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High Current Density Barrel Zinc Electroplating: Staying Competitive in a Global Market

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ABSTRACT

Barrel electroplating can result in extreme variations in current density. A novel technique allowed us to produce data to demonstrate this. The negative impacts from exceeding maximum current density for an acid zinc electroplating process are also detailed.

As the global finishing market gets more competitive, bulk finishers are seeing increasing need to maximize current densities of their processes in order to increase plating line yields. It is a common misleading notion in the plating industry that rack plating is a high current density process, and barrel plating is a low current density process. This belief is demonstrated by the fact that many plating laboratories use 2.0-Amp Hull cell panels to evaluate rack plating processes, but only 1.0-Amp for barrel processes. The concept is further strengthened by the frequent use of average current density to meet thickness requirements. Faraday calculations determining thickness over time are done when plating to a desired thickness is required. These average current densities are typically in the 2-5 A/ft² range (0.2-0.5 A/dm²) for barrel plating.

Countering assumptions

The assumption made by many after doing all those calculations for years is that all parts in the plating barrel are plating continuously. In practice, it is understood that barrel plating is a dynamic process, with parts on the exterior surface of the workload receiving most of plating at any given time. These parts are in the plating zone. The size or depth of the plating zone depends on the density of

the load, as in, how much space is there between parts. Small fasteners have a narrow plating zone. Wire goods or springs might have a deeper plating zone. While some parts are in the plating zone, other parts in the interior of the load are merely conducting current from the dangler to the parts in the plating zone. Some, like Geduld in “Zinc Plating”, have stated the variable nature of current density in barrel applications. Geduld states that current densities as high as 93 A/ft² (10 A/dm²) are possible. Our efforts have focused on proving or disproving this assertion, as it is important to know the range of current density that parts are exposed to in any plating process. This will ensure that the process is designed to handle all possible conditions, without producing defects in appearance or corrosion performance.

The problem

Practically speaking, it is not easy to study current density of individual parts in a barrel. Unlike rack plating, it is not at all practical to measure current on specific parts processed in bulk. It is only possible to monitor the current on an individual barrel. An experienced plater with a clamp-on ammeter will confirm that the current in an individual load will vary over time, as much as 5-25%, as the shifting load varies in degree of contact with the dangler.

Rack vs. barrel

As a result of the on-and-off nature of barrel plating, there is a basic but significant difference between rack and barrel plating. Rack plating results in a single contiguous layer, while barrel plating results in a series of many separate layers, each relying on the integrity of, and adhesion to, the underlying layer. Understanding this helps us act to counter defects typical to barrel plating.

In rack plating, it is common practice to calculate the actual current density that a specific part was exposed to on a rack. This is done after plating from Faraday calculations using measured thickness and plating time. This is a worthwhile technique in most cases, as the applied current in rack is fixed, and does not vary. Impact of cathode efficiency can also be accounted for. In barrel plating, since it is a variable process, these calculations provide no useful information regarding the current density on a given part at various points in time.

While acid zinc was the chosen electrolyte for this evaluation, the results do apply to any barrel plated electrolyte.

The solution

To counter this lack of data, a novel, yet simple, technique was developed to help study the variable nature of current density in barrel plating. The basic premise was to use short plating cycle times to indirectly determine current density. A high efficiency acid chloride zinc electrolyte was used for this evaluation to minimize impact of cathode efficiency. Measuring thicknesses allows us to calculate the current density of each tested part during the plating time used. Reducing test plating times was theorized to give a broader thickness distribution. As plating times are reduced, we see a more focused snapshot of the current density during that window of time. Plating times were evaluated from 10 minutes down to only 15 seconds using smaller, portable sized barrels. Fifteen seconds was determined to be the practical limit. The assortment of test parts used can be seen in Fig. 1. Parts from each load were tested for thickness by x-ray fluorescence (XRF). These thicknesses were then used to calculate current density.




