Dr. Fastener- Questions about Zinc Plating

Can You Explain What Zinc Electroplating is?

A: Electroplating is an electrochemical process that deposits a thin layer of one metal on another. In the case of fasteners, zinc electroplating is a common choice of customers and users and involves depositing a thin layer of zinc onto a steel substrate. The process essentially introduces an electric current into a "plating bath" resulting in zinc ions being stripped from solid zinc ingots, conducted through the plating bath and being re-deposited on the steel fasteners.

How does Zinc Electroplating Protect Steel Fasteners?

A: There are several different protection mechanisms that can be employed to protect parts from corroding. These can be a singular mode of protection or combined to provide even more protection. In the case of zinc electroplating the base zinc layer provides a sacrificial mechanism, meaning that the zinc layer behaves as an anode and sacrifices itself before the base substrate is attacked and damaged. As soon as the zinc layer has completely sacrificed itself and opened a pathway to the base substrate, corrosion will occur. Most zinc electroplates receive chromate treatment after plating. The chromate is a Chromium rich chemical that triggers a conversion at the surface of the plating layer that provides a passivation mechanism. This generates a more electrically passive layer which boosts the ability of the plating to resist corrosion. So, zinc electroplating protects parts using a combination of sacrificial and passivation protection mechanisms.

Why is Zinc Electroplating Popular?

A: There are several parts to this answer, but in a nutshell, zinc electroplating can be designed to provide moderate corrosion protection in a cost-effective manner. Additionally, it is available in every industrialized region, provides an attractive surface finish (bright and smooth), is available in multiple colors, possesses good adhesion, and has a long track record of successful application on fasteners.

What is Chromating and Why is It Added to the Zinc Plating?

A: This is partially answered in the protection mechanism question above, but further explanation is warranted. As described above, zinc protects the base metal by utilizing a sacrificial protection mechanism. The sacrificial activity of just zinc is quite rapid and aggressive. Therefore, to provide greater corrosion protection, it is best to slow this mechanism down. This can be accomplished by passivating or making the surface more electrically passive. In simple terms, **the passivated surface slows down the rapidity with which the anodic zinc disappears. This increases the corrosion protection by extending the time the parts can withstand accelerated corrosion testing, like the neutral salt spray test.** Chromates are made up of different forms of the Chromium atom, primarily either the hexavalent chromium ion or the tri-valent chromium ion. In the old days, chromates were comprised mostly of hexavalent chromium constituents. However, in the last twenty years hexavalent chromium has been exposed to be unhealthy to humans and the environment. Therefore, the European Union banned it from automobiles about twenty years ago and now it is mostly available only in the trivalent form.

Are There Differences in Chromates?

A: Yes, hexavalent chromates, in addition to possessing the passivation protection mechanism, were also self-healing. A self-healing mechanism is a particularly effective one that is able to repair itself when damaged. Stainless steel possesses this protection mechanism, which is one of the reasons it is such a strong performer for corrosion protection. In addition to providing a real ability to boost corrosion protection, hexavalent chromium-based chromates could be formulated to naturally produce a variety of colors. Trivalent chromium-based chromates, at least in the early days, did not possess either of these advantages. They were unable to produce the variety of colors that the market had become accustomed to and were weak in regard to adding to Zinc's corrosion protection.

Has the Industry been Able to Overcome These Challenges?

A: The simple answer is, mostly, yes. **Trivalent chromates are still not as effective as their hexavalent counterparts, but they have been improved and today they are able to naturally reproduce many of colors that were previously available.** Additionally, **the surface finishing industry developed and added many sealer options** that enhance corrosion protection by creating additional barriers to penetrating the surface.

Are There Other Challenges Posed by Choosing Zinc Electroplating?

A: Yes, there are a couple of other considerations that fastener engineers need to keep in mind when specifying zinc electroplating. 1. Electric Current Density- this refers to the way that the electric current distributes itself across a part. In areas of the part where the electric current density is high, plating (the depositing of zinc on the surface of steel parts) occurs more quickly and efficiently. Conversely in areas of low current density, deposition occurs more slowly. In most instances the current density is higher at the ends of a part than it is in the middle. This makes zinc electroplating of long parts tricky because meeting the minimum required plating thickness everywhere on the parts means leaving it in the plating bath long enough for the areas of low electric current density to reach the minimum thickness. However, plating thickness continues to grow in the areas of high electric current density, giving the overall plating layer a dog bone shape. This wouldn't be problematic except that most fasteners have threads on one or both ends, so that **the maximum plating thickness occurs in the threaded region and results in potential gage or thread fit issues.** 2. The ability of a plating or coating to get into recesses or hollow features on a fastener is called throw. **Zinc electroplating generally has poor throwing capability, meaning that it either does not deposit at all or very minimally in recesses and hollow features.** That will make fastener features like drive recesses more vulnerable than surfaces where throw is not a concern.

