MACLEAN POWER SYSTEMS
A MacLean-Fogg Company

Engineering Test Report

M-571
Thermal Diffusion Galvanizing
For Pole Line Hardware

Revision D 11.17.2017	Added further Corrosion Test results and Abrasion Test results
Revision E 02.13.2018	Added UV testing
Revision F 09.05.2018	Relabeled pictures
Revision G 10.02.2018	Format updated for clarity
Revision H 02.16.2021	Changed Actual UTS to “As Tested”

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1. Introduction to Thermal Diffusion Galvanizing

a. Overview

Thermal diffusion galvanizing (TDG) is a process that uses a zinc alloy powder to provide a protective coating for ferrous-based parts. The TDG process provides parts with enhanced corrosion resistance superior to traditional hot dip galvanizing and a service life approaching items made from stainless steel. The applicable standard for TDG items is ASTM A 1059.

b. Process Notes

To create a thermal diffusion galvanized part, the parts are placed in a cylindrical drum along with zinc alloy powder. The cylindrical drum allows the parts to be rotated to ensure all surfaces are evenly coated. The reaction of zinc adhering to the parts begins when the temperature inside the cylinder reaches approximately 400° C, which is below the melting point of zinc and allows the zinc powder to vaporize. The vapor adheres to the steel or iron parts, creating a uniform zinc-iron alloy on the surface. This process continues until the coating reaches the desired thickness.

c. Characteristics of Thermal Diffusion Galvanizing

The list below compares traditional hot dipped galvanizing to thermal diffusion galvanizing.

Hot Dipped Galvanizing	Thermal Diffusion Galvanizing
ASTM A 153 is the applicable standard	ASTM A 1059 is the applicable standard
Molten zinc coats part	Vaporized zinc coats part
Metallurgical bonding of zinc and iron	Also has metallurgical bonding of zinc and iron
Touch up allowed due to missed spots	Touch up not necessary
Drips and dross possible (can foul threads)	Not possible for drips and dross to occur
Surface layer is pure zinc and is soft	Surface layer is zinc/iron intermetallic and is harder
Provides barrier and cathodic protection	Also provides barrier and cathodic protection
Process is harsh on the environment: * process results in significant waste streams * acid pickling used to prepare parts	Environmentally friendly process: * minimal amount of waste * shot blast to clean parts (no acids)
Significant red rust at 1000 hours of salt spray	Exceeds 3000 hours of salt spray; less than 5% red rust
	TDG process is longer in duration than HDG

d. Product Offering from MacLean Power

MacLean Power Systems has partnered with Greenkote (Brook Park, Ohio) to protect pole line hardware using the TDG process. Greenkote has seventeen years of TDG processing experience and uses a proprietary system design to produce TDG coatings that exceed a 3000-hour salt spray exposure.

The Greenkote process uses the same basic steps and equipment common among TDG providers. However, Greenkote uses proprietary powders to control surface reaction chemistry and promote an optimized coating structure. Powder particle size, purity, and alloying elements are designed to maximize diffusion reactions and develop an intermetallic layer that is harder than typical TDG

processes. Furthermore, using aluminum as an alloying element in the powder results in aluminum-rich regions congregated at the outermost layers of the coating. These regions develop passive properties and add to the corrosion resistance of the TDG coating. Figure 8 in the appendix shows the basic Greenkote TDG process.

Lastly, a topcoat is used to extend corrosion resistance of the part (as do other providers of TDG hardware). The TDG layer and topcoat work together to achieve a salt spray test resistance of a minimum of 3000 hours.

MacLean Power designates TDG coated hardware with a suffix "-T" added to the catalog number. All MacLean Power TDG items conform to ASTM A 1059 (class 20 to 40) and are finished with a silicate-based topcoat (designated as Z3K by MPS). The pole line hardware offered includes machine bolts, washers, cross arm pins, and eye bolts. A representative hardware offering is included in the appendix.