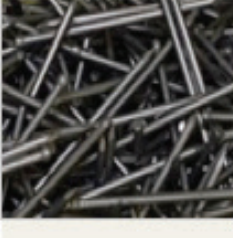
Small Screws	Hydraulic Shells	Plugs	Nails
14 variations	2 variations	8 variations	2 variations
Mesh barrel	Mesh barrel	Perf barrel	Perf barrel
Focused primarily on load size	To demonstrate different geometry	Focused primarily on time	To focus in on initial stages of plating
			

Figure 1 - Matrix of test parts

Fill level and dangles

The overall thickness-based test method was validated by the stripping of parts and dangles, and analyzing the strip solution for zinc by microwave plasma Auger electron spectroscopy (AES). This technique resulted in data that matched well with the thickness of the test parts, validating the methodology. This testing was also used to study the effect of fill level on plate rate (Figs. 2, 3, 4).

These results show the effect that fill level had on plating rate, and on the proportion of zinc that plated on the dangles vs. on the parts. Once the fill level exceeded 40%, the amount of zinc plated on the dangle was minimal compared to the parts. Below 40% full, the amount of zinc on the dangle was significant. Also, as the fill increased to 90%, so did the standard deviation on the thickness, as the mixing of parts in the barrel was limited. This maximum and minimum fill level will vary for larger production barrels, but the premise remains the same. Further testing was performed in the 40-60% fill level range.

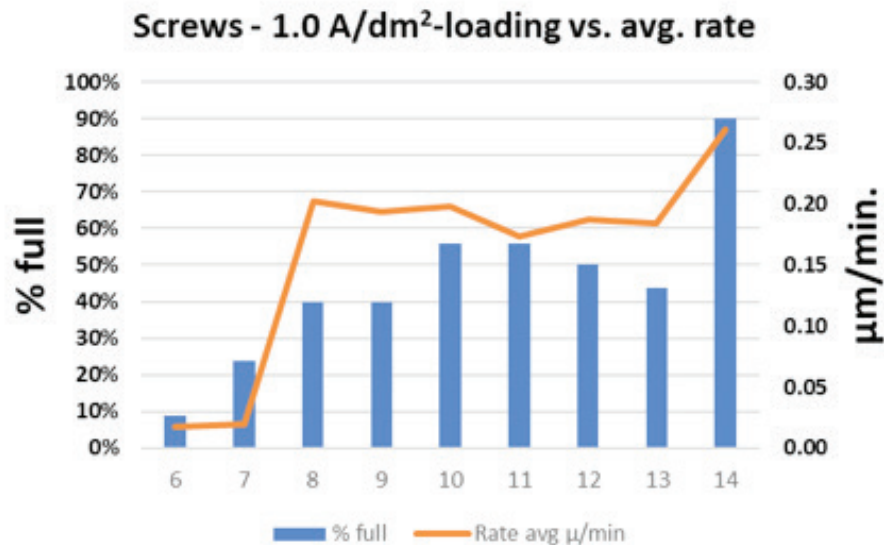


Figure 2 - Percentage of barrel filled vs. plating rate.

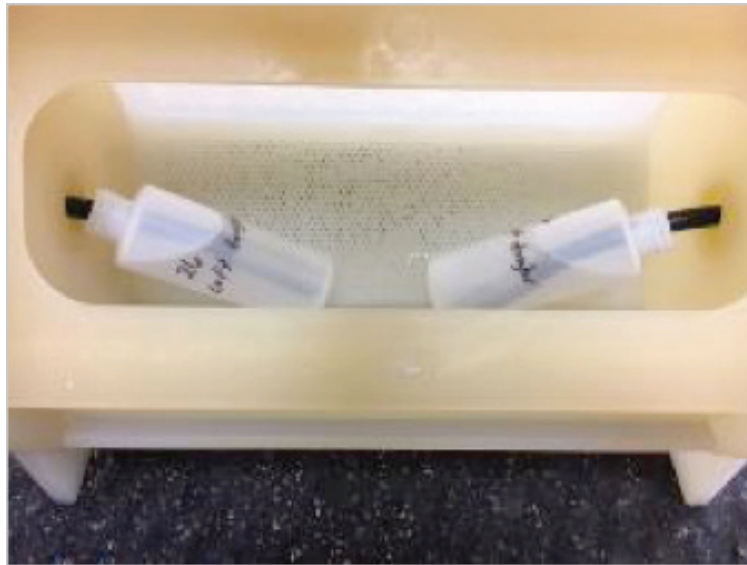


Figure 3 - Stripping of dangles for zinc analysis.

