

Draft Final Report for Project Entitled:

Corrosion of Roofing Fasteners

Performance Period: 9/8/2015 – 6/30/2016

Submitted on

June 1, 2016

Presented to the

Florida Building Commission
State of Florida Department of Business and Professional Regulation

by

Kurtis R. Gurley, Ph.D., kgurl@ce.ufl.edu, (352) 392-9537 x 1508
Forrest J. Masters, Ph.D., P.E., masters@ce.ufl.edu, (352) 392-9537 x 1505

Designated Project Leader: Kurtis R. Gurley

Engineering School for Sustainable Infrastructure & Environment



Table of Contents

1. Disclaimer	1
2. Applicable Sections of the Code and related documents.....	1
3. Review of phase 1 and phase 2 and Executive Summary of phase 3	1
4. Project Description	2
4.1. Test protocol (TAS 114 Appendix E)	2
4.2. Description of specimens tested	2
4.2.1. Test-1 (160 samples).....	2
4.2.2. Test-2 (60 samples).....	3
4.2.3. Test-3 (110 samples).....	3
4.3. Corrosion scale – performance metric.....	4
5. Results of corrosion scoring	5
5.1. Test-1 Results (completed)	5
5.1.1. Test-1 Discussion	7
5.2. Test-2 Results (completed)	8
5.2.1. Test-2 Discussion	9
5.3. Test-3 Status (testing not yet completed).....	9
6. Conclusions to date.....	10
7. Appendix A: Test-1 Corrosion results (photos and scores for samples of each specimen type)	11
8. Appendix B: Test-2 Corrosion results (photos and scores for samples of each specimen type)	24
9. Appendix C: Test-3 mid-test Corrosion results (765 of 1000 hours)	30

1. Disclaimer

This report presents the findings of research performed by the University of Florida. Any opinions, findings, and conclusions or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the sponsors, partners and contributors. The Roofing Technical Advisory Committee of the Florida Building Commission will provide a final disposition on the implications for the Florida Building Code.

2. Applicable Sections of the Code and related documents

- 1622.1.2, Florida Building Code—Building
- 1506.4 – 1506.7, Florida Building Code—Building
- 1517.5.1 – 1517.5.2, Florida Building Code—Building
- TAS 114 Appendix E
- ASTM A 90
- ASTM A 641
- ASTM B117-11
- ASTM G85-11

3. Review of phase 1 and phase 2 and Executive Summary of phase 3

The project goal is to experimentally evaluate the corrosion resistance of metal fasteners for roof systems and screen enclosures. The 2013 - 2014 survey study (phase 1) found that corrosion is commonly observed. Electrogalvanized fasteners were most likely to exhibit corrosion among the common corrosion resistant applications, and thus the focus of the 2014 – 2015 experimental study of corrosion (phase 2 study). The roofing fastener test sequence consisted of electrogalvanized 1¼ inch roofing coil nails. Three manufacturers were tested. Configurations included a) out of the box (control), b) installed into substrate and tested (in-situ case), and c) installed into substrate, removed and tested (extreme case). Testing was conducted in accordance with TAS 114 Appendix E. An integer 1 - 8 corrosion scale was created to score the degree of corrosion on the head and shaft of the fasteners. It was found that one manufacturer clearly outperformed the other two with regard to corrosion resistance of out of the box fasteners. The specimens tested in phase 2 (2014 -2015) were electrogalvanized, but no standard compliance was noted (e.g. ASTM A641, Miami-Dade approved, TAS 114 App-E, etc.). Thus the phase 2 study results represent a baseline of the scattered performance of fasteners classified only as electrogalvanized.

The current 2015 – 2016 experimental study (phase 3) continues the testing roof system fasteners in a corrosion chamber, applying the TAS 114 Appendix E protocol and applying the customized corrosion scoring scale created for phase 2. In phase 3, the emphasis is on testing fasteners that are ASTM A641 compliant (prescriptive) or Miami Dade County approved (performance based TAS 114 Appendix E). Electrogalvanized, electroplated, mechanically galvanized, hot dipped, and stainless steel fasteners are included in the test matrix. Roofing, deck/patio, screen enclosure, and tile screw fasteners are included.

This report presents the results of testing completed on 220 specimens to date, as well as the status of an additional 110 specimens currently undergoing testing. Among the 220 tested specimens, 160 were tested simultaneously in test-1, and the remaining 60 were tested simultaneously in test-2. The results and analysis of test-1 were documented in the interim

report issued on February 15, 2016, and will be repeated herein as well for completeness of this document. The results and analysis of test-2 will be documented herein for the first time.

Test-3 consists of the 110 specimens currently undergoing testing. These specimens are sheet metal and concrete screws commonly used for screen enclosures. Test-3 consists of 500 cycles of testing, where one cycle is one hour of testing and one hour of drying (1000 hours total). To date test-3 has been run for 382 of 500 cycles (765 of 1000 hours). A status report will be provided on the corrosion performance to date. This status report will be updated in an amended report when testing is completed for the full 1000 hours.

4. Project Description

4.1. Test protocol (TAS 114 Appendix E)

The test protocol followed TAS 114 Appendix E, which calls for compliance with ASTM G85 Annex A5. The corrosion testing apparatus was factory programmed to follow the ASTM G85 Annex A5 protocol. The acetic acid-salt spray (fog) test was conducted for 140 cycles (test-1 and test-2) or 500 cycles (test-3), where one cycle consists of one hour of fog exposure and one hour of dry-off. The sequences were run without interruption. The salt solution composition, chamber temperature, and water purity were monitored to conform to requirements.

4.2. Description of specimens tested

All test samples were procured off the shelf from Florida suppliers.

4.2.1. Test-1 (160 samples)

Test-1 includes electrogalvanized (EG), mechanically galvanized (MG), electroplated (EP), hot dipped (HD) and stainless steel (SS) fasteners. 10 samples of each of 16 different specimen types were tested, for a total of 160 samples. All samples were tested out-of-the-box. Table 1 describes these specimen types. Test-1 was run for 280 hours (140 cycles).

Group number	Product type	Coating type	Certification	Supplier location
1	1 ¼ nail	EG	ASTM F1667	Orlando
2	1 ¼ nail	EG	Not marked	Orlando
3	1 ¼ coil nail	EG	Not marked	Orlando
4	1 ¼ coil nail	EG	ASTM F1667	Gainesville
5	1 ¼ coil nail	EG	ASTM A153 Class D	Orlando
6	#8 2 ½ tile screw	MG	ASTM B695 Class 55 2006 IRC Compliant	Orlando
7	#8 2 ½ tile screw	EP	Not marked	Bradenton
8	1 ¼ coil nail	EG	ASTM F1667	Bradenton
9	1 ¼ coil nail	HD	Not marked	Sarasota
10	1 ½ screws	HD	Not marked	No info
11	10d 3" RS	SS	MDC Approved	Miami
12	1 ¼ RS nail	HD	ASTM F1667	Miami
13	1 ¼ nail	EG	MDC Approved ASTM F1667	Miami
14	1 ¼ coil RS nail	EG	MDC Approved ASTM A641	Miami
15	1 ¼ coil RS nail	EG	MDC approved, ASTM A641	West Palm

16	#8 2 ½ tile screw	MG	ASTM B695 Class 55 2006 IRC Compliant	West Palm
Notes: ASTM F1667 → ASTM A641 compliant ASTM A153 Class D thicker zinc coating than ASTM A641 ASTM B695 → mechanical galvanizing standard, Class 55 → 0.0022" zinc thickness EG → electrogalvanized, EP → electroplated, MG → mechanically galvanized, HD → hot dipped, SS → stainless steel				

4.2.2. Test-2 (60 samples)

The results of test-1 (to be described in Section 5) indicated that hot dipped fasteners performed very well. Feedback from FRSA members (January 22, 2016) included the suggestion that the hot dipped coating application may produce a zinc layer that is brittle, and therefore more susceptible to damage from the field installation process. Test-2 was designed to determine whether the process of fastener installation damages the corrosion resistant coating of hot dipped nails. Test-2 includes one electrogalvanized (EG) specimen type as a control, and two hot dipped (HD) specimen types. For each of the three specimen types, 10 were tested out-of-the-box, and 10 were installed into a wood block and removed prior to testing. The removal process was to cut away the wood substrate rather than pull the nail, in order to avoid causing additional surface damage to the sample.

