Comparison Study: Hot Dipped and Thermal Diffusion Galvanizing

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Note

• Due to time requirements, I will only present a subset of the research conducted.

• If your company is a member of NEETRAC, please see me and I will put you on the list to receive the full report when it comes out. (Anticipated November 2018.)

• This presentation is made available to the IEEE PES with permission from NEETRAC Members.
Galvanizing Process Differences

Hot Dip Galvanizing
- Temperature: 435 – 455 ºC
- Immersion Time: Generally 5 – 7 minutes

Thermal Diffusion Galvanizing
- Temperature: 320 – 480 ºC
- Galvanizing Time: 2 – 4 hours

(Source: precimaxonline.com)

(Source: Youtube Distek process video)
Background

• More utilities and manufacturers look to have their parts coated domestically.

• TDG offers potential benefits over HDG:
  – More environmentally friendly – less process waste
  – No pickling pretreatment – no risk of hydrogen embrittlement (makes steel brittle)
  – No collecting in the treads of threaded fasteners.
Project Purpose / Scope

• Compare the corrosion resistance, mechanical strength, and torque characteristics of thermal diffusion coatings with hot dip galvanized coatings
• Provide information and analysis that will help utilities and manufacturers decide whether to stay with hot dipped galvanizing or change to thermal diffusion galvanizing for fasteners and other hardware
Questions This Project Answers

How does TDG compare to HDG?
- Difference in strength
- Manufacturer has an influence

What else do you need to know about?
- Galvanizing thickness
- PGT
A Word About Samples

- HDG manufacturers galvanized to ASTM A153
  - Tensile and corrosion coupons – 2.2 mil
  - Fasteners – 1.7 mil
- TDG manufacturers were given 3 thickness targets.
  - 1, 1.5, and 2 mil
  - Manufacturers 1 & 2 provided: 1, 1.5, 2 mil samples
  - Manufacturer 3 provided: 1, 2, 3 mil samples – Unable to provide 1.5 mil samples
- Thermal diffusion manufacturers 1 and 2 provided samples with Post-Galvanizing Treatment (PGT) and without. Manufacturer 3 only provided samples with PGT.
Test Procedures
Mechanical Tests

• Pulled galvanized & untreated samples until failure
  – Breaking strength
  – Elongation: how much it stretched
• Compared results to non-galvanized samples
• All samples are 1018 Low-Carbon steel – ¼” x ¾” x 12”
Corrosion Resistance – Corrosion Coupons

Front – Thickness and Scratch

Back – Impact

Thickness Measurement Locations

Scratch

Impact
Corrosion Resistance – Corrosion Coupons

- Samples placed in NEETRAC’s corrosion test chamber and exposed to salt fog for 1000 hours to ASTM B117
## Corrosion Resistance – Corrosion Coupons

<table>
<thead>
<tr>
<th>Green Dot</th>
<th>Orange Dot</th>
<th>Red Dot</th>
</tr>
</thead>
</table>
| • Minor Corrosion  
  • <10% red rust | • Moderate Corrosion  
  • Red rust between 10 - 50% | • Major Corrosion  
  • >50% red rust |

- Visual evaluation
- Only consider red rust – indicates steel corrosion
- White rust ignored – galvanizing corrosion
## Typical Results HDG (2.2 mil) vs TDG (1 mil)

<table>
<thead>
<tr>
<th></th>
<th>HDG 1</th>
<th>HDG 2</th>
<th>HDG 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG. Thickness</td>
<td>5.9 mil</td>
<td>1.5 mil</td>
<td>2.4 mil</td>
</tr>
<tr>
<td></td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TDG 1 - No PGT</th>
<th>TDG 2 - No PGT</th>
<th>TDG 3 - With PGT</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG. Thickness</td>
<td>0.7 mil</td>
<td>0.8 mil</td>
<td>did not provide</td>
</tr>
<tr>
<td></td>
<td><img src="image4" alt="Image" /></td>
<td><img src="image5" alt="Image" /></td>
<td>samples without</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>PGT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TDG 1 - With PGT</th>
<th>TDG 2 - With PGT</th>
<th>TDG 3 - With PGT</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG. Thickness</td>
<td>0.8 mil</td>
<td>1.2 mil</td>
<td>2.0 mil</td>
</tr>
<tr>
<td></td>
<td><img src="image6" alt="Image" /></td>
<td><img src="image7" alt="Image" /></td>
<td><img src="image8" alt="Image" /></td>
</tr>
</tbody>
</table>
## Typical Results HDG (2.2 mil) vs TDG (1.5 mil)

