Final Report for Project Entitled:

Corrosion of Roofing and Screen Enclosure Fasteners Systems

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by

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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
- Guide to Aluminum Construction in High Wind Areas
- TAS 114 Appendix E
- ASTM A 90
- ASTM A 641
- ASTM B117-11
- ASTM G85-11

3. Executive Summary

This is a draft final report. The final version will be submitted prior to the end of the project performance period after the Roofing Technical Advisory Committee provides feedback.

The project goal is to experimentally evaluate the corrosion resistance of metal fasteners for roof systems and screen enclosures. The 2014 study regarding the corrosion of metal roof fasteners found that corrosion is commonly observed. Electrogalvinized fasteners were most likely to exhibit corrosion among the common corrosion resistant applications, and thus the focus of the current study with regard to roofing fasteners.

The March 20, 2015 interim report presented the proposed fastener types and corrosion test sequences for the study. A timeline was proposed that projected completion of one test sequence of roof fasteners, and two test sequences of screen enclosure fasteners. Delays in delivery and a manufacturing defect in the corrosion testing apparatus resulted in a delay in this schedule. As of June 15, the test sequence for roofing fasteners has been completed, and the first of two test sequences for screen enclosure fasteners is being prepared for testing. This report presents the results and analysis of the roofing fastener test sequence.

The roofing fastener test sequence consisted of electrogalvalized 1¼ inch roofing coil nails. Three manufacturers were tested, including pneumatic and hand installed types. 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). Substrate installations include bare wood, through flashing into wood, and through shingles into wood. Testing was conducted in accordance with TAS 114 Appendix E. An integer 1 - 8 corrosion scale was created to score the degree of corrosion to the head and shaft of the fasteners. In addition, each fastener was scored as pass/fail in accordance with the TAS 114 criterion.

It was found that one manufacturer clearly outperformed the other two with regard to corrosion resistance of out of the box fasteners, which is the condition that corresponds to TAS 114. Visual analysis comparing out of the box against installed – tested and installed – removed – tested fasteners indicate a possibility that installation alters corrosion resistance. However, the companion statistical analysis reveals that the observed differences in performance cannot be separated from experimental scatter with acceptable statistical significance.

The primary outcome of the current results is a baseline demonstration that the corrosion resistant performance of electrogalvalized nails can vary widely among different manufacturers. Thus, electrogalvinization alone is an insufficient indicator of the suitability of the fastener corrosion resistance. Future research should focus on the relative performance of fasteners that are certified as ASTM A 641 compliant, as well as fasteners compliant with TAS 114 Appendix E. This will provide more specific evidence with respect to the suitability of current code requirements in Florida.

3.1. Description of issues

- Anecdotal information indicates that corrosion of fasteners has been observed across a range of installations
- The problem is more serious in coastal environments due to presence of chloride ions
- Increased manufacturing of these products outside the United State may be contributing to the problem
- The 2013-2014 survey study of roofing contractors regarding their observation of roof fastener corrosion corroborated each of the above three issues
- The 2013-2014 survey study report recommended a follow up fastener corrosion test program to isolate the primary causes and provide evidence to support the pursuit of code changes
- It is not known whether the process of installation negatively affects the corrosion resistance of fasteners

4. Scope of Work

- Cyclic Corrosion Testing equipment (Q-Lab Corporation) was purchased.
- Evaluate the degree of corrosion resistance for screen enclosure fasteners embedded in aluminum and concrete substrates. Withdrawal tests will be performed to evaluate the change in mechanical resistance. New, installed, and installed/removed fasteners will be evaluated
- Apply TAS 114 Appendix E testing (Section 2.6.1) to evaluate the relative degree of corrosion resistance for a random sample of US and non-US manufactured ASTM A 641 Class 1 fasteners. Testing will be conducted on both new and installed/removed fasteners to determine the influence of installation on corrosion resistance
- Interpret results and produce a report that explains the results and implications

5. Deliverables

- A final report providing technical information on the problem background, results and implications to the Code submitted to the Program Manager by June 15, 2015. The final report will be presented to the Commission’s Roofing Technical Advisory Committee at a time agreed to by the Contractor and the Department’s Project manager.
- A breakdown of the number of hours or partial hours, in increments of fifteen (15) minutes, of work performed and a brief description of the work performed. The Contractor agrees to

provide any additional documentation requested by the Department to satisfy audit requirements

6. Detailed Project Description

6.1. Test configurations and codes for roofing system fasteners

6.1.1. Definitions:

Test sequence – one complete 140 cycle (12 day) or 180 cycle (15 day) test as per TAS 114 Appendix E

Subject – one particular fastener type (e.g. 1 ¼ inch roofing coil nails), to be tested in multiple configurations

Configuration – a given preparation for a subject. E.g. 1 ¼ inch roofing nail out-of-the-box, installed into wood, and installed through flashing into wood are three configurations of one subject

Specimen – any single fastener subject in any single configuration

Sequence matrix – the complete collection of specimens in a single test sequence, consisting of multiple subjects and configurations

Control – a subject tested out-of-the-box (non-installed condition)

Conditioned – a subject tested in an installed configuration or installed and removed configuration. A conditioned specimen cannot be a control specimen

Install method – hand driven or pneumatic driver

6.1.2. Description of test configurations

Roofing system fasteners: 1¼ inch roofing coil nails were tested since they are used for multiple roofing systems (dry-ins, shingles, flashing). Control and conditioned configurations were tested. The three conditioned configurations include installed in wood substrate, through shingles into wood, and through flashing into wood. Conditioned specimens were tested as installed within the substrate. Another set of identically conditioned specimens were removed from the substrate prior to testing. Removal was conducted by slowly splitting the wood by hand driving multiple closely spaced screws so as not to damage the fastener specimen. Hand driven and pneumatic installs were included. Samples were procured from three manufacturers.

The code assignment is: Configuration – Manufacturer – Install method – Substrate

Configuration

OB:	tested out of the box	(4 samples each)
I:	installed in substrate and tested	(3 samples each)
II:	installed and removed from substrate and tested	(3 samples each)

Manufacturer: A, B, C

A: electrogalvanized, origin - unknown, similar products origin – China
B: electrogalvanized, origin – China
C: electrogalvanized, origin - unknown

Install method:
H: installed by hammer (manufacturers A and C)
Pn: installed by pneumatic driver (manufacturers B and C)

Substrate
F: installed through metal flashing into wood
S: installed through asphalt shingle into wood
W: installed into bare wood

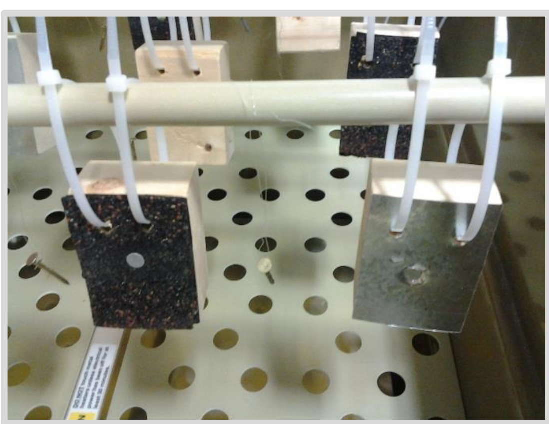
This produced a total of 88 individual specimens. The codes are shown in Table 1.