Table 2 describes the specimen types for test-2. Test-2 was run for 280 hours (140 cycles). As noted at the bottom of the table, the hot dipped specimens were the same types as those in test-1.

Table 2: test-2: 3 specimen types, 10 samples of each out-of-the-box, 10 samples of each installed and removed prior to testing Status: completed 280 hours (140 cycles)				
Group number	Product type	Coating type	Certification	Testing Configuration
1	1 ¼ coil nail	EG	Not marked	Out of box
2	1 ¼ coil nail	EG	Not marked	Installed and removed
3*	1 ¼ coil nail	HD	Not marked	Out of box
4*	1 ¼ coil nail	HD	Not marked	Installed and removed
5**	1 ¼ RS nail	HD	ASTM F1667	Out of box
6**	1 ¼ RS nail	HD	ASTM F1667	Installed and removed
Notes: ASTM F1667 → ASTM A641 compliant * same specimen type as Group 9 in test-1 ** same specimen type as Group 12 in test-1				



4.2.3. Test-3 (110 samples)

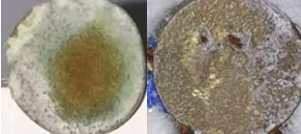

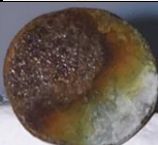
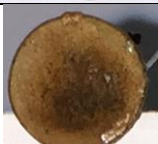


Test-3 focusses on sheet metal and concrete screws commonly used for screen enclosures. 10 samples of each of 11 different stainless steel ceramic coated specimen types were tested, for a total of 110 samples. All samples are being tested out-of-the-box for 1000 hours (500 cycles). At this time 765 hours (382 cycles) have been completed. Table 3 describes these specimen types.

Table 3: test-3: 11 specimen types, 10 samples of each, and 5 specimen types, 8 samples of each Status: 765 hours of 1000 hours completed (382 out of 500 cycles completed)				
Group number	Product type	Use	Certification	Coating
1	Hex 3/8 x 5 304 Stainless white	Masonry	MDC Approved	Ceramic
2	Hex 3/8 x 7 304 Stainless white	Masonry	MDC Approved	Ceramic
3	Hex 1/4 x 3 ¼ 304 Stainless silver	Masonry	MDC Approved	Ceramic
4	Hex 1/4 x 2 ¼ 304 Stainless silver	Masonry	MDC Approved	Ceramic
5	Hex 1/4 10 x 2 SMS 316 Stainless bronze	Screen enclosure	TBD	TBD
6	Hex 1/4 12 x ¾ SDS 316 Stainless bronze	Screen enclosure	TBD	TBD
7	Hex 5/16 14 x 1 SDS 316 Stainless bronze	Screen enclosure	TBD	TBD
8	Hex 3/8 14 x 1 SDS 316 Stainless bronze	Screen enclosure	TBD	TBD
9	Hex 5/16 12 x 2 SDS 316 Stainless bronze	Screen enclosure	TBD	TBD
10	Hex 1/4 12 x 3/4 SDS Stainless white	Screen enclosure	TBD	TBD
11	Hex 1/4 10 x 2 SMS Stainless white	Screen enclosure	TBD	TBD

4.3. Corrosion scale – performance metric

The TAS 114 Appendix E pass/fail criterion is greater than 5% surface corrosion indicates failure. However, the purpose of this study is to investigate the relative performance of fasteners. This requires a finer gradation of performance than pass/fail can provide. An integer scale of 1 – 8 was created to classify the degree of corrosion observed on the fasteners, where 1 indicates no corrosion and 8 indicates heavy corrosion with scaling. Table 4 provides a description of these classifications as well as a visual sample of each. The assignment of a corrosion score for each fastener is subjective to some degree, but the scale is designed such that this subjectivity does not span more than two adjacent scores. For example, 7 vs. 8 may be subjective, but 6 vs 8 provides a clear distinction. In this manner, the subjectivity does not dilute the significance of results when viewed on an eight-point scale.

Table 4: Corrosion scale description and sample images	
1: No corrosion observed	
2: Edge corrosion only	

3: Light partial surface corrosion	
4: Light full surface corrosion	
5: Partial heavy surface corrosion	
6: Partial heavy and partial light full surface corrosion	
7: Heavy full surface corrosion without scaling	
8: Heavy full surface corrosion with scaling	

5. Results of corrosion scoring

The 1-8 corrosion score was assigned to each tested specimen separately for the head and shaft of the fastener. The scores were assigned based on visual inspection of the specimens as well as inspection of post-test photos taken of each specimen. Photos and scores for one or two samples of each specimen type are provided in Appendices A, B and C. Photos of one sample are provided for groups whose results were very consistent among its ten samples. Photos of two samples are provided groups whose results are variable among its ten samples.

5.1. Test-1 Results (completed)

Test-1 results were previously presented in the February 15, 2016 interim report, and repeated here. The full scoring results (ten samples from each of the 16 groups) are provided in Figures 1 through 4. In each of these figures, the commonly colored bars correspond to the 10 individual samples of that specimen type. The bottom of the graph identifies the specimen type by group number as defined in Table 1 and referenced in Appendix A. The vertical axis presents the 1-8 corrosion scale score. The light blue bar spanning each commonly colored bar group is the mean value of the 10 samples in that group. The results are separated into figures 1 through 4 as follows:

- Figure 1: All 1 ¼" electrogalvanized (EG) nails compliant with ASTM A641, but not approved for Miami-Dade. Nail head results (left) and nail shaft results (right).
- Figure 2: All 1 ¼" EG nails compliant with ASTM A641, and approved for Miami-Dade (HVHZ). Nail head results (left) and nail shaft results (right).
- Figure 3: #8 2 ½" roof tile screws, two mechanically galvanized specimen types and one electroplated specimen type. Head and shaft results were identical.
- Figure 4: Two hot dipped 1 ¼" nail specimen types, one hot dipped 1 ½" screw fastener specimen type, and one 10d 3" stainless steel patio/deck nail specimen type. Head results shown. Shaft results almost identical, not shown.

