MACLEAN POWER SYSTEMS
A MacLean-Fogg Company

Engineering Test Report

M-571
Thermal Zinc Diffusion Galvanizing
For Pole Line Hardware

Revision D 11.17.2017 Added further Corrosion Test results and Abrasion Test results

Prepared by

Jessica Mastrofilipo
Application Engineer

Matt Gaertner
Engineer Manager

Ron Kmiecik
Product Manager,
Hardware

1. Introduction to Thermal Zinc Diffusion Galvanizing

a. Overview

Thermal zinc diffusion galvanizing (TZD) is a process that uses a zinc alloy powder to provide a protective coating for ferrous-based parts. The TZD 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 zinc 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 Zinc 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
	TZD 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 TZD process. Greenkote has seventeen years of TZD processing experience and uses a proprietary system design to produce TZD coatings that exceed a 3000-hour salt spray exposure.

The Greenkote process uses the same basic steps and equipment common among TZD 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 TZD

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 TZD process.

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

MacLean Power designates TZD coated hardware with a suffix "-T" added to the catalog number. All MacLean Power TZD 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 #1: Hot dip galvanizing compared to TZD

Samples of 5/8" machine bolts with a TZD 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 the appendix (Figure 10). 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

		Required load (lbs.) per:		Actual:
Catalog Number	Description	ANSI C135.1	ASTM A 307	UTS (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

Test #2: Oval Eyebolt TZD

Samples of 5/8" oval eyebolts with a TZD 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

		Required load (lbs.) per:		Actual:
Catalog Number	Description	ANSI C135.1	ASTM A 307	UTS (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 #3: Cold Bend with TZD

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.

MacLean TZD bolts after bend test.

3. Corrosion Testing

Two comparative tests were 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 #1: Hot dip galvanizing compared to TZD

A J8810 machine bolt (hot dip galvanized per ASTM A 153) and a J8812-T machine bolt (thermal diffusion galvanized per ASTM A 1059, class 20-40), were exposed to a salt spray (ASTM B 117) for 1000 hours. The results are noted in the table below, and Figures 1 and 2 depict the visual condition of the bolts after testing.

Table 3: Corrosion Test #1 Results

Specimen	Description	Hours	% Red Rust
1	Hot Dip Galvanized (J8810)	1000	100%
2	Thermal Diffusion Galvanized (J8812-T)	1000	n/a

Figure 1: HDG after 1000 Hours Salt Spray

Figure 2: TZD after 1000 Hours Salt Spray

Test #2: TZD 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 TZD item revealed less than 2% of red rust and the 4000 hours test revealing approximately 7% of red rust as noted in Table 3 below. The test specimens are shown in Figure 3.

Table 4: Corrosion Test #2 Results

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

Figure 3: J8052-T after 3000 Hours Salt Spray and 4000 Hours Salt Spray (right)

Test #3: TDG items exposed to 1000 hours

Pole line hardware is subjected to varying degrees of handling before and during installation. The MacLean Power TZD bolts noted in the table below were subjected various conditioning techniques to demonstrate the resilience of TZD and the topcoat. After conditioning, the bolts were exposed to a salt spray (ASTM B 117) for 1000 hours. Photographs of the below bolts can be found in the appendix (Figure 11 to 17).

Table 5: Corrosion Test #3 Results

Specimen	Item	Description	Conditioning Description	Hours	% Red Rust
1	J9412-T	5/8" X 12" Eye bolt	Threads manually wire brushed	1000	5%
2	J8810-T	5/8" X 10" Machine bolt	Nut run down thread once	1000	1%
3	J9412-T	5/8" X 12" Eye bolt	Nut run down thread ten times	1000	1%
4	J9412-T	5/8" X 12" Eye bolt	Washer clamped with two nuts	1000	0.30%

Based on the visual evidence after the 1000 hour salt spray, it can be concluded that running the nut up and down the threads had no effect on the coating resilience. Wire brushing was found to have a minor effect on coating resilience.

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 Zinc 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 TZD 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).