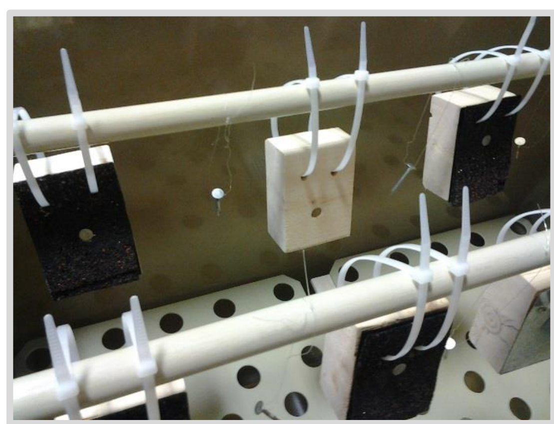
Table 1: code key for the 88 tested roof fastener specimens grouped by configuration

Configuration: OB Out of the box (control) 4 each	Configuration: II Installed – removed – tested 3 each	Configuration: I Installed – tested 3 each
OB-A-H	II-A-H-F	I-A-H-F
OB-B-Pn	II-A-H-S	I-A-H-S
OB-C-H	II-A-H-W	I-A-H-W
OB-C-Pn	II-B-Pn-F	I-B-Pn-F
	II-B-Pn-S	I-B-Pn-S
	II-B-Pn-W	I-B-Pn-W
	II-C-H-F	I-C-H-F
	II-C-H-S	I-C-H-S
	II-C-H-W	I-C-H-W
	II-C-Pn-F	I-C-Pn-F
	II-C-Pn-S	I-C-Pn-S
	II-C-Pn-W	I-C-Pn-W

6.1.3. Images of samples in the test chamber

The test chamber accommodated all of the 88 specimens. Figure 1 presents images of the specimens placed in the test chamber prior to testing. Each specimen was suspended from a rod by either zip-ties (installed specimens) or fishing line (bare specimens). No specimen was in contact with any other, and all suspension rods were in the same horizontal plane.





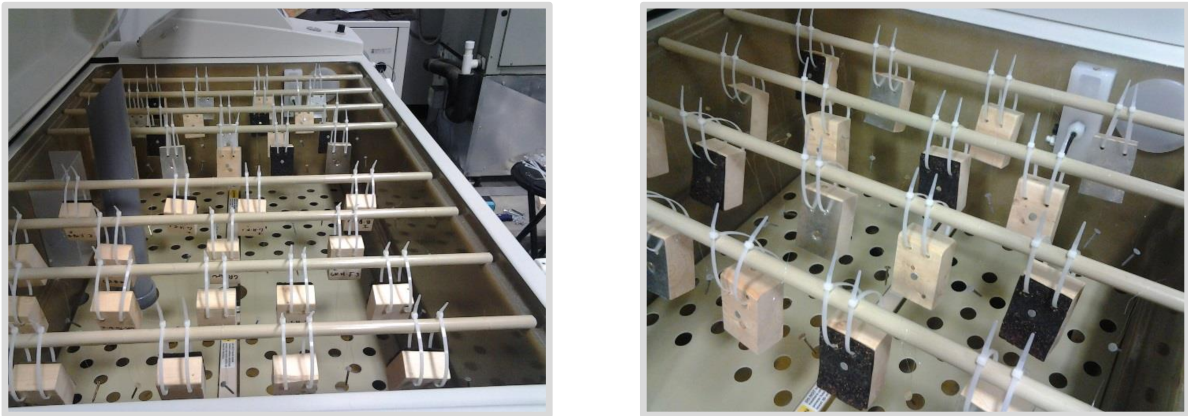


Figure 1: Images of the prepared roof fastener specimens within the test chamber

6.2. 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, where one cycle consists of one hour of fog exposure and one hour of dry-off. The sequence was run without interruption over a 12 day period. The salt solution composition, chamber temperature, and water purity were monitored to conform with requirements. There is no conversion of this protocol to an equivalent time of in-field exposure to real conditions.

6.3. 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 electrogalvalized fasteners in both out of the box and multiple installed conditions. 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 2 provides a description of these classifications as well as a visual sample of each. The assignment of a corrosion score for each fastener (described in the next section) 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.

6.4. Tabular results of corrosion score assignment

The 1-8 corrosion score was assigned to each tested specimen. 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 each specimen are provided in Appendix A. For configurations in which the shaft was exposed during testing, separate scores were assigned to the shaft and head. This includes the out of the box specimens and those installed in substrate and removed prior to testing. In the case of the specimens tested installed in substrate, only a head corrosion score was assigned. However, upon completion of testing these specimens were removed from the substrate for shaft corrosion evaluation. No corrosion was found on the shaft of any such specimen.

Tables 3 – 5 present the corrosion scale score for the fasteners tested out of the box, tested after installation and removal, and tested as installed, respectively. The code follows that provided in Section 6.1.2. A graphical and statistical presentation of these results will be provided in the next sections along with a discussion of observations.

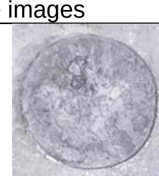
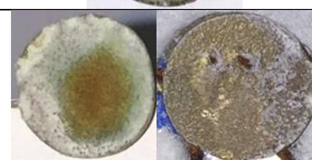
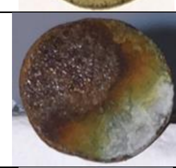
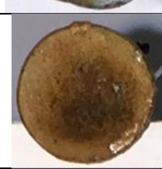
Table 2: Corrosion scale description and sample images	
1: No corrosion observed	
2: Edge corrosion only	
3: Light partial surface corrosion	
4: Light full surface corrosion	
5: Partial heavy surface corrosion	
6: Partial heavy and partial light full surface corrosion	
7: Heavy full surface corrosion without scaling	
8: Heavy full surface corrosion with scaling	

Table 3: Corrosion scale results for 16 roof fasteners tested out of the box (configuration OB)								
	Spec. 1 head	Spec. 1 shaft	Spec. 2 head	Spec. 2 shaft	Spec. 3 head	Spec. 3 shaft	Spec. 4 head	Spec. 4 shaft
OB-A-H	7	6	7	8	7	8	8	8
OB-B-Pn	4	4	7	8	7	4	3	1
OB-C-H	1	1	1	1	1	3	3	3
OB-C-Pn	1	3	2	1	6	3	2	3

Table 4: Corrosion scale results for 36 roof fasteners tested after installation and removal (configuration II)						
	Specimen 1 head	Specimen 1 shaft	Specimen 2 head	Specimen 2 shaft	Specimen 3 head	Specimen 3 shaft
II-A-H-F	8	7	6	6	8	8
II-A-H-S	8	8	7	7	8	7
II-A-H-W	8	8	6	7	8	8
II-B-Pn-F	8	3	8	8	4	3
II-B-Pn-S	1	1	4	4	3	3
II-B-Pn-W	3	3	1	1	3	3
II-C-H-F	1	3	1	3	1	1
II-C-H-S	1	1	6	4	1	1
II-C-H-W	1	1	4	6	2	6
II-C-Pn-F	3	3	3	4	8	7
II-C-Pn-S	1	1	8	8	4	3
II-C-Pn-W	3	3	1	3	8	8