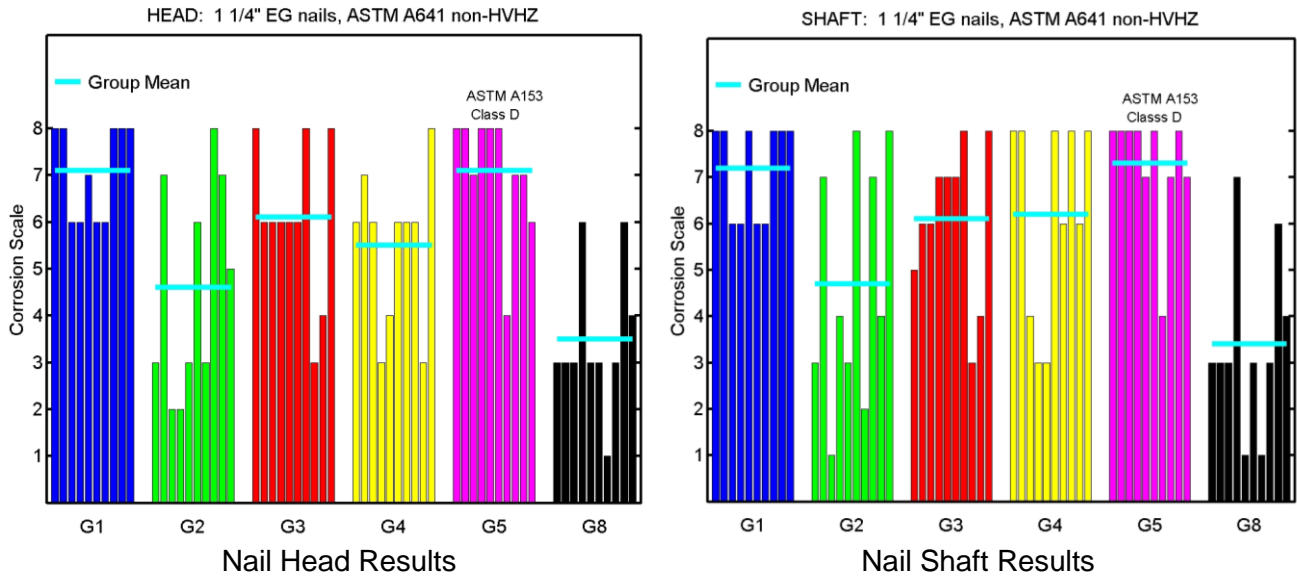


Figure 1: Test-1 Corrosion scale results for 1 ¼" EG nails, not HVHZ compliant.

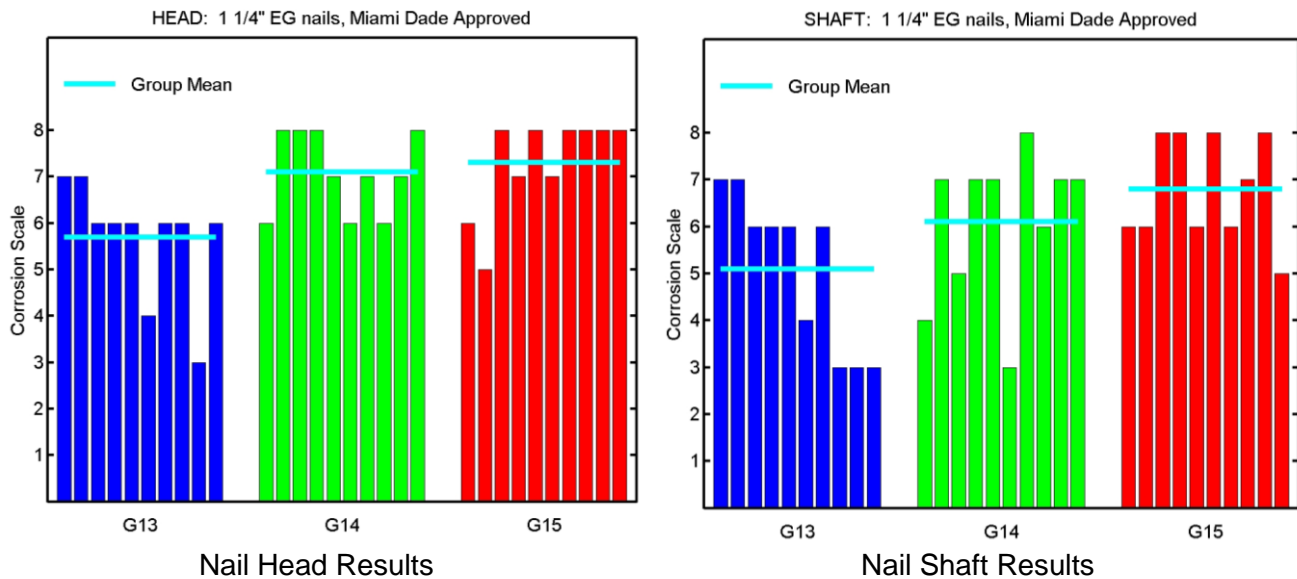


Figure 2: Test-1 Corrosion scale results for 1 ¼" EG nails, HVHZ compliant.

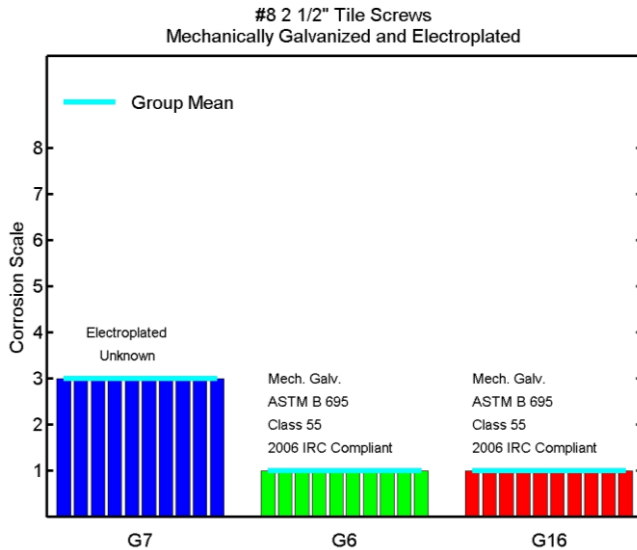


Figure 3: Test-1 Tile screws (head and shaft results identical)

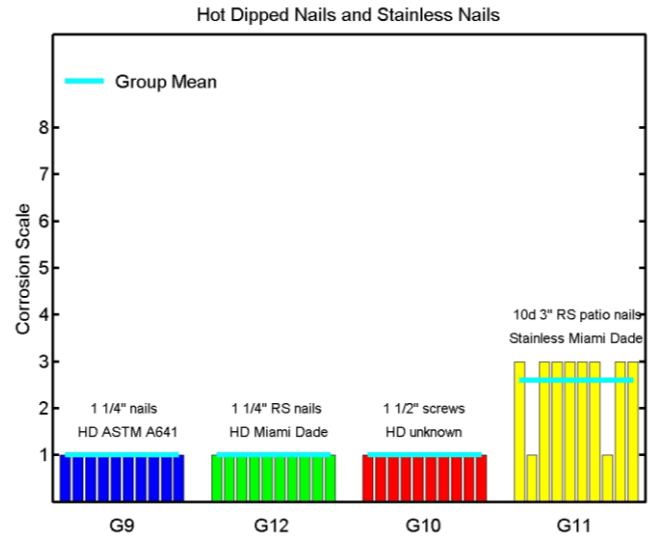


Figure 4: Test-1 Hot dipped and stainless steel (head shown, shaft results almost identical)

5.1.1. Test-1 Discussion

Findings are summarized as follows. Refer to Appendix A for sample photos of the specimen types being discussed (G1 – G16).

- Figure 1: Electrogalvanized fasteners that are marked as ASTM A641 compliant did not generally perform any better than those in the phase 2 2014-2015 study. Only the G8 specimen type (page 17) demonstrated a consistent resistance to corrosion, where the predominant result was partial light surface corrosion. The other specimen types (G1 through G5, pages 11-15) resulted in at least half, more typically all, samples with heavy corrosion.
- Figure 1: The electrogalvanized fastener marked as ASTM A153 Class D compliant should have a thicker zinc coating than ASTM A641 compliant fasteners. However, specimen type G5 (page 15) was among the worst performers.
- Figure 2: Electrogalvanized fasteners that are marked as Miami-Dade compliant show no better performance than the ASTM A641 fasteners in Figure 1. Specimen types G13 through G15 (pages 20-22) had heavy corrosion in at least half of all samples.
- Figure 3: The mechanically galvanized roof tile fasteners (G6 and G16, pages 16 & 23) showed no sign of corrosion. The test was not run for the required 500 cycles.
- Figure 3: The electroplated roof tile fasteners (G7, page 16) showed only partial light corrosion in all samples tested. The test was not run for the required 500 cycles.
- Figure 4: The two hot dipped nail specimen types (G9 and G12, pages 18 & 19), and the one hot dipped screw specimen type (G10, page 18) showed no corrosion.
- Figure 4: The stainless steel ring shank patio/deck nail specimen type (G11, page 19) showed partial light corrosion on the shaft, and very light to no corrosion on the head.

