Hot-Dip Galvanized

FASTENERS

Advantages of and design considerations for hot-dip galvanized fasteners

American Galvanizers Association

Hot-Dip Galvanized Fasteners

To be galvanized, fasteners are placed in a perforated metal basket and completely immersed in a molten zinc bath. Once the metallurgical reaction is complete and the fasteners are completely coated, the zinc is then drained from the basket. The basket is then spun to remove excess zinc and ensure a smooth coating that will provide superior corrosion protection.

Fastener Corrosion Protection

Perhaps the most critical choice made in the design of fabrication connections is how to protect the fasteners from corrosion. The protection of fasteners is imperative, because if the fasteners corrode and fail, the integrity of the structure is at risk. Hot-dip galvanizing (HDG) delivers long-term, maintenance-free corrosion protection of fasteners, thus eliminating the concern. Whether used in atmospheric, concrete, soil, or water (fresh or salt) applications, hot-dip galvanized steel provides maximum time to first maintenance. Additionally, because of galvanizing's maintenance-free quality, there will be no difficult field repairs nor labor and material costs associated with those repairs.

So, why hot-dip galvanize? The answer is in the many benefits hot-dip galvanized fasteners provide. The following information will explain how and why hot-dip galvanized fasteners provide superior protection for connections, as well as some design considerations when using galvanized fasteners.

How Does Hot-Dip Galvanizing Protect Steel?

Left unprotected, steel eventually will corrode and suffer loss of mechanical properties and integrity. Hot-dip galvanizing prevents corrosion by offering barrier and galvanic protection to the base steel. The galvanized coating is metallurgically bonded to the underlying steel, forming an impervious barrier between the steel substrate and the corrosive environment. The hot-dip galvanized coating also preferentially corrodes to protect the underlying steel and is able to protect small areas of steel that may become exposed when scratched or abraded. Hot-dip galvanizing is the most effective method for delivering long-term barrier and cathodic protection.

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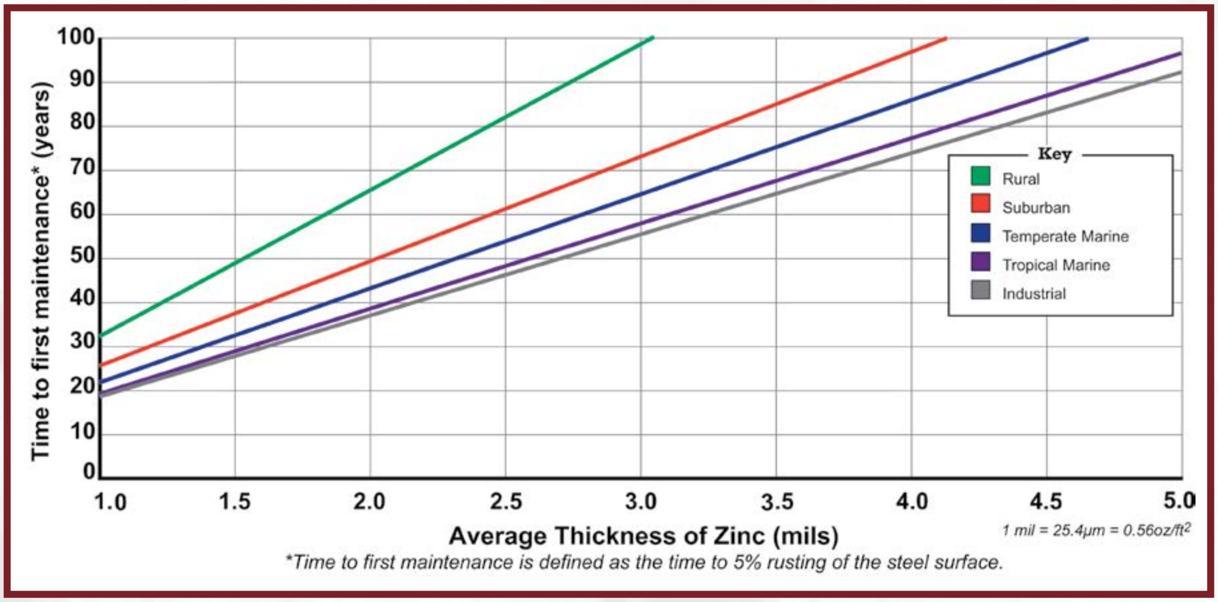
What is the Time to First Maintenance?