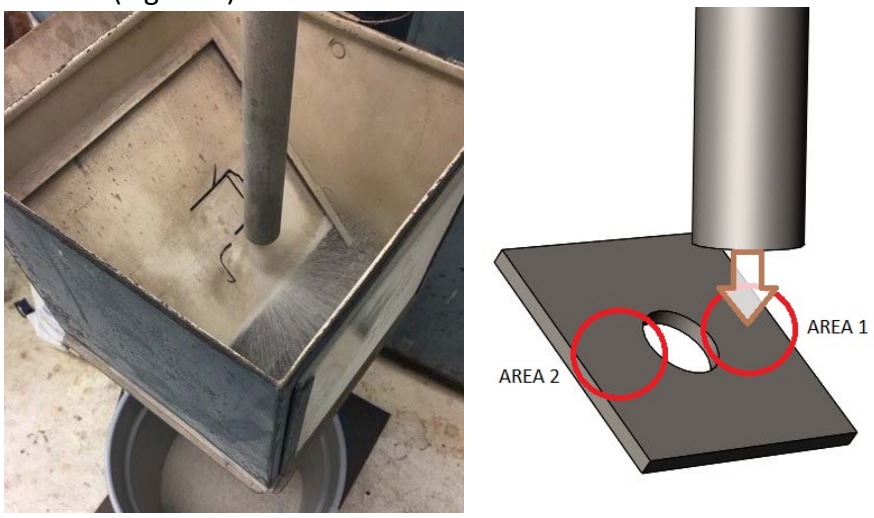


Figure 4: Abrasion Test Setup

Test #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 5). The second sample resulted in a similar outcome with some red rust showing through after the 500 hours of salt spray (Figure 6).

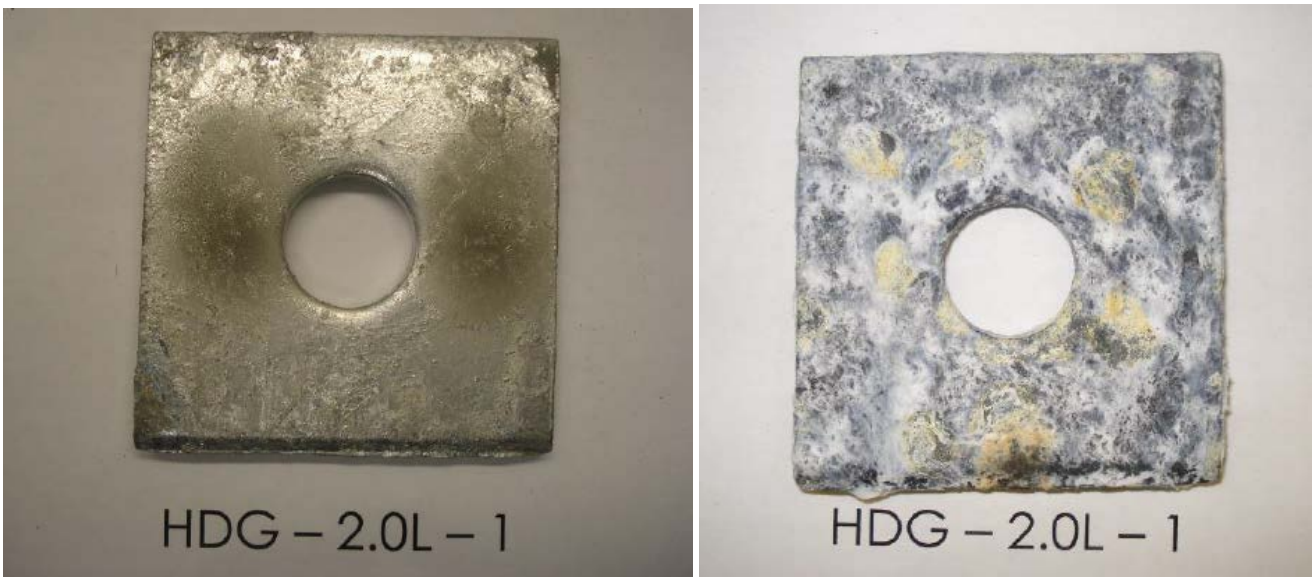


Figure 5: HDG sample 1 after 2.0L sand (left) and 500 hours salt spray (right).

