Important New Tools for Plating & Anodizing Engineering

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Electroplating and anodizing process energy and material costs are very important considerations in product manufacturing, but the most important criteria, however, are the overall quality and plated uniformity of deposited metals or anodized coatings. Sophisticated plating and anodizing simulation tools help to obtain significantly better results. New simulation tools are now available that will run on PC/Windows and can point the way to optimizing many common electrolytic processes. The tools are versatile and user-friendly and have been designed to optimize electroplating and anodizing cells and their associated rack configuration. Sophisticated and accurate analyses are required to determine electrode potentials, distribution of deposited thickness, and true current densities. Good simulation tools can assist engineering teams to simulate and design optimum rack configurations based on the geometrical description of the rack, the parts to be plated or anodized and from calculation of the electrochemical properties of the process being studied.

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We can think of very few plating applications that are as critical or more important than Airline and Aerospace plating. Functionally, plated or anodized substrates in aerospace and airline service see some of the most rigorous work cycles and hostile environments of any parts manufactured in industry today. It's especially important that plating deposit uniformity and integrity are maintained in the plating process.

An example that comes to mind is hydrogen embrittlement induced by the plating process. It is generally believed that hydrogen embrittlement is simply inherent in some electroplating processes and that controlling the current density on the substrate can minimize its effect.

Hydrogen embrittlement from a plating process would usually be more severe on the high current density area of a plated substrate than on intermediate or low current density areas. Emerging electroplating technology software is capable of creating accurate 3D plating simulations that can give engineers an important tool in minimizing the high-to-low current density differences on a plated substrate.

An example of the importance of plating deposit uniformity can be found in a production plating environment….a scenario where numerous parts are mounted on a plating rack. To achieve the required minimum thickness on the inner parts, over-plating of the outer parts occurs. Where there is over-plating, or non-uniform plating, there is usually a large current density variance.

Over-plating, or non-uniform plating, has a detrimental effect on the plating cycle time, not to mention the overall consumption of plated metal. Numerous examples abound.

Figure 1 is a photograph of a plating rack holding 216 pulleys. These pulleys are utilized in the manufacture of engine components, and are plated for function: they must have good balance because they spin at high revolutions, but they are also plated for corrosion resistance.

In order to achieve the specified plating thickness, serious over-plating occurred on the outer edges of the exterior rows of pulleys. This resulted in a high rate of scrapped parts, potentially constituting the entire outer rows of pulleys, or up to 38% of the total on both sides of the rack.

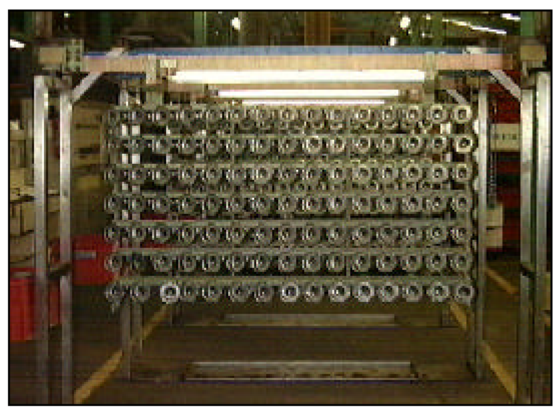

Figure 1

Analysis of the process utilizing 3D modeling in electroplating simulation, *Figure 2*, showed that individual pulleys were being over-plated around the perimeter edge by nearly 100%.

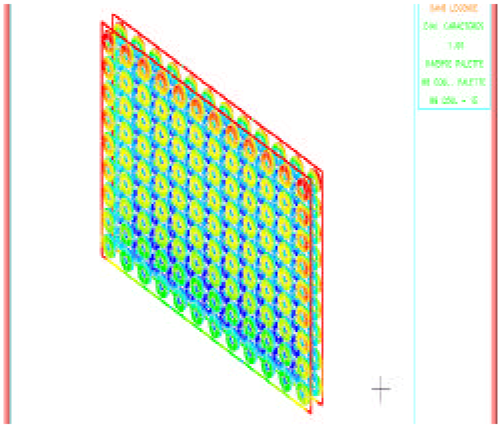

Figure 2

For a pulley that must be properly balanced in order to provide a smooth running engine component, this clearly is unacceptable. Accurate, 3D electroplating simulation permitted optimizing the entire process so that current density variations were minimized, overplating was reduced, and plating efficiencies were maximized.

