ArmorGalv® CORROSION RESISTANCE THICKNESS ANOMALY

By Martin Straus

***Abstract**:*

*Over the last 15 years of production coating **ArmorGalv®**, we have discovered that high corrosion resistance, of at least **3000 hours of B-117 NSS,** is achieved with coating thicknesses from between **20 and 75µ (0.0008" - 0.003")** of the sacrificial **ArmorGalv®** zinc/iron base coat. This phenomenon seems to be inconsistent with the belief that the greater the zinc thickness, the more the corrosion resistance. We will explain why this is no longer true for **ArmorGalv®**, while it remains true for all other zinc and zinc alloy coatings.*

*3,000 HOURS of NSS was chosen as the "**Benchmark"** because 300 series Stainless Steel shows signs of red corrosion at this level.*

Up to now, the thickness of a zinc based sacrificial coating is predictive of the corrosion resistance required. A low thickness would result in a lower than required salt spray resistance.

*The **Armorgalv®** **Anomaly** states:*

***"Any thickness greater than 25 microns will exceed 3,000 hours of B-117 NSS"**.*

How Did We Become Aware That the Anomaly Exists?

When the **Florida Department of Transportation** wanted to evaluate the **ArmorGalv®** coating, samples of rebar were prepared for them with 40µ (0.0015") of **AG 3000**. The expected **NSS** was for **3,000** hours minimum. The photo below, from their official report of Jan 10, 2014 (available upon request), showed the following after **10,700 of NSS** testing. (1 year 2 1/5 months):

Figure 4 Armorgalv® process after 10,700 hours in salt fog exposure

Additionally, the **FDOT** ascertained that the appearance of “red” was, in fact, what the **ASTM 1059** THERMAL DIFFUSION SPECIFICATION refers to as “staining,” and not base metal corrosion. This was verified by a cross section analysis of the coating after salt spray at the 3,000 hour mark. It is readily apparent that it is the “free iron” in the coating that is “rusted”, with no loss of coating, and definitely no base metal corrosion:

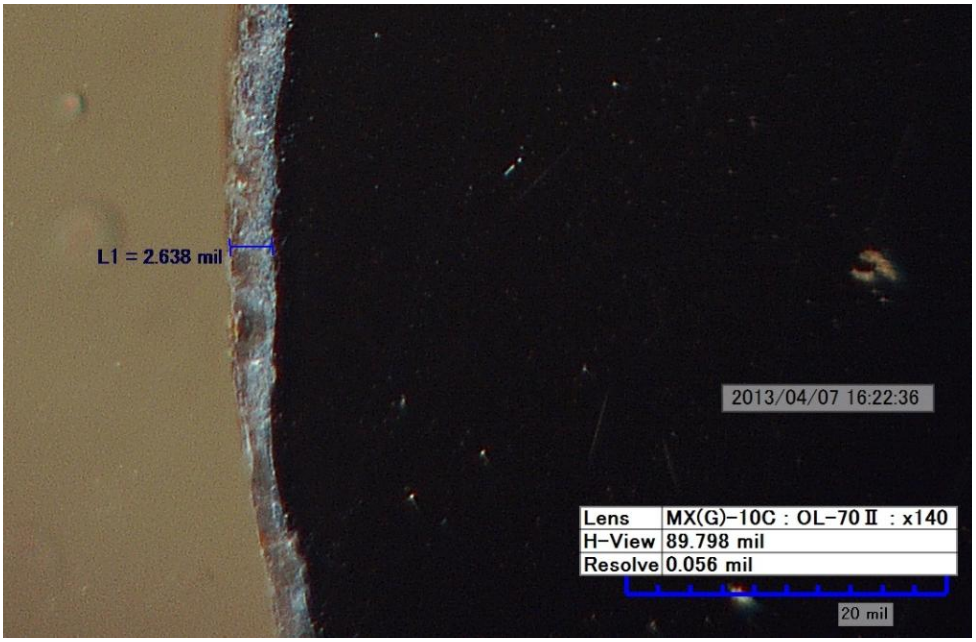


Figure 6 ArmorGalv® after 3000 hours in salt fog environment

NOTE: Since the above evaluation was completed, the FDOT has specified **AG3000** coated bolts and hardware to be used on bridges and, to date, several bridges have so been equipped.

When the **EVINRUDE DIVISION of BRP Canada** wanted to replace 300 series stainless steel bolts, used in their overboard marine engines, with carbon steel bolts coated with **AG 3000**, they real-life evaluated assembled engine bolts at their Port St. Lucie FL test site. The bolts were coated to a **25µ (0.001”**) maximum thickness to avoid over-tapping the threads. All test assemblies met the requirements to replace stainless steel and the **AG3000** system was subsequently approved for production, replacing the Stainless-Steel bolts they have traditionally used for many years.