2. Mechanical Testing

Test #2.1: Hot dip galvanizing compared to TDG

Samples of 5/8" machine bolts with a TDG coating were tensile tested to destruction per ASTM F 606. For comparison, machine bolts processed with hot dipped galvanizing were also tensile tested. The test results are found in Table 1 and the test set up can be found in Figure 2.1). The minimum requirement for MacLean Power 5/8" machine bolts is 13,550 lbs. Both processes resulted in bolts with mechanical strengths exceeding the minimum requirement.

Table 1: Mechanical Test Results of 5/8" Machine Bolts

Catalog Number	Description	Required load (lbs.) per: ANSI C135.1	ASTM A 307	As Tested (lbs.)
J8810	5/8" X 10" Machine Bolt (Hot dip galv.)	12,400	13,550	19,186
J8810	5/8" X 10" Machine Bolt (Hot dip galv.)	12,400	13,550	18,880
J8810	5/8" X 10" Machine Bolt (Hot dip galv.)	12,400	13,550	18,157
J8810-T	5/8" X 10" Machine Bolt (TDG)	12,400	13,550	19,858
J8810-T	5/8" X 10" Machine Bolt (TDG)	12,400	13,550	19,322
J8810-T	5/8" X 10" Machine Bolt (TDG)	12,400	13,550	19,772

Figure 2.1: Tensile test set up (apparatus used: Instron #300DX-C3A).

Test #2.2: Oval Eyebolt TDG

Samples of 5/8" oval eyebolts with a TDG coating were tensile tested to destruction per ASTM F 606. The test results are found in Table 2 and the test set up can be found in the appendix (Figure 10). The test process resulted in bolts with mechanical strengths exceeding the minimum requirement.

Table 2: Mechanical Test Results of 5/8" Oval Eyebolts

Catalog Number	Description	Required load (lbs.) per: ANSI C135.1	ASTM A 307	As Tested (lbs.)
J9412-T	5/8" X 12" Oval Eye Bolt (TDG)	12,400	13,550	17,903
J9412-T	5/8" X 12" Oval Eye Bolt (TDG)	12,400	13,550	19,716
J9412-T	5/8" X 12" Oval Eye Bolt (TDG)	12,400	13,550	19,468

Test #2.3: Cold Bend with TDG

A cold bend test was performed per ANSI C135.80 – 2012. The non-threaded portion of the bolts shall be capable of being bent while at room temperature at any point through and angle of 180 degrees, about a diameter equal to the diameter of the bolt without cracking the steel on the outside bent portion. In case of completely threaded bolts, the threads shall be removed and the 180 degree bend shall be about the diameter equal to the reduced diameter of the bolt. The parts passed, showing no signs of cracks in the material or the topcoat. (Figure 2.3)

Figure 2.3 MacLean TDG bolts after bend

3. Corrosion Testing

Corrosion testing was conducted at an independent A2LA accredited laboratory (reference report number 1609-27-1613 from TTM Laboratory in Cleveland, Ohio). The third test was similarly conducted by an A2LA laboratory (reference report number D276392 from Applied Technical Services, Incorporated in Marietta, Georgia).

Test #3.1: TDG items exposed to 3000 and 4000 hours

A J8052-T thimble eyebolt (thermal diffusion galvanized per ASTM A 1059, class 20-40), was exposed to a salt spray (ASTM B 117) for 4000 hours. After the 3000 hour test, the TDG item revealed less than 2% of red rust and the 4000 hours test revealing approximately 7% of red rust as noted in Table 3.1 below. The test specimens are shown in Figure 3.1.