In *Figure 3*, the color red represents the thickest deposits. The optimum, or specified thickness shows as a light blue color.

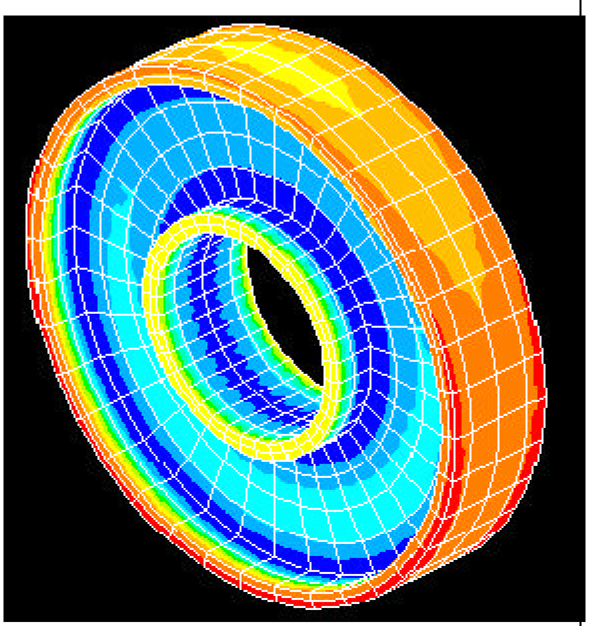

Figure 3

As this example was an existing plating operation, the ability to make major changes to equipment configurations was limited. The plating engineering effort therefore concentrated on optimizing the rack design.

Using 3D modeling, it was found that the addition of current thieves around the outer edges of the pulleys produced substantially better plating results so that virtually no parts were scrapped. A detailed section of the plating rack is depicted with initial, intermediate and final simulations, *Figure 4*.

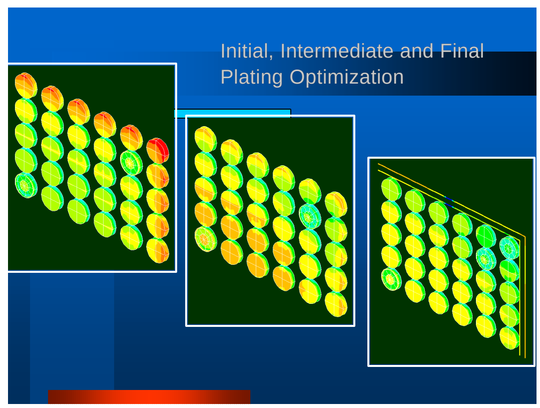

Figure 4

The goal of the plating simulation steps in this case is to get the colors to be more uniform, thus signifying better plating deposit thickness distribution. This minimizes current density differences and enables the plating engineer to make informed decisions about plating most substrates.

The following examples represent additional simulations depicting several “what if” scenarios: in *Figure 5* alternate anode size and shape are simulated.

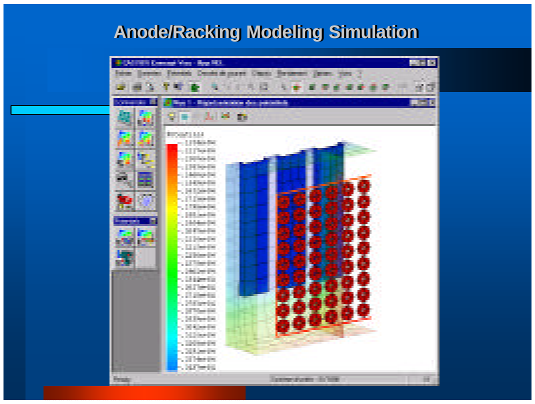

Figure 5

In *Figure 6*, a graphically detailed current density analysis of both the electroplated part and the anode is visible. Take special note of the "hot spot" on the anode.