After it was determined that some of the major fires in California were caused by rusted pole line hardware components that allowed power lines to fall, **Pacific Gas & Electric** wanted to eliminate **HDG** and use a more **corrosion** and **heat resistant** coating. They evaluated **Distek NA**’s **AG 3000** coating system with **50µ (0.002”)** coating. The requirement was to pass **3,000 hours of B-117 NSS**. The requirements were met, and **AG 3000** has been specified for production since 2014.

An **ArmorGalv®** sacrificial base coat of **25µ (0.001”), 40µ (00015”) or 50µ (0.002”)** all perform equally as well. That’s the **ArmorGalv® Anomaly.**

Explanation of the ArmorGalv® "Anomaly:

The anomaly can be attributed to the physical and chemical properties of the **ArmorGalv®** technology.

Physical Characteristics of the ArmorGalv® Coating:

The **ArmorGalv®** sacrificial base coat is deposited onto steel substrates from a zinc gas created from a proprietary zinc dust powder mixture which "sublimates" at a temperature of significantly lower than the melting point of zinc. The zinc gas combines with the available iron in the substrate at 50% zinc and 50% iron. As the deposit increases, three distinct zinc/iron phase layers are created, as illustrated below.

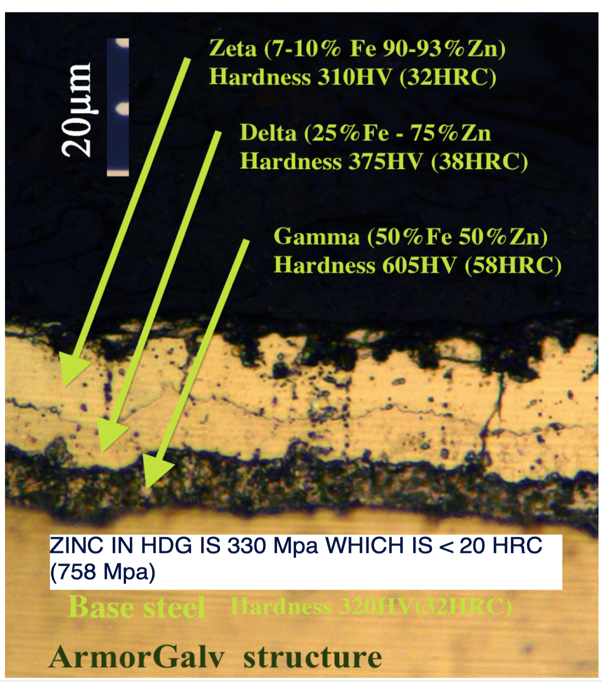
GAMMA LAYER 50% Fe/50% Zn - extremely hard/dense (**58 HRC;** 2250 Mpa), corrosion resistant and exceptionally adherent layer.

DELTA LAYER 25% Fe/75% Zn - very hard/dense (**38 HRC** 1115 Mpa), with less corrosion resistance than that of the Gamma layer.

ZETA LAYER 10%Fe/90% Zn - hard/randomly microporous (32 HRC; 1,000 Mpa), with less corrosion resistance than that of the Delta layer.

The **ArmorGalv®** coating contains **no pure zinc.** All three of **AG** Zn/Fe phases are harder than zinc, which has a hardness of only 330 Mpa, while the bulk hardness of the **AG** coating is >1,000 Mpa.

Although Hot Dip Galvanize (HDG) does form some **Gamma** and **Delta** phases, most of the coating is pure soft **Eta** phase zinc, and it tends to behave that way. As we'll see below.



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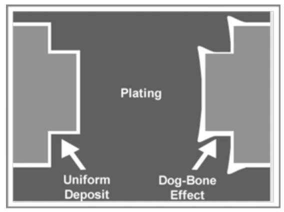
Physical Characteristics of ArmorGalv® in Relation to the Uniformity Part Coverage

Depending on the type of the zinc coating, there are different issues relating to the uniformity of the coatings.

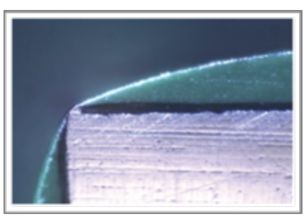
Zinc Electroplating:
The most common type of zinc electroplating bath is the Acid Zinc electrolyte. This technology deposits zinc with more thickness on sharp edges, thread edges and on the ends of parts and much less thickness in thread roots, inside Philip's heads and very little, if any, on internal surfaces. Rusting occurs preferentially in those low coverage areas. This technology is also prone "Dog Boning".