<table>
<thead>
<tr>
<th></th>
<th>HDG 1</th>
<th>HDG 2</th>
<th>HDG 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG. Thickness</td>
<td>5.9 mil</td>
<td>1.5 mil</td>
<td>2.4 mil</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TDG 1 – No PGT</th>
<th>TDG 2 – No PGT</th>
<th>TDG 3 did not provide samples for 1.5 mil nominal thickness.</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG. Thickness</td>
<td>1 mil</td>
<td>1.1 mil</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TDG 1 – With PGT</th>
<th>TDG 2 – With PGT</th>
<th>TDG 3 did not provide samples for 1.5 mil nominal thickness.</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG. Thickness</td>
<td>2.1 mil</td>
<td>1.2 mil</td>
<td></td>
</tr>
</tbody>
</table>
### Typical Results HDG (2.2 mil) vs TDG (2 mil)

<table>
<thead>
<tr>
<th>HDG 1</th>
<th>HDG 2</th>
<th>HDG 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG. Thickness = 5.9 mil</td>
<td>AVG. Thickness = 1.5 mil</td>
<td>AVG. Thickness = 2.4 mil</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TDG 1 – No PGT</th>
<th>TDG 2 – No PGT</th>
<th>TDG 3 did not provide samples without post-galvanizing treatment.</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG. Thickness = 2.0 mil</td>
<td>AVG. Thickness = 2.1 mil</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TDG 1 – With PGT</th>
<th>TDG 2 – With PGT</th>
<th>TDG 3 – With PGT</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG. Thickness = 2.2 mil</td>
<td>AVG. Thickness = 2.1 mil</td>
<td>AVG. Thickness = 2.3 mil</td>
</tr>
</tbody>
</table>
## Typical Results HDG (2.2 mil) vs TDG (3 mil)

<table>
<thead>
<tr>
<th>HDG 1</th>
<th>HDG 2</th>
<th>HDG 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG. Thickness = 5.9 mil</td>
<td>AVG. Thickness = 1.5 mil</td>
<td>AVG. Thickness = 2.4 mil</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TDG 1 did not provide samples for 3 mil nominal thickness.</th>
<th>TDG 2 did not provide samples for 3 mil nominal thickness.</th>
<th>TDG 3 did not provide samples without post-galvanizing treatment.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDG 1 did not provide samples for 3 mil nominal thickness.</td>
<td>TDG 2 did not provide samples for 3 mil nominal thickness.</td>
<td>TDG 3 – With PGT AVG. Thickness = 2.7 mil</td>
</tr>
</tbody>
</table>
Corrosion Resistance – Corrosion Fasteners

- Three connection plate materials
- Used to incorporate galvanic corrosion effects
  - Aluminum (AL)
  - Hot Dipped Galvanized Steel (HS)
  - Stainless Steel (SS)
- All the nuts were HDG regardless of coating type.
- Not all 216 samples fit into NEETRAC’s salt fog chamber. Instead, two sets of 108 samples were corroded consecutively.
### Corrosion Resistance – Corrosion Fasteners

<table>
<thead>
<tr>
<th>Green Dot</th>
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<th>Red Dot</th>
</tr>
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</table>
| • Minor Corrosion  
  • <10% red rust | • Moderate Corrosion  
  • Red rust between 10 - 50% | • Major Corrosion  
  • >50% red rust |

