ILZRO RESEARCH PROGRAM ZC-26

Performance of galvanized steel coupons & nails in contact with preservative treated wood

Prepared for
ILZRO

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REVIEW DRAFT

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NAHB RESEARCH CENTER℠

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Disclaimer

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EXECUTIVE SUMMARY

International Zinc Association (formerly ILZRO) Project ZC-26, Project on Pressure Treated Wood, is a research effort aimed at providing relevant performance data for galvanized steel products used in combination with wood preservative treatments.

The NAHB Research Center commenced work on this project in October of 2007 with the construction of an outdoor test deck at its campus in Upper Marlboro, MD. The test deck was completed in November of 2007 and corrosion test specimens were installed in April of 2008. The specimens consisted of G90 and G185 galvanized coated steel coupons attached to ACQ-D or CA-B preservative treated wood. The specimens were attached using typical joist hanger nails with two different galvanized coatings, hot dipped galvanized and hot galvanized. A total of eight sets of test specimens were installed. Four sets of control specimens were also installed; two indoors and two outdoors underneath the test deck.

A total of four retrievals were conducted over the first year at 3-month intervals. Mass loss measurements from all four exposure periods demonstrate that specimens attached directly to preservative treated wood exhibited significantly greater mass loss than those specimens not attached to preservative treated wood. On average, specimens attached to preservative treated wood exhibited five times greater mass loss than the control specimens exposed to the same environmental conditions. Specimens attached to ACQ-D preservative treated wood exhibited 1.4 greater mass losses on average than those attached to CA-B treated wood. Less than 9% of the specimens attached to treated wood showed damage to the base metal. Where damage did occur it was in the form of minor pitting around the nail locations. Mass loss measurements from both nail coating types demonstrated that nails coated by the hot dipped galvanizing process exhibited far greater mass loss on average than nails coated by the hot galvanizing process. Hot dipped galvanized nails, however, did not exhibit damage to the base metal, where as several hot galvanized nail specimens exhibited minor pitting.

INTRODUCTION

Lumber products used in residential construction in areas where they are exposed to moisture are typically pressure treated with chemicals to prevent mold and rot. Historically, one of the most widely used chemical treatments was Chromate Copper Arsenate (CCA). As of December 31, 2003 the use of CCA chemical treatment was discontinued by the wood preservative industry. Several alternative types of treatment were introduced, including Arcylated Copper Quaternary (ACQ) and Copper Azoles (CA). One drawback to these new treatments is the added amount of copper that they contain, which can accelerate the corrosion of adjoining metal framing and connectors.

Several studies have been conducted to investigate the performance of metals and galvanized coatings used in combination with these new treatments [1][2][3]. One such study done by the NAHB Research Center in 2007 [3], investigated the relative performance of four different zinc coatings attached to CCA, CA and ACQ treated wood when exposed to an accelerated salt spray test program. Results showed that metal specimens attached to ACQ and CA pressure treated wood exhibited greater mass loss that those specimens attached to CCA treated wood.

PURPOSE

The purpose of this research program is to investigate the corrosion performance of zinc coated sheet metal products in contact with ACQ-D and CA-B preservative wood treatments placed in an outdoor environment.

TEST MATERIALS

Testing was conducted at the NAHB Research Center located in Upper Marlboro, MD. The sheet metal coupon samples were provided by Simpson Strong-Tie Company, Inc. All other test materials were purchased from local providers.

Table 1 provides a summary of the specimen and deck materials used in the testing.

Table 1 – Test materials

Coupon Specimens	
2.875-inch by 4-inch coupons	0.033” nominal thickness G90 zinc coating (0.90 oz/ft^2)
	0.054” nominal thickness G185 zinc coating (1.85 oz/ft^2)
Nail Specimens	
9 gauge (0.15-inch) x 1.5-inch Grip Rite Fas’ner joist hanger nails	Hot dipped galvanized (designated HDG for testing)
	Hot galvanized (designated HG for testing)
Deck Joist Lumber	
Nominal 2x8 Southern Yellow Pine #2 grade pressure treated lumber	Arcylated Copper Quaternary, Type D (ACQ-D) w/ 0.25 pcf retention
	Copper Azole, Type B (CA-B) w/ 0.10 pcf retention

Sheet metal specimens received from Simpson were 3.5 inches by 12 inches in size. The coupons were divided into three, 2.875-inch by 4-inch size samples. All four edges of each sample were sheared and had no galvanized coating.

TEST METHOD

Table 2 provides a test matrix outlining the number of retrieved specimens of the various combinations of coupon coating thickness, fastener type and wood preservative treatment. Each coupon specimen had a 3/16-inch nail hole pre-drilled near each end and was labeled according to the test matrix. After pre-drilling and labeling, each specimen's initial weight was measured using a digital electronic balance with a precision of 0.0001 grams. Initial specimen thickness was also measured at three locations using an electronic micrometer with a precision of 0.00001 inches. Each set of nails was also measured for initial weight prior to installation.

Table 2 – Test matrix

Wood Preservative Treatment	Coupon Galvanized Coating Thickness	Nail Galvanized Coating Type	Exposure Duration			
			3 months	6 months	9 months	12 months
CA-B	G90	HDG	3	3	3	3
		HG	3	3	3	3
	G185	HDG	3	3	3	3
		HG	3	3	3	3
ACQ-D	G90	HDG	3	3	3	3
		HG	3	3	3	3
	G185	HDG	3	3	3	3
		HG	3	3	3	3
Outdoor Controls	G90	---	3	3	3	3
	G185	---	3	3	3	3
Indoor Controls	G90	---	3	3	3	3
	G185	---	3	3	3	3

All twelve sets of specimens were installed in April of 2008. Figure 1 provides a photo of the test deck. The deck is approximately 3 feet off of the ground and constructed with 2x8 joists spaced at 24 inches on center and 2x6 deck boards attached to each joist with two wood screws. There is a 1/16 inch gap between each deck board.

Specimens were installed on the faces of the deck joists, spaced at approximately 4 inches on center. The joists were pre-drilled using a 1/8-inch diameter drill bit. This diameter is slightly smaller than the fastener diameter and allowed the specimens to be installed and removed with the least amount of damage. The nails were installed using a rubber headed mallet and driven until the entire face of the coupon was in contact with the joist. Figure 2 provides a photo of the installed specimens.