5.2. Test-2 Results (completed)

Test-2 was conducted after the submission of the February 15, 2016 interim report. The full scoring results (ten samples from each of the 6 groups) are provided in Figures 5 and 6. In both of these figures, the commonly colored bars correspond to the 10 individual samples of that specimen type. The bottom of the graph identifies the specimen type by group number as defined in Table 2 and referenced in Appendix B. The vertical axis presents the 1-8 corrosion scale score. The light blue bar spanning each commonly colored bar group is the mean value of the 10 samples in that group.

- Figure 5: 1 ¼" electrogalvanized (EG) nails, no code compliance marked on box. Nail head results (left) and nail shaft results (right). Tested out-of-the-box and installed-removed as marked in the figure.
- Figure 6: 1 ¼" hot dipped smooth shank coil nail specimen (no code compliance marked), 1 ¼" hot dipped rink shank nail specimen (ASTM F1667). Tested out-of-the-box and installed-removed as marked in the figure.

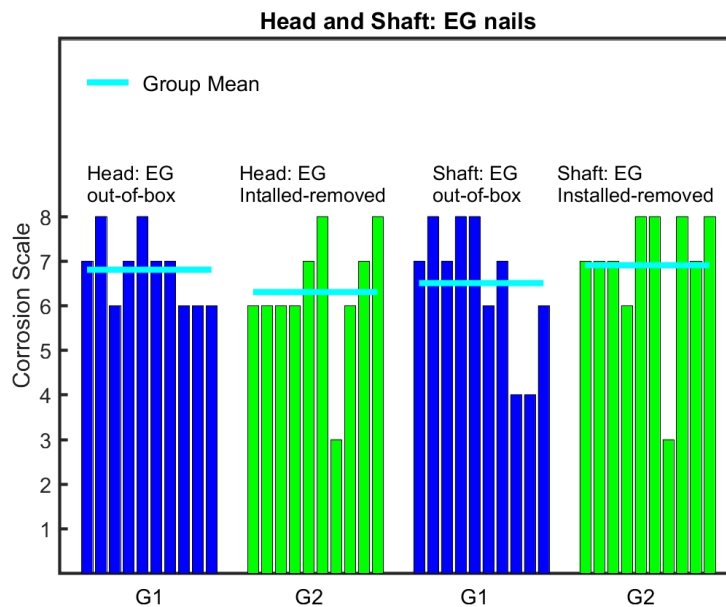


Figure 5: Test-2 Corrosion scale results for 1 ¼" EG nails, no certification marking. Blue: tested out-of-the-box. Green: installed-removed prior to testing

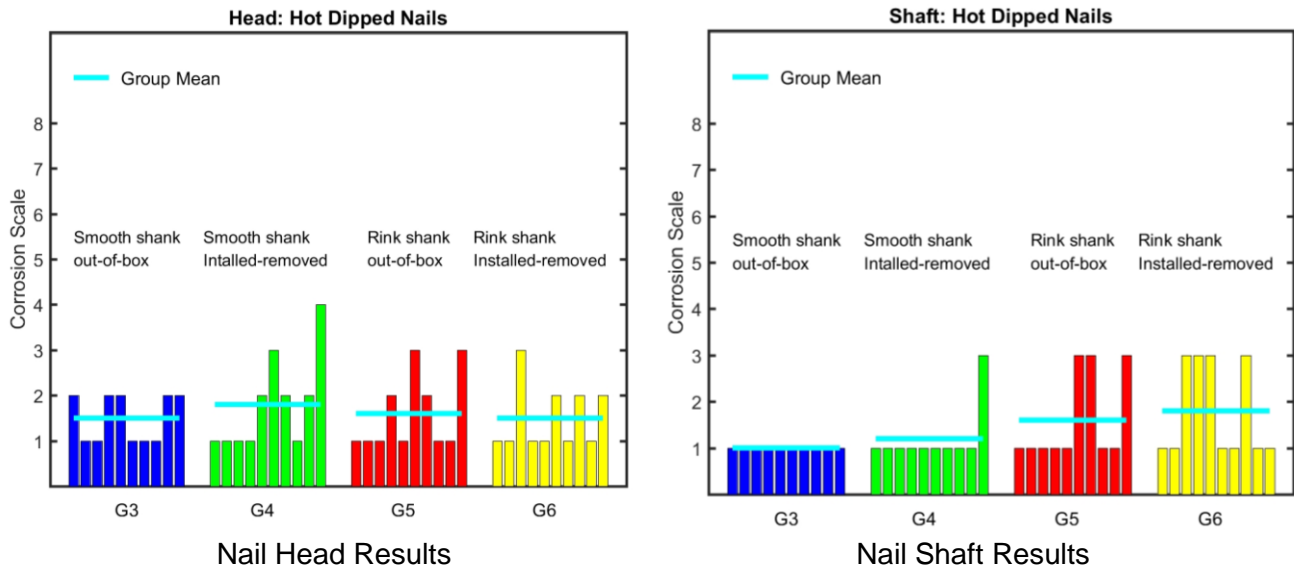


Figure 6: Test-2 Corrosion scale results for 1 1/4" Hot dipped nails, tested out-of-the-box and installed-removed as noted

5.2.1. Test-2 Discussion

Findings are summarized as follows. Refer to Appendix B for sample photos of the specimen types being discussed (G1 – G6).

- Figure 5: Results are consistent with those of test-1 EG nails, demonstrating a high level of head and shaft corrosion. The process of installing and removing the fasteners did not improve or worsen the corrosion performance.
- Figure 6: The two hot dipped nail specimen types tested out-of-the-box (G3 and G5) performed well, with a few samples showing very minor spots of corrosion on the head and shaft. Those two same specimen types tested after installation and removal (G4 and G6) also demonstrated good corrosion resistance. Those samples with a score of 2 had very minor corrosion on the edge of the head. Those samples with a score of 3 had only minor corrosion on a very small portion of the surface area. Note that a score of 2 does not apply to shaft results, as is specifically applies to the edge of the nail head. No significant difference between the corrosion resistance of installed-removed vs out-of-the-box tested nails was observed.

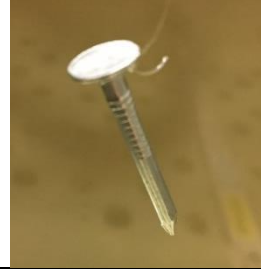





5.3. Test-3 Status (testing not yet completed)



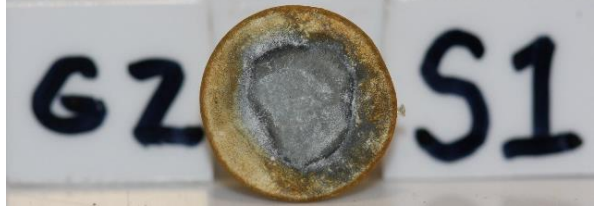



Test-3 has not yet been completed. Therefore no scoring was conducted, as that process requires the removal of the specimens from the test chamber. Appendix C provides photographs of the specimens both prior to testing and after the completion of 765 out of 1000 hours. It can be observed that corrosion does not appear to be present on any specimens to date.







