CONSIDERATIONS FOR THE ELECTROLESS NICKEL PLATING OF LARGE PARTS

By Daniel A. Brockman
Techmetals, Inc.
Dayton, Ohio

ABSTRACT

The money that can be saved by engineering in electroless nickel on large parts is much more significant than on smaller components. However, close consideration must be given to the complexity of plating these parts. While there is great economic incentive to have large components plated, the mind set and equipment required to plate these parts make their cost per mill square inch much greater than that of small parts. This paper will look at some of the advantages of electroless nickel plating on large parts, but will get into more detail on the practical issues involved in the actual plating.

INTRODUCTION

Although there is great economic advantage for the manufacturer to engineer in electroless nickel on his parts, there are also greater costs. The transition from plating small parts to plating large parts is not as simple as it appears. This paper will look at some of these advantages, and then organize around five factors: Mass, volume, surface area, conductivity and chemistry, along with other considerations regarding large parts. The implications of these factors on processing of larger components will be discussed, along with suggested techniques to compensate for adverse effects.

ADVANTAGES OF ELECTROLESS NICKEL ON LARGE PARTS

If there is reason to electroless nickel plate smaller parts and there are many, then there are even more reasons to electroless nickel large parts due to the value of the parts and the cost to machine them. Electroless nickel is often used as a replacement for stainless steel on large parts. It is very expensive, and often difficult to find a source to cast large stainless steel components. As an example, making large parts out of cast iron and electroless nickel plating them for corrosion resistance and wear is an easy conversion when looking at the time and money saved.

In the case of large machined parts that require a wear surface or corrosion resistance and close tolerances, electroless nickel is also a natural. Conventional electrodeposit such as hard chrome or electrolytic nickel need to be machined after plating to hold dimensional accuracy. This remachining on large, electroplated parts can cost hundreds to thousands of dollars per unit. With electroless nickel you can machine the part to size (allowing for plating plate the part and you are done. Not only do you cut costs, but you increase throughput.

Electroless nickel allows you to use such light—weight materials as aluminum, and plate them to size with a corrosion resistant, high phosphorous deposit. If surface hardness is a major concern a very hard low phosphorous electroless nickel deposit is the answer.

EOUIPMENT AND METHODS FOR PLATING LARGE PARTS

While the equipment and methods for plating small parts are readily available, this is not the case for large components. Many make the mistake of thinking that all one needs to change to plating large parts is the size of the plating tank. This paper will review some of the practical difficulties of plating large components, and will also discuss practical solutions to these problems.

Five critical factors to be considered in plating large components are the part mass, volume, surface area, conductivity and chemistry. The mass of the part affects the sizing of cranes and fixture needed, as well as the thermal profile of both part and the solution it is in contact with. The volume of the part affects the solution displacement when the part enters the bath. The surface area affects rates of reactions, sizing of rectifiers, and leads. The conductivity of the part affects the voltage drop along the length of the part. The chemistry of the pretreatment line as well as the strip tank are critical to the integrity of the part. Each of these factors, as well as other areas, will be discussed in depth, and solutions, that have been implemented in our plating facilities to achieve high quality finishes, will be presented.

I. MASS

One of the more obvious differences in plating large parts is the greatly increased mass, or weight, each part. This increased weight must be taken into account when sizing cranes, designing fixtures and compensating for the effects on the temperature uniformity, or thermal profile, of both the part and the processing solutions.

CRANE SIZING - As parts become larger, and heavier, some means of moving the part in and out of the processing solutions and around the plating shop must be used. Hoists and overhead bridge cranes can be used, but care must be taken in their selection and sizing.

The first consideration is that the crane or hoist be sized to lift the maximum weight of the parts anticipated not only must the hoist be sized to handle the weight, but the building and support for the hoist must be strong enough to handle the increased weight of not only the part, but also of the structure and mechanism of the hoist itself.

Another pitfall that can easily occur is forgetting to take into account the weight of the fixtures used to process the part. While the hoist may be sufficient to lift the part; when the fixtures and leads are added, the total weight exceeds the lift capacity of the hoist.