Table 5: Corrosion scale results for 36 roof fasteners tested as-installed (configuration I)			
	Specimen 1	Specimen 2	Specimen 3
I-A-H-F	5	2	3
I-A-H-S	7	6	3
I-A-H-W	8	7	8
I-B-Pn-F	2	3	3
I-B-Pn-S	8	5	4
I-B-Pn-W	3	3	3
I-C-H-F	1	1	1
I-C-H-S	2	1	2
I-C-H-W	3	1	1
I-C-Pn-F	1	1	1
I-C-Pn-S	3	3	3
I-C-Pn-W	1	3	2

6.5. Relating the corrosion score to the TAS 114 Appendix E pass/fail criterion

The TAS 114 Appendix E pass/fail criterion is greater than 5% surface area corrosion for failure. With respect to the corrosion scale created for this study (Table 2), a sample that passes that criterion corresponds with scores of 1, 2 or 3. However, 3 could either be a failure (left picture for score 3 in Table 2), or a pass (right picture for score 3 in Table 2). Additionally, the TAS 114 Appendix E applies to both the head and shaft. Thus a specimen with a head score of 1 or 2 and a shaft score of 4 would be considered a failed specimen. The 88 specimens were evaluated based on the TAS 114 Appendix E pass/fail criterion utilizing the scores provided in Tables 3 – 5 and visual inspection. Tables 6 – 8 present the results. Table 9 summarizes these results by grouping all results by manufacturer and presents the percent failed by configuration (OB, I, II). Configuration I is the closest replica of field conditions, as the shaft is not directly exposed to the air. Thus it is reasonable to more heavily weight the results of this configuration. It is observed that only manufacturer C produces what may be considered acceptable performance. However, in the spirit of the TAS 114 Appendix E requirement that the full exposed fastener be tested and considered in the 5% surface area corrosion criterion, all specimens show an unacceptable level of failure for both configuration OB and configuration II.

Table 6: TAS 114 Appendix E pass/fail results for 16 roof fasteners tested out of the box (configuration OB)

	Specimen 1	Specimen 2	Specimen 3	Specimen 4
OB-A-H	fail	fail	fail	fail
OB-B-Pn	fail	fail	fail	pass
OB-C-H	pass	pass	pass	fail
OB-C-Pn	pass	pass	fail	fail

Table 7: TAS 114 Appendix E pass/fail results for 36 roof fasteners tested after installation and removal (configuration II)

	Specimen 1	Specimen 2	Specimen 3
II-A-H-F	fail	fail	fail
II-A-H-S	fail	fail	fail
II-A-H-W	fail	fail	fail
II-B-Pn-F	fail	fail	fail
II-B-Pn-S	pass	fail	fail
II-B-Pn-W	fail	pass	fail
II-C-H-F	pass	fail	pass
II-C-H-S	pass	fail	pass
II-C-H-W	pass	fail	fail
II-C-Pn-F	fail	fail	fail
II-C-Pn-S	pass	fail	fail
II-C-Pn-W	fail	fail	fail

Table 8: TAS 114 Appendix E pass/fail results for 36 roof fasteners tested as-installed (configuration I)

	Specimen 1	Specimen 2	Specimen 3
I-A-H-F	fail	pass	pass
I-A-H-S	fail	fail	fail
I-A-H-W	fail	fail	fail
I-B-Pn-F	pass	pass	pass
I-B-Pn-S	fail	fail	fail
I-B-Pn-W	fail	fail	fail
I-C-H-F	pass	pass	pass
I-C-H-S	pass	pass	pass
I-C-H-W	pass	pass	pass
I-C-Pn-F	pass	pass	pass
I-C-Pn-S	pass	pass	fail
I-C-Pn-W	pass	pass	pass

Table 9: Summary of % failed results in Tables 6 - 8

Manuf.	OB: out of the box	II: installed-removed-tested	I: installed-tested
A	100%	100%	77.8%
B	75%	77.8%	66.6%
C	37.5%	66.7%	5.6%

6.6. Graphical results of corrosion score assignments

6.6.1. Presentation of corrosion score graphs

The 5% surface area corrosion criterion is not well suited for a detailed study of relative performance. A specimen with light corrosion over 7% would be lumped in with a specimen with full heavy corrosion. Further, there is subjectivity involved in the assignment of corroded surface area, and what constitutes corrosion. The finer gradation of the corrosion scale developed for this study makes it possible to better determine relative performance by delineating light and heavy corrosion, as well as the location and amount of corrosion.

The tabular corrosion scale results in Tables 3 – 5 are presented in graphical form in figures 2 - 5. Figure 2 presents the out of box test results (configuration OB) as documented in Table 3. The vertical axis denotes the corrosion scale presented in Table 2. The colors delineate the manufacturer-install method combinations as labeled on the plot (A-H, B-Pn, C-H, C-Pn), the clusters with four bars each correspond to the four specimens tested in identical conditions, and head and shaft results are presented separately on the left and right half, respectively. The light blue circle associated with each four bar cluster shows the mean score among those four identically tested specimens.

Figures 3 and 4 present the tested after installation and removal results (configuration II), for head and shaft, respectively, as documented in Table 4. The colors delineate manufacturer-install method as labeled (A-H, B-Pn, C-H, C-Pn). The substrate labels (flashing, shingle, wood) delineate the substrate corresponding to the clusters of three specimens tested in identical conditions. The light blue circle associated with each three bar cluster shows the mean score among those three identically tested specimens. The colored triangular icons will be explained in Section 6.6.4.

Figure 5 presents the tested as-installed results (configuration I) as documented in Table 5. These results are head-only, as the shaft was within the substrate during testing, and post-test removal showed no corrosion in any specimen that was within a substrate during testing. The colors delineate manufacturer-install method as labeled (A-H, B-Pn, C-H, C-Pn). The substrate labels (flashing, shingle, wood) delineate the substrate corresponding to the clusters of three specimens tested in identical conditions. The light blue circle associated with each three bar cluster shows the mean score among those three identically tested specimens. The colored triangular icons will be explained in Section 6.6.4.

6.6.2. Out of the box results

Figure 2 demonstrates that the manufacturer C products (red and black bars) performed substantially better than manufacturer A (blue bars) and B (green bars) products when tested out of the box. This is apparent when comparing either the individual bars or the mean corrosion scores (light blue dots) among manufacturers. This is significant in that TAS 114 Appendix E is applied only to out of the box specimens. The difference in performance among manufacturers is not as clear when viewing performance in terms of the pass/fail criterion in Table 9. This suggests that a grading scale may be worth pursuing as a replacement for the current pass/fail requirement.

6.6.3. The Influence of installation on corrosion resistance – visual analysis

Figures 3 and 4 present the installed – removed – tested results (configuration II). The purpose for this configuration is to detect any influence the process of installation may have on corrosion resistance due to damage caused by the driver or friction with the substrate, or due to contact with the substrate. This configuration is worst case, or conservative scenario for the shaft resistance, as any damage incurred during installation is then exposed directly to the corrosive environment, in contrast with field conditions.