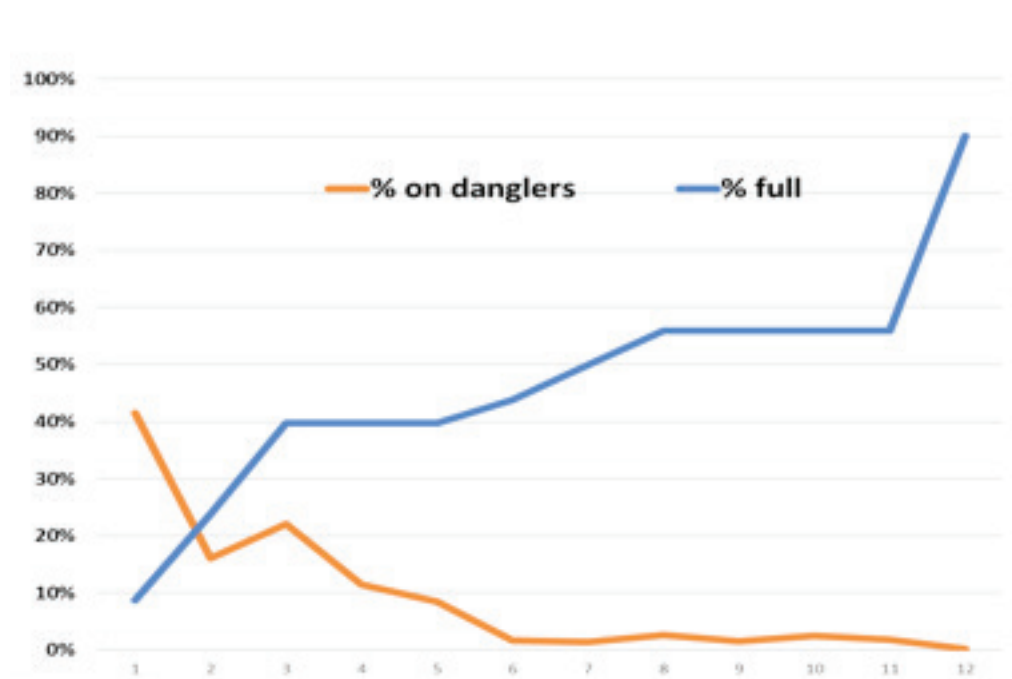


Figure 4 - Percentage of barrel filled vs percentage of plating on dangles.

Plating time

The plating time was evaluated to determine the effect on calculated current density. After several series, it became clear that shorter times consistently demonstrated the presence of higher maximum current density based on thickness data (Fig. 5).

Small fasteners	Run A	Run B
Time, s	600	15
Applied CD A/dm ²	1.1	1.1
High CD, A/dm ² calc.	12.4	61.6

Figure 5 – Maximum CD increases with decreasing plating time.

100 A/ft² / 10.8 A/dm²

Small finishing nails were plated using a 15-second cycle. Using the validated method, we were able to prove maximum current densities above 100 A/ft². Worth noting is how varied the coverage is at 15 seconds (Figs. 6, 7, 8, 9). While all parts had some amount of zinc, some nails were covered on just one end. Two percent of the parts exceeded 100 A/ft² (10.8 A/dm²) and 15% exceeded 47 A/ft² (5 A/dm²).