A third pitfall related to hoist, is forgetting the need for headroom. It is easy to forget that while the part may fit into all of the processing tanks, and the hoist is sufficient to lift the part, the distance between the top of the tallest tank, and the maximum lift point of the hoist, must be greater than the length of the part.

A fourth consideration in the sizing of cranes is the speed at which the crane can move in all three axis. The hoist should be capable of lift/lower speeds of at least 15 feet per minute, with higher speeds desirable. This is needed to insure that the parts, especially long parts, can be transferred from one tank to the next quickly enough. Both horizontal axis should have speeds that are fast enough to allow transfer of parts from one tank to the next, but not too fast, as this can make the part difficult to control.

MOMENTUM — A second effect of mass that is closely related to the use of cranes is the momentum effect. Momentum is the product of the mass of a body and its acceleration. Mathematically, momentum is defined as:

$$F=ma(1)$$

Where F is the force vector, m is the mass of the object, and a is the acceleration vector. A part hanging from a crane essentially forms a pendulum, which when set in motion is difficult to slow. When moving parts using a crane, great care must be taken to not impart a momentum to the part that would cause it to start to swing, possibly going out of control. Should a part start to swing, one technique to slow the swing is to move the crane slightly in the opposite direction by stepping the crane motor as the part reaches the peak of it's amplitude.

FIXTURE DESIGN - The fixtures used in the plating of heavy parts must be carefully designed to provide for safe transport of the part during processing. In the first place, the structural design must be sufficient to handle not only the mass of the part, but also a large safety allowance for the likely side forces that will be generated while moving the parts through the plating line as well as heat that can be generated in electrocleaning.

In plating of heavy parts, caution should be observed in the use of high-strength, hardened, steel bolts. If the bolts are submerged in the solution, and exposed to hydrogen, they can become severely embrittled. If placed under severe loading, particularly side loading, the bolts can fail. Fasteners should be masked and protected during the plating steps to minimize the risk of failure.

THERMAL PROFILE - Thermal properties are closely related to the mass of an item, as the Specific Heat, or Heat Capacity of a material is a function of the mass of the material. These thermal properties must be considered when plating large parts, although for most small parts they can easily be ignored, as the mass is rather small. Two aspects of thermal properties will be covered here, the effect on the part, and the effect on the bath.

PART - When the part is placed into a hot solution, such as a soak cleaner operating at 170 degrees F, it absorbs heat from the solution. The temperature in the center (Tc) of a steel sphere or cylinder, with diameter D and initial temperature Ti, t hours after it has been placed into a hot solution, of temperature Ts, can be estimated by:

Tc = Ts + (Ti-Ts) . F (2)

Where F is a correction factor dependent upon, (4at/D~to the 2nd power), where a is the Thermal Diffusivity of the material. Values for a and F can be looked up in a tables. For example, a steel cylinder weighing 2000 lbs, that is 2 feet in diameter, with a starting temperature of 70 degrees F, is placed into a soak cleaner operating at 170 degrees F, after 20 minutes the temperature in the center will be (using a = 0.31):

4at/D~= 4oO.31~(20/6O)/(2)~- = 0.26			(3)
F	(0.26)	= "——~.33	(4)
Tc	= 170	+ (70—170)o .33	(5)
Tc	= 170	+ (—33)	(6)
Tc	137	degrees F	(7)

Two problems can arise from the heat that is retained by the part. First as the part is removed form the soak cleaner, flash evaporation can take place during the time the part is being transferred to the rinse tank. If this occurs, highly tenacious and insoluble scales can be formed on the part, that are extremely difficult to remove, and will cause poor adhesion of any subsequent deposits. This problem can be overcome by continuously spraying the part with water as it comes out of the soak clean tank, and during the transfer to the rinse tank. This can be done using handheld sprayers, or by use of a shower mounted on the crane hook.