Is Zinc Electroplating Subject to Internal Hydrogen Embrittlement?

A: Per ASTM F2708, Hydrogen embrittlement is a permanent loss of ductility in a metal or alloy caused by hydrogen in combination with stress, either externally applied or internal residual stress. Hydrogen embrittlement failures take two forms, Internal Hydrogen Embrittlement (IHE), where the source of hydrogen comes from the manufacturing process and Environmental Hydrogen Embrittlement (EHE), where the hydrogen source is usually a by-product of Cathodic Hydrogen Absorption from localized corrosion. It is important to remember that hydrogen embrittlement does not occur unless several key factors intersect in sufficient quantity. Those factors are material susceptibility, presence of hydrogen, and tensile stress. Today we know that **the most influential of these factors regarding hydrogen embrittlement risk and ultimate failure is material susceptibility.** Long-term research has shown that fasteners become highly susceptible when they possess a Rockwell Hardness above HRC39. That means that all metric property class 12.9 parts and inch socket head cap screws processed to ASTM F574 are quite vulnerable. It is for this reason that **metric PC12.9 and inch socket head cap screws should not be zinc plated.**

The two most common and concerning sources of hydrogen for IHE are from part cleaning and electroplating. Both are parts of the electroplating process. Recent research into hydrogen embrittlement in fasteners has identified that not all platings are the same. In fact, platings that create dense, very impermeable layers are higher risk for hydrogen embrittlement than those that possess a more permeable layer. The reasoning for this is that the more permeable finishes have more pathways to allow the hydrogen to get out. Electroplated zinc happens to form a very impermeable layer. Thus, zinc plated parts are at higher risk than those possessing many other platings and coatings. It is also the reason that manufacturers and users of high strength fasteners (metric fasteners in PC 12.9 and above and inch fasteners above 150,000psi) should take great care when using zinc electroplating on these parts. In fact, the best practice would be to avoid zinc (or any other high-risk electroplating) altogether on these high strength (highly susceptible) parts. However, if a customer is resolute on using zinc electroplating on highly susceptible parts it is important that the manufacturer takes every step to minimize hydrogen embrittlement, including baking for sufficient time (like 16 to 24 hours or more), testing each lot for hydrogen embrittlement, minimizing the plating thickness, and only using applicators that employ statistically controlled plating processes.

Are There New Developments in Zinc Electroplating?

A: Yes. As mentioned above, when hexavalent chromates were banned in favor of trivalent and non-chrome systems, it posed problems with eliminating color choices and lessening corrosion protection. Much has been accomplished in the last twenty years to reestablish some of this lost performance. Today trivalent chromated systems can be obtained with both yellow and black coloring that does not depend on dye additives. These color choices are ultimately improving in UV stability since they depend less on dyes. Sealers are now added to almost all zinc plating systems. **These topcoat sealers can dramatically improve corrosion protection and usually do so without adding significant thickness to the zinc layer.**

Torque tension ability (lubricity) has also become a key feature desired by many customers. **Friction modifiers lessen the effort to drive fasteners,** making zinc plated, friction modified fasteners desirable for ergonomic and safety reasons. Additionally, friction modified parts lessen the amount of variation in both torque and tension during installation. Even small reductions in installation variation can keep an assembly line running more smoothly.

About thirty years ago, zinc alloy platings began to emerge. These included Zinc-Nickel, Zinc-Iron, Zinc-Cobalt, and Zinc-Tin. Each of these zinc plating alternatives have strengths that make them interesting to application specific uses. However, in the last ten years Zinc-Nickel has emerged as a strong alternative to cadmium, making it a leading contender in cadmium replacement programs. Additionally, Boeing set out several years ago to see if they could develop a lower hydrogen embrittlement zinc-nickel option. They have succeeded with that by developing a low hydrogen embrittlement alkaline zinc nickel finish. They did this by studying and carefully controlling plating bath constituents and chemistry. The resulting zinc-nickel layer is quite permeable, but parts are dull and not bright looking like traditional zinc electroplating. This technology is still evolving, and commercial applicators are few. However, in the future this is likely to change, and industrial capacity will grow. ■