Hot-dip galvanized coatings have a proven performance under numerous environmental conditions. The corrosion resistance of zinc coatings is linear to the thickness of the zinc. The thicker the coating, the longer the maintenance-free protection will last. Coating thickness is primarily determined by the steel chemistry and thickness of the fastener material. Hot-dip galvanized coatings are much thicker than other cathodic protection systems such as zinc-plated and electroplated coatings, and painted coatings offer only barrier protection.

The excellent performance of hot-dip galvanized fasteners, articles, and structures has been monitored since the mid 1920s. For fasteners galvanized to ASTM A 153/A 153 M (*Zinc Coating [Hot-Dip] on Iron and Steel Hardware*) or CSA G 164-M 92 (*Hot-Dip Galvanizing of Irregularly Shaped Articles*), first maintenance will not be required for many years. According to the Time to First Maintenance chart (*Figure 1*), a galvanized fastener with 2.5 mils of zinc will require no maintenance for 45-49 years in an industrial environment, the harshest environment regularly examined.

Note: Galvanized fasteners not produced to ASTM standards, including ASTM A 325 for chemistry and structural integrity, the galvanizing process as defined in ASTM A 153, or using ASTM B 6 zinc may not meet design criteria and safety/performance expectations.

Figure 1: Time to First Maintenance



What are the Steps in the Galvanizing Process?

As with any coating system, surface preparation is the key to complete coverage and long-lasting performance. Galvanizing has a built-in quality control system: the metallurgical reaction between zinc and steel will not occur unless the steel is completely clean. The cleaning process for fasteners involves immersion in a series of solutions. The first solution is a caustic (hot alkali) solution to remove organic contaminants. Following thorough rinsing, the fasteners are pickled in a diluted acidic solution to remove scale and rust. Then, after another rinse, the third and final cleaning step, fluxing, takes place. Fluxing removes oxides and prevents further oxidation from forming prior to immersion in the molten zinc bath.

Fasteners in perforated basket are removed after being spun to remove excess zinc.

To hot-dip galvanize fasteners, they are placed in a perforated metal basket and completely immersed in molten zinc. Once the metallurgical reaction is complete and the fasteners are completely coated, the zinc is drained from the basket. The basket is then spun to remove excess zinc, ensuring a smooth coating and clean threads.

Inspection is the final step in the sequence conducted at the galvanizer's plant. With proper cleaning, inspection is simple, if the coating looks good, it is good. The metallurgical reaction produces a well-adhered metallic coating and the fasteners are completely covered with corrosion-protecting zinc.

What Makes the Galvanized Coating a Good Choice for Fasteners?

The hot-dip galvanized process delivers an excellent fastener for a variety of reasons. The following examines many of the reasons why, as well as a comparison of hot-dip galvanizing to other fastener coatings (*Figure 2*). Hot-dip galvanizing provides:

- Complete & consistent coverage: The complete immersion in molten zinc ensures excellent corrosion protection for 100% of the exposed surfaces, with a consistent zinc thickness, including corners and edges, interior, and threads.
- Coating thickness: Hot-dip galvanized fasteners, depending upon diameter, will have from 1.7 to 3.4 mils (43 to 86 microns) of impervious zinc coating.
- Cathodic protection: Unlike other barrier coatings, such as paint, zinc is a sacrificial metal and preferentially corrodes to protect the underlying steel.
- Bond strength: The coating is extremely difficult to damage, as galvanized fasteners have a coating bond strength in the range of 3,600 psi (24.82 MPa).
- Hardness: Hot-dip galvanized fasteners have zinc-iron alloy layers, formed during the galvanizing process, that are harder than the base steel itself. These abrasion resistant layers make the galvanized coating difficult to damage during tightening.
- Temperature range: Galvanized fasteners perform well across a broad temperature range, from continuous exposure in the arctic climates to the extremes of 392°F (200°C) in processing plants.
- Paintable: Prepared according to ASTM D 6386 (*Practice for Preparation of Zinc [Hot-Dip] Galvanized Coated Iron and Steel Product and Hardware Surfaces for Painting*), hot-dip coatings are successfully painted, providing long-lasting underfilm corrosion protection.
- Applicability: Hot-dip galvanizing is a factory-controlled process, independent of weather conditions, and touch-up in the field is rarely necessary. However, should field touch-up or repair of the galvanized coating be needed, zinc coatings can be repaired following the guidelines of ASTM A 780 (*Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings*).
- Suitability: The thicker zinc coating on hot-dip fasteners translates into excellent performance in extreme weather and atmospheric conditions. Larger connections are most commonly hot-dip galvanized. Additionally, hot-dip galvanized fasteners are suitable for use in contact with treated wood.