Table 3.1: Corrosion Test #3.1 Results

Specimen	Description	Hours	% Red Rust
1	Thermal Diffusion Galvanized (J8052-T)	3000	1%
2	Thermal Diffusion Galvanized (J8052-T)	4000	7%

Figure 1.1: J8052-T after 3000 Hours Salt Spray and 4000 Hours Salt Spray (right)


Pre Exposure


Post Exposure


Pre Exposure


Post Exposure


Pre Exposure


Post Exposure

4. Abrasion Testing

An abrasion test was performed at A2LA accredited laboratory (Touchstone Testing Lab in Triadelphia, WV) where samples of Hot Dip Galvanized and Thermal Diffusion Galvanized square washers were abraded with 2.0 Liters of falling sand (per ASTM D968), and then exposed to 500 hours of salt spray (per ASTM B1117). This test is another method of stressing the TDG and topcoat to determine resiliency.

Test Setup:

The washers were placed in an abrasion tester that allowed the 2.0L of sand to fall on a single point of the washer at a time (Figure 4.1).

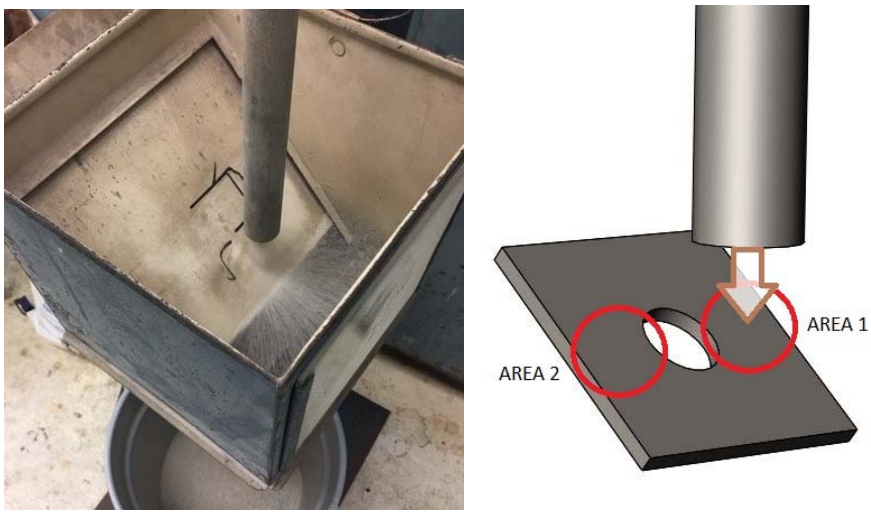


Figure 4.1: Abrasion Test Setup

Test #4.1 Results: Hot dip galvanized samples abraded and exposed for 500 hours:

The first sample of HDG washer displayed some discoloration from the 2.0L of sand abrasion. This sample was then exposed to 500 hours of salt spray causing obvious oxidation of the zinc galvanizing (Figure 4.2). The second sample resulted in a similar outcome with some red rust showing through after the 500 hours of salt spray (Figure 4.3).

