Mass Nickel Electroplating: A Comparison Study

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Mass plating gains importance in today's finishing world as we increasingly see smaller parts needing to be plated in large quantities. There are two main mass-plating methods and corresponding types of equipment to choose from on the market: barrel plating, performed in horizontal or oblique barrels, and the relatively recent vibratory technique for which several different types of units are being offered.

The choice of a suitable plating technique for a particular application is governed by technical as well as cost-effectiveness considerations. In this article, results and interpretations on a comparison study of these two mass-plating methods as applied to nickel electroplating are presented.

EXPERIMENTAL

The purpose of the investigation was the selection of a mass-plating method suitable for obtaining moderately heavy (5–40 μm/0.2–1.5 ml) nickel electrodeposits out of a standard sulfamate bath on steel and aluminum substrates. The dimensions of parts to be plated were small (0.5–10 mm/0.02–0.4 inch). This determined the choice of the test equipment (see Fig. 1)—the smallest available conventional plating barrel and a small vibratory plating unit. Metal rivets were used as test parts. The following parameters, important to the intended application of the process, were evaluated in each test run: plating efficiency, nickel thickness distribution (apparent throwing power) on individual parts, and plating consistency, understood as thickness variations between different parts from the same test run.

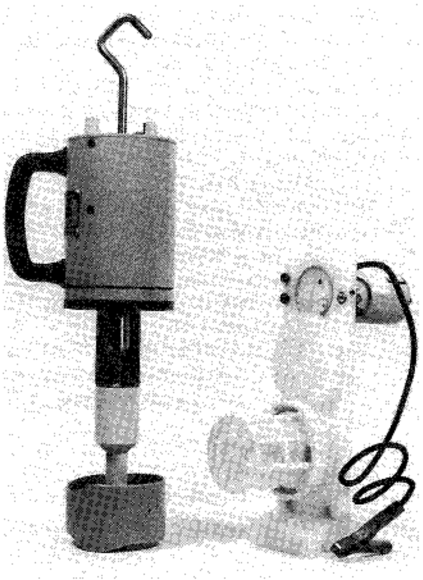

Fig. 1. The vibratory and barrel platers used in the study. Dimensions—vibratory basket: ID = 3.5 inches; barrel: ID = 2.5 inches; length = 2.75 inches.

The number of parts in a load for each batch was determined based on the equipment manufacturers' recommendations and provided for a complete covering of the barrel or basket cathode contacts and free movement and mixing of parts. Both units were equipped with controls, which enabled setting the speed of rotation of the barrel and the amplitude and frequency of vibrations of the basket. The lowest settings that provided for a continuous smooth movement of parts during plating were selected. It was difficult to quantify the vibration parameters of the basket as the controls were not graduated. The barrel rotation speed was set at 10–15 rpm.

Conventional methods were used to clean and activate test parts before plating. Plated parts were thoroughly rinsed and dried in a convection oven.

OBSERVATIONS AND RESULTS

Dozens of test runs were plated using various current/plating time combinations and different substrates. Data for several typical experiments are presented in Table I.

From the very beginning of the investigation, a number of differences

Table I. Typical Plating Results

Test No.	Plating Method	Substrate/ Total Surface Area, dm²	Current A	Time Hr:Min	Weight Gain, grams		Efficiency, % Apparent/Actual
					Parts	Contacts	
1	Vibro	Aluminum 4.13	2	3:07	1.64	4.31	24/87
2	Vibro	Steel 4.1	2	3:07	2.02	4.03	30/89
3	Vibro	Steel 4.1	2	2:54	2.29	3.73	36/95
4	Barrel	Aluminum 9.38	4	5:25	22.3	—	94
5	Barrel	Aluminum 9.5	4	2:55	12.45	—	98
6	Barrel + Vibro	Aluminum 7.0	2	1:01	0.58	0.82	26/63
7	Vibro + Barrel	Steel 8.17	4	2:00	8.49	—	97

Note: For test runs 6 and 7 the efficiencies listed are those for the latter plating cycle.

between the vibratory and barrel-plating techniques were noticed.

