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High-Speed Electroless Nickel - PTFE Plating

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This paper presents information on a revolutionary electroless nickel-PTFE composite plating process. The process is revolutionary as it represents a quantum leap in plating rate, process, quality and environmental properties. 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. PTFE is one of the most commonly used materials in such plating. This is due to the exceptionally low-friction and release properties of PTFE. However, there are many drawbacks to current commercial EN-PTFE plating bath systems. This paper demonstrates a new system with exceptional advantages over the present state of the art.

The challenge

As with all composite EN plating systems, the key to stability, quality and consistency are materials known as PMSs. PMSs, or particulate matter stabilizers, are a group of materials including such things as surfactants, dispersants, wetting agents, etc. A key function of a PMS is to modify the charge, or zeta potential, of the particulate matter to maintain its inertness, and isolate each particle from the others.

PTFE is an especially difficult material to incorporate into plating baths and subsequently into coatings. The properties that make PTFE non-sticking also make PTFE particles difficult to wet and combine with the surfactants that apply a charge to the particle. This charge is the means by which the particles are dispersed into the plating solution without substantial agglomeration and allow them to be co-deposited into the coating.

In order to get PTFE particles into EN deposits, therefore, an exceptional amount of PMSs must be dispersed onto the particles before they are introduced to the plating bath. The state of the art and common practice for such plating is to disperse the PTFE particles through a complex process with a combination of different surfactants into a dispersion product. Commercially available dispersions are generally about 60 vol% PTFE solids combined with PMSs and a solvent.

While this type of dispersion allows the PTFE to be wetted, incorporated into an EN plating bath, and codeposited into a composite coating, the nature and extreme concentration of the PMSs cause a number of drawbacks for the EN-PTFE systems in use to date.

The first drawback is the effect these dispersions have on the operation of the bath. Because the PTFE dispersions only embody a relatively loose bond (or encapsulation) of the PMSs around the PTFE particles, the bath cannot be agitated by the same means as a traditional EN bath or other EN composite baths such as diamond, silicon carbide, boron nitride, etc. Moderate agitation by air, centrifugal pumps and so forth can shear the PMSs off of the PTFE particles. This causes the PMSs to remain in the bath and the PTFE to float to the top of the solution. This then prohibits optimal coating properties especially the percent PTFE in the deposit which is generally in the range of 20 to 25% in most commercial applications with the potential to increase or decrease according to the needs of the specific application.

The second drawback, yet one that has been globally accepted by the industry, is the slow plating rate of EN-PTFE baths. The extreme concentration of PMSs in the dispersion, and consequently the bath, drastically reduces the plating rate of the bath. Addition of the prescribed amount of dispersion into an EN bath will drop the plating rate from roughly 20 μm/hr to just 7.5 μm/hr. The most effective baths commercially available to date are those that are specifically formulated to accommodate the chemistry of such dispersions, but still the plating rate is a fraction of the bath's potential. As energy, labor and other overhead costs have climbed, the cost to plating shops due to the slow rate of EN-PTFE plating has been exacerbated. It is also a complicating factor for shops

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in their need to provide fast turnaround times to meet customer demands.

Similarly, a third drawback exists due to the high concentration of PMSs, which is a much lower bath life. Instead of a traditional eight to ten metal turnovers, EN-PTFE baths only achieve about three metal turnovers before the accumulation of PMSs and byproducts interfere with the co-deposition mechanism and the bath's ability to plate uniformly. As nickel metal prices and disposal costs have risen substantially in recent years, the "drawback" of a highly shortened bath life has become increasingly challenging for many plating shops to bear.

The breakthrough

Research was undertaken to overcome these and other drawbacks of EN-PTFE plating. All of the traditional factors influencing plating rate were applied to a variety of EN-PTFE baths. Modifications were made to pH, temperature, stabilizers, agitation, replenishment dynamics, multiple reducing agents, concentrations and other parameters, but none provided a significant increase in plating rate.

Instead a new bath/dispersion formulation was developed that yielded the desired results, with no adverse affects on the plating process or the resulting deposit.

Validation

The new EN-PTFE system was developed in a laboratory, but validated in two different plating shop tanks. Standard tank, heating, agitation methods were used and are suitable for this new process. The following results demonstrate the properties of steel panels plated in this new process. The data shows the properties across 3.3 metal turnovers.

Bath life

There is a wide range of bath life times achieved by plating shops with the various EN-PTFE baths in the market. Many shops are grateful to achieve one metal turnover. Others claim to achieve five metal turnovers, though the quality of the deposit, especially the percent PTFE included in the deposit, at that point is suspect. Therefore a common benchmark for an acceptable EN-PTFE bath is three metal turnovers. As nickel and other material costs as well as the expense to dispose of used baths continue to grow, the need for baths that can achieve an acceptable bath life is important.

The baths tested with the newly formulated components described in this paper were able to reach the three metal-turnover benchmark. In fact, testing was conducted up to 3.3 metal turnovers before testing was discontinued.