- Only the fastener is evaluated; the plate and nut are ignored.
<table>
<thead>
<tr>
<th></th>
<th>HDG 1</th>
<th>HDG 2</th>
<th>HDG 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AVG. Thickness = 4.25 mil</td>
<td>AVG. Thickness = 2.42 mil</td>
<td>AVG. Thickness = 4.48 mil</td>
</tr>
<tr>
<td>Batch 1</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Batch 2</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TDG 1 – No PGT</th>
<th>TDG 2 – No PGT</th>
<th>TDG 3 did not provide samples without Post-Galvanizing Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AVG. Thickness = 1.62 mil</td>
<td>AVG. Thickness = 1.97 mil</td>
<td>Note: All pictures used in the analysis are post-1000 hours of salt fog.</td>
</tr>
<tr>
<td>Batch 1</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Batch 2</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>TDG 1 – With PGT</th>
<th>TDG 2 – With PGT</th>
<th>TDG 3 – With PGT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AVG. Thickness = 2.23 mil</td>
<td>AVG. Thickness = 2.34 mil</td>
<td>AVG. Thickness = 2.88 mil</td>
</tr>
<tr>
<td>Batch 1</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Batch 2</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
</tbody>
</table>
Torque Test Set-Up (1 of 2)

- The test setup consists of a clamp load cell, two load leveling washers, two 18-8 stainless steel washers, an HDG nut from an independent supplier, and a reaction torque sensor.
Torque Test Set-Up (2 of 2)

- DAQ System
- Socket wrench
- Reaction torque sleeve
- Sample in compression load cell
Torque – Clamp Load Relation

- The K-factor relates clamp load and torque.
- This is used to determine torque requirements.
- Torque tests were run to determine if the K-factor is different between HDG and TDG.

\[ T = KDF \]

- Bolt diameter
- Torque
- Clamp load
- K-factor
Results
Questions This Project Answers

How does TDG compare to HDG?
- Difference in strength
- Manufacturer has an influence

What else do you need to know about?
- Galvanizing thickness
- PGT
Strength Remaining & Elongation (1 of 2)

Note: Strength results are displayed as a percentage of the non-galvanized strength; elongation is the raw percentage.

Test your parts. Ask for strength reports. Do they meet your strength requirement?

Difference in elongation – check your designs with long components.
One supplier was able to do Hot Dipped in a way that didn’t affect strength or elongation.

One TDG manufacturer appears to have two processes.
Corrosion Coupon Rust Evaluation

- HDG
  - 25.0% Minor Corrosion
  - 75.0% Moderate Corrosion
  - Sample Size = 12

- TDG
  - 16.7% Minor Corrosion
  - 33.3% Major Corrosion
  - Sample Size = 24

- TDG - PGT
  - 36.1% Moderate Corrosion
  - 63.9% Minor Corrosion
  - Sample Size = 36
Corrosion Coupon Rust Evaluation by Manufacturer (1 of 3)

Coating = TDG

<table>
<thead>
<tr>
<th>TDG1</th>
<th>TDG2</th>
</tr>
</thead>
<tbody>
<tr>
<td>66.7% Major Corrosion</td>
<td>33.3% Minor Corrosion</td>
</tr>
<tr>
<td>66.7% Moderate Corrosion</td>
<td>66.7% Moderate Corrosion</td>
</tr>
</tbody>
</table>

Sample Size = 12
Corrosion Coupon Rust Evaluation by Manufacturer (2 of 3)

Coating = TDG – PGT
By Manufacturer

TDG1
- 58.3% Moderate Corrosion
- Sample Size = 12

TDG2
- 33.3% Moderate Corrosion
- 66.7% Minor Corrosion
- Sample Size = 12

TDG3
- 16.7% Moderate Corrosion
- Sample Size = 12

83.3% Minor Corrosion

Sample Size = 12
I would leave this for your manuf slide
Hartlein, Richard A, 7/30/2018
Corrosion Coupon Rust Evaluation by Manufacturer (3 of 3)

Coating = HDG By Manufacturer

HDG1
Sample Size= 4
100.0%
Minor Corrosion

HDG2
Sample Size= 4
25.0% Minor Corrosion

HDG3
Sample Size= 4
100.0%
Minor Corrosion

Moderate Corrosion 75.0%

Sample Size= 4
Manufacturer Influence

• TDG’s performance is influenced by the manufacturer more than in HDG.
  – TDG is still developing
  – Less standardized than HDG
  – Manufacturer determines several process components:
    • 2 – 4 hour galvanizing time
    • Proprietary alloying and anti-oxide compounds in zinc powder
    • Drum rotation speed
    • Proprietary PGT treatments
  
• The bottom line is that the manufacturer matters.
Torque Test Results (1 of 3)
Torque Test Results (2 of 3)

Bolt manufacturer specifies 16 ft-lb to achieve 2000 lb clamp load with HDG fastener.