Figure 1 – Test deck

Figure 2 – Installed specimens

Two sets of control specimens not in contact with preservative treated wood were also tested. The first set of controls was hung underneath the test deck between the deck joists (see Figure 3) and was exposed to the same environmental conditions as the specimens attached directly to the joists. The second set of controls was located in an interior environment with an average temperature of 72 ℉ and 55% relative humidity.

Figure 3 – Installed controls

At the end of each exposure period, three specimens of each combination of coating thickness, fastener type and preservative treatment were removed using a small nail remover wrapped in cloth to prevent damage. Upon removal, the specimens were placed with the interior controls until such time as they could be analyzed. The typical time between removal and analysis was less than one week, with the exception of the first set of retrievals which sat idle for approximately 2 months. This delay was associated with finalizing the proposed cleaning methods.

CLEANING PROTOCOL

Cleaning was conducted in two stages. The first stage removed any corrosion by-products on the specimens; the second stage removed the remaining galvanized coating and allowed the specimens to be visually inspected for damage to the base material.

The first stage of cleaning and analysis was conducted using the protocol outlined in ASTM G1-03 *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens*. The ASTM G1 standard outlines several cleaning practices suitable for metal specimens with corrosion by-products on the surface. The cleaning methods are meant to remove the corrosion by-products without removing any of the metal coating or substrate underneath. Once cleaned, the specimens can be weighed and compared to their original weight. Any subsequent weight loss is attributed to corrosion of the coating and/or substrate.

A set of preliminary cleanings were done on un-corroded galvanized samples using the Ammonium Persulfate solution (100g Ammonium Persulfate in 1000ml reagent water at 25℃) outlined in Table A1.1 of ASTM G1 (this solution is specifically recommended for use with galvanized steel specimens). The preliminary cleaning, however, yielded significant weight loss

after only three 2-minute-long cleaning cycles. This meant that the cleaning solution was attacking and removing the galvanized coating, which would skew the test results towards a higher mass loss than was actually caused by corrosion of the coating.

Therefore, an alternative cleaning solution was adopted using an Ammonium Acetate solution (100g Ammonium Acetate in 1000ml reagent water at 70°C), also outlined in Table A1.1 of ASTM G1. Preliminary testing of this solution with un-corroded specimens resulted in very minor weight loss and corresponding zinc coating removal. This weight loss was on the order of 0.005 grams and is considered negligible for the purposes of this study.

The following provides a summary of the procedure used in the first stage of cleaning for all coupon and nail specimens, including controls:

1. Before chemical cleaning, each specimen was weighed and then lightly brushed 5 times in each direction for a total of 10 passes with a non-metallic brush.
2. Specimens were then dipped in solution for 2 minutes.
3. Specimens were removed, rinsed in reagent water, and dried.
4. Specimens were weighed immediately upon drying.
5. This process was repeated for a minimum of three cycles or until the total weight loss versus time curve exhibits a sharp decrease in slope, indicating that the corrosion products have been removed

This cleaning method was effective in removing the corrosion by-products, but proved lengthy when used on specimens with heavier corrosion, requiring a large number of cleaning cycles before reaching equilibrium. Therefore, Evapo-Rust[1], an over-the-counter rust remover, was also used on the 9-month and 12-month specimens.

If equilibrium was not reached after 5 cycles of cleaning with the Ammonium Acetate solution, the specimens were additionally cleaned as follows:

6. Specimens were dipped in Evapo-Rust cleaner for 5 minutes.
7. Specimens were removed, rinsed in reagent water, and dried.
8. Specimens were weighed immediately upon drying.
9. Process was repeated until relative equilibrium was reached.

Figure 4 shows example results from the first round of cleaning of a coupon specimen using both Ammonium Acetate and Evapo-Rust cleaning solutions.

[1] Evapo-Rust" is included in the new proposed version of the AWPA E12 standard. *Standard of Determining Corrosion of Metal in Contact with Treated Wood*. American Wood Preservers Association. Birmingham, AL.

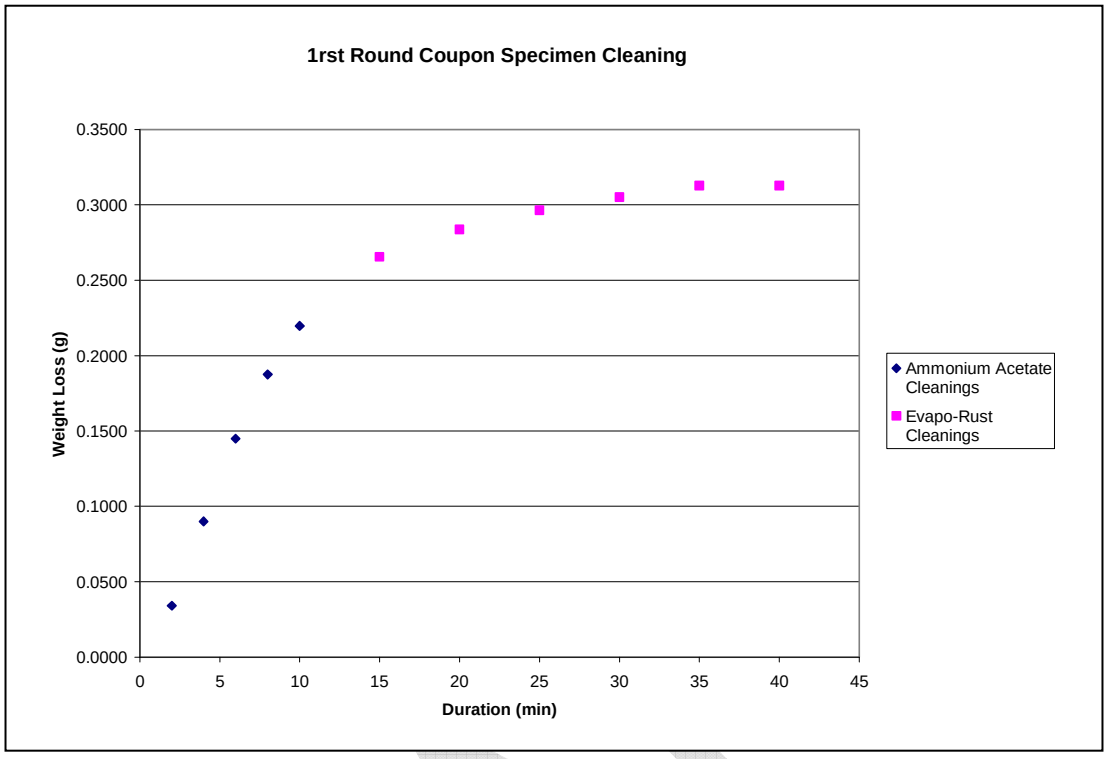


Figure 4 – Example weight loss vs. time curve during round 1 cleaning of coupon specimen