6. Conclusions to date







- It is assumed that Miami-Dade approved EG fasteners have been certified as TAS 114 Appendix E compliant. However, the results thus far did not reveal a single EG sample that passed that standard's criterion of < 5% surface corrosion. Each of the 30 such fastener samples tested had a score of at least 3 (partial light surface corrosion) on both the head and shaft, and most samples displayed significant heavy corrosion. Each of the three EG specimen types marked as Miami-Dade approved (test-1 G13 through G15) only referenced ASTM A641, not TAS 114 Appendix E.
- To date only the hot dipped and mechanically galvanized specimens demonstrated little or no corrosion among test-1 and test-2.
- The corrosion resistance of hot dipped specimens does not appear to be influenced (damaged) by installation. However, due to a relatively small sample size and the inclusion of only two specimen types, this conclusion is indicative rather than definitive.







7. Appendix A: Test-1 Corrosion results (photos and scores for samples of each specimen type)





Test-1 Group 1: Set up and two of ten samples 1 ¼" EG, ASTM A641, non-HVHZ	
Sample pre-testing	Group pre-testing
	
Sample 3 Head classification: 6	Sample 3 Shaft classification: 6
	
Sample 10 Head classification: 8	Sample 10 Shaft classification: 8
	

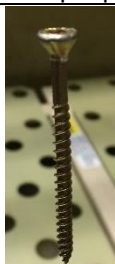



<p style="text-align: center;">Test-1 Group 2: Set up and two of ten samples 1 ¼" EG, ASTM A641, non-HVHZ</p>	
Sample pre-testing	Group pre-testing
	
<p>Sample 1 Head classification: 3</p>	<p>Sample 1 Shaft classification: 3</p>
	
<p>Sample 6 Head classification: 6</p>	<p>Sample 6 Shaft classification: 8</p>
	







Test-1 Group 3: Set up and two of ten samples 1 ¼" EG coil, ASTM A641, non-HVHZ	
Sample pre-testing	Group pre-testing
	
Sample 9 Head classification: 4	Sample 9 Shaft classification: 4
	
Sample 10 Head classification: 8	Sample 10 Shaft classification: 8
	





Test-1 Group 4: Set up and two of ten samples 1 1/4" EG coil, ASTM A641, non-HVHZ	
Sample pre-testing	Group pre-testing
	
Sample 4 Head classification: 3	Sample 4 Shaft classification: 3
	
Sample 7 Head classification: 6	Sample 7 Shaft classification: 6
	





Test-1 Group 5: Set up and two of ten samples 1 1/4" EG coil, ASTM A153 Class D, non-HVHZ	
Sample pre-testing	Group pre-testing
	
Sample 7 Head classification: 4	Sample 7 Shaft classification: 4
	
Sample 10 Head classification: 6	Sample 10 Shaft classification: 7
	

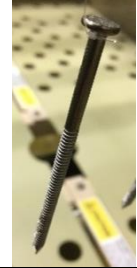



Test-1 Group 6: Set up and one of ten samples #8 2 1/2" mechanically galvanized tile screw, ASTM B 695 Class 55 2006 IRC Compliant	
Sample pre-testing	Group pre-testing
	
Sample 1 Head classification: 1	Sample 1 Shaft classification: 1
	

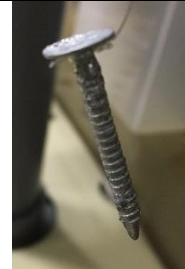



Test-1 Group 7: Set up and one of ten samples #8 2 1/2" electroplated tile screw, Compliance unknown	
Sample pre-testing	Group pre-testing
	
Sample 1 Head classification: 3	Sample 1 Shaft classification: 3
	







Test-1 Group 8: Set up and two of ten samples 1 ¼" EG coil, ASTM A641, non-HVHZ	
Sample pre-testing 	Group pre-testing 
Sample 4 Head classification: 6	Sample 4 Shaft classification: 7
	
Sample 7 Head classification: 1	Sample 7 Shaft classification: 1
	

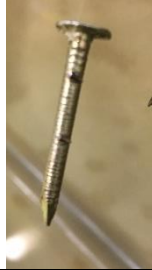





<p style="text-align: center;">Test-1</p> <p style="text-align: center;">Group 9: Set up and one of ten samples</p> <p style="text-align: center;">1 ¼" Hot Dipped coil, Compliance unknown, non-HVHZ</p>	
Sample pre-testing	Group pre-testing
	
Sample 7 Head classification: 1	Sample 7 Shaft classification: 1
	







<p style="text-align: center;">Test-1</p> <p style="text-align: center;">Group 10: Set up and one of ten samples</p> <p style="text-align: center;">1 ½" Hot Dipped screws, compliance unknown</p>	
Sample pre-testing	Group pre-testing
	
Sample 3 Head classification: 1	Sample 3 Shaft classification: 1
	





<p>Test-1 Group 11: Set up and one of ten samples 10d 3" ring shank Stainless Steel, patio/deck nails, HVHZ</p>	
Sample pre-testing	Group pre-testing
	
Sample 8 Head classification: 1	Sample 8 Shaft classification: 3
	

<p>Test-1 Group 12: Set up and one of ten samples 1 1/4" Hot Dipped ring shank coil, ASTM A641, HVHZ</p>	
Sample pre-testing	Group pre-testing
	
Sample 7 Head classification: 1	Sample 7 Shaft classification: 1
	







<p style="text-align: center;">Test-1 Group 13: Set up and two of ten samples 1 ¼" EG, ASTM A641, HVHZ (?)</p>	
<p>Sample pre-testing</p> 	<p>Group pre-testing</p> 
<p>Sample 4 Head classification: 6</p> 	<p>Sample 4 Shaft classification: 6</p> 
<p>Sample 9 Head classification: 3</p> 	<p>Sample 9 Shaft classification: 3</p> 







<p style="text-align: center;">Test-1 Group 14: Set up and two of ten samples 1 1/4" EG ring shank coil, ASTM A641, HVHZ</p>	
Sample pre-testing	Group pre-testing
	
<p>Sample 3 Head classification: 8</p>	<p>Sample 3 Shaft classification: 5</p>
	
<p>Sample 6 Head classification: 6</p>	<p>Sample 6 Shaft classification: 3</p>
	







<p style="text-align: center;">Test-1 Group 15: Set up and two of ten samples 1 1/4" EG ring shank coil, ASTM A641, non-HVHZ (?)</p>	
<p>Sample pre-testing</p> 	<p>Group pre-testing</p> 
<p>Sample 7 Head classification: 8</p> 	<p>Sample 7 Shaft classification: 6</p> 
<p>Sample 9 Head classification: 8</p> 	<p>Sample 9 Shaft classification: 8</p> 







Test-1 Group 16: Set up and one of ten samples #8 2 ½" mechanically galvanized tile screw, ASTM B 695 Class 55 2006 IRC Compliant	
Sample pre-testing	Group pre-testing
	
Sample 3 Head classification: 1	Sample 3 Shaft classification: 1
	







8. Appendix B: Test-2 Corrosion results (photos and scores for samples of each specimen type)







Test-2 Group 1: Pre-test and two of ten samples 1 ¼" EG unrated: out-of-the-box	
Sample pre-testing	Group pre-testing
	
Sample 3 Head classification: 6	Sample 3 Shaft classification: 7
	
Sample 8 Head classification: 6	Sample 8 Shaft classification: 4
	

<p style="text-align: center;">Test-2 Group 2: Pre-test and two of ten samples 1 ¼" EG unrated: installed and removed</p>	
<p>Sample 2 pre-testing</p> 	<p>Sample 4 pre-testing</p> 
<p>Sample 2 Head classification: 6</p> 	<p>Sample 2 Shaft classification: 7</p> 
<p>Sample 4 Head classification: 6</p> 	<p>Sample 4 Shaft classification: 6</p> 

