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COST SAVINGS IN ELECTROLESS NICKEL DESPITE HIGH WORLD MARKET METAL PRICES

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This paper presents a novel way to combat the high price of nickel in today's world metal commodity market, and actually reduce coating costs. The method discussed in this paper is actually a relatively simple and viable method to achieve cost savings, and not a major technological breakthrough. We platers know that it is often these simpler insights that offer the greatest practical assistance in an economically and technologically challenging industry.

As nickel metal has reached historic highs on the London Metal Exchange (see Chart 1) and world markets, so too have the prices of all nickel-plating baths, including electrolytic and electroless nickel. I have visited plating shops around the world with bars on their windows and other security measures in an effort to combat frequent break-ins to steal their metal anodes for resale on the scrap market. Some applications traditionally coated with electrolytic nickel have been re-specified to electroless nickel in order to reduce metal usage by a) the incorporation of phosphorous in the electroless nickel deposit and b) eliminating the overplating of nickel at edges and other high current density areas inherent in electrolytic plating.

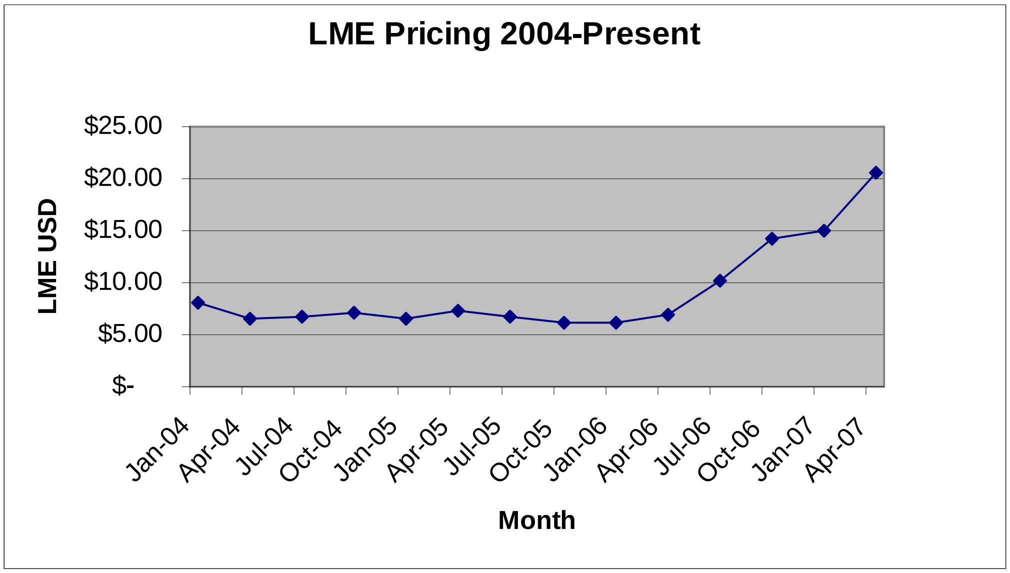
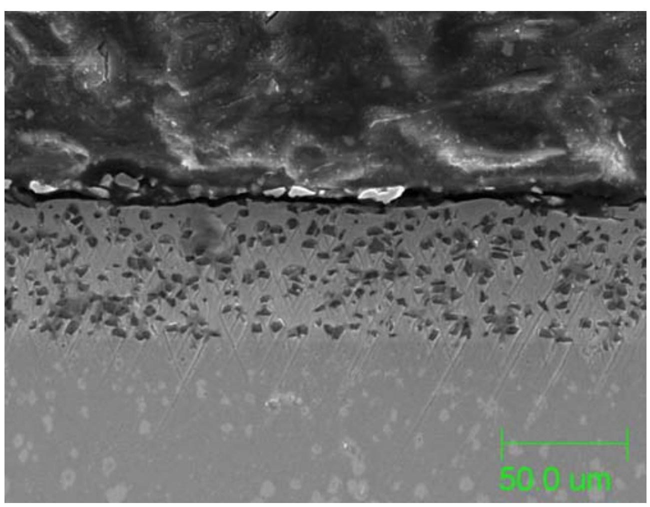


Chart 1 – 2004 to Present - London Metal Exchange Pricing for Nickel in US $ per pound

Platers are doing what they can to manage this challenge by operating more efficiently, avoiding excess plating, stretching the life of their plating baths, and so on. The solution proposed by this paper is to reduce nickel consumption by incorporating particles into the plating. The rationale is straightforward: the plater can reduce costs by replacing a significant portion of the costly metal alloy with lower cost particles. In today's market, this rationale is worthwhile due to 1) the high cost of nickel metal, 2) the reliability of composite plating baths, and 3) the decreased cost of particulate dispersions for plating baths due to the growing economies of scale that has been achieved with the increased popularity of composite electroless nickel plating. Moreover, there are a number of secondary and tertiary cost savings and benefits including thinner layers with greater wear resistance, longer bath life, performance and environmental advantages. These points will be discussed later in this paper.