Interpretation of results in Figures 3 and 4 is best conducted in contrast with the Figure 2 out of the box configuration results. Consider the head results in Figure 2 with the head results in Figure 3. The poor performance of the manufacturer A product is not degraded further by installation, because the out of the box performance is initially so poor. For manufacturer B, the scatter among the four green bars in Figure 2 is reflected in the scatter among the nine green bars in Figure 3. No clear degradation of performance can be observed due to installation. Although the installation through flashing into wood has a slightly higher mean score than the out of the box mean score, the corresponding shingle and bare wood installation results have the counter result, indicating the cause is due to experimental scatter rather than a clear influence of flashing. These head observations also apply when comparing the shaft results in Figures 2 and 4. Conclusions based on manufacturer A and B comparisons are constrained (hindered) by the poor baseline performance in the out of the box results.

For manufacturer C products, the red and black head results in Figure 3 shows several specimens with more significant corrosion than the red and black bars (for head) in Figure 2 out of the box results, more so for the black bar pneumatic installation. The same observation applies to the shaft results between Figures 2 and 4, with more cases of more corrosion for shafts than heads. Overall, there is some evidence that installation may influence corrosion resistance, but this is tempered by the fact that only 36% of the installed manufacturer C specimens showed corrosion score of 4 or higher. There is also modest evidence that pneumatic installation has slightly more influence than hand driven.

Figure 5 interpretation is also best conducted in contrast with the Figure 2 out of the box configuration results. Manufacturers A and B show mixed results compared with Figure 2, where performance improves in some cases and remains poor in other cases. This is attributable to experimental scatter. Manufacturer C tested as installed performance is consistent with the out of the box results, with very little corrosion observed on the installed heads.

The above observations based on visual inspection of Figures 2 – 5 are limited by the necessarily low sample numbers used in this study. This hinders the ability to separate experimental scatter from clear differences in performance by visual inspection alone. The next section applies a statistical hypothesis test to investigate the differences between configuration OB and configuration I and II results.

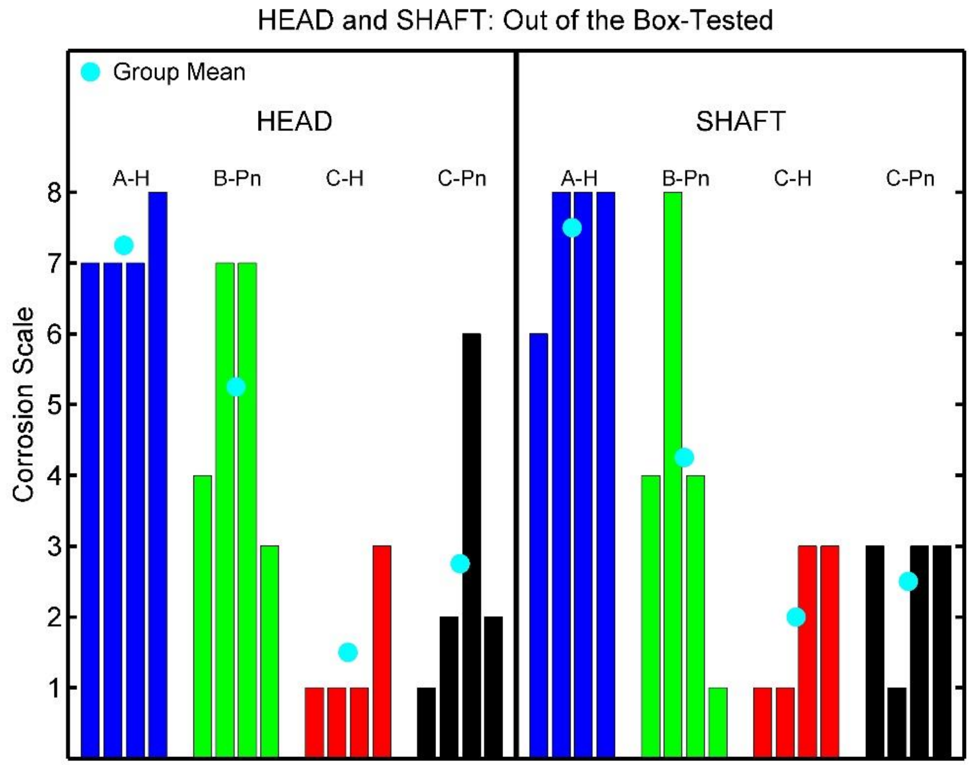


Figure 2: Corrosion scale results for 16 roof fasteners tested out of the box (configuration OB)

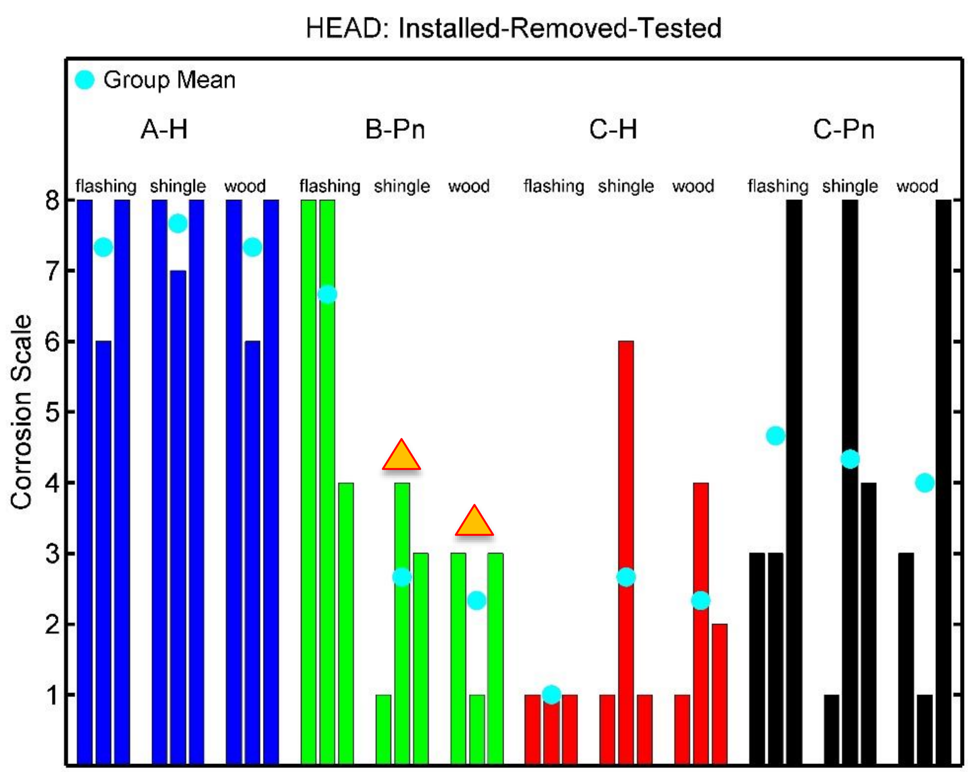


Figure 3: HEAD: Corrosion scale results for 36 roof fasteners tested after installation and removal (configuration II)