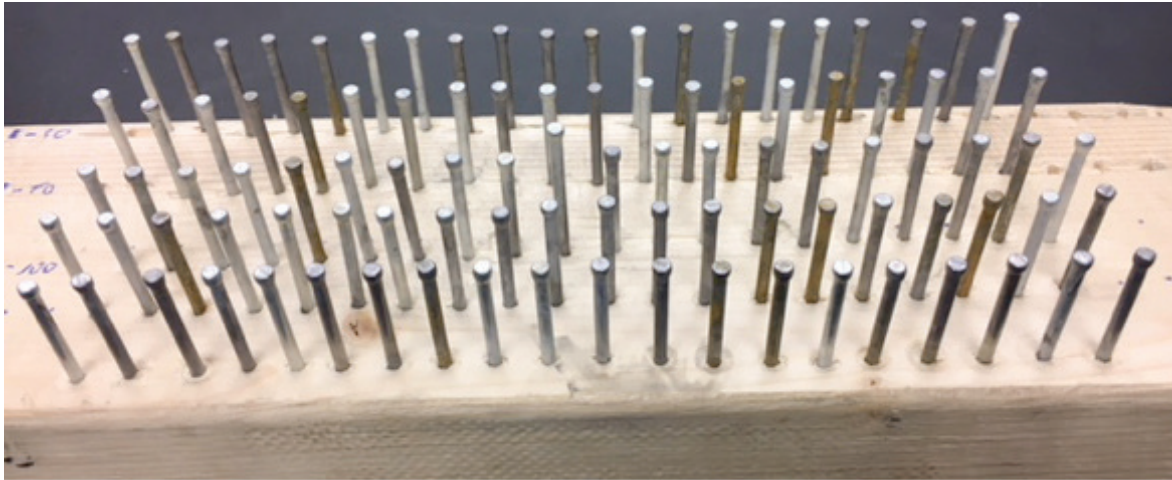


Figure 6 - Appearance of plated nails demonstrates variable coverage at 15 sec..

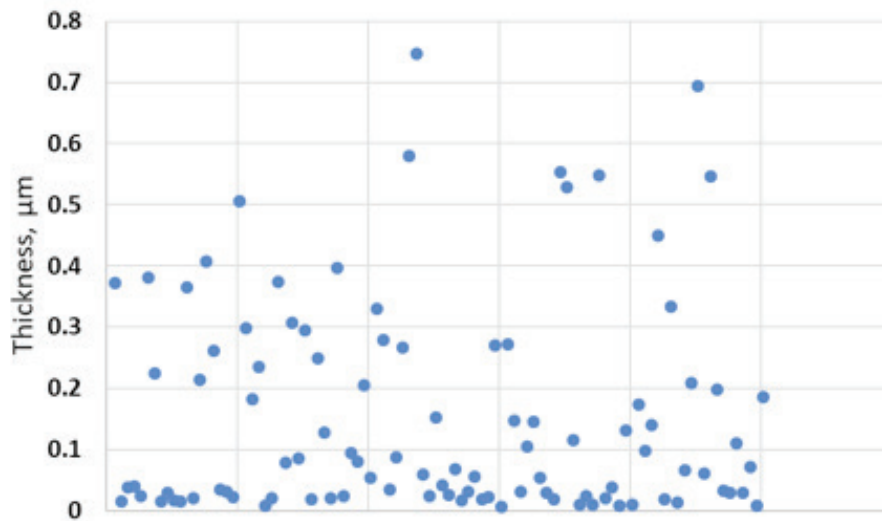


Figure 7 – Thickness variability in a single load at 15-second plating time.