The second problem that can arise from the retained heat is that of accelerated rates of reaction in subsequent processing steps. This is particularly a problem in the acid activation step. While the solution used may not excessively etch or pit the deposit when used at room temperature, it may attack a part that retains heat form a prior step, as described above. While the overall solution temperature may not change much when the part is immersed, it should be remembered that the metal/solution interface, the solution will be rapidly heated to near that of the part. While dipping a part into a 150 degree F hydrochloric acid bath would never be considered, some would think nothing of immersing a 150 degree F part into the bath. Should this prove to be a problem, the use of extended cold or room temperature rinses will allow the part to cool sufficiently to reduce the attack.

An often overlooked fact about plating and baking large parts, is that they need long periods of time to cool down after they have been heated up. This can have a rather dramatic impact on production rate, and turnaround times. The thicker the cross sectional area of the part, and the greater the mass, the longer it will hold heat. If the processing calls for the part to be moved shortly after it has been heated up, such as to remove masking materials prior to a hydrogen embrittlement relief bake, some means of rapidly cooling the part will need to be provided.

BATH - The heat removed from a plating solution when a part is immersed can be calculated form Eq(8):

Btu/hr = W x Cp x T (8)
Where: W = Weight of metal introduced (lbs./hr.)
Cp = Specific Heat of Metal
(Btu/lbs. degrees F)
T = Temperature rise in degrees F

For example, if the part to be plated weight 1200 lbs, with a starting temperature of 65 degrees F is placed into an electroless nickel bath at 195 degrees F, and the specific heat of the metal is 0.12, the heat loss from the bath that will need to be made up is 31,200 BTU's, or 9.15 KwHr. This heat loss must be compensated for to avoid chilling the bath. The heaters used in the plating tanks should be sized to accommodate the large heat demand from the parts to be plated.

II. VOLUME

SOLUTION DISPLACEMENT - A second property of large components that must be considered when plating them, is that a part will displace a volume of solution, equal to the volume of the part. When plating smaller parts, this normally is not much of a consideration, as the volume that is displaced is small. As parts occupy a greater volume, some provision must be made for the solution displaced when the part is placed into the tank. To simply allow the solution to overflow to a drain results in loss of the bath contents, and an accompanying cost to waste treat and dispose of the contents. The use of surge tanks, with a pump—back system allow this material to be recovered and reused in the process.

Not only is volume displacement a problem when placing parts into the tank, but the reverse problem occurs when the parts are removed. The volume of the part must be replaced with solution, or the bath level will drop, possibly exposing other parts that are in the same tank. The use of extra freeboard area can help in reducing this problem, as the bath level can be raised prior to removing the part.

III. SURFACE AREA

The third property of the parts that must be taken into consideration when dealing with larger parts is the surface area. This factor effects the heat transfer properties of the part, the rates of reactions in some processes, the sizing of the rectifier, and connecting leads required for cleaning.

HEAT TRANSFER EFFECTS - Thermal conductivity, the amount of heat that can be transferred through a given area of until thickness at a given temperature difference, is highly dependent upon the surface area exposed. Spheres of a given material will cool, or heat up, more slowly than a thin flat sheet, even if both have the same mass, as the sheet has greater surface area exposed. As mentioned above, the heat transfer properties of a part effect many other operating tanks with pump-back system allow this material to be recovered and reused in the process.

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RATE OF REACTION - Particularly with electroless plating processes, rates of reactions are dependent upon solution loading, measured in area per unit volume, such as square feet to be plated/gallon of solution. When plating large components two extremes are frequently encountered, too much area for the volume of the bath, and too little area for the bath volume. The first of these can lead to decomposition of the plating solution, as the amount of energy generated exceed the capability of the stabilizer package used to hold the metal in solution, and to control the plating rate. This is often encountered in plating powder metallurgy parts, and can be encountered in plating of many large components as well.

The second problem, that of too little area, arises from the need to use a large plating tank to physically contain the part to be plated, but the actual area to be plated is small. This can lead to very slow or erratic plating rates, as the activation energy needs of the process are not being met, the solution is overstabilized.