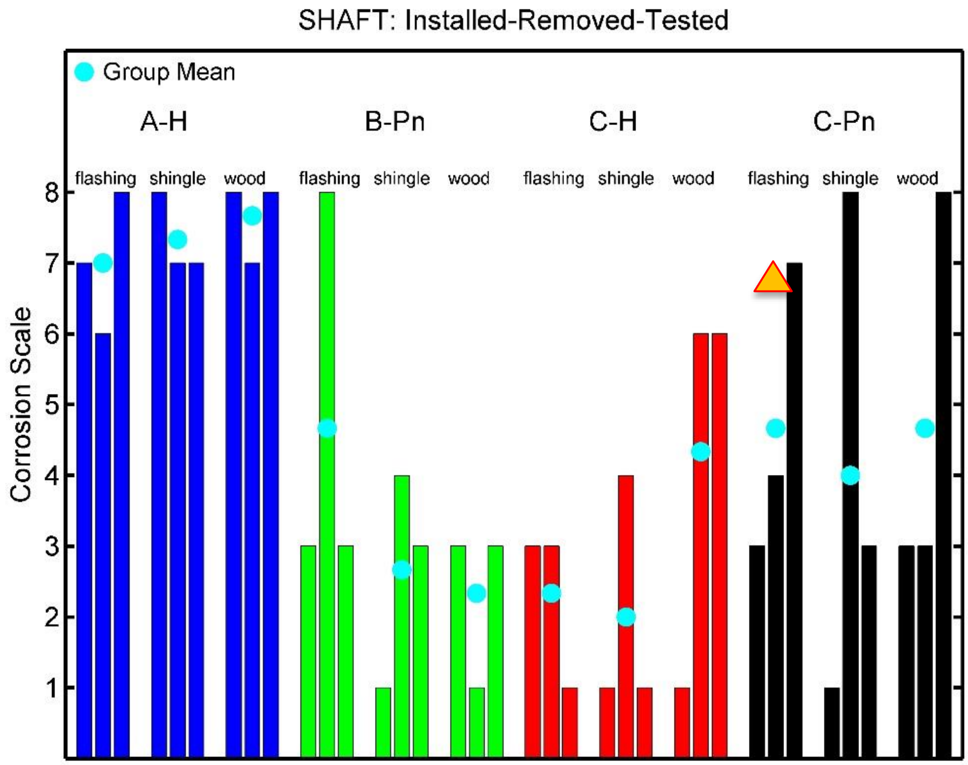


Figure 4: SHAFT: Corrosion scale results for 36 roof fasteners tested after installation and removal (configuration II)

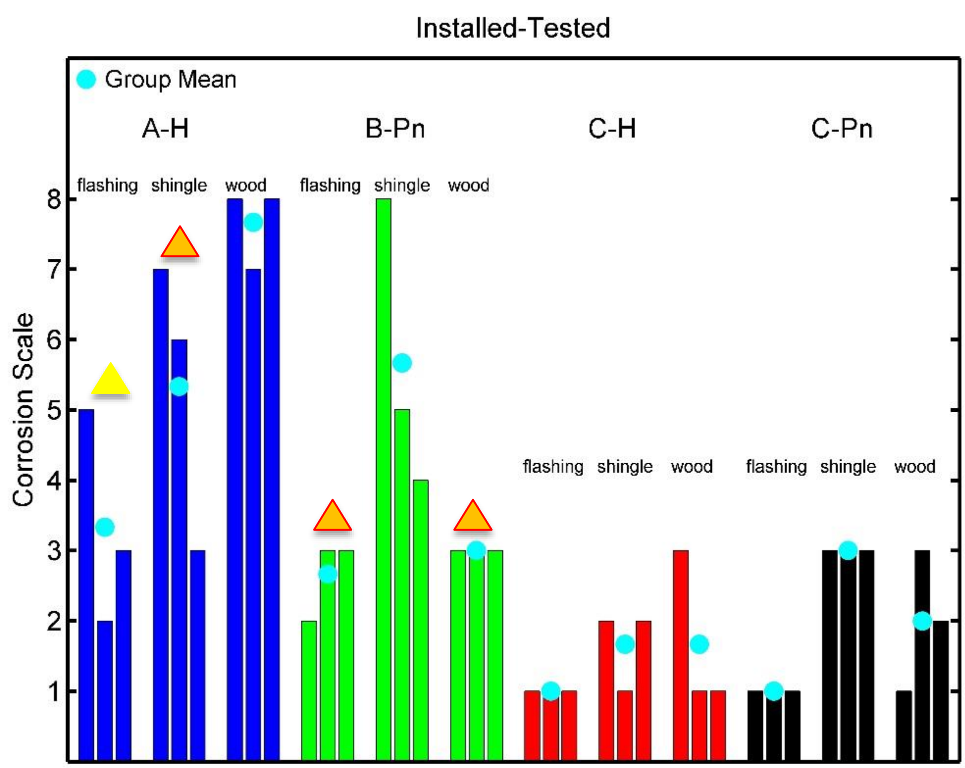


Figure 5: Corrosion scale results for 36 roof fasteners tested as-installed (configuration I)

6.6.4. The Influence of installation on corrosion resistance – statistical analysis

This section analyzes the results in a statistical manner by applying the Welch's t test (Welch 1947). The goal of the test is to determine whether the samples contained in two different data sets can be reasonably assumed to belong to the same parent data set. That is, the test can provide the statistical probability that the differences observed in the previous section are significant, or conversely inseparable from experimental scatter. Welch's t test is a variation of the student t test, and is appropriate for cases where the sample sets being compared have different sample amounts and different variances, as is the case in this study.

The test requires a baseline dataset of observations and a comparative set of observations. The null hypothesis is that the baseline and comparative observations are random samples of the same distribution, and therefore differences between the two sets are statistically insignificant. Two parameters are returned from the Welch's t test: P and H. P indicates the probability of observing the specific set of given baseline and comparative observations under the null hypothesis, and ranges from zero to one. A low P score justifies a rejection of the null hypothesis, meaning that the baseline and comparative sets are different with statistical significance. The standard accepted P value that justifies rejecting the null hypothesis is 0.05 or less, indicating with 95% confidence that the observations are statistically different. The second parameter (H) is binary, and indicates an acceptance (H=0) or rejection (H=1) of the null hypothesis.

In this analysis, the out of the box OB configuration observations are the baseline sets, and the configurations I and II observations are the comparative sets. Sets with like conditions are compared. For example, OB manufacturer A head corrosion scores are compared with configurations I and II manufacturer A head corrosion scores, stratified by substrate. Table 10 provides the baseline and comparative sets tested, their P scores and the conclusion regarding null hypothesis (H). A total of 48 tests were run on various stratifications of the data, and includes sets that combines the substrate results (F, S, W) into a single larger comparative set (indicated by "Combined" in the description in Table 10).

In Table 10 only a single test indicates statistically significant differences. This test is located in row 5, and highlighted in yellow. This is the comparison between the out of the box (OB) - manufacturer A - hand driven nails - head corrosion results and the tested as installed (I) - manufacturer A - hand driven nails - through flashing into wood substrate. This rejection of the null hypothesis is also indicated in Figure 5 as the yellow triangle above the appropriate grouping.