The second staged of cleanings was done in accordance with ASTM A90/A90M - 01 *Standard Test Method for Weight [Mass] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings* to bring the specimens down to bare metal. This round of cleanings used a solution of 500ml Hydrochloric Acid, 500ml reagent water and 15ml (1.5% by volume) Acid Aid GL inhibitor. The following is a summary of the stage 2 cleaning procedure:

1. Specimens were dipped in solution until the violent evolution of hydrogen has ceased, typically after 5 minutes for the coupon specimens (nail specimens took significantly longer; up to 4 hours in some cases).
2. Specimens were rinsed with water immediately after being removed from solution.
3. Specimens were dried and weighed.

ANALYSIS

The results from the coupon specimens were analyzed in accordance with Section 8 of ASTM G1-03 to determine the corrosion rate of the specimens over the exposure period. This analysis was not performed on the fastener specimens because of the difficulty in accurately determining the surface area of the fasteners.

Corrosion Rate = $\frac{KW}{ATD}$

Where:

K = 8.76 x 10^7 microns per year (µm/yr, per Section 8.1.2 of ASTM G1-03)
T = Time of exposure in hours
A = Area of both faces of specimen, in cm^2
W = Mass loss in grams
D = 7.14 g/cm^3 (Density of zinc coating in g/cm3 per Table X1.1 of ASTM G1-03)

The following is an example calculation of the corrosion rate after three months of exposure of a G185 coating specimen attached to CA-B wood with hot galvanized nails.

Specimen CABG185HG2:

T = 2,160 hrs (90 days)

A = $2*\left(\left(3.995"*2.835"\right)-\left(\frac{0.375"}{2}\right)^2\pi\right)$ (actual area of 2 sides minus drill holes)

= 143.26 cm^2

W = 0.1214 grams

Corrosion Rate = $\frac{87{,}600{,}000*0.1214g}{143.26cm^2*2{,}160hrs*7.14g/cm^3}$

= 4.81 µm/yr

RESULTS

Table 3 provides a summary of the average mass loss, in grams, of the steel coupon specimens retrieved after exposure periods of 3 months, 6 months, 9 months and 12 months.

Table 3 – Summary of average weight loss of coupon specimens

Wood Preservative Treatment	Coupon Galvanized Coating Thickness	Nail Galvanized Coating Type	Avg. Weight Loss (g) Exposure Duration			
			3 months	6 months	9 months	12 months
CA-B	G90	HDG	0.057	0.077	0.142	0.129
		HG	0.073	0.123	0.336	0.312
	G185	HDG	0.092	0.230	0.253	0.401
		HG	0.389	0.422	0.392	0.456
ACQ-D	G90	HDG	0.164	0.276	0.295	0.269
		HG	0.198	0.328	0.399	0.381
	G185	HDG	0.332	0.359	0.340	0.278
		HG	0.339	0.640	0.503	0.448
Outdoor Controls	G90	---	0.018	0.035	0.076	0.087
	G185	---	0.018	0.038	0.094	0.103
Indoor Controls	G90	---	0.006	0.017	0.032	0.028
	G185	---	0.013	0.013	0.052	0.024

Figures 5 and 6 provide comparisons of the average weight loss of the coupon specimens by wood preservative treatment type for both the G90 and G185 zinc coatings. Figure 7 provides a comparison of the average weight loss of the control specimens by location.