1. The average current density, determined as the total current per load divided by the total surface area of parts being plated, could not be increased much over 0.5 A/dm^2 (5 A/ft^2) in the vibratory process without giving rise to strong gassing from the basket, whereas the barrel-plating technique lent itself well to operating at average current densities over 1 A/dm^2 (10 A/ft^2).
2. The contact buttons mounted inside the vibratory basket flush with its bottom tended to plate heavily and had to be stripped after each plating cycle. The barrel cathode contact attracted very little nickel and did not require stripping after tens of hours of operation. Both the barrel and basket contacts were made of stainless steel.
3. The buildup of nickel on the contacts of the vibratory plater tended to slow down the movement of parts in the basket. This required increasing the frequency and amplitude during the plating cycle to sustain the movement of parts. The rotation speed of the barrel remained constant throughout the plating cycle.
4. Using the vibratory technique, it was impossible to deposit a continuous nickel plate on aluminum rivets even at extended plating times. The high current density areas plated, the rest of the surface remained bare. The steel rivets invariably developed red rust during drying indicating a thin and porous deposit.

None of these conditions were encountered during barrel plating with either substrate. The plating efficiency for each test run was calculated using the formula:

$$\text{Efficiency}(\%) = [\text{Weight gain}/(1.095 \times A \times T)] \times 100$$

Where A is the plating current in amperes, T is the plating time in hours, and 1.095 is the theoretical nickel yield per 1 Amp-hour at 100% efficiency.

The apparent efficiency (based on the parts weight gain) was very low with the vibratory unit. The large amount of nickel plated onto the contacts caused this effect. When the total weight gain (for both parts and contacts) was considered, the actual efficiency came out closer to values normally observed in nickel electrolytes. Both numbers are listed in Table I.

Because too little metal plated on the barrel contact to be measured accurately, the barrel plating efficiency calculations were based on the weight gain of the parts only.

Metallurgical cross sections were used to evaluate the nickel distribution over the surface of plated parts. As can be seen from Fig. 2 and Table II, a more uniform plating thickness was achieved on barrel-plated steel rivets with less than a 2:1 ratio between the high and low current density areas. The vibratory-plated parts showed a much higher variation. The difference was even more striking on aluminum rivets where, as mentioned earlier, no continuous nickel layer was deposited by the vibratory technique. The barrel-plated aluminum rivets showed no difference from their steel counterparts.

Both methods had very consistent part-to-part uniformity with less than 20% thickness variation.

ANALYSIS AND CONCLUSIONS

It is possible to explain the observed differences between the vibratory- and barrel-plating results based on the mechanics of part movement. Parts move with the rotating barrel up to the crest where they break away from the barrel wall and slide and tumble down across the surface formed by the bulk of the load. They essentially remain in contact with other parts and never lose contact with the cathode. This is not the case in the vibratory basket, where the up-and-down high-frequency vibrations cause loss of contact with the cathode buttons. When the direction of movement of the basket abruptly changes from upward to downward at the apex the parts continue to move up by inertia. Due to gravity the parts slow down and change direction, eventually regaining contact with the basket cathode buttons. The next upward swing of the unit repeats this process. When the layer of parts becomes suspended above the surface of the cathode contacts, the entire mass apparently turns into a loose bipolar anode. Portions of it continue to plate while others dissolve nickel depending on the polarization at any given point in the load. The only parts of the system that plate continuously are the contact buttons themselves.

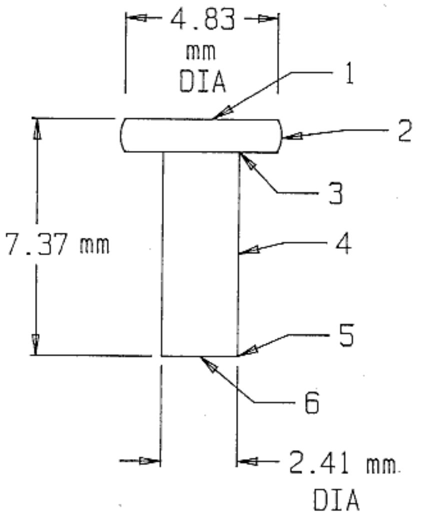

Fig. 2. Dimensions of a test part and points where the nickel thicknesses were measured (points 1–6).