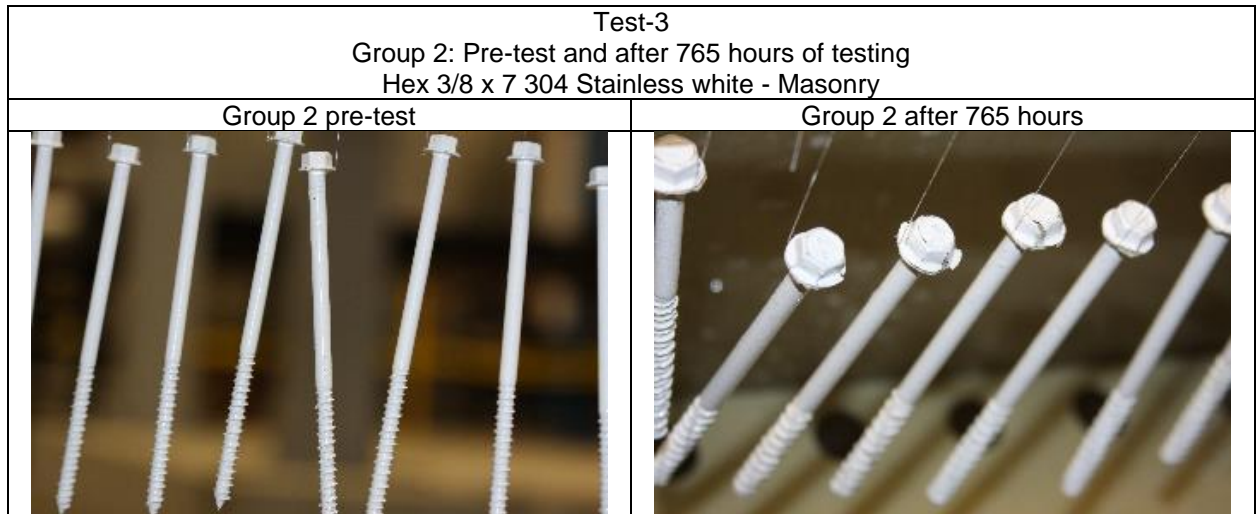
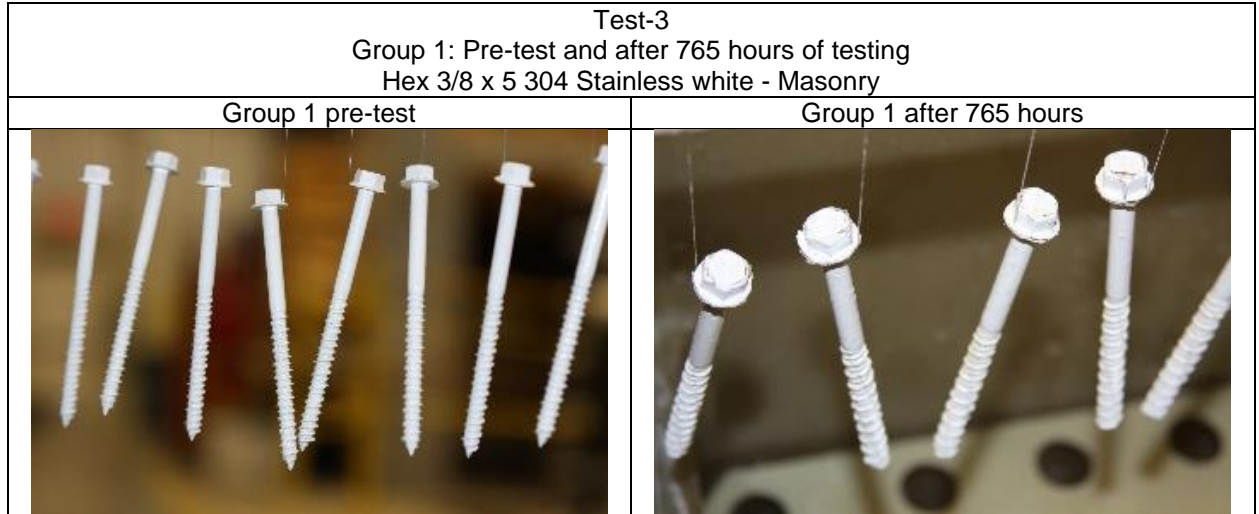
Test-2 Group 3: Pre-test and two of ten samples 1 1/4" Hot Dipped smooth shank: out-of-the-box	
Sample pre-testing	Group pre-testing
	
Sample 3 Head classification: 1	Sample 3 Shaft classification: 1
	
Sample 4 Head classification: 2	Sample 4 Shaft classification: 1
	

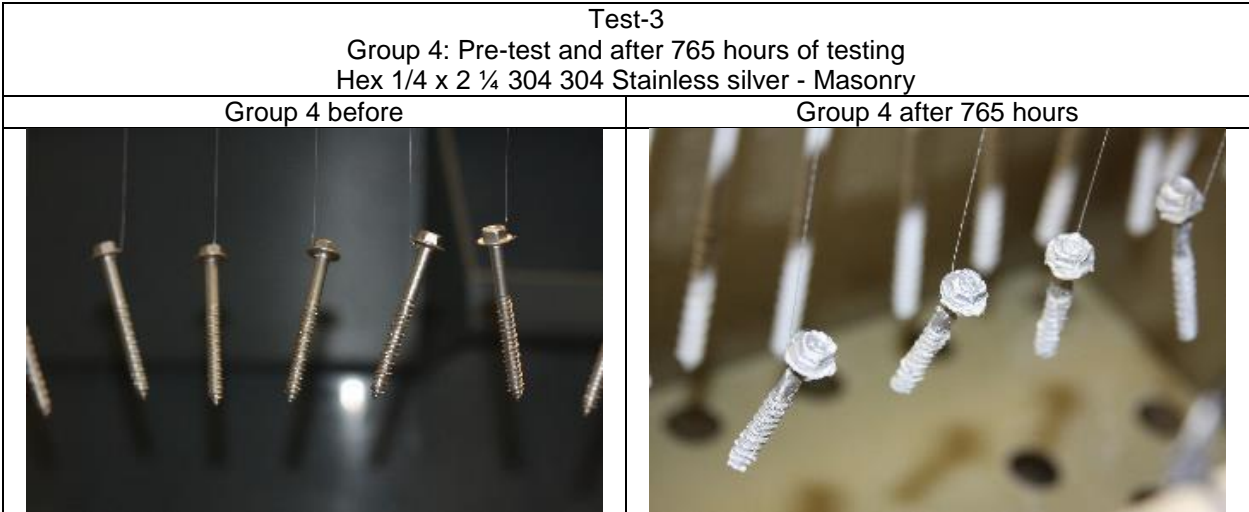
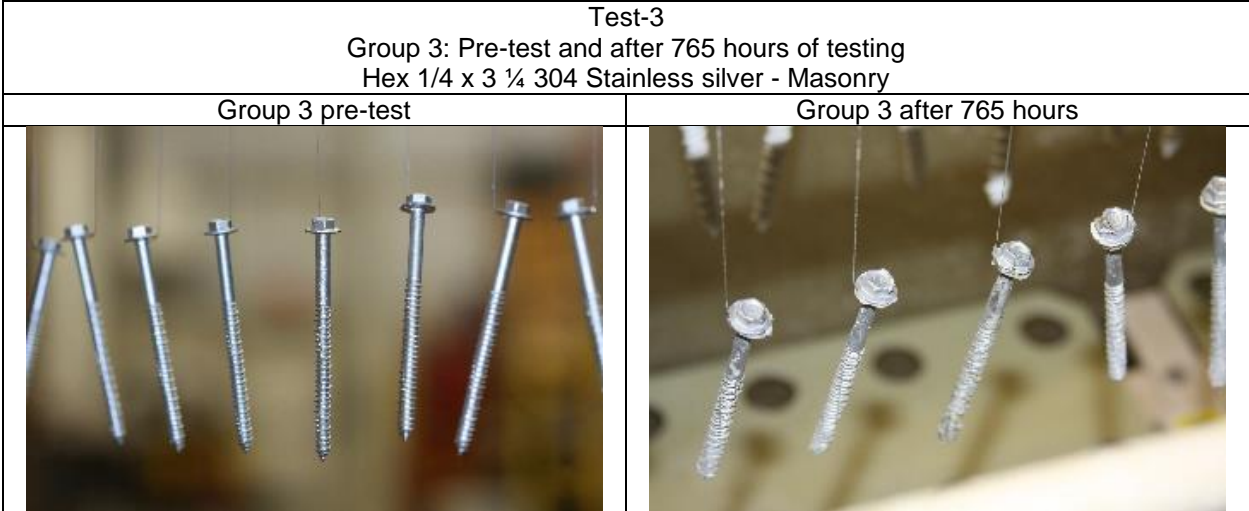
Test-2 Group 4: Pre-test and two of ten samples 1 1/4" Hot Dipped smooth shank: installed and removed	
Sample 5 pre-testing	Sample 9 pre-testing
	
