience, which can be essential to the maintenance technicians and others in the wind energy industry.

Image 5: A 400x view of the surface of a coating incorporating structured micro taggants to permit authentication of a product simply by microscopic examination

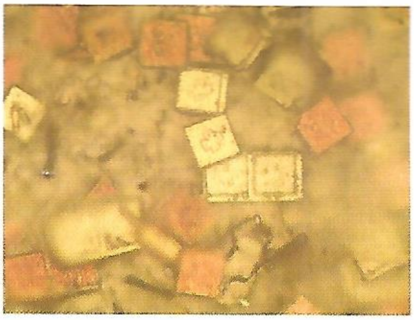


Image 6: A 1,000x view of one example of structured micro taggants showing an intricate design able to be imparted into the taggant

Micro Taggants

This variety of coating technology provides a fourth means of authentication of a product simply by inspection of the surface under magnification. A key to making this type of coating useful in authentication and product protection is that the micro taggants are manufactured by a complex and proprietary process.

The ability to customize the taggants in these ways means that their design can be modified on a continual basis to thwart counterfeiters or incorporate product identification and tracking information right on the surface of the product within a hard and durable coating.

MULTI-LAYER COMPOSITE EN SOLUTIONS

Underlayers

When a degree of corrosion resistance is needed above the level already provided by a CEN coating, as is often the case in wind energy equipment, it is routine to apply an underlayer to a part before it is coated with a CEN. This underlayer is most often a high phosphorous alloy of EN. This provides a barrier layer for corrosion, and the outward functional layer will still be the CEN for part performance.

Overcoating

Overcoating is a procedure often utilized for composite wear-resistant coatings. Composites containing particles (as discussed earlier) are smooth to the touch and sufficient for most applications. When the coating is intended to contact certain delicate materials, these protruding particles may be deleterious or require a break-in period of use to smooth the surface. A break-in period is a luxury that most applications in wind energy equipment cannot afford. So, instead of employing mechanical means to smooth the surface, and instead of operating a coated part for a less productive break-in period, an overcoat can be applied. For a CEN coating, an overcoat layer of only about 5 microns of conventional EN is sufficient to cover the composite surface and provide a new, smoother surface.

CONCLUSION

The performance requirements of components used in the wind energy industry are exceptionally diverse. They range from wear resistance, low friction, high friction, heat transfer, and authentication to identification. For this reason, the ability to tailor CEN coatings with an array of synergistic particles makes these coatings uniquely beneficial for applications in the wind energy industry.