Assuming that the weight gain of the parts in the levitation phase is zero, which is true if the anodic and cathodic efficiencies in the layer are equal, the apparent plating efficiency should be roughly equal to the fraction of the cycle when parts make contact with the cathode. It can be seen from the table that this percentage is 24–26% for aluminum parts and 30–36% for steel rivets. The difference here can be explained by the difference in the densities of the two materials (see the box section of this article on substrate density and plating efficiency.) The greater specific gravity makes steel

Table II. Typical Cross-Section Results

	Plating Thickness, microinches					
Plating Procedure/Substrate	*1*	*2*	*3*	*4*	*5*	*6*
Barrel/aluminum or steel	656	787	459	525	919	984
Vibratory/steel	197	525	66	98	591	1444
Barrel over vibratory/steel	722	919	394	525	1181	1444
Vibratory over barrel/aluminum	591	656	262	394	787	1115

* For positions 1 to 6 see Fig. 2.

parts drop and regain contact with the cathode sooner than aluminum, resulting in a slightly shorter "off" and longer "on" period with a higher effective plating rate. Nevertheless, both materials experience periodic-reverse rather than continuous plating in the vibratory basket, which evidently results in much poorer throwing power than in barrel plating. While we were not able to find any data on the throwing power for periodic-reverse nickel plating, several researchers have established[1,2] that pulsing the current slightly reduces the throwing power in nickel-plating baths. Our data indicate that adding an anodic component to the plating current makes matters significantly worse.

In order to confirm the assumption that vibrations cause periodic-reverse rather than continuous plating, a load of parts already plated in the barrel was further plated in the vibratory unit (see test run 6 in Table I). Cross sections were prepared and examined after each plating cycle. It was found that the nickel thickness in the low current density areas became lower after vibratory plating than after the initial barrel plating (see Fig. 2), while the opposite sequence of plating helped significantly to improve the plating uniformity (see test run 7 in Table I and corresponding cross section in Fig. 2). The observed lower overall plating efficiencies in vibratory plating of aluminum parts (see Table I) can further be explained by the periodic reversal of current. Because of the much poorer adhesion between the electroplated nickel and the aluminum substrate, which unlike nickel and steel do not form a metallurgical bond, the very thin and porous nickel layer in the low current density areas of the parts gets damaged mechanically by the vibrations and gets partially stripped by the anodic current. Eventually, small nickel flakes lose adhesion altogether and peel off the parts. They can actually be observed floating freely in the plating bath. This metal does not get included in the measured weight gain of the plated lot, leading to lower observed efficiencies.

This theory also helps explain excessive gassing from the vibratory basket at low average current densities. Conceivably, hydrogen evolution takes place at the cathode contacts of the basket, which become exposed to very high (50–100 A/dm²/500–1000 A/ft²) local current densities during those periods of the plating cycle when the whole load is suspended above the contacts. In these moments, the entire load current plates the contacts, whose surface area is hundreds of times lower than the total area of the parts, which also explains why the contacts plate heavily.

SUBSTRATE DENSITY AND PLATING EFFICIENCY

Consider a body with a mass density D immersed in a liquid with a mass density of d (see Fig. 3). The two forces acting on the body due to gravity and buoyancy result in a net downward (for an object heavier than the liquid) vertical force F given by the formula:

$$F = v \times g\ (D - d) \tag{1}$$

where v is the volume of the body and g is gravitational acceleration. These conditions exist for any metal parts immersed in a plating bath.