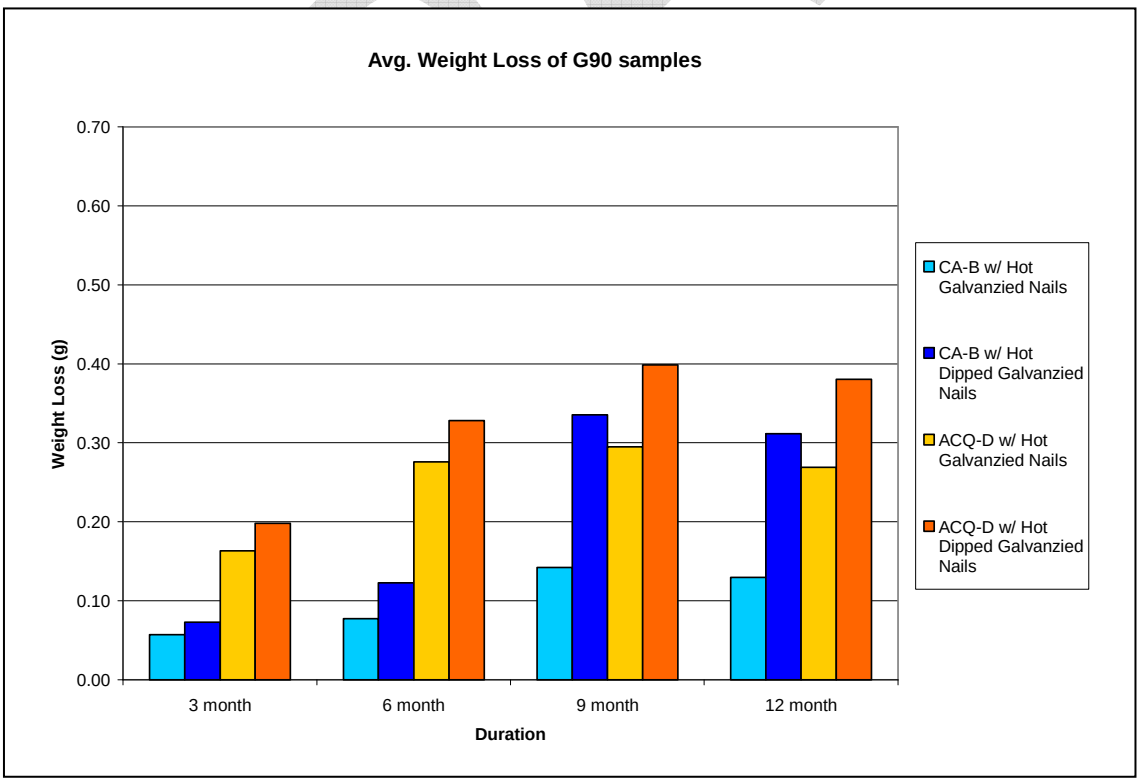


Figure 5 – Average weight loss of G90 samples

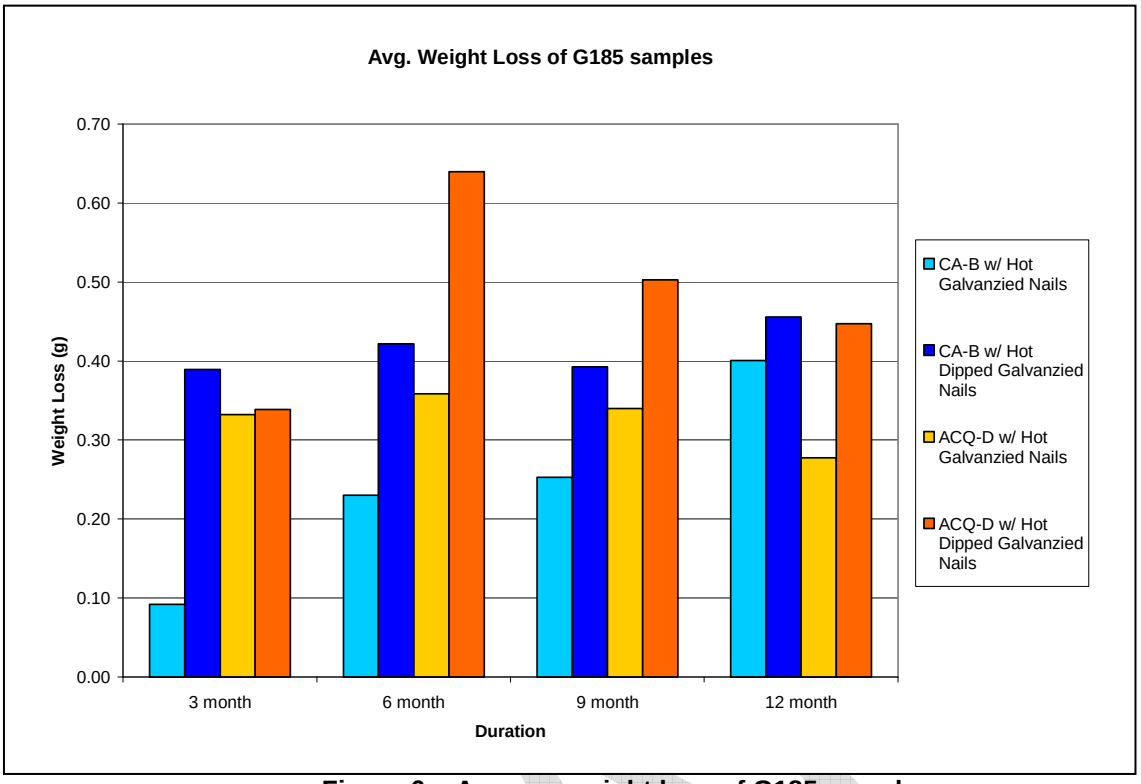


Figure 6 – Average weight loss of G185 samples

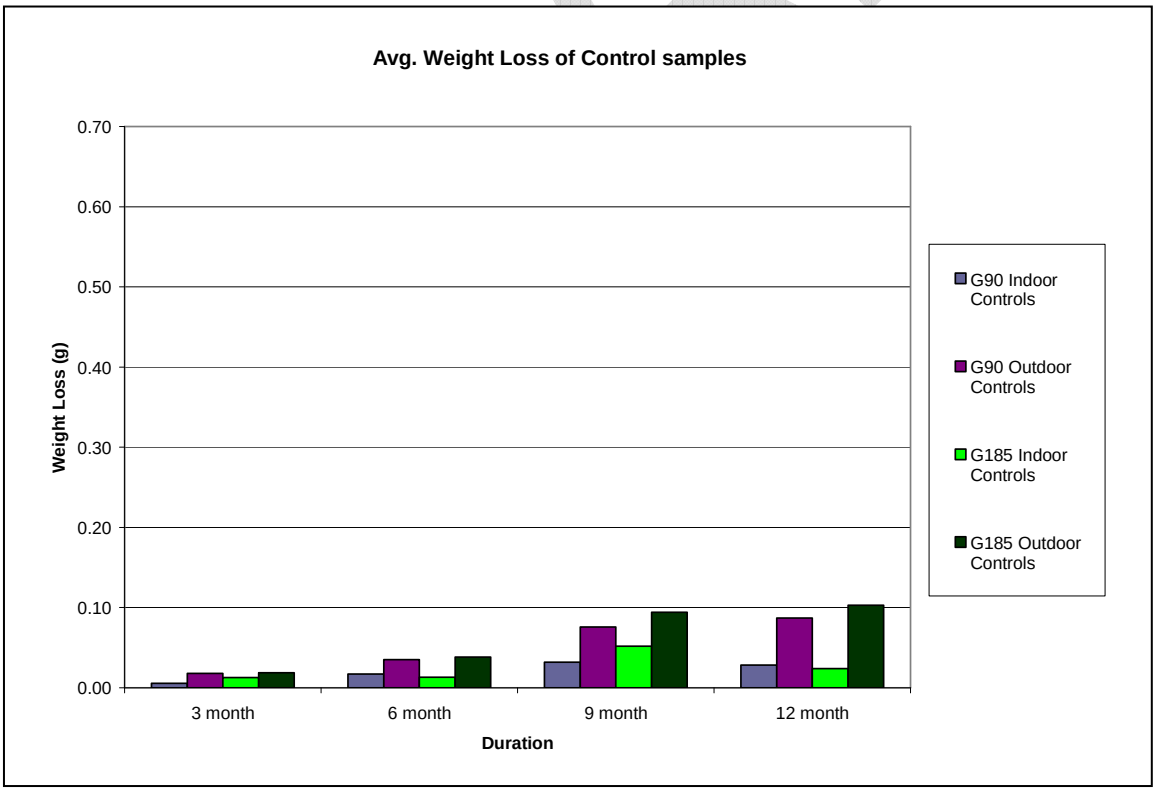


Figure 7 – Average weight loss of control samples

Table 4 provides a summary of the average corrosion rates, in microns per year, for the steel coupon specimens retrieved after exposure periods of 3 months, 6 months, 9 months and 12 months.