Plating rate

The plating rate (*i.e.*, the rate at which a plated coating deposits from the plating bath onto the part being plated) is measured by the thickness of coating achieved per unit of time. Microns or mils per hour are common measures of plating rate. Also often used is the term of tenths per hour, which relates to how many tenths of a thousandth of an inch are plated in one hour of plating time. One tenth equals 0.0001 inch, which equals 2.54 microns.

In standard EN-PTFE baths, the plating rate is about 7.5 microns or three-tenths per hour. However, with the newly developed chemistry, the plating rate was a consistent 18 to 22.5 μm/hr over the course of the life of the trial bath. This rate therefore is two and a half to three times faster than that of standard EN-PTFE baths.

Interesting to note is that this new bath is much more tolerant of agitation than conventional EN-PTFE baths. As described above, tolerance to agitation is a drawback of conventional EN baths, and it is a significant improvement that the new system is better able to withstand moderate agitation. When the agitation was higher, the plating rate did decrease but only to the lower end of the range towards 18 μm/hr, and the agitation did not cause quality problems to the deposit, nor did it cause de-wetting of the PTFE from the bath.

PTFE incorporation

The percent of PTFE incorporated into the deposit is an important parameter. Figure 1 depicts the volume percentage of PTFE in panels plated in the new bath at various points in bath life across the trial. The PTFE content was measured by stripping the deposits, weighing the reclaimed PTFE to the tenth of a milligram, comparing this weight to the total weight of the coating stripped from the panel, and converting the weights to volume numbers according to the respective densities of the PTFE and the EN alloy.

The trial work was done with a commonly used concentration of 6.0 g/L PTFE dispersion in the plating bath. As is known in the industry, the percentage of PTFE in the deposit can be readily increased by increasing the concentration of PTFE dispersion in the bath. This was confirmed in the new system in additional trials where greater than 25 vol% PTFE was achieved by a relatively small increase in PTFE concentration in the plating bath.

Hardness

Hardness is primarily related to four factors: the percentage of nickel, phosphorus and PTFE in the deposit, and if any heat treatment is applied to the deposit after plating. The presence of PTFE in such a composite coating has two significant ramifications on the hardness of the deposit. Firstly, PTFE is a soft material relative to the EN alloy, and the more PTFE in the coating, the lower the hardness. This is the case regardless of the plating rate of the bath. Secondly, because PTFE will decompose at a temperature well below that which is optimal to heat-treat EN for maximum hardness, the presence of the PTFE makes it impossible to even get the EN alloy to its hardest potential state.

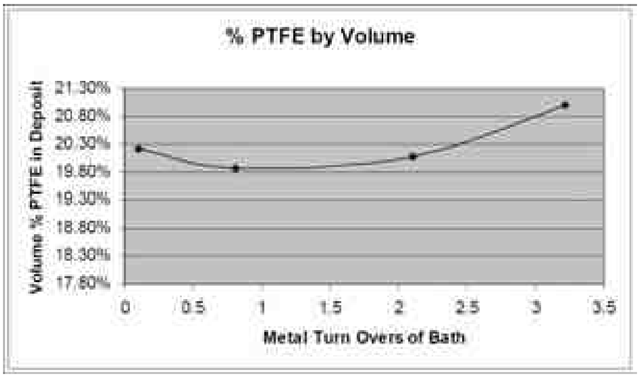

Figure 1—Volume percent of PTFE in the EN-PTFE deposit over three metal turnovers.

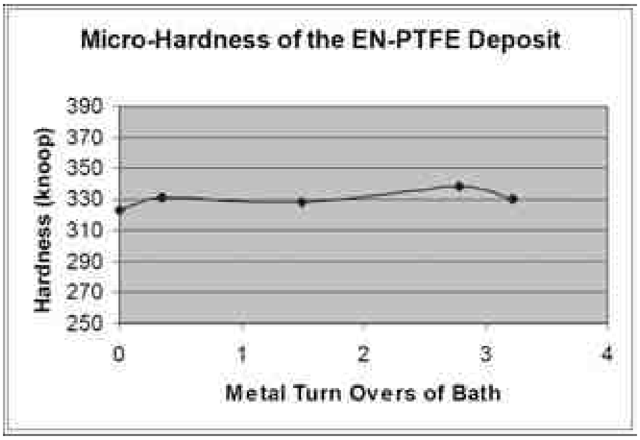

Figure 2—Microhardness of the EN-PTFE deposit over three metal turnovers.

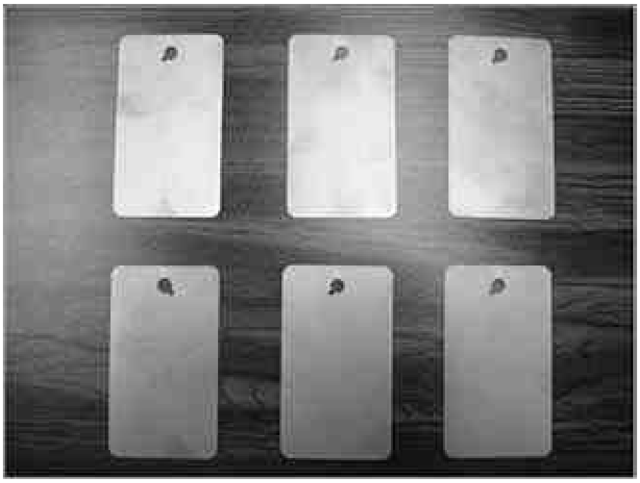

Figure 3—Consistency of deposit appearance at various points in the life of the EN-PTFE bath.