Incorporation of particles into plated layers is known as composite plating. Composite electroless nickel is a widely accepted and growing segment of the plating industry. The inclusion of particulate matter within electroless nickel deposits can be a powerful enhancement of the coating's inherent characteristics, and, in many instances, adds entirely new properties to the plated layer. For decades platers worldwide have used PTFE in electroless nickel to produce low friction coatings. Composite electroless nickel with diamond and/or ceramics has replaced hard chrome plating in a large array of industries, especially in recent years as environmental and performance pressures rise. There are also numerous other categories of composite plating technologies commercially available including frictional, heat transferring, light emitting, flame retarding, and others.

Chemistry and processing methods have been developed to make such plating systems economical and reproducible. Uniform incorporation of particles into plated layers, as exemplified in the speckled middle band in Photograph 1, is routine. Properly formulated plating baths to generate such layers can have stability, plating rates, and bath lives equal to conventional electroless nickel plating baths. Composite plating baths are available in many varieties to suit specific applications such as low, medium and high phosphorous; lead and cadmium free; and much about the particles can be deliberately varied as further discussed below.



Photograph 1 – 1000x Cross Sectional View of Diamond Particles within Electroless Nickel

Most particles used in composite electroless nickel plating are a few microns in size, though certain formulations utilize particles as small as a few nanometers or as large as about 50 microns, depending on the application. The size and type of particles affects the density (a.k.a. concentration or volume) of particles within the plated layer. Electroless nickel with PTFE typically has about 20-25% density of PTFE particles. Electroless nickel with one to five micron sized silicon carbide typically has about 25-30% by volume of such particles in the composite layer. Diamond with an average particle size of five to eight microns can consistently achieve a density of 35-40% particles in the coating.

The decision of which particulate matter is best to incorporate into electroless nickel to replace nickel and save costs is the subject of the following discussion. While PTFE can replace a significant volume of nickel in the coating, it is not an ideal choice since the plating rate of current electroless nickel-PTFE systems is uniquely slow, and therefore less economical from a broader production perspective. In instances where a lubricating particle is desired to reduce nickel usage and cost while providing a low friction surface, the preferred material to use would be hexagonal boron nitride which has a) an equal or better effect on the coefficient of friction of an electroless nickel coating; yet b) greater wear resistance, c) a plating rate of 0.0008 to 0.0009 per hour which is comparable to conventional electroless nickel, and d) a bath life comparable to conventional electroless nickel which is multiple times that of current electroless nickel-PTFE systems.

Diamond has long been practical and economical to use commercially in electroless nickel. Chart 2 presents Taber test wear rates for hardened tool steel and two coatings: electroplated hard chrome and composite electroless nickel with diamond.

Chart 2 – Taber Wear Rates

Coating or Material	Wear Rate/1000 cycles (10^4 mils^3)
Composite diamond-EN	1.159
Electroplated hard chromium	4.699
Tool steel, hardened R_c 62	12.815

Chart 3 depicts result of an abrasive slurry test. These results demonstrate that the unique nature of diamond provides unsurpassed hardness and wear resistance over a similar composite electroless nickel with silicon carbide particles. Also of interest to the plater is that diamond particles are available in a higher level of sizing uniformity and purity than is available with silicon carbide and most other materials suitable for composite plating. But diamond is naturally priced higher than common ceramics such as silicon carbide. So solely for the objective of cost savings, diamond may not be the ideal material, though the following analysis has implications for such material selection.

Chart 3 - Abrasive Slurry Wear Resistance of Composite EN Coatings

Coating	Wear Constant	Wear vs. Steel	Wear vs. EN
None	28	—	1.75
Electroless Nickel	16	0.57	—
Composite EN-SiC	12	0.42	0.75
Composite EN-Diamond	7	0.25	0.44

Silicon carbide has been used for decades in composite electroless nickel for its hardness and wear resistance, particularly as a replacement for hard chrome plating. Chart 3 confirms the wear resistance enhancement resulting from the inclusion of silicon carbide over conventional electroless nickel. The geometry and material density of silicon carbide particles generally allows an incorporation of such particles into electroless nickel to about 25% by volume when using typical 3-5 micron sized particles. While a higher volume is achievable, the following analysis relies on a conservative 25%.