Sample 5 Head classification: 2	Sample 5 Shaft classification: 1
	
Sample 9 Head classification: 2	Sample 9 Shaft classification: 1
	

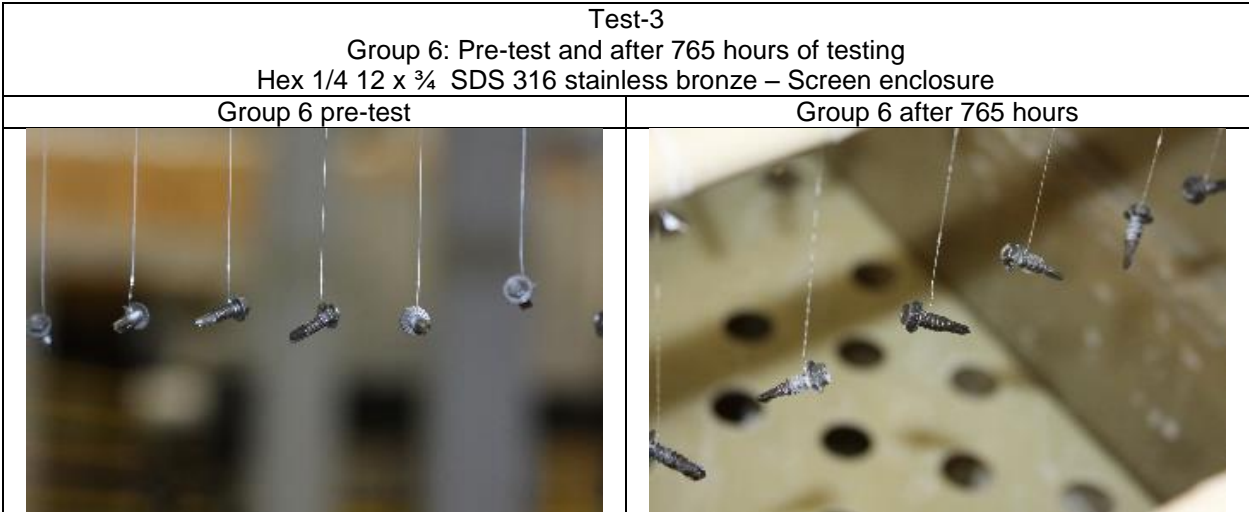
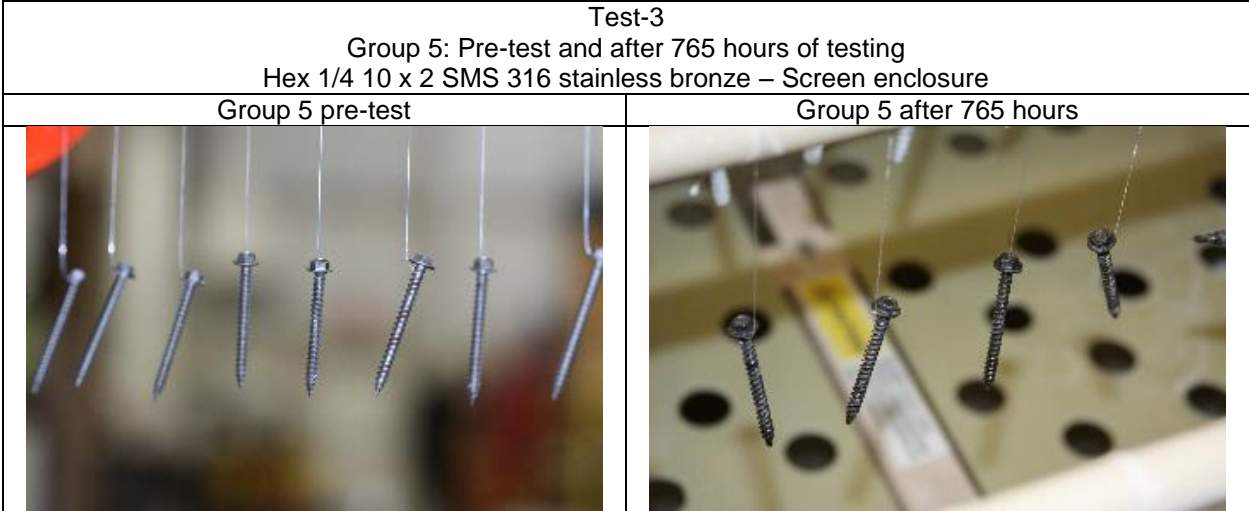
Test-2 Group 5: Pre-test and two of ten samples 1 ¼" Hot Dipped ring shank: out-of-the-box	
Sample pre-testing	Group pre-testing
	