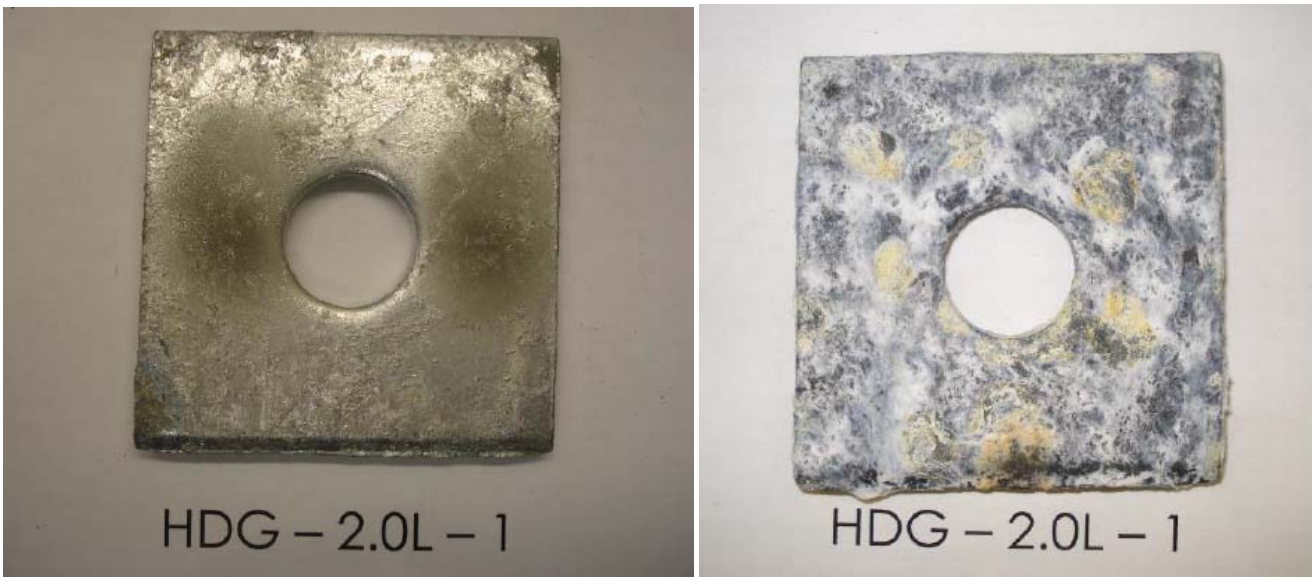


Figure 4.2: HDG sample 1 after 2.0L sand (left) and 500 hours salt spray (right).