Mechanical Galvanizing:
The use of various sizes of glass beads "cold welds" zinc dust onto parts to form a zinc coating. The uniformity of the coating in recesses and thread roots are problematical. Parts heavier than 500 grams and longer than 6" are problematic to uniformly coat.

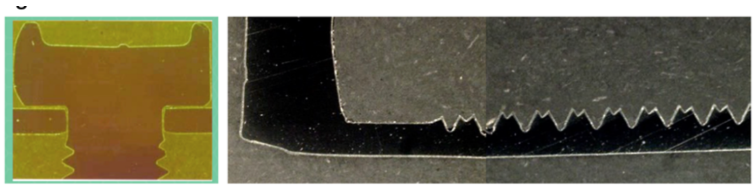
Hot Dip Galvanizing:
The molten zinc tends to puddle in recesses. The coating does suffer from many uniformity issues, very often requiring expensive and time consuming secondary cleaning and thread chasing operations.

Zinc Rich Dip/Spin Paint:
Recess fill is a perennial problem in this coating system. It can also suffer from edge pullback.



ArmorGalv®:
A coating that starts life as a gas has the capability to go everywhere and anywhere a gas can go. If it holds air and has a hole **ArmorGalv®** will get there and coat all exposed ferrous surfaces.

It should be noted that the thicker the **Armorgalv®** coating, the less will the thickness uniformity be. A good thickness specification range is Target Thickness ± 15%.



Screw with Captive Washer   RivNut® with Internal Threads

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Effect of the ArmorGalv® Coating Uniformity on Torque/Tension (C of F) and Bolt Function.

The primary function of a bolt is to **reliably** hold two structural members together over the lifetime of that member. This is accomplished by its Torque/Tension properties. The corrosion resistance of the bolts determines its "lifetime". The higher the corrosion resistance, the greater its longevity and reliability.

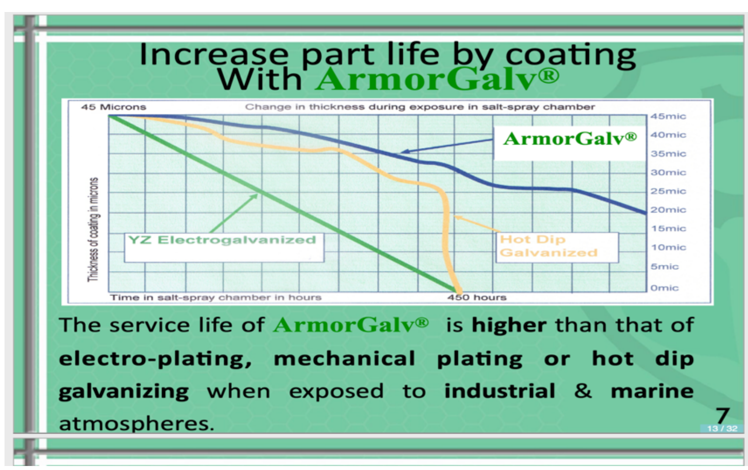
The **uniformity** and the unique inherent **anti-galling Tribology** of the **ArmorGalv®** coating, guarantees a consistent and reliable Coefficient of Friction on each and every bolt, resulting in its enhanced ability to function for the purpose it was created – securing members together. The **ArmorGalv®** coating is also particularly effective when applied to A325 TC Bolts to guarantee the proper "snap off" of the tip while providing for the specified Torque/Tension needed to properly secure the member.

The Tribology of **ArmorGalv®** gives it **anti-galling** properties, very similar to that of Cadmium plating. An important benefit of this characteristic is that even after corrosion sets in, the **ArmorGalv®** coated bolts can, unlike zinc coated bolts, be removed/replaced without the need of cutting or burning. A wrench is all that is needed. This is particularly useful for bolts that are replaced during a **Hot Bolting** operation.

A good thickness specification range is Target Thickness of ± 15%.

Can It Be Demonstrated That Each Phase Layer of The ArmorGalv® Coating Is More Corrosion Resistant Than the Next?

In order to demonstrate that this is the case, parts were coats with 45µ of zinc electroplate, HDG and **ArmorGalv®** basecoat. The parts were subjected to ASTM B-117 NSS and observed for thickness loss over time.