The differences between baseline and comparative sets increase in significance as P gets lower, with 0.05 as the selected "too far apart" threshold. However, this threshold can be relaxed to identify other comparisons that are different, but not at the 0.05 standard. All tests where $0.05 < P < 0.25$ are highlighted in orange in Table 10, indicating that these tests still support the null hypothesis, but with relatively low confidence. That is, although the Welch's t test indicates that differences in the orange highlighted sets are within experimental scatter, this conclusion can be viewed with some uncertainty. These orange highlighted cases in Table 10 are also indicated in Figures 3 – 5 with an orange triangle above the appropriate grouping.

Among the 48 total comparison tests, only one rejected the null hypothesis, and an additional eight accepted with relatively low confidence. Viewing these results as the colored triangles in Figures 3-5, it is striking that all but one of these cases indicate an increase in corrosion performance in manufacturers A and B products when tested installed or installed, removed and tested, as compared to the out of the box configuration. As there is no known physical justification for the conclusion that installation can improve the corrosion resistance of electrogalvalized fasteners, this observation is attributed to experimental scatter rather than an acceptance of this conclusion. Had the statistical analysis produced more than a handful of such cases, the attribution to scatter would be more difficult to support.

A single case of manufacturer C product (Figure 4, shaft, pneumatic driver - installed through flashing, removed and tested) indicates a modest (P = 0.205) likelihood that the installation process reduced corrosion performance compared to the out of the box results. This evidence is not sufficiently substantial, and the difference is again attributed to experimental scatter.

6.7. Summary and Conclusions

The following bullet points summarize the findings presented in this report.

- Sections 6.3 through 6.5 convey the corrosion scale used in this study, the scores assigned to the specimens, and the comparison of these results to the TAS 114 Appendix E pass/fail criterion. Manufacturer C had the lowest failure rate for out of the box specimens at 37.5%, while manufacturers A and B failed at 100% and 75%, respectively. For configuration I (tested as installed), the failure rates for A, B and C were 77.8%, 66.6% and 5.6%, respectively
- The corrosion scale introduced in this study provides a more valuable metric than the TAS 114 pass/fail criterion for the purposes of comparative corrosion performance evaluation
- Section 6.6.2 presents the visual analysis of corrosion scale results for out of the box testing. Figure 2 and Table 6 clearly show that manufacturer C performs significantly better than manufacturers A and B. This is significant in that TAS 114 Appendix E is applied only to out of the box specimens in practice. All tested products are electrogalvanized fasteners of identical dimensions
- Section 6.6.3 presents the visual analysis of corrosion scale results, comparing out of the box (configuration OB) results with installed and tested results (configuration I) and installed, removed and tested results (configuration II). Some differences in performance were observed. Some of these differences are counter-intuitive, such as corrosion resistance of installed specimens improving relative to out of the box, while other differences show degradation of performance. This suggests that observed differences may be attributed to experimental scatter pending a statistical analysis
- Section 6.6.4 presents a hypothesis testing statistical analysis to complement the visual analysis in Section 6.6.3. The Welch's t test was applied to test the hypothesis that corrosion scores from the out of the box configuration and configurations I and II are random samples from the same distribution (i.e. performance differences are inseparable from experimental scatter). The results (Table 10) show that the vast majority of comparisons accept this hypothesis. Further, the single comparison that rejects this hypothesis is counter-intuitive (improved performance with installed fasteners), as are the majority of the comparisons that accept the hypothesis with low confidence. A single case of manufacturer C product indicates a modest likelihood that the installation process reduced corrosion performance compared to the out of the box results
- The visual and statistical analyses provide insufficient evidence that installation alters the corrosion resistance performance of the tested fasteners

Table 10: Welsh's t-test results comparing the OB configuration with configurations I and II

Null hypothesis: the baseline and comparative sets are random samples from the same distribution

Row	Baseline set	Comparative set	P	0: accept null hypothesis 1: reject null hypothesis
1	OB-A-H-Head	II-A-H-F-Head	0.915	0
2		II-A-H-S-Head	0.374	0
3		II-A-H-W-Head	0.915	0
4		II-A-H-Combined-Head	0.625	0
5		I-A-H-F	0.039	1
6		I-A-H-S	0.249	0
7		I-A-H-W	0.374	0
8		I-A-H-Combined	0.051	0
9	OB-A-H-Shaft	II-A-H-F-Shaft	0.545	0
10		II-A-H-S-Shaft	0.793	0
11		II-A-H-W-Shaft	0.793	0
12		II-A-H-Combined-Shaft	0.777	0
13	OB-B-Pn-Head	II-B-Pn-F-Head	0.447	0
14		II-B-Pn-S-Head	0.115	0
15		II-B-Pn-W-Head	0.066	0
16		II-B-Pn-Combined-Head	0.343	0
17		I-B-Pn-F	0.083	0
18		I-B-Pn-S	0.804	0
19		I-B-Pn-W	0.117	0
20		I-B-Pn-Combined	0.270	0
21	OB-B-Pn-Shaft	II-B-Pn-F-Shaft	0.858	0
22		II-B-Pn-S-Shaft	0.393	0
23		II-B-Pn-W-Shaft	0.291	0
24		II-B-Pn-Combined-Shaft	0.550	0
25	OB-C-H-Head	II-C-H-F-Head	0.391	0
26		II-C-H-S-Head	0.562	0
27		II-C-H-W-Head	0.467	0
28		II-C-H-Combined-Head	0.537	0
29		I-C-H-F	0.391	0
30		I-C-H-S	0.793	0
31		I-C-H-W	0.851	0
32		I-C-H-Combined	0.925	0
33	OB-C-H-Shaft	II-C-H-F-Shaft	0.723	0
34		II-C-H-S-Shaft	1.000	0
35		II-C-H-W-Shaft	0.294	0
36		II-C-H-Combined-Shaft	0.349	0
37	OB-C-Pn-Head	II-C-Pn-F-Head	0.397	0
38		II-C-Pn-S-Head	0.540	0
39		II-C-Pn-W-Head	0.631	0
40		II-C-Pn-Combined-Head	0.325	0
41		I-C-Pn-F	0.213	0
42		I-C-Pn-S	0.836	0
43		I-C-Pn-W	0.578	0
44		I-C-Pn-Combined	0.557	0
45	OB-C-Pn-Shaft	II-C-Pn-F-Shaft	0.205	0
46		II-C-Pn-S-Shaft	0.549	0
47		II-C-Pn-W-Shaft	0.322	0
48		II-C-Pn-Combined-Shaft	0.075	0

Color Codes

(yellow)	Null hypothesis rejected with 95% confidence (P < 0.05)
(orange)	Null hypothesis accepted, but 0.05 < P < 0.25 (weak acceptance)

6.8. Recommendations and Future work

- The March 20, 2015 interim report presented a timeline that projected completion of one test sequence of roof fasteners, and two test sequences of screen enclosure fasteners. Delays in delivery and a manufacturing defect in the corrosion testing apparatus resulted in a delay in this schedule. This report will be appended as screen enclosure fastener testing and analysis are completed
- TAS 114 Appendix E pass/fail criterion of 5% surface area corrosion should be updated or appended with a graded scale of corrosion to better delineate performance
- The disparity in the performance of electrogalvanized fasteners from different manufacturers warrants further exploration

6.9. Proposed research for the 2015-2016 fiscal year

The following proposed work will greatly advance the goals of this study. The corrosion testing apparatus utilized over a 12 month performance period will produce datasets that better elucidate the unresolved issues remaining from the current study, and provide the time necessary to address additional issues as they arise.