Table 4 – Summary of average corrosion rates of coupon specimens

Wood Preservative Treatment	Coupon Galvanized Coating Thickness	Nail Galvanized Coating Type	Avg. Corrosion Rate (µm/yr) Exposure Duration			
			3 months	6 months	9 months	12 months
CA-B	G90	HDG	2.25	1.50	1.84	1.24
		HG	2.90	2.38	4.40	2.97
	G185	HDG	3.63	4.50	3.30	3.81
		HG	10.25	8.18	5.12	4.35
ACQ-D	G90	HDG	6.49	5.38	3.82	2.58
		HG	7.90	6.40	5.18	3.62
	G185	HDG	13.18	6.97	4.39	2.66
		HG	13.51	12.36	6.55	4.29
Outdoor Controls	G90	---	0.70	0.68	0.99	0.82
	G185	---	0.73	0.49	1.23	0.98
Indoor Controls	G90	---	0.22	0.33	0.41	0.27
	G185	---	0.50	0.25	0.68	0.23

Figures 8 and 9 provide comparisons of the average rates of the coupon specimens by wood preservative treatment type for both the G90 and G185 zinc coatings. Figure 10 provides a comparison of the average corrosion rates of the control specimens by location.

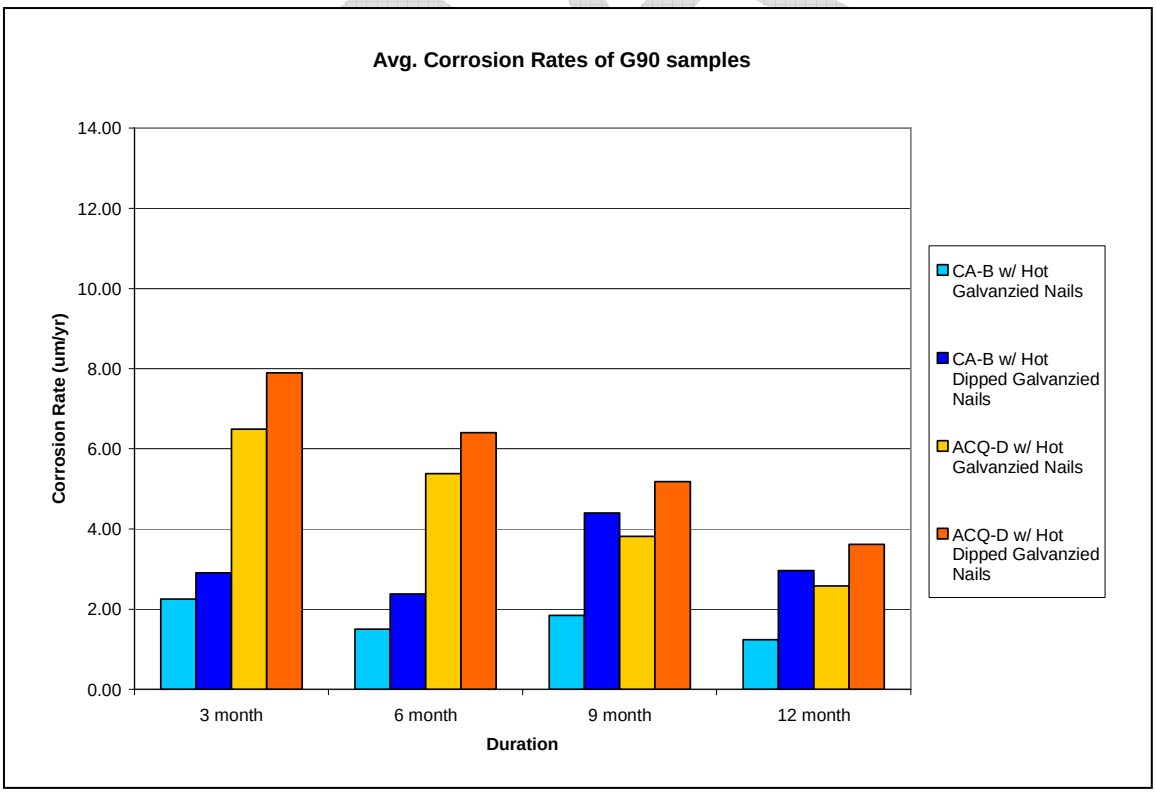


Figure 8 – Average corrosion rates of G90 samples

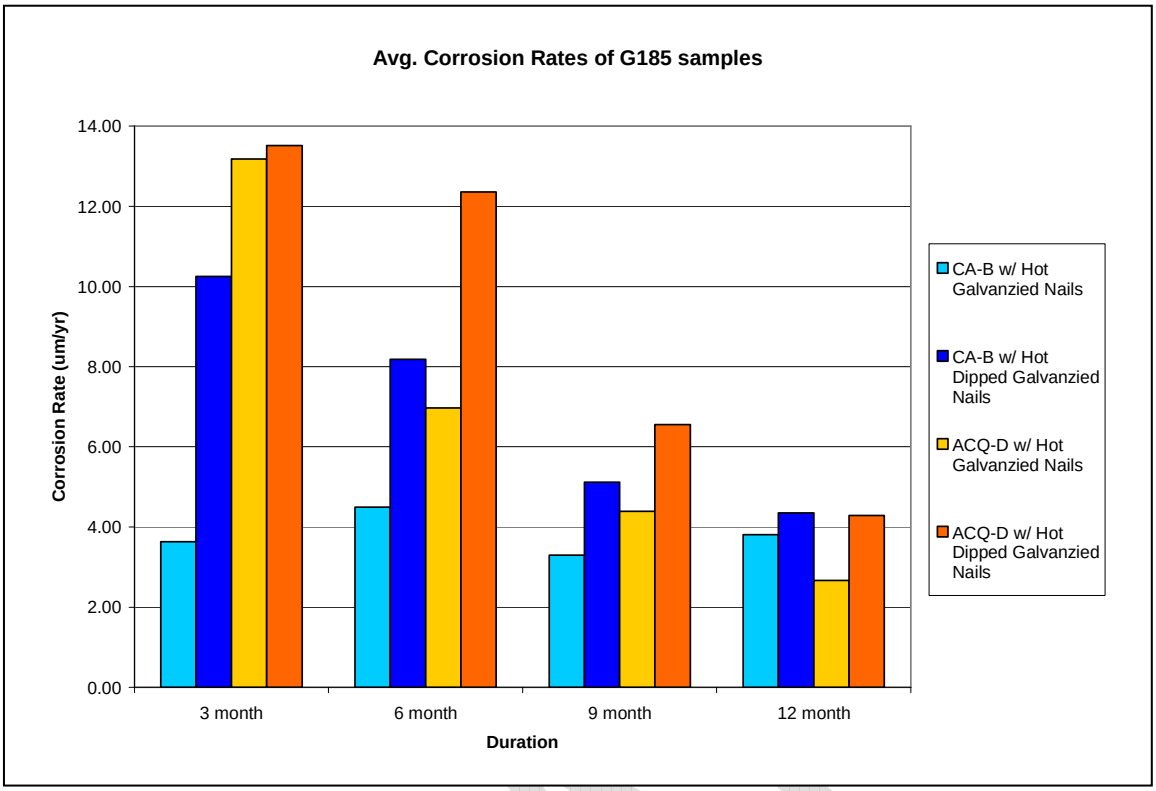


Figure 9 – Average corrosion rates of G185 samples

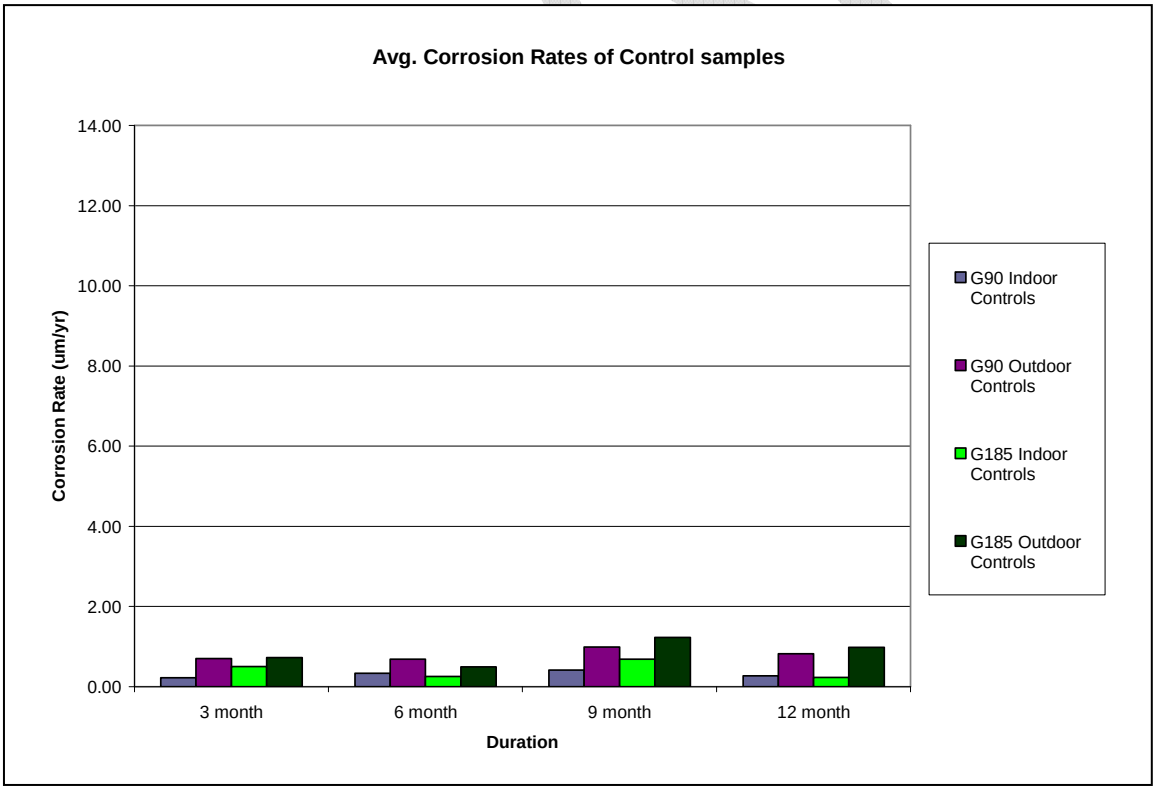


Figure 10 – Average corrosion rates of control samples

Table 5 shows a summary of the average weight loss, in grams, of the two fastener types after the 3-month, 6-month, 9-month and 12-month exposure periods.

Table 5 – Summary of average weight loss of fastener specimens

Wood Preservative Treatment	Nail Galvanized Coating Type	Avg. Weight Loss (g)			
		Exposure Duration			
		3 months	6 months	9 months	12 months
CA-B	HDG	0.001	0.000	-0.002	0.001
	HG	0.019	0.024	0.096	0.071
ACQ-D	HDG	0.001	0.006	-0.001	0.002
	HG	0.061	0.100	0.116	0.069

Figure 11 provides a comparison of the average weight loss of the fasteners by coating and wood preservative treatment type.