The chart below clearly indicates that homogeneous zinc electroplate coating sacrificed itself at a steady rate. Although the HDG coating resisted weight loss for a time, it performed no better than did the pure zinc coating of equal thickness in the long run**The ArmorGalv® base coat, however, shows a gradual flattening of the corrosion curve, indicating a slowing of the rate of corrosion due to the increased corrosion resistance of the second Delta phase compared to that of the first Zeta phase.**

Protecting The Sacrificial Zinc Coating with a Barrier Coat(s).

HDG zinc coatings are highly reactive and quickly exhibits a type of corrosion known as **white rust**. This type of rust occurs when the **HDG** has not had enough time to fully develop the protective carbonate layer. Instead, the surface remains with a zinc hydroxide layer, which has a white, powdery appearance, which easily washes off.

Freshly galvanized steel progresses through a natural weathering process forming a **Patina** as a barrier coat. During the first few weeks after an article has **HDG**, it develops a natural protective patina. If allowed to develop properly, the patina itself provides a corrosion protection layer for the active zinc metal.

The formation of the zinc patina begins with the development of a thin layer of zinc oxide particulates on the freshly coated surface. These particulates react with water, from rainfall or dew, to form a porous, gelatinous zinc hydroxide. During drying, this product reacts with carbon dioxide present in the atmosphere and converts into a thin, compact and tightly adherent layer of corrosion products consisting mainly of basic zinc carbonate. The rate of patina formation varies according to the environmental conditions. **Typically, it takes approximately 6-12 months to fully develop.**

Handling and storage conditions can inhibit the formation of the patina. Storage areas that are high in humidity and lack air circulation tend to promote excessive growth of zinc oxide and zinc hydroxide. Adequate ventilation must be provided so that the build-up and retention of excessive water on the surface of the galvanized steel are avoided.

The Patina formation, therefore, is dependent on uncontrolled and unknown natural conditions. There is no guarantee of an effective long term barrier Patina always being formed.

Only a barrier coating that is factory applied under strictly controlled conditions can ensure effective, long term and consistent corrosion resistance as is the case with the ArmorGalv® coating.

Chemical And Physical Characteristics of ArmorGalv® AG 3000

The **ArmorGalv® AG 3000** system incorporates a specially formulated ultra-thick (**>1500 nm**) true Trivalent Chromium Passivate/Barrier, **TRITOP®,** that is **REACH** and **California Prop 65 Compliant**. Most commercially available trivalent passivate **(TCC)** systems for zinc can only achieve **100-700 nm** of thickness and incorporate **Cobalt** in their chemistry making them **not** REACH or Prop 65 Compliant. This type of passivate is not a true barrier coating because it relies on the reaction of the cobalt and the chrome that creates some **HEXAVALENT** chrome during the corrosion process which protects the zinc base. When, additionally, as the traditional passivate solution builds up with zinc, its corrosion protection DIMINISHES to the point when a limit of 10 g/l of zinc builds up in the bath it must be discarded and made fresh.