- A repeat of the coil nail test sequence matrix should be conducted to provide additional samples to the data set. The additional specimens will improve the statistical hypothesis testing, providing a more reliable conclusion regarding the influence of installation on corrosion resistance
- Additional manufacturers' products should be tested in order to include a wider swath of products currently used in Florida within the test program
- Conduct test sequences on fasteners that are identified as compliant with ASTM A 641, and other identified as compliant with TAS 114 Appendix E. This will provided needed evidence with regard to the significance of current requirements in Florida

7. References

ASTM designation: G85 – 11. Standard practice for modified salt spray (fog) testing.

Testing Application Standard (TAS) No. 114-95. Test procedures for roof system assemblies in the high-velocity hurricane zone jurisdiction. Appendix E. Test procedure for corrosion resistance of fasteners, batten bars and stress distribution plates.

Welch, B. L. (1947). "The generalization of "Student's" problem when several different population variances are involved". *Biometrika* 34 (1–2): 28–35. doi:10.1093/biomet/34.1-2.28. MR 19277.

8. Appendix A: Coil nail corrosion results (photographs and classification)

The code assigned is: Configuration – Manufacturer – Install method – Substrate

<u>Configuration</u>

OB: tested out of the box	(4 samples each)
I: installed in substrate and tested	(3 samples each)
II: installed and removed from substrate and tested	(3 samples each)

<u>Manufacturer</u>: A, B, C

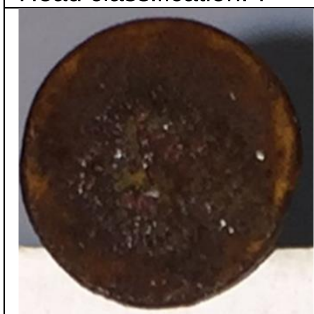
<u>Install method</u>
H: installed by hammer (manufacturers A and C)
Pn: installed by pneumatic driver (manufacturers B and C)

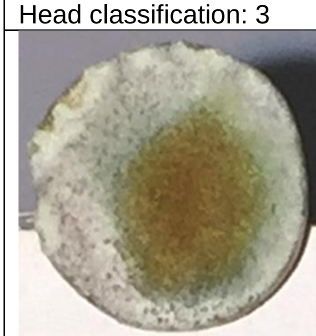
<u>Substrate</u>
F: installed through metal flashing into wood
S: installed through asphalt shingle into wood
W: installed into bare wood

For corrosion classification scale, refer to section 6.3

Order of presentation:

Configuration: OB Out of the box tested 4 each	Configuration II: install – remove – test 3 each	Configuration I: install – test 3 each
OB-A-H	II-A-H-F	I-A-H-F
OB-B-Pn	II-A-H-S	I-A-H-S
OB-C-H	II-A-H-W	I-A-H-W
OB-C-Pn	II-B-Pn-F	I-B-Pn-F
	II-B-Pn-S	I-B-Pn-S
	II-B-Pn-W	I-B-Pn-W
	II-C-H-F	I-C-H-F
	II-C-H-S	I-C-H-S
	II-C-H-W	I-C-H-W
	II-C-Pn-F	I-C-Pn-F
	II-C-Pn-S	I-C-Pn-S
	II-C-Pn-W	I-C-Pn-W

CODE: OB-A-H	
Sample 1 Head classification: 7	Sample 1 Shaft classification: 6
	 
Sample 2 Head classification: 7	Sample 2 Shaft classification: 8
	 
Sample 3 Head classification: 7	Sample 3 Shaft classification: 8
	 
Sample 4 Head classification: 8	Sample 4 Shaft classification: 8
	 

CODE: OB-B-Pn	
Sample 1 Head classification: 4	Sample 1 Shaft classification: 4
	 
Sample 2 Head classification: 7	Sample 2 Shaft classification: 8
	 
Sample 3 Head classification: 7	Sample 3 Shaft classification: 4
	 
Sample 4 Head classification: 3	Sample 4 Shaft classification: 1
	 

CODE: OB-C-H	
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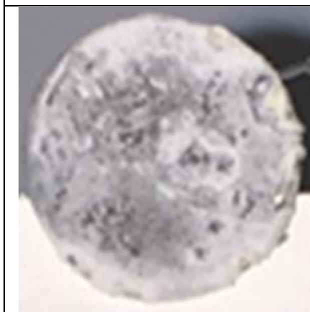	 
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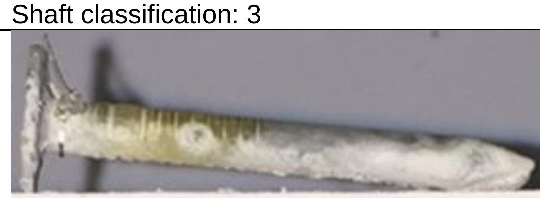
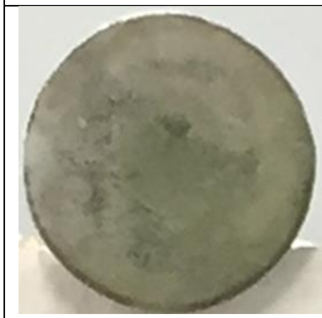
Sample 3 Head classification: 1	Sample 3 Shaft classification: 3
	 
Sample 4 Head classification: 3	Sample 4 Shaft classification: 3
	 

CODE: OB-C-Pn	
Sample 1 Head classification: 1	Sample 1 Shaft classification: 3
	 
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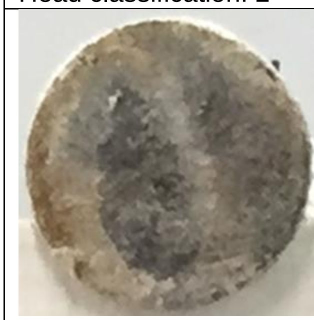	 
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Sample 4 Head classification: 2	Sample 4 Shaft classification: 3
	 

CODE: II-A-H-F	
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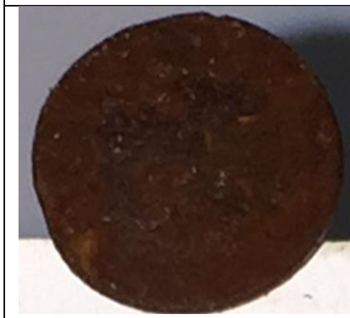	 
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Sample 3 Head classification: 8	Sample 3 Shaft classification: 8
	 