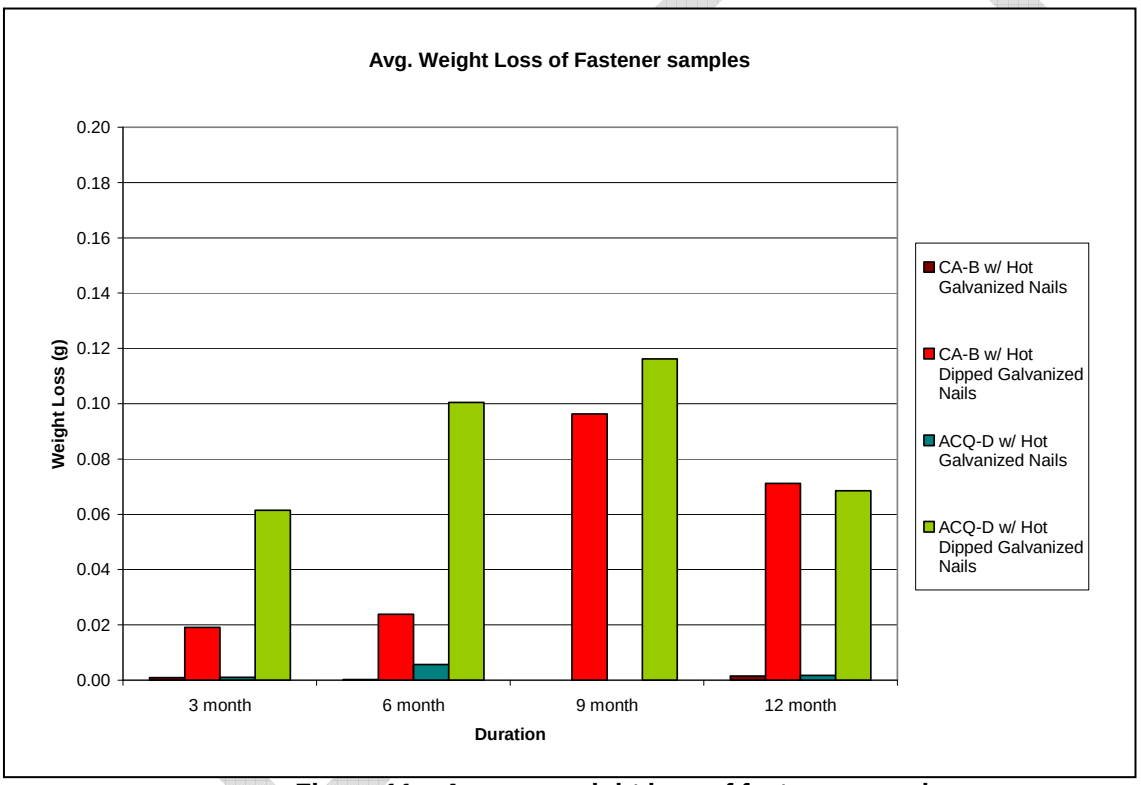


Figure 11 – Average weight loss of fastener samples

Exterior weather conditions, including the daily average temperature, relative humidity and total rain fall were monitored over the course of the study. Figure 12 provides a summary of the exterior weather data collected.

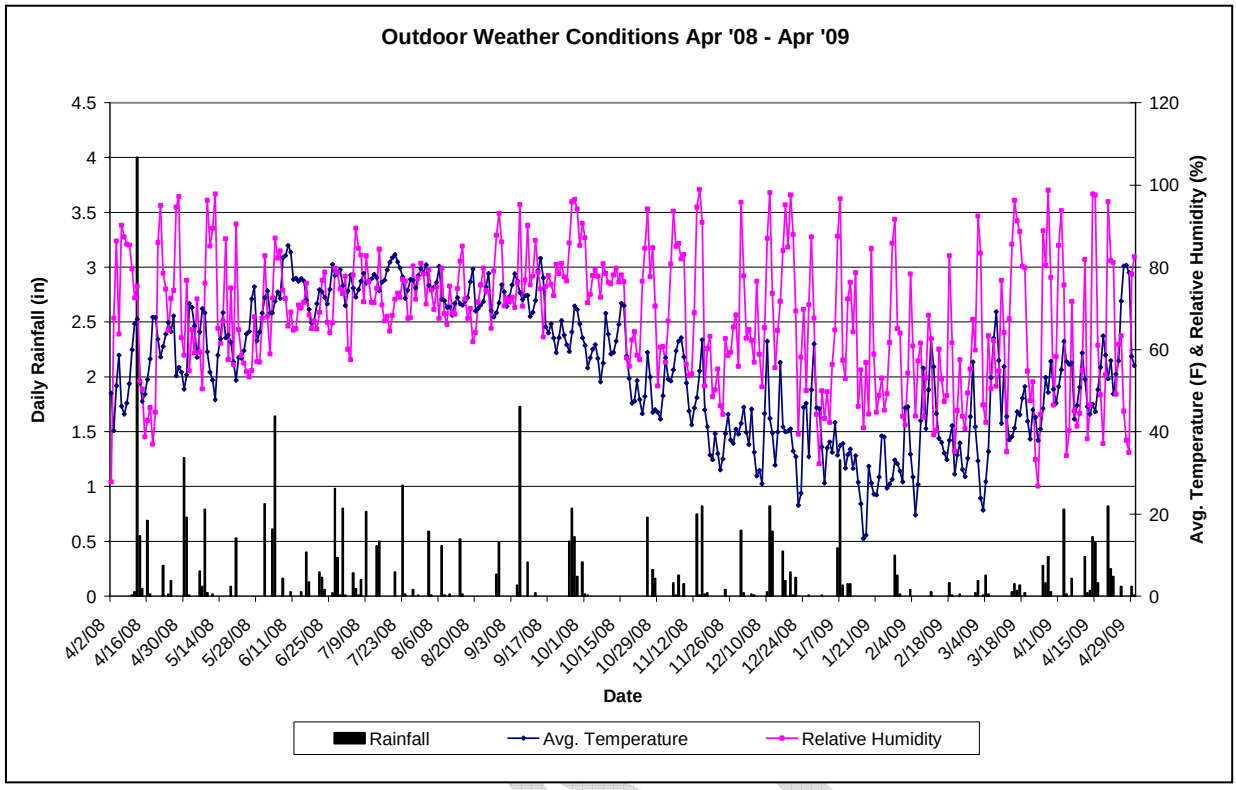
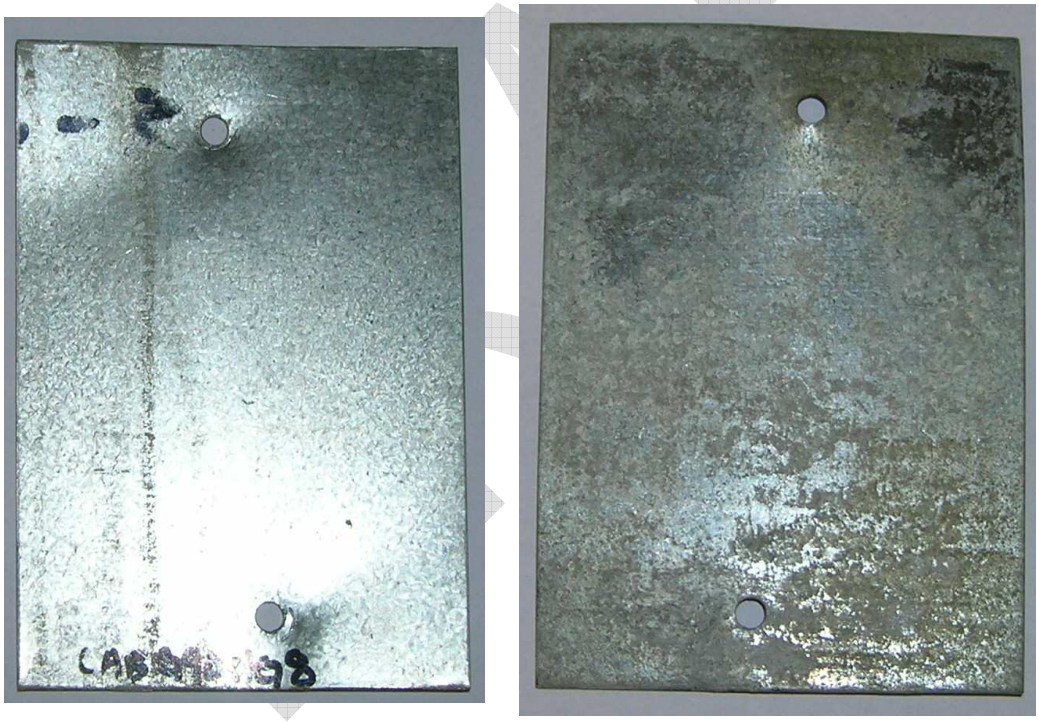