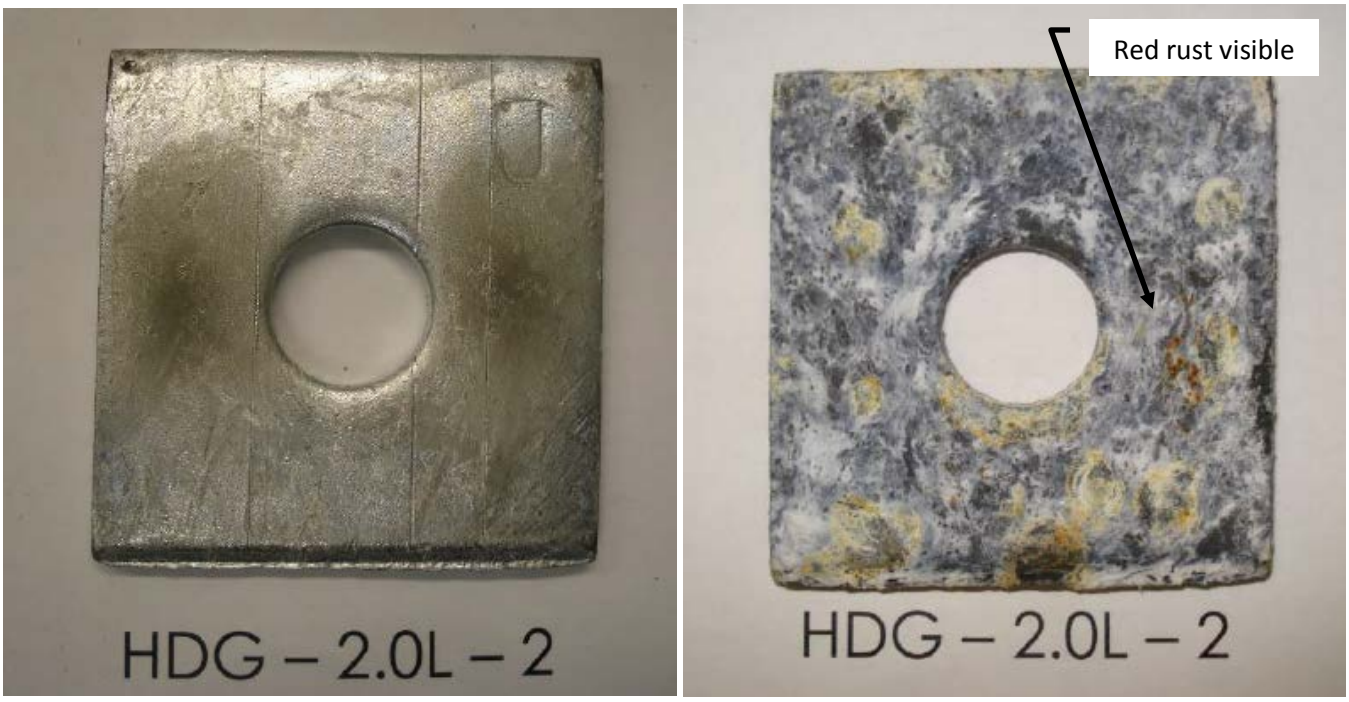


Figure 6: HDG sample 2 after 2.0L sand (left) and 500 hours salt spray (right).

Test #2 Results: TZD samples abraded and exposed for 500 hours:

The first sample of the TZD 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 7). The second sample of TZD produced similar results with less noticeable discoloration after the 2.0L sand abrasion (Figure 8).