CODE: II-A-H-S	
Sample 1 Head classification: 8	Sample 1 Shaft classification: 8
	 
Sample 2 Head classification: 7	Sample 2 Shaft classification: 7
	 
Sample 3 Head classification: 8	Sample 3 Shaft classification: 7
	 

CODE: II-A-H-W	
Sample 1 Head classification: 8	Sample 1 Shaft classification: 8
	 
Sample 2 Head classification: 6	Sample 2 Shaft classification: 7
	 
Sample 3 Head classification: 8	Sample 3 Shaft classification: 8
	 

CODE: II-B-Pn-F	
Sample 1 Head classification: 8	Sample 1 Shaft classification: 3
	 
Sample 2 Head classification: 8	Sample 2 Shaft classification: 8
	 
Sample 3 Head classification: 4	Sample 3 Shaft classification: 3
	 

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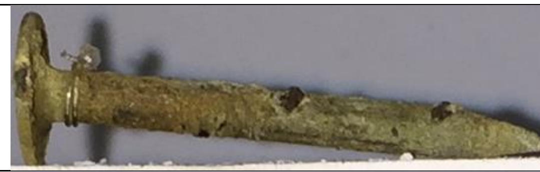
<tr><td rowspan="2"></td><td></td></tr>
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Sample 2 Head classification: 1	Sample 2 Shaft classification: 1
	 
Sample 3 Head classification: 3	Sample 3 Shaft classification: 3
	 

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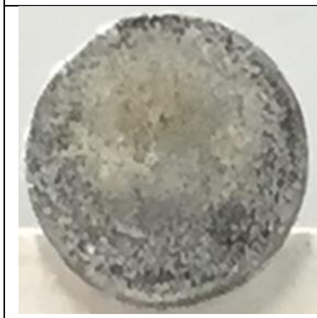
<tr><td rowspan="2"></td><td></td></tr>
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Shaft classification: 3</td></tr>
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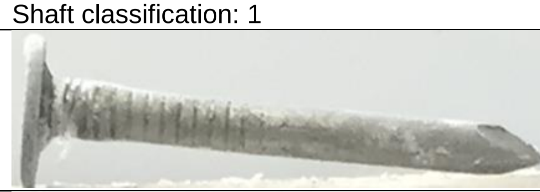
<tr><td rowspan="2"></td><td></td></tr>
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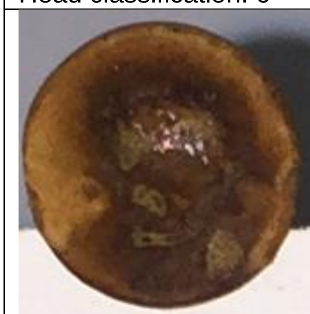
<tr><td rowspan="2"></td><td></td></tr>
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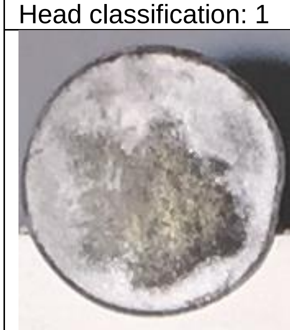
<tr><td rowspan="2"></td><td></td></tr>
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Sample 3 Head classification: 2	Sample 3 Shaft classification: 6
	 

CODE: II-C-Pn-F	
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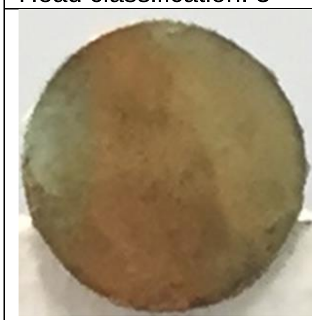
Sample 2 Head classification: 3	Sample 2 Shaft classification: 4
	 
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CODE: II-C-Pn-S	
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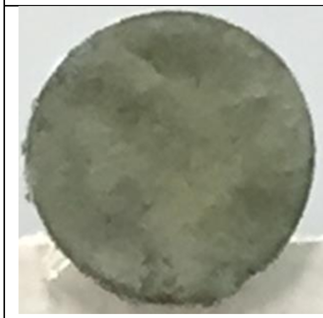	 
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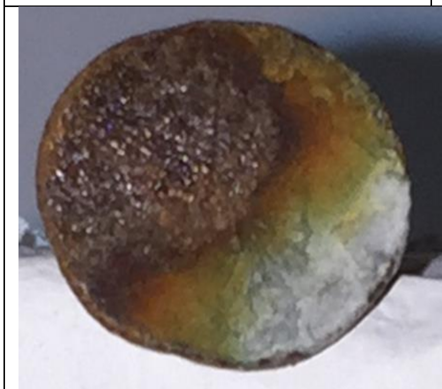		

CODE: I-A-H-S		
Sample 1 Classification: 7	Sample 2 Classification: 6	Sample 3 Classification: 3
		

CODE: I-A-H-W		
Sample 1 Classification: 8	Sample 2 Classification: 7	Sample 3 Classification: 8
		

CODE: I-B-Pn-F		
Sample 1 Classification: 2	Sample 2 Classification: 3	Sample 3 Classification: 3
		

CODE: I-B-Pn-S		
Sample 1 Classification: 8	Sample 2 Classification: 5	Sample 3 Classification: 4
		

CODE: I-B-Pn-W		
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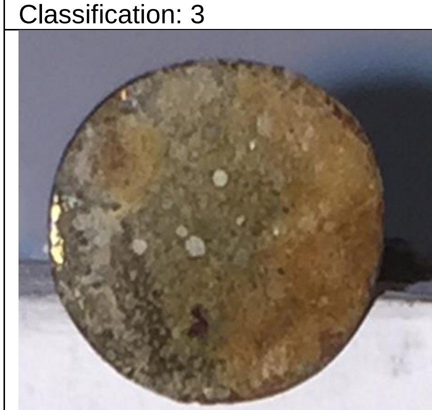		

CODE: I-C-H-F		
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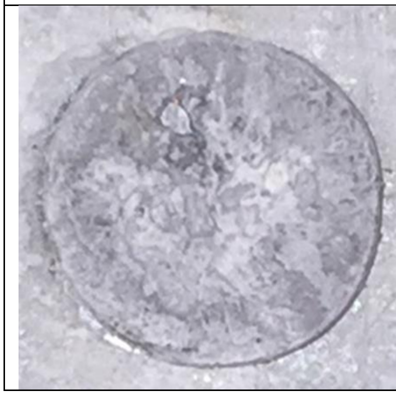		

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		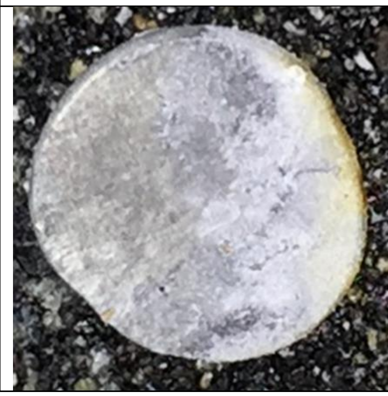

CODE: I-C-H-W		
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CODE: I-C-Pn-F		
Sample 1 Classification: 1	Sample 2 Classification: 1	Sample 3 Classification: 1
		

CODE: I-C-Pn-S		
Sample 1 Classification: 3	Sample 2 Classification: 3	Sample 3 Classification: 3
		

CODE: I-C-Pn-W		
Sample 1 Classification: 1	Sample 2 Classification: 3	Sample 3 Classification: 2