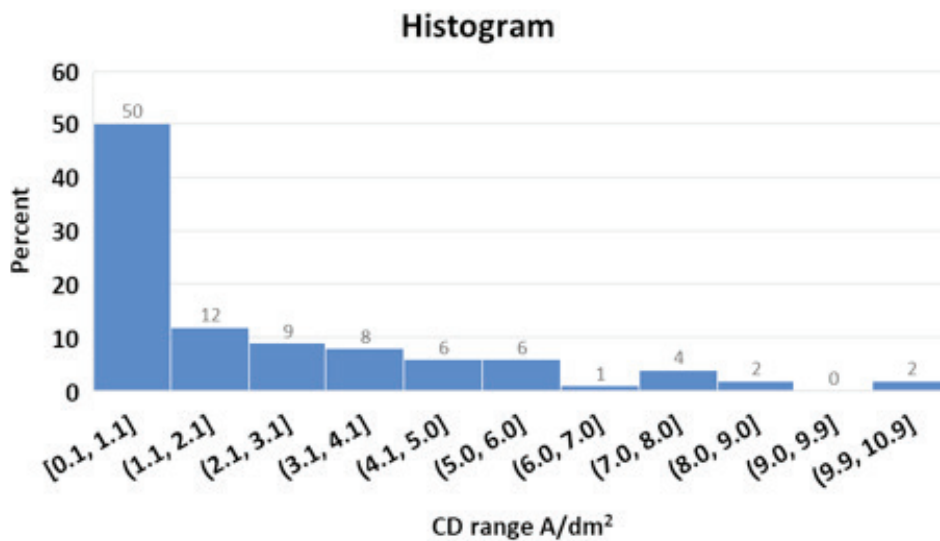


Figure 8 – Statistical distribution by current density: 2% of parts are >10 A/dm²; 15% are >5 A/dm².

Finishing nails	1	2
% full	50	50
Time, s	30	15
Applied CD A/dm ²	1.1	1.1
Low CD, A/dm ² calc.	0.09	0.14
High CD, A/dm ² calc.	8.0	10.8 ASD (100.3 ASF)

Figure 9 – Maximum current density exceeds 100 A/ft²/10 A/dm².

Stardusting

Stardusting is flaking or roughness in a barrel plated deposit that causes small particles of nonadherent zinc to delaminate from the surface. It may be visible after handling the plated parts, or it may be visible in the containers used for shipping parts. This condition leads to reduced zinc thickness, and exposure of unpassivated zinc, which makes it a common cause of premature white and red corrosion failure. Stardusting is frequently linked to “burning” in the plating process, or exceeding the maximum design current density for a process. Frequently there is no visible sign of burning.

To study stardusting, parts were processed to induce a burn effect by shortening the anode distance in an asymmetric fashion, forcing current to one side of the barrel. This produced parts with the characteristic barrel hole spots. These parts were analyzed by scanning electron microscopy (SEM)(Figs. 10, 11, 12). Figure 12 shows dendritic growth in the spot area. This is not visible in the adjacent normal area. Due to the multilayered nature of barrel plating, this dendritic structure will likely result in weak interlayer adhesion. In some cases, barrel parts can have hundreds of plated layers, which will present multiple opportunities for loss of interlayer adhesion, leading to stardusting. To prevent stardusting, a high performance, high current density system is recommended. This is especially critical when operating at 5-10 A/ft², as desired by high productivity barrel lines. Other potential causes for stardusting have been determined, and can be prevented with good monitoring.

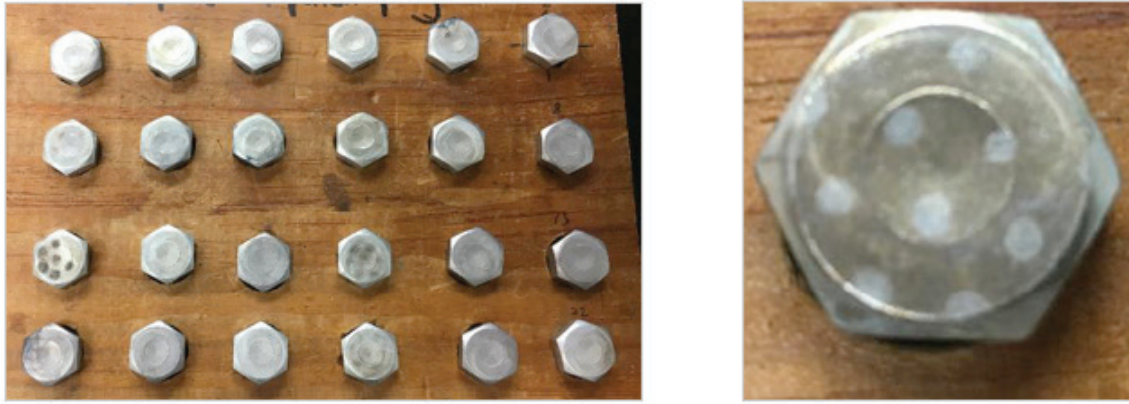


Figure 10 – Induced barrel hole burn with anode proximity.