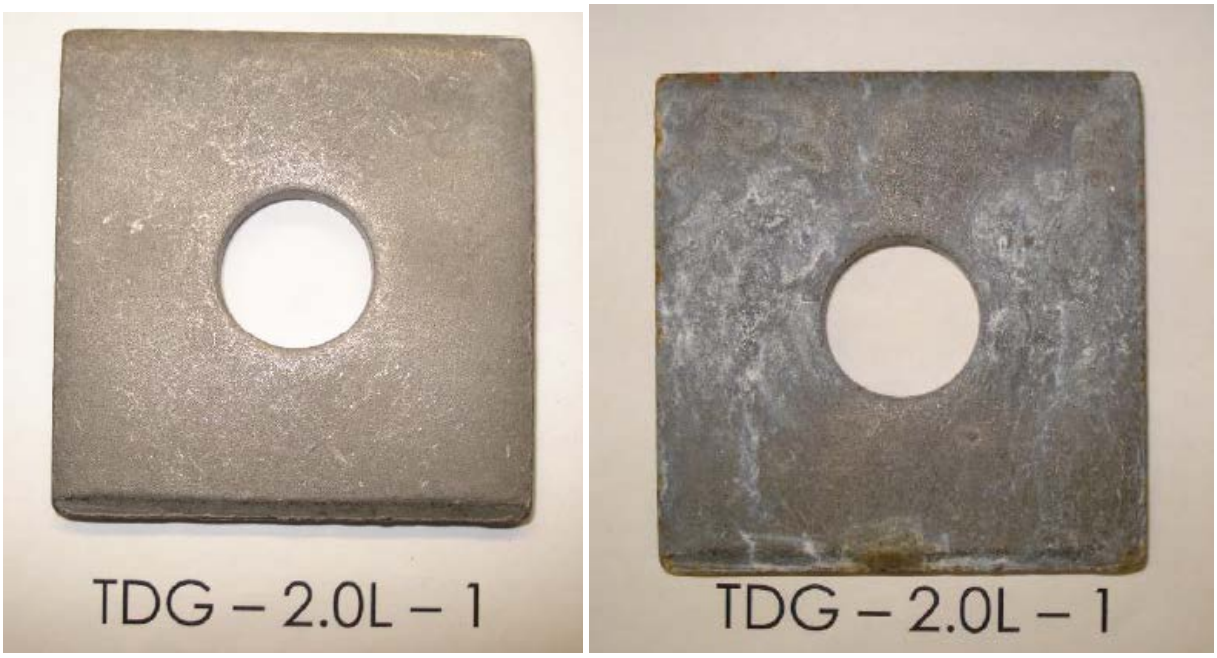


Figure 7: TZD sample 1 after 2.0L sand (left) and 500 hours salt spray (right).

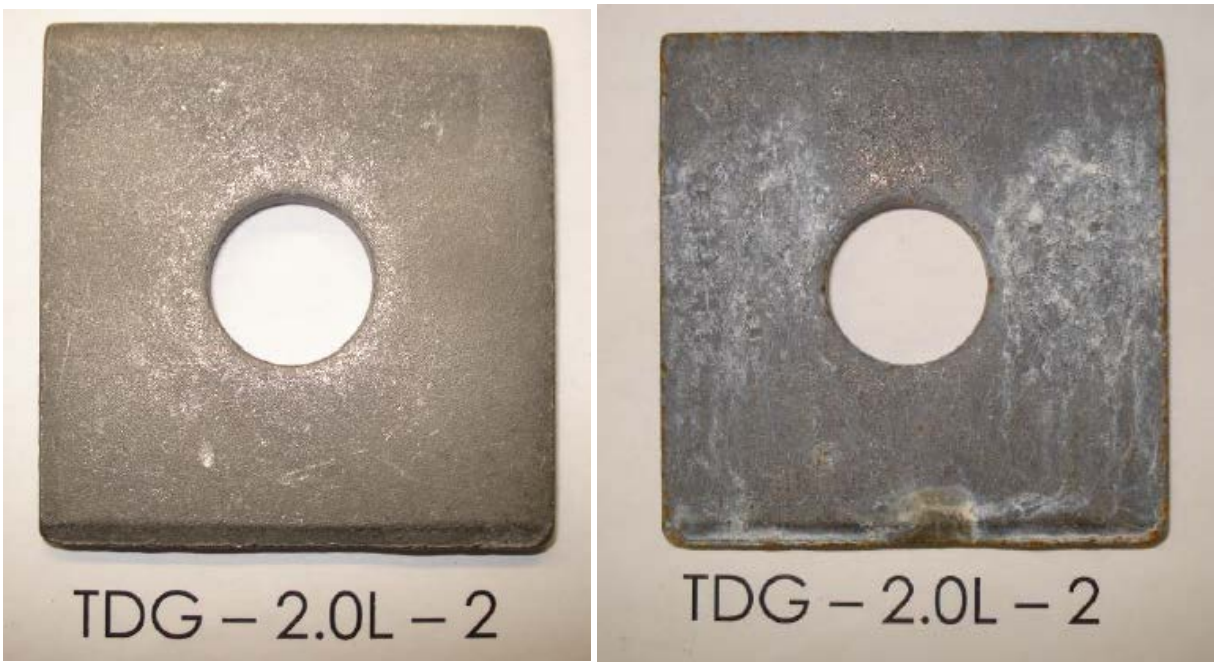


Figure 8: TZD sample 1 after 2.0L sand (left) and 500 hours salt spray (right).