It is difficult to overcome the first problem if all of the area is on one piece. Short of going to a larger plating bath volume, or plating only part of the piece at a time, there are no easy answers. With some plating systems, it is possible to increase the stabilizer concentration to allow running at higher bath loadings, and still maintain a safe plating rate. This could be determined experimentally in the lab, and as long as no important deposit properties are altered, this could provide a means of getting by in a smaller tank.

To overcome insufficient area in the plating bath, several easy techniques can be used.

First, additional work or dummy parts could be added to increase the surface area in the tank. Obviously using other production parts is more advantageous, as the metal is going to a useful purpose. Secondly, plastic pipes filled with water can be placed in the plating tank to occupy some of the volume, reducing the volume of plating solution needed to cover the parts.

RECTIFIER SIZING - The total amperage needed to strike or clean a part is determined by multiplying the total surface area to be plated by the current density desired. While this seems obvious, it is an often overlooked factor in plating large parts, especially for cleaning and activating tanks. While the available rectifiers may easily handle the 40-50 ASF needed in the nickel sulfamate tank, they may not provide the 4-6 ASI needed for a sulfuric-bifluoride activating step. Many times this is not realized until the part is coming down the line, too late to quickly make corrections. Many times this problem will dictate the use of alternative preparation cycles, as the rectifier needed is not available to run the tart according to the normal process.

CONNENECTING LEAD SIZING - Related to the sizing of the rectifier, the connecting leads must be sized appropriately to carry the current needed to strike or clean the part. Use of connecting leads that are too small results in heat build—up, and can cause the lead to melt, or break. Tables are available in the common plating handbooks as to the maximum current carrying capacities of various metals and crass sectional areas for leads. (1) On large parts you should never use the fixture that holds the part as the means to introduce current to the work piece. In the event that there is a poor connection, you can generate significant heat. If this heat is generated through the holding fixture, it quite often causes the fixture to fail and the part to drop through the bottom of the tank, or worse yet weaken the fixture allowing it to drop the part while moving it.

IV. CONDUCTIVITY

The conductivity of the metal from which the part has been made can become a very important factor in plating of large parts. Conductivity, or its inverse resistivity, is a property of materials that varies with material type, length and cross sectional area of the part. These factors can be used to determine the resistance, R, of the part using the equation

$$R= . L/A \qquad (10)$$

Where is the specific resistance for the material, obtained from a handbook (2), L is the length of the current path, and A is the cross—sectional area of the current path. Once the resistance is known, the voltage drop through the part --can be approximated using Ohm's Law:

$$E = I . R \qquad (11)$$

Where E is the voltage, and I the current applied.

VOLTAGE DROP - The voltage drop in long, thin parts can be rather dramatic. This leads to problems in variations in the degree of cleaning or activation in the preplate line. While this voltage drop is often negligible for many common alloys, the specific resistance of some typical aerospace materials can make this a significant problem. For instance, wrought cobalt based superalloys can have specific resistances as high as 188) .am, and some titanium alloys are 199) .am.

Most long parts should use current insertion points on both ends of the part, and at other points if possible, to achieve the best uniformity. Careful positioning of anodes can also be beneficial, such as placing all of the anodes near the center of a long part that is being fed from the ends, to counteract the voltage drop.

INSERTION POINTS - Due to the large currents that are often involved in cleaning large parts, more attention must be given to the current insertion points, than is normally needed to strike or clean smaller parts. Sufficient contact area must be provided to prevent a high resistance point at the connection. High resistance leads to heat build up, and can cause localized overheating of the part. The resistance of the connection can be approximated using Eq. (10), with L being negligible. This estimate of the resistance will be less than the actual resistance, due to the contact resistance between the two mating surfaces, but is useful in determining the minimum contact area that should be used to avoid heat generation.

CHEMISTRY

When plating large parts in many cases the chemistry of their pretreatment line needs to be modified to accommodate the unique characteristics of large parts. Stripping of large parts must also be dealt with as a possibility on every part.