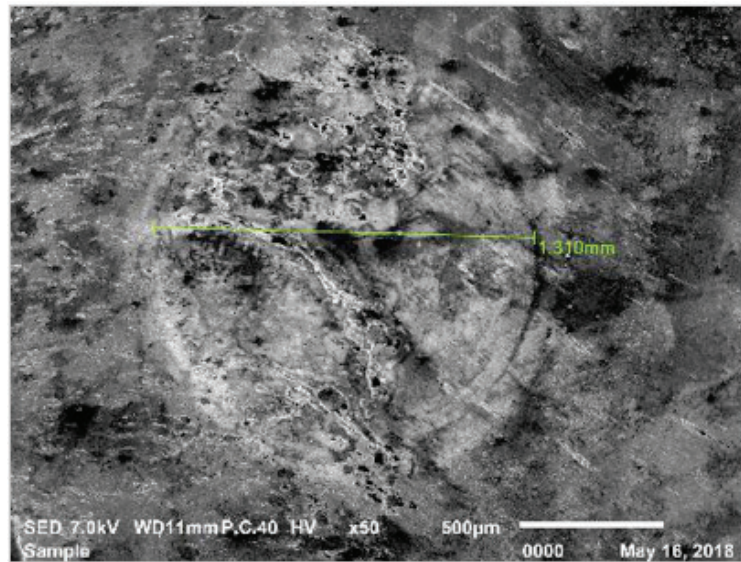


Figure 11 – SEM/SED scan of barrel hole burn.

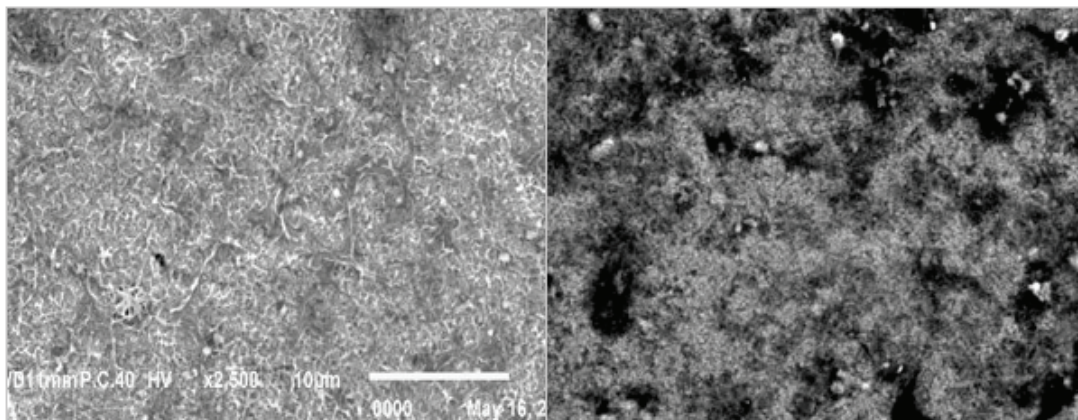


Figure 12 – (L) Dendritic growth seen in burn area from hole pattern; (R) Normal adjacent area.

Figure 13 shows parts processed in a high current density process at 20 A/ft² (2.2 A/dm²) without star-dusting.



Figure 13 – Pavco SmartZinc Premier barrel plated at 2.2 A/dm², 13 µm on bolt heads in 15 min, with no stardusting.

The Takeaway

It turns out Herb Geduld was right. The technique used proved that barrel processes can hit extremely high current densities, even beyond his stated 10A/dm². It is expected that as similar testing is done in larger production barrels, even higher current densities will be found than our controlled environment. If you want to try this in your shop, feel free to contact me.

Barrel finishers need to produce higher corrosion protection with increased volume to stay profitable and keep customers satisfied. Plating at high current densities is necessary to make that happen. Be sure your process is up to meeting these demanding requirements.

Acknowledgements

Compliments to Rick Rauppius and Heather Wright, who moved a lot of barrels and crunched copious data in the process of this study, with impressive results. Many thanks.

References

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