A reasonable cost figure for the plating chemicals alone to produce electroless nickel is currently about $2.20 per mil-square foot (one mil = 0.001" = 25.4 microns thick coating on one square foot of surface area). Replacing 25% of this electroless nickel with silicon carbide particles therefore saves $0.55 per mil-square foot (i.e. 25% of the $2.20 cost). So what does the silicon carbide cost? If the silicon carbide required to fill 25% of the coating costs more than $0.55, then the premise of this paper is not valid at current costs. If however the silicon carbide costs less than $0.55, and there are no additional costs associated with application of the composite electroless nickel-silicon carbide coating, then there is merit to the logic of this paper.

There are two ways of looking at the cost of the silicon carbide particles. The cheapest figure would simply be the bulk cost of the raw, dry particles. However, raw particles of any type are not well suited for composite electroless nickel plating. Plating baths are surface area dependent and insoluble particles represent a dramatic amount of surface area. This could have drastic implications for the stability of the bath. Raw or impure particles could form defects in the coating, cause the plating tank itself to plate, and/or decompose the plating bath. The cost of any one of these problems justifies the use of the proper particle formulation for composite plating.

The state of the art in composite electroless plating relies of the utilization of precise surfactants, wetting agents, and dispersants (broadly termed "particulate matter stabilizers" or PMS's) to keep the particles, inert, dispersed in the bath, and best situated for codeposition. While some of the particulate matter stabilizers may be formulated into the plating bath, optimal results are obtained when high quality particles are dispersed with PMS's in a dispersion composition that is added to the plating bath. For this reason, and to be further conservative with the cost implications of replacing some of the electroless nickel with silicon carbide, this paper bases the cost of the silicon carbide on the volume of the appropriate commercially available silicon carbide dispersion.

The list cost of a commercially available and ideally formulated silicon carbide dispersion is \$108.75 per gallon. There are 1,325 grams of silicon carbide in this gallon of dispersion. The equivalent cost of the silicon carbide dispersion per gram of silicon carbide is \$0.082. In 25% of one mil-square foot of coating there are 1.9 grams of silicon carbide particles. The cost of the silicon carbide dispersion containing 1.9 grams of silicon carbide particles is therefore \$0.15 (1.9 x \$0.082). So by incorporating \$0.15 of the silicon carbide dispersion you can save \$0.55 of electroless nickel costs, netting a savings of \$0.40, which is equal to a savings of 18% of the \$2.20 mil-square foot cost of the conventional electroless nickel. 18% savings sounds pretty good, but that is not even the bottom line.

If you refer back to Chart 3, and recall the exceptional wear resistance of composite electroless nickel with silicon carbide compared to conventional electroless nickel, it is logical that a significantly thinner layer of composite silicon carbide electroless nickel will have a wear life equivalent to a thicker layer of conventional electroless nickel or hard chrome. Chart 3 shows 25% less wear to the composite silicon carbide coating compared to conventional electroless nickel in this test method (12 wear constant / 16 wear constant). In most commercial applications the increased durability of silicon carbide over conventional electroless nickel is generally greater than 25%, but we will base the following calculations on a 25% improvement to be conservative. Therefore, three quarters of a mil (0.00075" = 19 microns) of silicon carbide will perform equal in wear to one mil of conventional electroless nickel. The cost of three quarters of a mil-square foot of composite electroless nickel silicon carbide is \$0.90 ({\$2.20 for one mil of electroless nickel less 25% material replacement plus \$0.15 for silicon carbide} times 0.75 for three quarters of a mil = \$01.35), compared to \$2.20 for one mil-square foot of electroless nickel. This represents a savings of 39% (\$1.35 / \$2.20). Exceptional, but that's not all.

Reducing the plating thickness required not only reduces material costs. It dramatically reduces utilities, labor, and increases productivity. Less plating per part means more parts plated per bath, and lower bath waste treatment costs associated per part.

Now, lets look back to diamond since it is unsurpassed in wear resistance and see the effect on cost by using this option. It is possible to achieve a 40% reduction in electroless nickel material by incorporating diamond into a composite electroless nickel coating because of the unique shape, density and quality properties of diamond. This is obviously significantly higher than the typical 25% amount of metal replacement possible with silicon carbide and other particles. In addition, the superior wear resistance provided by the diamond allows a 56% reduction in coating thickness commensurate with the 56% less wear of a composite electroless nickel-diamond coating compared to conventional electroless nickel (as demonstrated in Chart 3). Therefore 0.44 mil (11 micron) thick of composite electroless nickel-diamond coating will have at least as much wear resistance as one mil of conventional electroless nickel. Again, industrial applications generally show even greater improvement due to the incorporation of diamond than the standardized test methods, but to be conservative, we will base the following calculations on a 56% wear reduction.