Now consider the movement of parts in the vibratory plater. Assuming that at the moment of separation from the basket (see main text) the parts are moving vertically upward with a velocity of V, the amount of time required for them to go up and come down to their original position in space can be calculated based on laws of motion. For the sake of simplicity ignore the forces of friction, noting only that their effect would be to slow down the movement of parts thereby increasing their return time. According to the law of conservation of energy, at the time of their return to the basket, the parts will be moving (in the absence of friction) downward with the same velocity they originally moved up with. The following equation will describe this motion:

$$-V = V - a \times t \tag{2}$$

where a is the downward acceleration of the parts and t is the time from the moment the parts started moving up to the moment of their return to the original position. Solving this equation for t we find:

$$t = 2V/a \tag{3}$$

Because from the point of separation until the reestablishment of contact with the basket, the only force acting on the parts is the force given by Eq. (1), it can be used to determine the acceleration, a, according to Newton's second law of motion:

$$a = F/m \tag{4}$$

where m is mass of the body. Substituting the values of F and $m = v \times D$ in Eq. (4), you obtain:

$$a = g(1 - d/D) \tag{5}$$

Using this value for a in Eq. (3) one can find the ratio of "out of contact times" $t1$ and $t2$ for two metal parts with different mass densities $D1$ and $D2$ but the same volume v and original velocity V:

$$t1/t2 = (1 - d/D2)/(1 - d/D1) \tag{6}$$

For the actual case of steel ($D1$ = 8 g/cc) and aluminum ($D2 = 2.8$ g/cc) rivets in the nickel plating solution ($d = 1.25$ g/cc), the ratio is 0.656, which shows that the denser particles will indeed return to the basket sooner than the lighter ones.

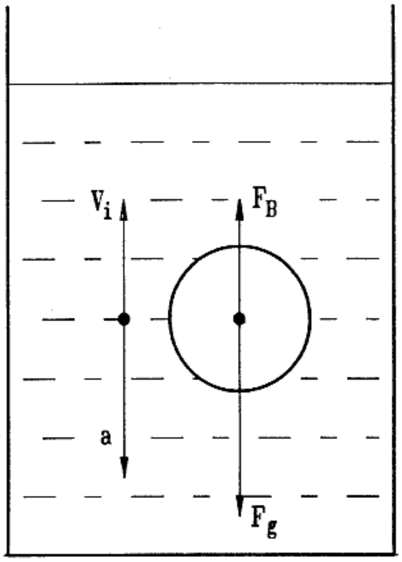

Fig. 3. Balance of forces acting on a body immersed in a fluid. F_b, *force of buoyancy,* F_g, force of gravity; V_i, *initial velocity of the body;* a, *net acceleration.*

There seems to be a contradiction between our findings and the general consensus among commercial vibratory platers, who praise the superior plating uniformity and overall performance of their equipment. The lack of published data on throwing power and efficiency in commercial- and laboratory-size vibratory plating processes makes it difficult to interpret the apparent contradiction, but one explanation may lie in the fact that commercial vibratory units are much bigger (3- to 10-times larger in diameter) than the apparatus we worked with. The difference in size probably changes the character of vibrations of parts in the basket lowering the amplitude and, consequently, shortening the anodic part of the periods, which cause the negative effects we observed.

Several facts support this point of view in addition to our results. Many practical users will agree that plating efficiency in vibratory units falls off as their dimensions grow smaller. According to unpublished work, plating in small vibratory units was significantly improved by replacing cathode buttons mounted flush with the bottom of the basket with variously shaped contacts protruding above it. In one instance a series of contact studs gave very good results. It is obvious that such an arrangement would prevent the total loss of contact of vibrating parts described earlier, and improve conditions for uniform metal distribution and higher efficiency.

Although more testing is necessary to completely understand the size- and material-related effects in vibratory plating, some of which may also be electrolyte specific, at least two conclusions can already be drawn:

1. Until reliable methods of upscaling are developed it is necessary to test the applicability of a mass plating method using life-size equipment rather than small test units.
2. Barrel units are more suitable than vibratory for nickel plating of small batches of small-sized parts. **MF**

References

1. Puippe, L.J., and F. Leaman, (Eds.), *Theory and Practice of Pulse Plating*, AESF, Orlando, Florida, p. 109, 1986
2. Kleinekathofer, K., et al., *Deposition of Nickel by Pulse Plating*, Forschungsinstitut für Edelmetalle und Metallchemie, Schwabisch Gmund, Germany