Figure 2: Comparison to Other Coatings

CRITERIA	HOT-DIP GALVANIZING	ELECTROPLATING	ZINC PLATING	PAINT
Corrosion Protection	Cathodic & barrier	Cathodic & barrier	Cathodic & barrier	Barrier
Coverage on Corners/Edges	Uniform coverage, including corners, edges, and threads	Maybe thin or no coating in difficult to access areas	Maybe thin or no coating in difficult to access areas	Holidays and pin holes possible, coating tends to thin on edges/corners
Coating Thickness	1.7 to 3.4 mils	0.2 mils	Up to 1 mil	1-3 mils
Bond Strength	3,600 psi	300-600 psi	300-600 psi	300-600 psi
Hardness	Alloy layers harder than base steel, with DPN hardness ranging from 179-250	50% as hard as base steel	50% as hard as base steel	Soft & susceptible to handling damage
Temperature Range	-100 C to 200 C	-100 C to 200 C	-100 C to 200 C	Dependent on paint formulation
Paintability	Can be painted	Can be painted	Can be painted	n/a
APPLICATION:	Shop	Shop	Shop	Shop or field
Conditions	Independent of weather	Independent of weather	Independent of weather	Temperature & humidity restrictions
Procedure	After cleaning with series of chemicals, Dipped in molten zinc bath, then spun to remove excess zinc	Clean steel, immerse parts in a zinc acid bath, and drive current through bath	Clean steel, immerse parts in a zinc solution; using a zinc electrode, drive current through bath to part	Clean steel, rinse, dry, brush or spray multiple coats
PERFORMANCE: Time to First Maintenance	50+ years	10+ years	15+ years	10-20 years
Suitability	Outdoor and indoor, applications	Outdoor sparingly, indoor main application	Indoor and outdoor sparingly	Outdoor and indoor applications

Figure 3: Arrangement of Metals in the Galvanic Series

Any one of these metals and alloys will theoretically corrode while offering protection to any other which is lower in the series, so long as both are electrically connected. **In actual practice, however, zinc is by far the most effective in this respect.**

CORRODED END Anodic or less noble
Magnesium
Zinc
Aluminum
Cadmium
Steel
Lead
Tin
Nickel
Brass
Bronzes
Copper
Nickel-Copper Alloys
Stainless Steels (passive)
Silver
Gold
Platinum
Cathodic or most noble PROTECTED END

Figure 4:

The fasteners below are small in comparison to the surface area of the steel plate.

Galvanized Fastener Design Considerations

As discussed earlier, corrosion protection of fasteners is imperative to any connection design. Regardless of what protection system is used, it must be factored into the fastener's design. When using hot-dip galvanized fasteners, specifiers and fabricators should be aware of a few design considerations to ensure quality connections.

Dissimilar Metals

As with all steel products, concern with dissimilar metals in contact is very relevant in the use of fasteners. When two metals are in contact, they form a corrosion cell known as a bimetallic couple. In the bimetallic couple, the metal which is more anodic (according to the Galvanic Series of Metals, *Figure 3*) will preferentially corrode to protect the other metal. This phenomenon is especially important when selecting fasteners. In addition to the location of the metals in the Galvanic Series, the relative surface area of the two metals in contact also plays a significant role in the corrosion cell.

For example, the zinc coating on a galvanized fastener used to connect two large bare steel plates would be rapidly consumed, because zinc is anodic to steel, and the relative surface area of the fastener is small in comparison to the surface area of the steel plates. (see *Figure 4*). The inverse of this scenario, where the plates were galvanized and the fastener was bare, would not cause as severe of a reaction. In that scenario, even though the zinc is still anodic to the bare steel, the surface area of zinc on the plates is very large in comparison with the bare steel fastener, and therefore could protect the fastener with little degradation of the zinc plates.