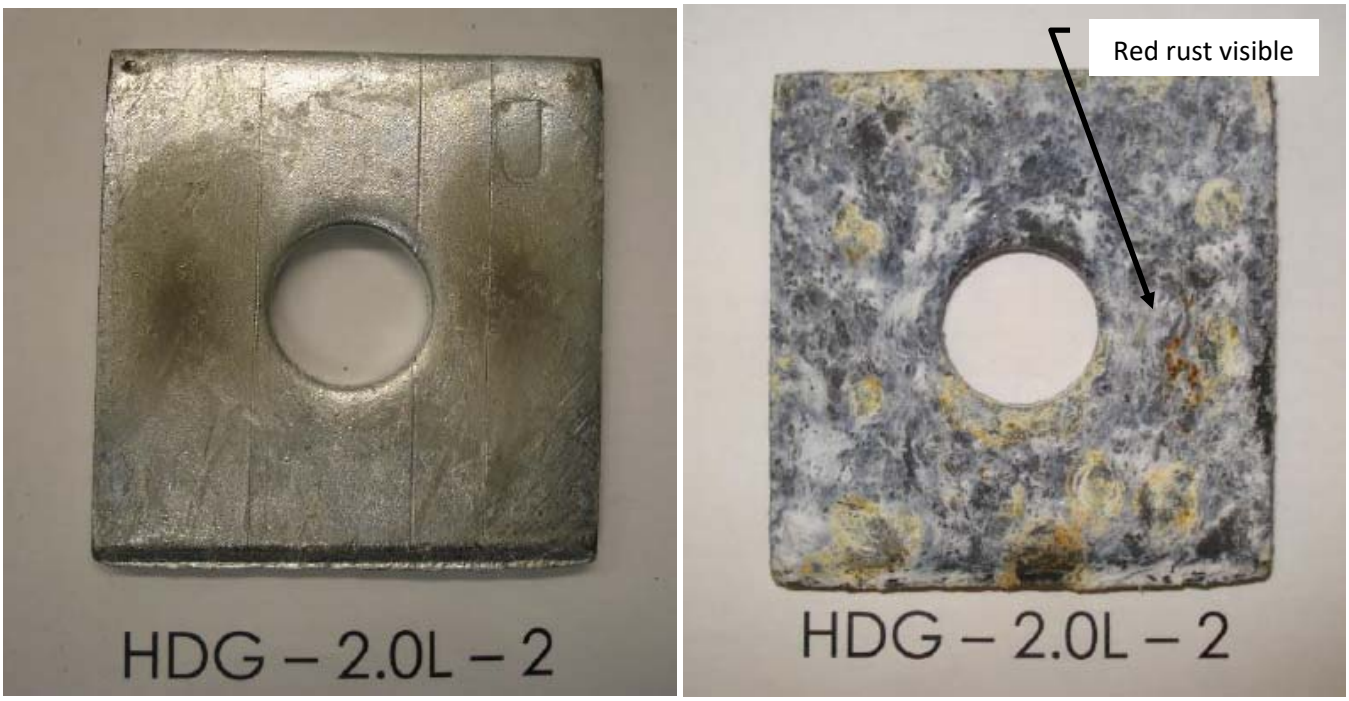


Figure 4.3: HDG sample 2 after 2.0L sand (left) and 500 hours salt spray (right).

Test #4.2 Results: TDG samples abraded and exposed for 500 hours:

The first sample of the TDG washer displayed very faint discoloration after the 2.0L sand abrasion. After the 500-hour salt spray exposure, a minor amount of oxidation was observed (Figure 4.4). The second sample of TDG produced similar results with less noticeable discoloration after the 2.0L sand abrasion (Figure 4.5).

Figure 4.4: TDG sample 1 after 2.0L sand (left) and 500 hours salt spray (right).

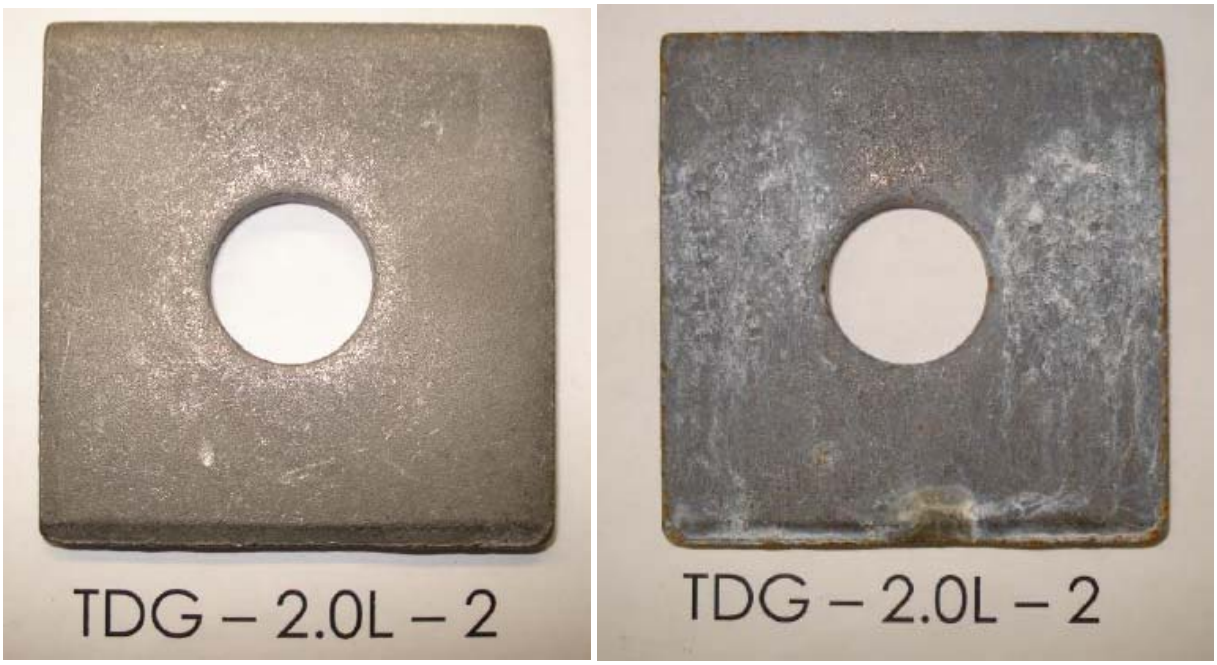


Figure 4.5: TDG sample 1 after 2.0L sand (left) and 500 hours salt spray (right).