An integral component of the technology makes it possible for engineering CAD drawings to be imported in a number of formats. They are analyzed and then modeled so that the parts they represent will plate in accurate simulations. This has been immensely helpful in the design and building of new plating equipment to accommodate specific and demanding plating specifications.

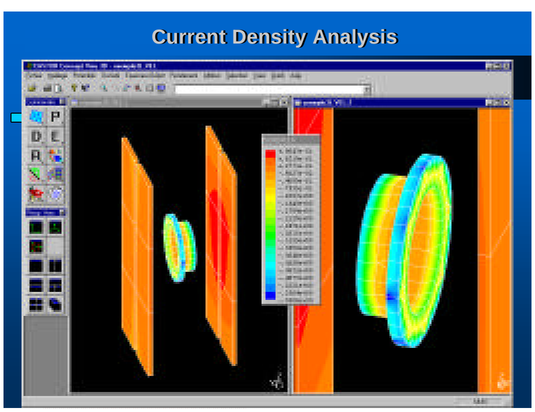

Figure 6

Plating deposit uniformity is especially important where precious metals are concerned. Overplating is costly. It's possible with accurate 3-dimensional modeling to "read" a specific location of the plated substrate and determine its thickness at any given point.

Further, the total amount of plated metal weight on the part can be calculated. With a "before and after" simulation of plating and optimization, it would be possible to calculate plated metal costs and better understand raw material requirements. This could be especially useful for determining the processing characteristics of new part designs. Such detailed analyses have not been possible with plating technologies historically available to industry.

Optimization of the plating process can apply to all electrolytic manufacturing disciplines where there is a defined electrolyte and a known cathode entity. Examples of other applications, i.e. plating valve components, *Figure 7*, demonstrate plating optimization.

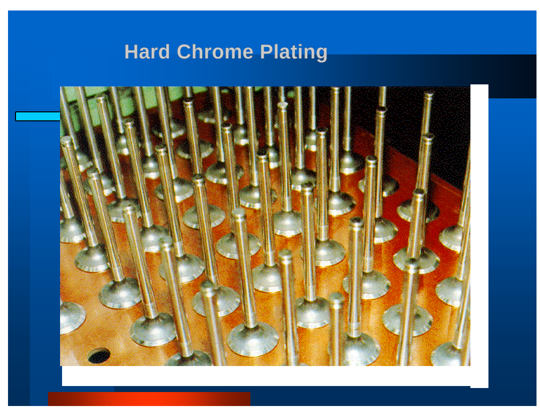

Figure 7

Figure 8 describes a plating fixture simulation for hard chrome plating of these valve components made possible using 3D modeling.

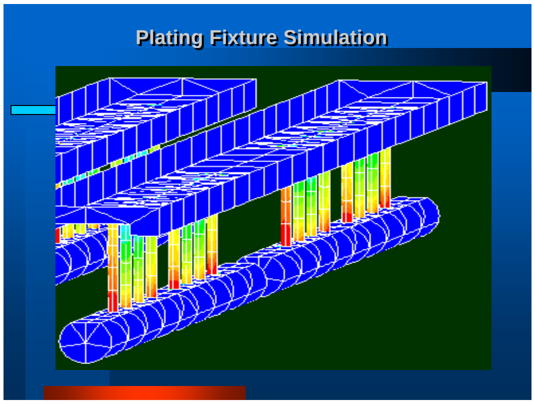

Figure 8

Prior to the plating optimization on these valves, hard chrome overplating and then “grinding back” to proper tolerances had been costly, but necessary, to produce acceptable parts. This is an example of technology that radically altered the valve manufacturing cycle. Plating to optimal thickness tolerances vs. plating and subsequent mechanical metal removal is definitely preferred.

Engineering the plating or anodizing current to preferentially flow where it’s needed is key to optimizing industrial electrolytic manufacturing processes, as we know them. However, coating thickness uniformity is not necessarily the primary concern or difficulty for anodizers. Current density uniformity is however, important.