The cost of 0.44 mil square foot of electroless nickel would be $0.97 ($2.20 x 0.44). This cost is then reduced by 40% due to the replacement of 40% of the nickel alloy with diamond so the actual electroless nickel used is only $0.58 ($0.97 – 40%). 0.44 mil square foot of composite electroless nickel-diamond contains 1.45 grams of diamond when the volume percent of diamond is 40% in the coating. Based on the retail price of a diamond dispersion specifically formulated for use in composite electroless nickel, the cost of 1.45 grams of diamond equals $1.03. Therefore the total cost of 0.44 mil square foot of composite electroless nickel – diamond would be $0.58 + $1.03 = $1.61. This represents a 27% cost savings over conventional electroless nickel ($1.61/$2.20).

And again, the thinner composite coating will also save production costs (utilities, labor), time, waste treatment, etc. The exact measure of these productivity savings depends on the actual cost structure of each plating shop, but will certainly be substantial in all cases.

It is also no small matter in this day and age that these composite coatings also have tremendous environmental advantages. Aside from using no chrome, composite electroless nickel coating can be routinely produced with up to 40% by volume of codeposited particles. This means that at least 40% less nickel is required to produce composite coatings of equal thickness compared with conventional coatings. Given that the deposit thickness of such coatings can be significantly less than conventional electroless or electroplated nickel coatings, even less nickel needs to be used. The less nickel the plating shop uses, the longer their baths will last. This means less baths required, less waste treatment, and less waste. And since these composite coatings last longer than conventional electroless nickel, parts need to be recoated or replaced or discarded less frequently, again, resulting in even less nickel used, and less nickel condemned to the environment from discarded parts.

So with all of these cost, performance, and environmental benefits of composite electroless nickel over conventional electroless nickel plating; perhaps the question is not, "Why would a plater use composite coatings," but rather, "Why wouldn't a plater use such coatings"? The three likely objections would be 1) the cost to install composite plating capacity, 2) the appearance of composite electroless nickel coatings, or 3) the corrosion resistance of such coatings. For the most part, however, none of these three objections will outweigh the benefits of composite electroless coatings, as we will see below.

Composite electroless plating is a relatively simple process to incorporate into an existing plating operation. The pretreatment of parts is the same as that prior to any conventional electroless plating bath. The maintenance of a composite plating bath is nearly identical to a conventional electroless nickel bath as long as it is a properly formulated composite bath designed for particle codeposition. Waste treatment is also standard.

The appearance of composite electroless coatings with diamond or silicon carbide is an attractive matte gray. Many end users actually prefer this color for its unique and distinguishing appearance. See Photograph 2 of three parts coated with a composite electroless nickel-diamond coating. Of course appearance of the coating is usually not relevant in wear applications, and only performance is the relevant property. And in situations where a bright appearance like conventional electroless nickel is desired, it is simple to apply a thin overcoat of conventional electroless nickel over the composite coating. An overcoat as thin as five microns easily accomplishes this surface modification, as can be seen in Photograph 2. Moreover, as a composite electroless coating is hard metal material, it is possible to finish it in a wide variety of ways including all types of plating, painting, powder coating, blasting, tumbling, polishing, and so on.

Photograph 2 – Three golf clubs coated with (left) a 0.001" thick under layer of high phosphorous electroless nickel followed by 0.001" thickness of a composite electroless nickel and diamond coating; (center) 0.001" thickness of a composite electroless nickel and diamond coating over coated with a 0.0002" thick layer of medium phosphorous electroless nickel; and (right) a single layer of 0.001" thickness of a composite electroless nickel and diamond coating

Conversely, an under layer can be applied prior to a composite electroless coating to insure high corrosion resistance. The most common such combination is a high phosphorous electroless nickel coating under a composite coating to achieve higher corrosion resistance in addition to cost, performance, and environmental properties. The part on the left of Photograph 2 shows how such an under layer can be applied for utility without affecting the final appearance of the subsequently composite coated part.

Conclusion

As presented in this paper and based on actual commercial experience, the use of fine particles in electroless nickel plating provides substantial cost savings to the plater. The end user receives performance advantages. And environmental benefits are generated for all. These significant benefits are possible with properly formulated plating bath and particle dispersions that insure optimal particle codeposition, consistency, plating rate, stability, and bath life.