Based on the visual evidence after the 500 hour salt spray, it can be concluded that the TDG and topcoat are more resilient to abrasion and provide corrosion protection superior to hot dip galvanizing.

5. UV Testing

The purpose of this test is to determine if UV exposure has any detrimental effect on the topcoat applied over the TDG coating. Two bolt samples were subjected to 1000 hours of UV exposure in a QUV chamber. A control sample was created by cutting one of the bolts in half prior to the test.

Results:

Sample	Description	UV Hours	Top Coat thickness
1	Control sample	0	3-5 microns
2	Exposed sample	1000	3-5 microns
3	Exposed sample	1000	3-5 microns

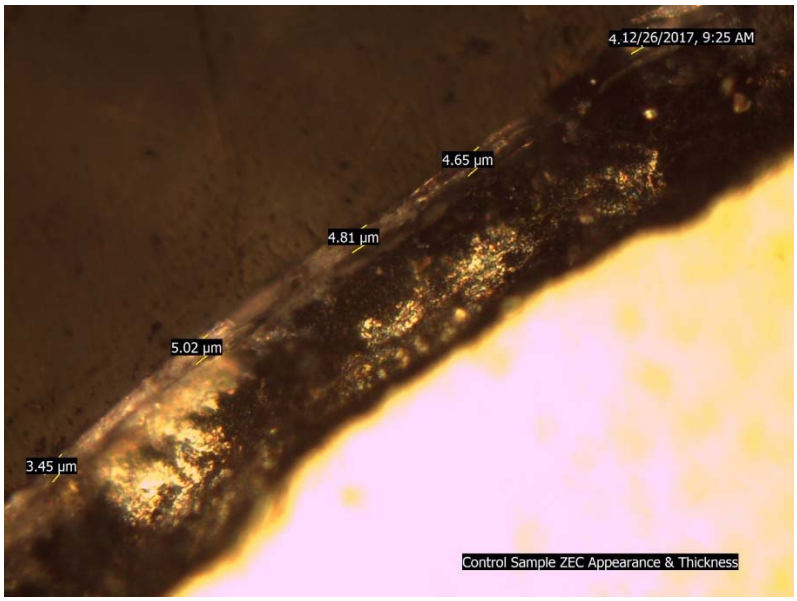


Figure 5.1 Control sample, no exposure.