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. Conclusion

MacLean Power thermal zinc diffusion galvanized hardware with a silicate-based top coat exceeds a 3000-hour salt spray test with minimal (less than 5%) red rust exposed. 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

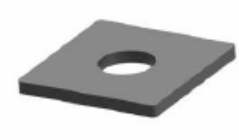
Washers

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

Round Washers

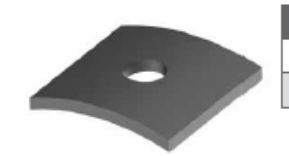
Outside Dia.	Hole Dia.	Bolt Dia.	Catalog #
1-3/4	11/16	5/8	J1088-T
2	13/16	3/4	J1089-T

Square Washers



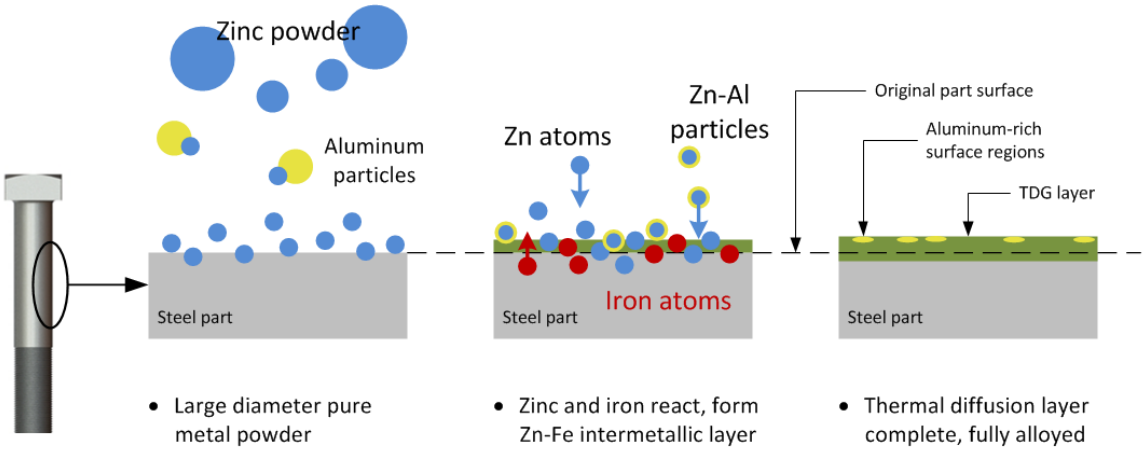
Size	Hole Dia.	Bolt Dia.	Catalog #
2 x 2 x 1/8	11/16	5/8	J1074-T
2-1/4 x 2-1/4 x 3/16	11/16	5/8	J1075-T
2-1/4 x 2-1/4 x 3/16	13/16	3/4	J1076-T

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 TZD coating process.

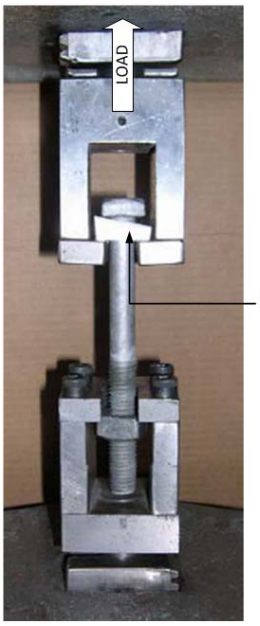


Figure 10: Tensile test set up (apparatus used: Instron #300DX-C3A).

Figure 11: Corrosion results after 1000 hrs with residue wire brushed off.

Figure 12: Corrosion results after 1000 hrs after nut run full on and off threads.

Figure 13: Corrosion results after 1000 hrs after full nut run ten times.

Figure 14: Corrosion results of J9412-T with washer clamped.

End of Report.