The design solution to dissimilar metals in contact is simple, avoid it whenever possible. It is always recommended to use hot-dip galvanized fasteners to connect galvanized structures. If dissimilar metals must be used, it may be necessary to isolate the two metals with a non-conductive buffer.

Slip Coefficient

Bolted structural joints are often designed to be slip resistant, in either bearing or friction connections. Bearing connections resist shear between the connected parts by allowing the plate to bear on the bolt. In bearing connections, the presence of coatings on the surfaces is not detrimental to their performance. In friction connections, shear is resisted between the parts by tightening or clamping the bolt and developing frictional force between the faying surfaces. If friction connections slip or have unexpected stress reversals, they may turn into bearing connections, which can be undesirable in certain design conditions.

Hot-dip galvanized steel slip coefficients have been misunderstood for a number of years. Newly galvanized steel tends to be very smooth, and thus has a lower slip coefficient than bare or mild steel. However, weathered galvanized steel and/or wire brushed newly galvanized steel increases the slip resistance of galvanized faying surfaces. Furthermore, over time, two galvanized faying surfaces in a friction connection will experience a lock-up phenomenon. As friction continues to build between the two zinc surfaces, they will start to bond to one another, causing the surfaces to lock-up, and reduce the slip.

Clearance Holes & Overtapping Nuts

Another important design consideration, often and easily overlooked, is oversizing clearance holes and overtapping nuts. The hot-dip galvanizing process adds a coating of zinc to steel in the range of 2-8 mils. When designing holes, it is necessary to plan for the increased thickness on both the fastener and the hole. If after galvanizing, the hole is still not large enough, it can be reamed. A small amount of reaming will not affect the corrosion protection.

A very similar process is suggested for nuts and threaded holes. Nuts and threaded holes are traditionally galvanized as blanks and threaded after galvanizing. The holes and/or nuts should be undersized, and the threads formed after galvanizing. The holes and/or nuts threaded after galvanizing, although bare, will be protected by the zinc on the coated threads of the fastener. The corrosion protection for the hole and/or nut is provided by the bolt's threads.

Hydrogen Embrittlement

Steel chemistry has a profound influence on the formation and appearance of hot-dip galvanized coatings. In addition to the chemistry of the steel, the tensile strength of the steel should also be considered. High-strength steels, (150 ksi or more) may cause hydrogen embrittlement of steel after galvanizing. Currently, according to ASTM, A 490 bolts cannot be galvanized because of concerns with hydrogen embrittlement. In Europe and other parts of the world, A 490 bolts are galvanized without hydrogen embrittlement by using a slightly different surface preparation process than used in the traditional galvanizing process. Studies are being conducted to have A 490 bolts approved for galvanizing in North America.

Treated Wood

In 2003, the chemicals used to protect pressure treated wood were changed to remove some of the potentially harmful elements. The ripple effect of the change in chemicals was an increase in the corrosivity of the wood to steel fasteners and other connections. The two most popular chemical treatments are alkaline copper quaternary (ACQ) and copper azole (CA). Both chemicals are active corrosion materials.

With the increase of the corrosivity of the treatments, a study was performed to evaluate the performance of steel connections in contact with the wood. The only corrosion protection systems recommended for use with ACQ or CA treated wood are hot-dip galvanized steel and stainless steel. The recommendation is for all parts in contact with the wood including plates, joist hangars, bracing plates, and fasteners of all types to be protected by hot-dip galvanizing or to be constructed of stainless steel.

Other Considerations

Comparison to Other Zinc Coatings

The hot-dip galvanizing process produces a coating that is a mixture of zinc and iron. The typical coating is four layers of specific intermetallic composition equaling a thickness greater than 0.002 inches. Other zinc coatings such as electroplating, zinc plating, or mechanical coating produce one layer coatings with thicknesses ranging from 0.0001 to 0.001 inches. Corrosion protection is a linear function of zinc coating thickness, so hot-dip galvanized steel has more zinc and lasts longer.

Fastener Requirements

For requirements of the fasteners after hot-dip galvanizing, refer to the newly issued ASTM Specifications, F 2329 and F 2674. These specifications detail the properties required for the hot-dip galvanized fasteners to be acceptable.

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