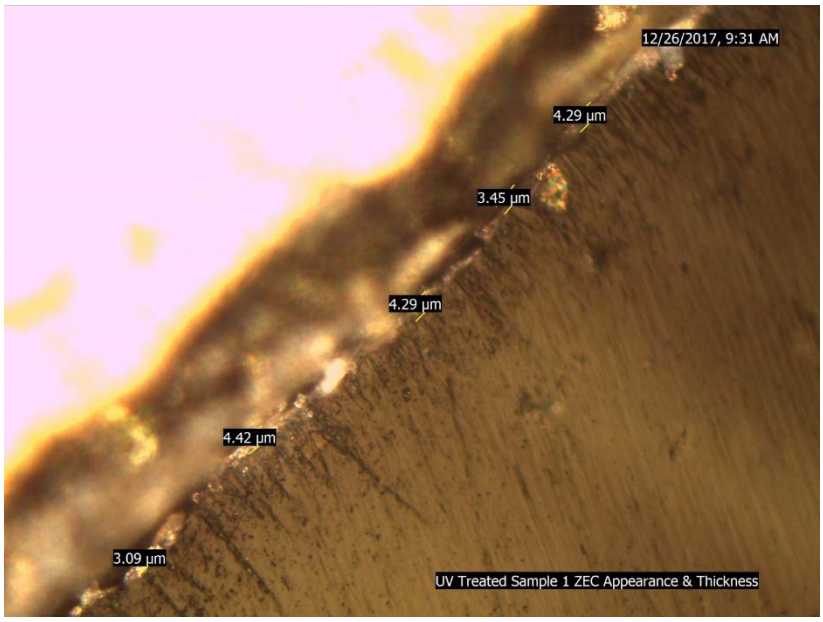


Figure 5.2. 1000 hrs UV

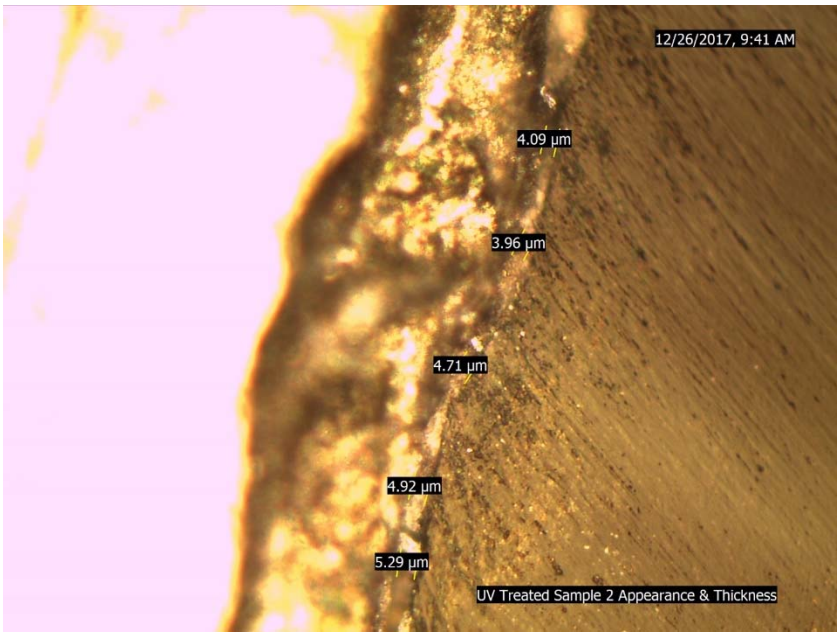


Figure 5.3. 1000 hrs UV

6. Conclusion

MacLean Power thermal diffusion galvanized hardware with a silicate-based top coat exceeds a 3000-hour salt spray test with minimal (less than 5%) red rust exposed. Additionally, the parts meet all other technical requirements regarding strength and durability. This result far surpasses the capability of traditional hot dip galvanized hardware. The hardware offering conforms to ASTM A 1059 for corrosion protection and to ANSI C135.80 for part functionality and strength.

Appendix

Representative catalog offering

Machine Bolts

- Square Head and Square Nut
- Roll threaded
- Cone point for easy driving
- TDG square nut is included
- Strength: 5/8" =13,550 lbs. and 3/4"= 20,050 lbs.

Material:
Carbon steel and protected with GREENKOTE®
(Thermal Diffusion Galvanizing per ASTM A 1059)

5/8" Machine Bolt	Bolt Length	Thread Length	Catalog #
	8	4	J8808-T
	10	6	J8810-T
	12	6	J8812-T
	14	6	J8814-T
	16	6	J8816-T
	18	6	J8818-T
	20	6	J8820-T

3/4" Machine Bolt	Bolt Length	Thread Length	Catalog #
	8	4	J8908-T
	10	6	J8910-T
	12	6	J8912-T
	14	6	J8914-T
	16	6	J8916-T
	18	6	J8918-T
	20	6	J8920-T

Oval Eye Bolts

- Eye inner diameter= 1-1/2" wide X 2" long
- Roll threaded
- Cone point for easy driving
- TDG square nut is included
- Strength: 5/8" = 13,550 lbs.