Because of the mass and length of these parts the acid cleaners are generally milder than on a conventional cleaning line. The mass of the large parts allows it to bring heat into the acids from the soak and electrocleaners. In addition, the length of the part allows the bottom of the work piece (first in, last out) to have a longer dwell time in the acid. Using a combination of a weaker acid and a longer submersion, time can usually overcome this problem.

Different materials create different opportunities. In the case of aluminum, as an example, you may find using an acid zinkate more appropriate as opposed to the normal alkaline zinkate. The acid zinkate allows a longer submersion time which may be essential when handling a large aluminum part.

STRIPPING - The chemistry of the stripping tank is a must consideration. Large parts have a large surface area, and as a result a greater opportunity for defects in the base material and in the plating itself. In addition, as you can see, plating of large parts is much more complex than plating of smaller parts leading to a greater chance for rework. When attempting to plate large parts, consideration must be given to the removal of the plating. This will usually involve a large alkaline strip tank. Nitric acid other than for aluminum is too dangerous due to the possibility of etching of these expensive parts, not to mention the disaster a nitric flair up would cause in a 1,000 to 5,000 gallon tank.

OTHER CONSIDERATIONS

QUALITY CONTROL

Running coupons on a rack or pulling a sample lot is fine for small parts, but quality control is much more complicated on larger parts. If you are checking for adhesion, as an example, there are strategic areas to check for. High current density areas, low current density areas, the bottom of the part, top of the part, or next to a recessed area. All of these areas could have seen different preplate cycles due to the geometry of the part, and many areas on the same part need to be checked to assure good quality.

A second area of consideration regarding quality control is in the checking of the process line. These tanks must be agitated while in use, as well as when you pull a sample for checking as the large tanks will quickly stratify and give you a false sample.

BACKUP EQUIPMENT

Backup power generator to run the bridge crane as well as two bridge cranes is important. Leaving a batch of parts in a plating tank or acid tank because of a crane failure or power failure can be disastrous.

Two tank system is recommended not only for operating reasons, but for repair or down time. It is not fast or easy to repair or replace large equipment. Backup heating and boiler systems as well as low pressure blowers for agitation are vital.

PLATING PARTS OUTSIDE OF THE PLATING TANK

This paper would not be complete without mentioning that many large parts are successfully plated outside of the plating line. Often the part itself can be used as the plating tank, or solutions can be pumped through the part. This area is an art itself, and while it is used on some very large parts, it would require a paper in itself to discuss the techniques and procedures involved.

LIABILITY

Large parts are generally very expensive, critical, and hard to replace. You need to have a very good system that firstly, reduces the possibility of scraping a part. Secondly, that deals up front with its repair or replacement. When there is $25,000 or $250,000 involved per part, it is important to have a consistent policy. It is often best to have a specific agreement with the customer that deals with the possibilities of rework and scrap. While it is often a difficult discussion, it is always easier before a part is damaged.

WASTE TREATMENT - This is another area of consideration, the liability and risk here is also greater than with smaller tanks. Large plating lines can cause large waste treatment problems, as an example, when you need to get rid of a cleaning or plating bath, or in the event of an accident, such as a part falling through a tank. The area and systems must be able to accommodate any such occurrence. This can be done with a large acid proof pit area and pumps to pump the chemicals into holding tanks for proper waste treatment.

SUMMARY

When designing large parts, electroless nickel should be considered if hardness, corrosion resistance, and wear are a concern.

Plating of large parts is much more complex and capital intensive than the plating of smaller parts. As a result, the cost to electroless nickel plate large parts is usually more per mil square inch, but because of the value of these large parts the savings is generally much easier to justify.

Electroless nickels properties and characteristics often give it a significant advantage over conventional materials and methods. With the correct equipment, mind set, and methods even the most difficult large part can be plated correctly and consistently.

Notes

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Dan Brockman is the Founder and President of Techmetals, Inc. Dan is a native Daytonian, graduated Chaminade High School, attended both Wright State University and Ohio State University in the Fields of engineering and management.

Dan is involved in the Businessmen's Rountable CEO Program, is a past President of Dayton's AESF, and is active in the Tri-State NAMF.