- Median Torque Requirement ~ 16 ft - lb
- Median Torque Requirement ~ 13 ft - lb

- Difference is found between HDG & TDG-PGT.
- No difference is found between HDG & TDG.

- Difference is found between HDG & TDG-PGT.
- No difference is found between HDG & TDG.
# Torque Test Results (3 of 3)

<table>
<thead>
<tr>
<th>Galvanizing</th>
<th>Sample Size</th>
<th>Mean K-factor</th>
<th>Different from HDG?</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDG</td>
<td>57</td>
<td>0.254</td>
<td>-</td>
</tr>
<tr>
<td>TDG no PGT</td>
<td>24</td>
<td>0.237</td>
<td>No</td>
</tr>
<tr>
<td>TDG with PGT</td>
<td>36</td>
<td>0.218</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Torque K-Factor

- The K-factor is different between 2 of the 3 TDG manufacturers (on samples with PGT).
  - Possibly caused by different types of PGT
- The K-factor was different between all 3 HDG manufacturers.
- Do you need to retrieve a K-factor from your specific supplier?
  - No. Published K-factors for HDG were obtained through numerous studies with many manufacturers.
  - Our results suggest a study like this is needed with TDG.

<table>
<thead>
<tr>
<th>Mfg.</th>
<th>K-Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDG 1</td>
<td>0.29</td>
</tr>
<tr>
<td>HDG 2</td>
<td>0.31</td>
</tr>
<tr>
<td>HDG 3</td>
<td>0.24</td>
</tr>
<tr>
<td>TDG 1</td>
<td>0.22</td>
</tr>
<tr>
<td>TDG 2</td>
<td>0.20</td>
</tr>
<tr>
<td>TDG 3</td>
<td>0.24</td>
</tr>
</tbody>
</table>
Questions This Project Answers

How does TDG compare to HDG?
- Difference in strength
- Manufacturer has an influence

What else do you need to know?
- Galvanizing thickness
- PGT
Thickmess Measurements

- Check incoming components
  - Galvanizing thickness

<table>
<thead>
<tr>
<th>Galvanizer</th>
<th>Total (Targets Thicknesses Met)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDG 1</td>
<td>3 of 3</td>
</tr>
<tr>
<td>HDG 2</td>
<td>1 of 3</td>
</tr>
<tr>
<td>HDG 3</td>
<td>2 of 3</td>
</tr>
<tr>
<td>TDG 1</td>
<td>3 of 9</td>
</tr>
<tr>
<td>TDG 2</td>
<td>5 of 9</td>
</tr>
<tr>
<td>TDG 3</td>
<td>6 of 9</td>
</tr>
</tbody>
</table>

Example of magnetic thickness gauge used to check galvanizing thickness
Strength Remaining & Elongation

Note: Strength results are displayed as a percentage of the non-galvanized strength; elongation is the raw percentage.
Post-Galvanizing Treatment (PGT) (1 of 2)

• At the beginning of this project, PGT was optional. At the end of the project, manufacturers said all parts will have PGT.
• As tests have shown, PGT improves the corrosion resistance of TDG parts and affects torque characteristics.
• The project scope was amended to better understand PGT.
Post-Galvanizing Treatment (PGT) (2 of 2)

• The Georgia Tech Materials Analysis Center (GTMAC) performed a series of tests to characterize the PGT layer.
  – Optical microscopy
  – SEM/EDS
  – FTIR
  – XRD
  – Metallographic cross-sectioning

• A set of samples were then conditioned by three (3) mechanisms to test the PGT layer robustness:
  – Abrasion
  – UV exposure
  – Chemical exposure

• GTMAC then characterized the layer post-conditioning.
Baseline Results – TDG 1

- The PGT layer is a thin glassy silica based coating.
- SEM images show cracks in the layer, revealing the galvanizing underneath.
- No polymer, organic, or crystalline components were detected.

• Distribution of silicon (blue line) in the sample cross section helps identify where the PGT treatment is present.
Baseline Results – TDG 2

• The PGT layer is polymer based.
• Metallic flakes are present throughout the layer.
• PGT layer is thick.