Material:
Carbon steel and protected with GREENKOTE®
(Thermal Diffusion Galvanizing per ASTM A 1059)

5/8" Oval Eye Bolts	Bolt Length	Thread Length	Catalog #
	6	4	J9406-T
	8	4	J9408-T
	10	6	J9410-T
	12	6	J9412-T
	14	6	J9414-T
	16	6	J9416-T
	18	6	J9418-T
	20	6	J9420-T

All Dimensions in Inches

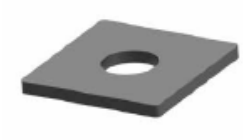
Washers

Material:
Carbon steel and protected with GREENKOTE®
(Thermal Diffusion Galvanizing per ASTM A 1059)

Round Washers

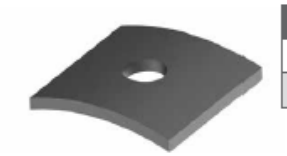
Outside Dia.	Hole Dia.	Bolt Dia.	Catalog #
1-3/4	11/16	5/8	J1088-T
2	13/16	3/4	J1089-T

Square Washers



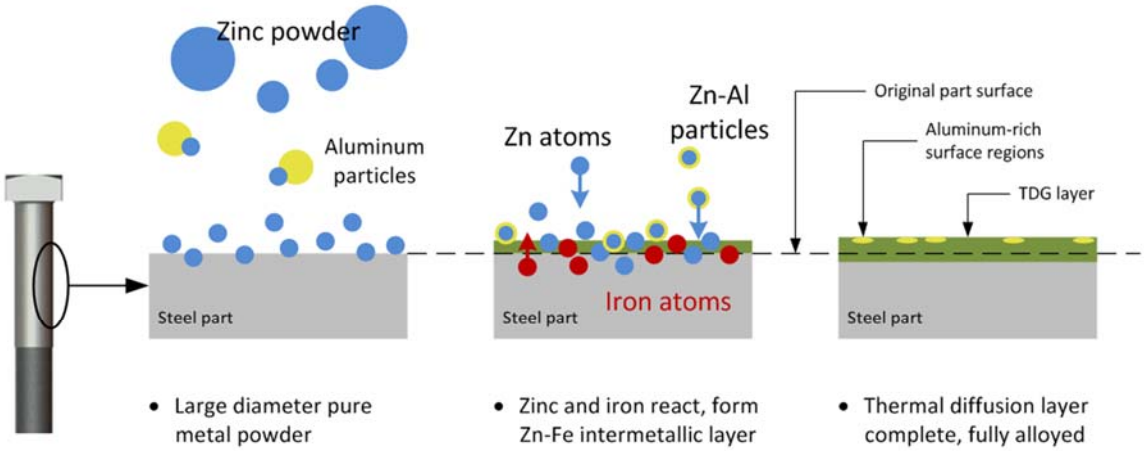
Size	Hole Dia.	Bolt Dia.	Catalog #
2 x 2 x 1/8	11/16	5/8	J1074-T
2-1/4 x 2-1/4 x 3/16	11/16	5/8	J1075-T
2-1/4 x 2-1/4 x 3/16	13/16	3/4	J1076-T

Square Curved Washers



Size	Hole Dia.	Bolt Dia.	Catalog #
2-1/2 x 2-1/2 x 3/16	11/16	5/8	J6822-T
3 x 3 x 1/4	13/16	3/4	J6823-T

All Dimensions in Inches



- Large diameter pure metal powder
- Alloying materials: aluminum
- Zinc reacts with the steel part and aluminum
- Diffusion into steel and aluminum

- Zinc and iron react, form Zn-Fe intermetallic layer
- Thickness builds as more zinc reacts with surface
- Zinc also reacts with aluminum, form Zn-Al particles

- Thermal diffusion layer complete, fully alloyed coating
- 1/3 of coating thickness is into steel part
- Zn-Al particles form aluminum-rich surface regions

Figure 9: Illustration of TDG coating process.

End of Report.