When the anodize process is initialized, current density can get very high because the oxide film is very thin and the resistance is low. If the anodizer isn't careful, the current density will get too high, and might cause burning. Many anodize systems have a "ramp up" cycle, keeping the voltage low and increasing it slowly or in specific increments as the oxide film increases. At a certain point, when the film is of sufficient thickness (after the "ramp up" period), the voltage levels out and stays fairly constant. To be able to determine the optimal point and avoid the ruin or burning of parts has been a "trial and error" process.

After a certain amount of time in the anodize tank, the oxide film reaches a "saturation" point, where the thickness doesn't increase much - even with current still applied. Determining where this point might be could aid in decreasing dwell times and increasing production, i.e. only leaving parts in the anodize tank as long as needed. Typical current density ranges for commercial anodizing are 10-20 asf and sometimes as high as 30 asf. If the current density is higher, the oxide film forms quicker, but is harder and less porous. If it’s too high you get burning. If the current density is too low, <10 asf for example, the film may be too thin, too soft, or too porous. Finding an ideal anodizing current density might be possible using simulation tools.

The simulation software is based upon mathematical models and a numerical method utilizing boundary element analysis, taking into consideration the overall configuration of the tank and utilizing the characteristics of the electrolyte itself in analyzing the process.

In *Figure 9*, the four basic elements of a plating tank are mapped with special consideration to the cathodic boundary Γ_C, anodic boundary Γ_A, plating tank Γ_R. The electrolyte Ω is effectively limited by each of these items.

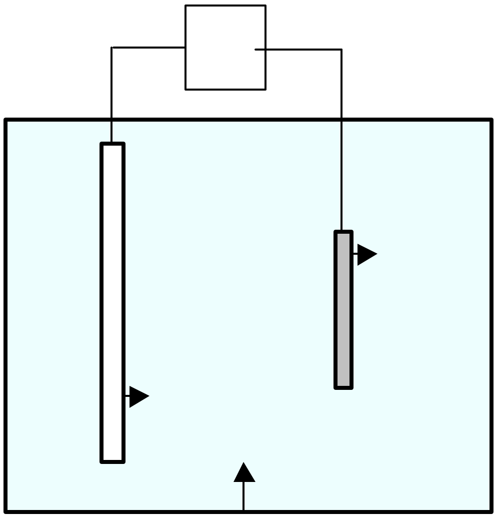

Figure 9

The plating process (P1) can be described by finding the potential $u(x)$ in the electrolytic domain, and the potential difference φ between the two electrodes:

$$P1 \begin{cases} -\nabla u(x) = 0 & \text{in } \Omega \quad (1) \\ \sigma\,(\partial u/\partial n) = f(u(x)) & \text{on } \Gamma_C \quad (2) \\ -\sigma\,(\partial u/\partial n) = g(u(x) - \sigma) & \text{on } \Gamma_A \quad (3) \\ \sigma\,(\partial u/\partial n) = 0 & \text{on } \Gamma_R \quad (4) \\ I = -\int_{\Gamma_C} \sigma(\partial u/\partial n)\,d\Gamma_C & \quad (5) \end{cases}$$

The total current I generated by the rectifier corresponds to the dual quantity φ between the two electrodes. The functions f and g represent cathodic and anodic polarization laws, describing the potential gap at the electrode/solution interface. These electrochemical behavior laws (f and g) are non-linear. Thus the entire system (P1) is non-linear as well.

The problem is solved by boundary element analysis, coupled with a Newton-Raphson technique.

At the power source, the dual global quantities (current I and potential difference φ) are linked by a non-linear function (a generalized Ohm's law).

The resolution of (P1) is inadequate, so an algorithm was developed, monitored by global current I. This current takes into consideration the working current density as recommended by the chemical manufacturer of a particular electrolyte additive. Calculated current densities are then utilized with Faraday's law to predict the plated deposit.

CONCLUSIONS:

The electrolytic system can be broken down into its many basic elements:

- Tank Design
- Cathode Design
- Anode Design
- Chemistry & Operating Parameters

These elements are better understood by accurately determining how each interacts with the others. Analyses of these complex interrelationships are made possible by new electrolytic process engineering technology rooted in software development, that is driving modern manufacturing to greater cost and cycle time efficiencies.

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