Hardness is best measured by a micro-hardness indentation test on a cross section of the deposit. Figure 2 shows the micro-hardness (in Knoop at a 25-g load) of samples plated in the new EN-PTFE formulation across the lifetime of the plating bath. These results confirm that while the plating rate was substantially higher than a conventional EN-PTFE bath, the hardness of the deposit from the new system was consistent with the standard.

Color

As platers know very well, even functional coatings need to be consistent in appearance. The color of EN-PTFE deposits is considered important as a way to differentiate it from standard EN. Figure 3 shows six panels from various points in the bath life of this new EN-PTFE formulation, and shows that the color is consistent through out more than three metal turnovers.

Adhesion

While not anticipated, an evaluation was made to see if the new chemistry developed for this high speed EN-PTFE system had any effect on the adhesion of the deposit to the substrate. Accordingly, a bend test was performed on sample steel test strips plated at seven different times during the life of this trial bath. The thickness of the EN-PTFE deposit on these samples was between 15 and 22 microns. All samples were bent 180°, according to ASTM specification B 571-97 subsection 3, where the diameter of the mandrel around which the panel was bent was four times the thickness of the panel. All samples passed this test without delamination or other failure of the deposit.

Plating on plastics

Until the development of this new EN-PTFE system, the concept of plating EN-PTFE on plastics was not practical. Plating on the most common types of plastics requires the plating process to remain below 70°C (158°F). Traditional EN-PTFE baths, therefore would not work on plastics since even the already slow plating rate at their standard operating temperature would not be possible if the bath temperature was dropped to that which is required for plating on plastic. As this new plating system's rate is so much faster, it is able to still achieve a plating rate of about 7.5 μm/hr at 70°C.

Environmental considerations

Composite plating, especially electroless nickel with PTFE, has become a widespread commercialized product around the world in many industries. However, in recent years, health and environmental concerns have been raised about the inclusion of certain materials in the PTFE dispersion that are used in composite plating systems. Specifically, the inclusion of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) and are materials that appear desirable to eliminate from such systems.

Commonly, all composite PTFE plating solutions used in our industry have been based on materials that introduce PFOS in the plating process. Specifically, PFOS is included in one or more of the surfactants or particulate matter stabilizers that are used to disperse the PTFE particles and make them compatible with plating process.

In addition, the actual PTFE particles are produced in a liquid containing PFOA. It is possible however to remove the PTFE particles from this PFOA-containing liquid, and then create a dispersion of the PTFE particles free of PFOA. However, this represents an additional challenge to manufacturing dispersions from such particles, especially ones that will work optimally in an electroless plating system.

PFOA and PFOS have become the topic of health and environmental concerns in recent years. Both materials have been found not to decompose over time. PFOS-containing materials are used on an even broader scale than just composite plating. Other applications include fume and fire suppression, sealers and others.

The United States Environmental Protection Agency has ruled that PFOS may not be manufactured or imported into the United States. United States companies may still use existing supplies of PFOS as long as the PFOS is not newly manufactured or imported into the United States. However, it is clear that the avoidance of PFOS and PFOA is a desirable and prudent goal given the concerns over these materials, and considering that they may eventually be banned from use as well as manufacture and importation to the United States.

The newly developed composite electroless nickel-PTFE system described in this paper has the further potential to be manufactured in a formulation free of PFOA and PFOS. This alternative has been tested and features the same plating rate and deposit properties.

This new system is also free of lead and cadmium, making it suitable for applications subject to environmental regulations such as ELV, RoHS and WEEE.

And when it comes to waste-treatment, EN-PTFE baths of the new formulations presented in this paper can be treated the same way as conventional EN-PTFE baths.

Conclusion

A new composite electroless nickel-PTFE system has been developed. This system features a revolutionary plating rate of about 20 μm/hr, vastly higher than the traditional 7.5 μm/hr inherent in EN-PTFE systems used in the plating industry to date. This exceptional rate yields benefits to productivity, labor, energy and other costs. In addition to this primary breakthrough in plating rate, the system is easier to use, lasts longer, embodies environmental benefits, and can even be used on certain plastics.

About the author

Michael D. Feldstein is President of Surface Technology, Inc., a world recognized leader in metal finishing founded in 1973. In this position, Mr. Feldstein directs the overall activities of the company, including the coating processes, manufacturing of proprietary electroless nickel solutions and innovative research and development in its state-of-the-art facility. He has been with Surface Technology, Inc. since 1989. Mr. Feldstein's education includes a B.A. from Tulane University and a M.A. from George Washington University. Mr. Feldstein has been widely published, and is the inventor on multiple patents. He has presented numerous papers at technical and industrial conferences worldwide. Mr. Feldstein is also a member of the NASF, AESF, ASTM and other organizations.