• Distribution of silicon (light blue) in the sample cross section helps identify where the PGT treatment is present.
Baseline Results – TDG 3

• No PGT layer was detected.
• PGT elemental compositions are proprietary and the tests performed may not be compatible (i.e., the tests could not detect a layer but the PGT may be there).
• NEETRAC consulted with GTMAC and the manufacturer.
• Determined GTMAC tests are not compatible with TDG 3’s PGT.
Post-Galvanizing Treatment (PGT)

- GTMAC baseline results show there are different “flavors” of PGT.
- Some things to know about PGT...
  - There are two main purposes:
    - Improve corrosion performance in the field and/or
    - Prevent wet storage stains and rust staining
- Know what you are buying. Work with the manufacturer to understand what it should do.
Conditioning Test – Abrasion

- Samples were placed in a box with 6/9 quartz abrasive medium.
- Samples were vibrated at 55 Hz (highway frequency) for 1 hour.

Samples were placed in a box and attached.
Abrasion Results – TDG 1

- PGT layer is thinned.
- Galvanizing layer is visible in some areas.

SEM image of PGT layer surface -1000x
Unconditioned sample

SEM image of PGT layer surface -500x
Conditioned sample
Abrasion Results – TDG 2

- PGT layer is thinned.
- Baseline results indicated metallic flakes present in PGT.
  - Metallic flakes are no longer present post-conditioning.
Abrasion Results – TDG 3

- Surface is smoothed.
- Appears less affected than TDG 1 or 2’s PGT
Abrasion Results – Conclusions

• Abrasion can compromise PGT layer integrity.
  – TDG 3 is affected less than TDG 1 or 2.
• Minimize time components spent on crew trucks before installation.
Conditioning Test – Chemical (1 of 2)

- Sought a chemical that affected the most Members
- Settled on corn fertilizer

Acreage of corn planted in 2015 (Dark green = 150,000+ acres)
Conditioning Test – Chemical (2 of 2)

• Samples were placed in a jar with CoRon Nitrogen based fertilizer.
• It was left for 1 week using ASTM D6943 as a guide.
Chemical Results – TDG 1

• PGT layer intact was not affected by the chosen chemical.
  – Other chemicals may have different effects.
• Diamond shaped crystals are from the fertilizer.
Chemical Results – TDG 2

• Similar to abrasion, PGT layer was severely affected.
• Baseline results indicated metallic flakes present in PGT.
  – Metallic flakes are no longer present post-conditioning.
Chemical Results – TDG 3

- Surface appears similar to baseline.
  - Chemical affected sample less than TDG 2.
- Oxide formations present
Chemical Results – Conclusions

• TDG 1 and 3 were not severely affected by the fertilizer.
  – Results may vary by chemical

• Look for areas in your system with high chemical concentrations.
  – Run offs from farm land
  – Down stream from factory / manufacturing plants

• Monitor components installed in these locations more closely for excessive degradation.
Conditioning Test – UV

• Samples were placed in NEETRAC’s QUV chamber for 1000 hours and exposed to UVA radiation per ASTM G154.
UV Results – TDG 1

• Some regions of PGT compromised
  – Galvanizing revealed
UV Results – TDG 2

• Metallic flake concentration was reduced compared to baseline.
• PGT layer was affected by UV.
UV Results – TDG 3

- Samples affected by UV
- Surface oxides present
UV Results – Conclusions

• All three manufacturer PGTs were affected by UV.
• Keep components out of direct sunlight while in storage.
The Bottom Line

• The bottom line is that TDG manufacturers’ processes are different and not standardized like HDG.
• These differences can have considerable influence over the part performance.
• NEETRAC recommends that anyone purchasing TDG hardware carefully review and compare test results to assess performance.
• This project has helped clarify the test methods needed to evaluate TDG performance.
Conclusions

• For the TDG and HDG components tested in this project:
  – TDG has reduced strength.
    • Ask for test reports; check component strength
  – Manufacturer has significant impact on corrosion resistance.
    • TDG is a developing technology.
    • It is less standardized than HDG and has more proprietary parts to the process.
    • Evaluate your specific supplier
  – Bolt torque requirements might change when using TDG with PGT parts.
  – PGTs vary by manufacturer.
Questions?