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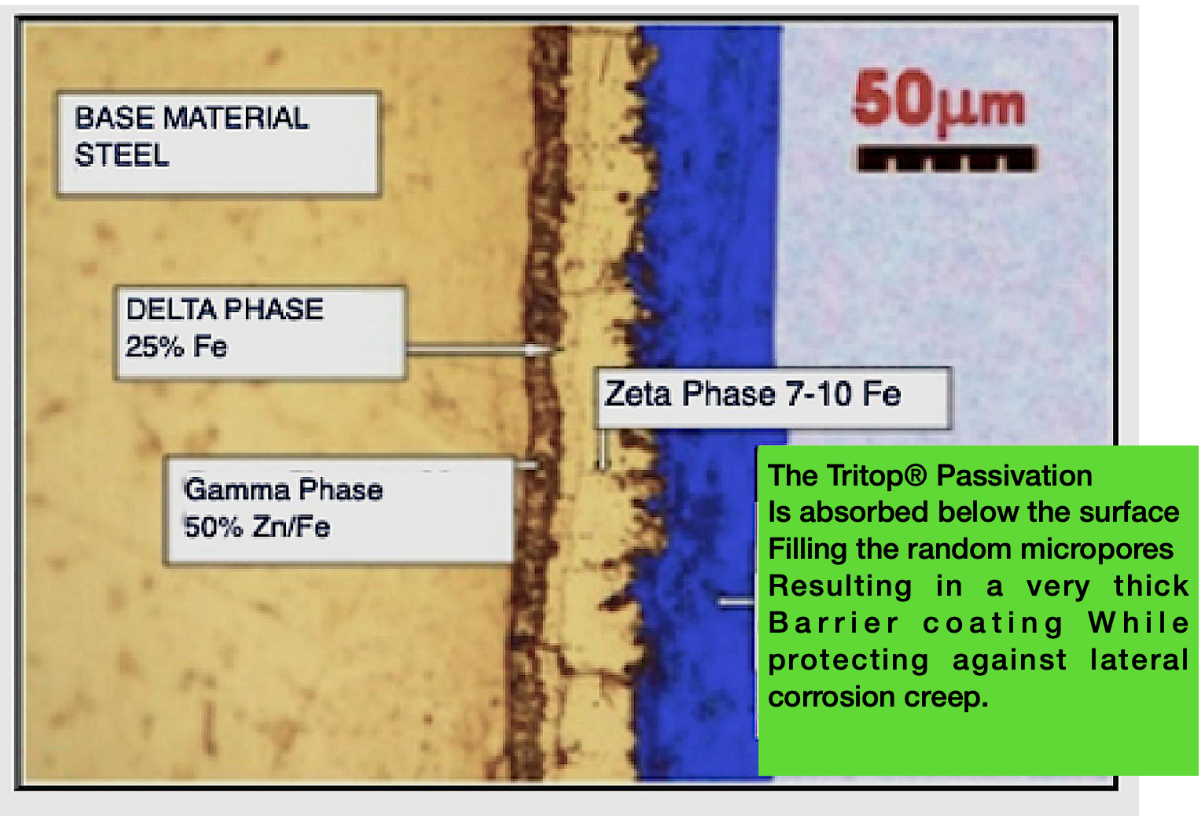
The Pièce de Résistance of the TRITOP® TRUE BARRIER PASSIVATION is that it is a non-reactive polymer topcoat. After a part has been coated with the TRITOP®, additional layers of TRITOP® can be added to increase the thickness and effectiveness to protect the zinc basecoat.

Traditional reactive TCC's, on the other hand, can be only applied ONCE! No additional thickness can be added.

The TRITOP® SOLUTION NEVER SELF CONTAMINATES and maintains its protective qualities indefinitely. Very sustainable.

The unique **ArmorGalv Tritop®** chemistry coupled with the **Randomly Microporous** surface of the **ArmorGalv® ZETA** phase layer results in a physiochemical effective barrier layer.

The illustration below, with the **TRITOP®** coating exaggerated in Blue, shows that the **TRITOP®** both coats the surface and is **absorbed** below the microporous surface. This results in an extremely effective barrier coating that is IMPOSSIBLE to achieve with HDG or any other sacrificial coating.



The **TRITOP®** Barrier coating is then further protected with a flexible hydrophobic silicate sealer - **SILFLEX®**. The combination of these two barrier coats imparts unparalleled corrosion resistance and provides for self-healing properties.

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DISCUSSION:

Given the increasing corrosion protection of each subsequent Zinc/Fe alloy layer, the microporous absorbent **Zeta** layer soaking up the unique thicker TRUE barrier **TRITOP®** Passivation and followed by the application of the flexible hydrophobic silicate sealer, **Silflex®**, the **ArmorGalv® AG3000** coating will always provide **exceptional corrosion and abrasion resistance** within a wide range of thicknesses. **No other coating can offer this "Anomaly".**

Why specify different thicknesses?

When replacing HDG, there are "real world" considerations to take into account. Standard "off the shelf" parts are already manufactured to accept the thickness of HDG coatings. **ArmorGalv®** can be applied to the same thickness as required for HDG for "fit and finish".

The thicker coatings are also useful to prevent damage caused by rough handling on job sites, or to provide for "belt and suspenders" peace of mind.

If you have any questions or comments, please contact me at:

martin@distekna.com

About The Author
After graduating from Northeastern University in Boston, MA, running the electroplating department of a motorcycle plant manufacturing company outside of Jerusalem, Israel, Senior Sales and Technical Specialist for Enthone, Inc., and Senior Sales Engineer for the 3M Company specializing in "acid" chloride zinc electroplating and Mechanical Plating and Galvanizing, Martin and partners started Chem-Plate Inds in an abandoned Buick dealership on the South Side of Chicago, IL in 1978. Since these humble beginnings, CPI has grown to include specializing in functional, sacrificial coatings predominantly for the fastener industry, heat-treating, zinc and zinc/nickel electroplating, dip-spin coatings, mechanical plating, sorting services and Thermal Diffusion coatings.
Martin became a principal in DISTEK NA LLC and will process work under the ArmorGalv® Trademark as well as sell and service the process and equipment to other applicators.