Sample 3 Head classification: 1	Sample 3 Shaft classification: 1
	
Sample 6 Head classification: 3	Sample 6 Shaft classification: 3
	

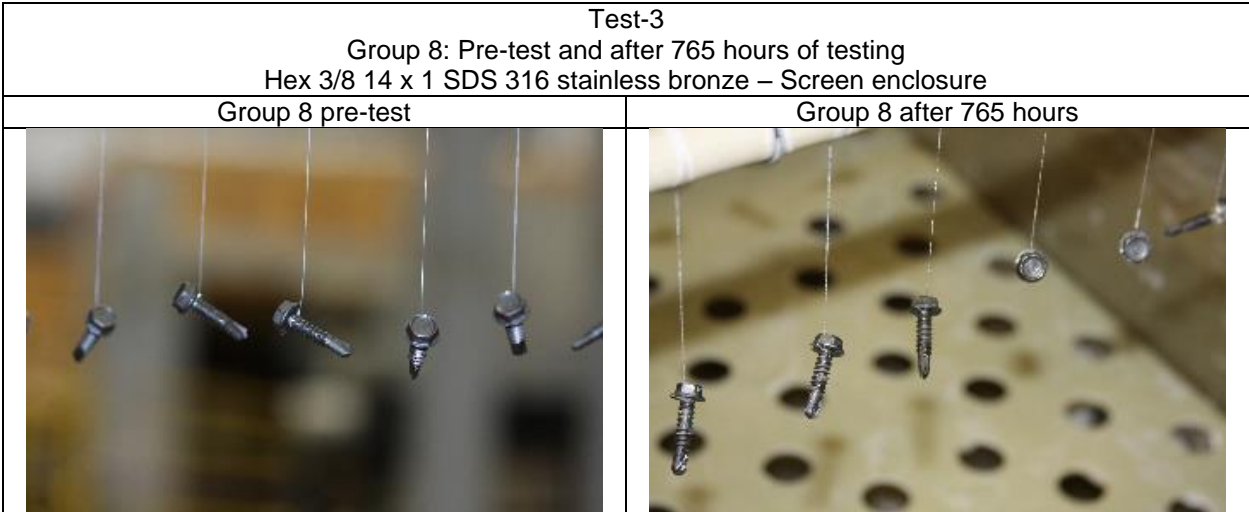
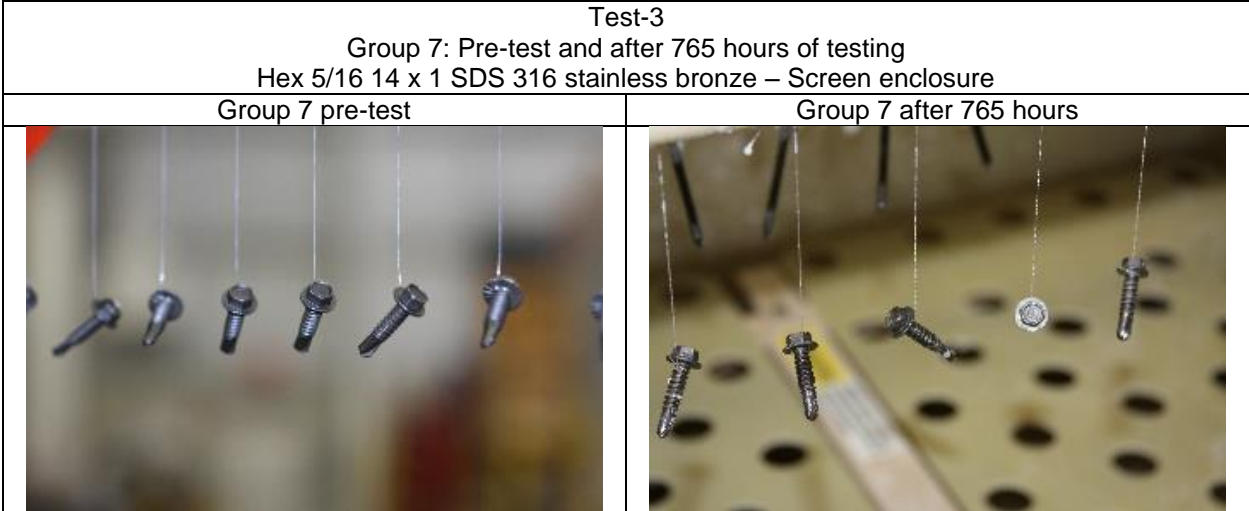
<p style="text-align: center;">Test-2 Group 6: Pre-test and two of ten samples 1 ¼" Hot Dipped ring shank: installed and removed</p>	
Sample 2 pre-testing	Sample 8 pre-testing
	
Sample 2 Head classification: 1	Sample 2 Shaft classification: 1
	
Sample 8 Head classification: 2	Sample 8 Shaft classification: 3
	

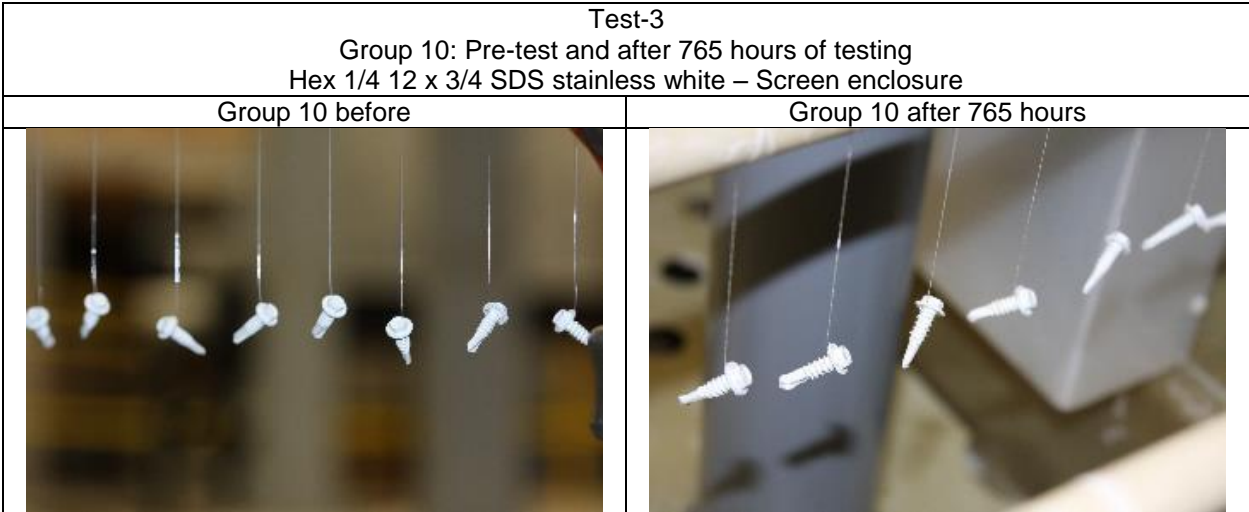
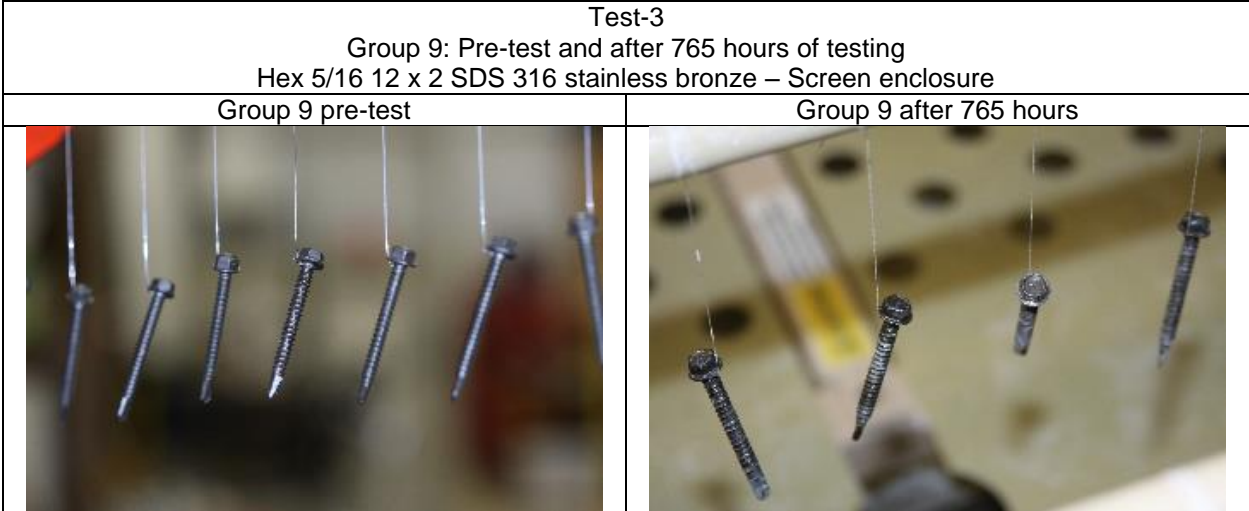
9. Appendix C: Test-3 mid-test Corrosion results (765 of 1000 hours)











Test-3

Group 11: Pre-test and after 765 hours of testing
Hex 1/4 10 x 2 SMS stainless white – Screen enclosure

Group 11 pre-test



Group 11 after 765 hours