Figure 12 – Exterior weather data (April 2008 – April 2009)

ANALYSIS

The specimens directly attached to the pressure treated lumber exhibited significantly greater mass loss than the outdoor control specimens that were hung from the framing lumber. Specimens with G90 coating that were attached to pressure treated lumber exhibited four times greater mass loss on average than the corresponding outdoor control specimens. The G185 coated specimens exhibited nearly six times greater mass loss on average than the outdoor controls. The mass loss of the G90 coated specimens followed a general increasing trend over time, where as the mass loss of the G185 coated specimens tended to level off. This leveling off is most likely due to the formation of a protective layer of white rust corrosion by-products over time that helped prevent further corrosion of the specimen. The thinner coating of the G90 specimens did not allow for sufficient development of this protective layer before corrosion of the base metal occurred (shown by the presence of red rust).

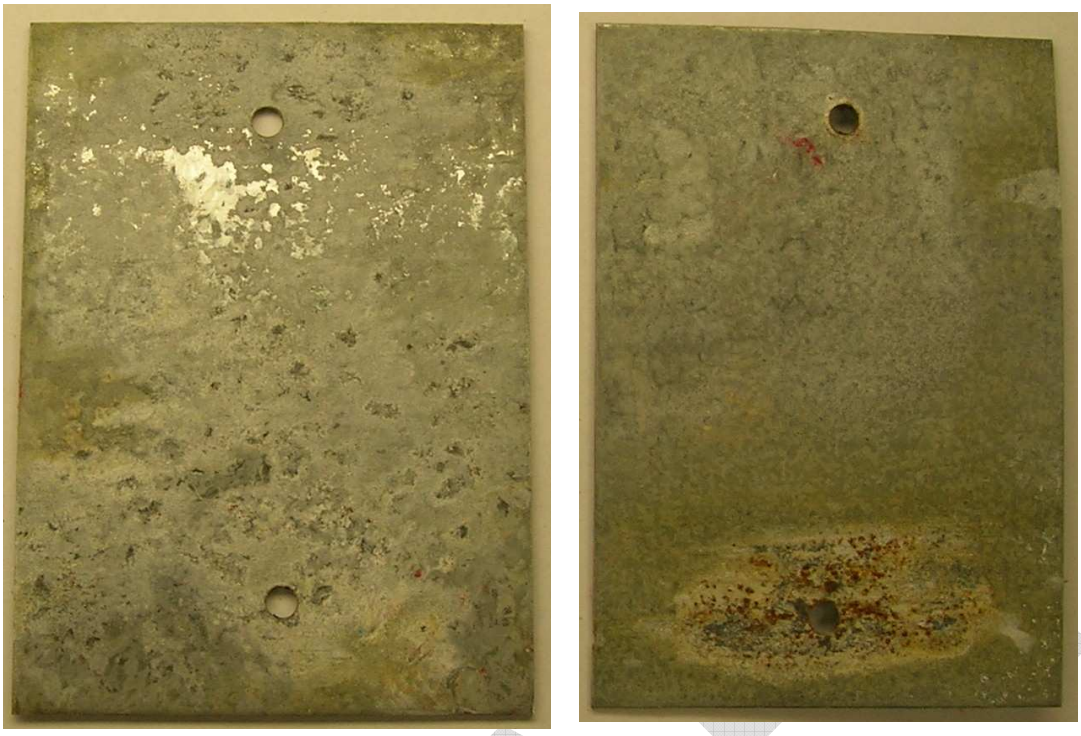
In all specimens and over all exposure periods, the face of the specimen in direct contact with the pressure treated lumber exhibited far greater corrosion and corrosion product that the exposed face of the specimen (See Figure 13).



Exposed Face Contacting Face

Figure 13 – Corrosion of exposed and contacting faces of a typical coupon specimen

Specimens tended to have corrosion across the entire contacting face, with the most severe corrosion occurring around the nail locations. Figure 14 provides an example of the typical corrosion patterns observed in both the G185 coated and G90 coated specimens.



G185 coating G90 coating

Figure 14 – Typical patterns of corrosion for G185 and G90 coated samples

For specimens coated with the G185 galvanized coating, the localized corrosion was minimal. For approximately half of the G90 coated specimens the localized corrosion was more pronounced with several specimens from both the 6-month and 12-month exposure periods showing complete removal of the galvanized coating, but only very minor pitting of the base metal. The most severe case of pitting occurred in a G90 specimen that was attached to ACQ-D wood with hot dipped galvanized nails (Figure 15).

Figure 15 – Pitting of G90 specimen (zinc coating removed) after 12 months of exposure

Results shown in Figures 5 and 6 exhibit a correlation between the type of preservative treatment and the amount of mass loss, with the specimens attached to lumber treated with the ACQ-D treatment showing higher mass losses compared to those attached to CA-B treated lumber (for the same coating and fastener type).

Figures 5 and 6 also indicated a correlation between mass loss and the coating type of the fastener. Specimens attached with hot dipped galvanized coated nails consistently experienced greater mass losses than specimens attached with hot galvanized coated nails. One possible reason for this is the difference in corrosion characteristics between the two fasteners and the fact that they were both in electrical contact with the coupon specimens. By being part of the galvanic circuit, the fasteners increased the surface area available for galvanic reaction and in turn increased the corrosion rate of the adjoining coupon specimen. This is in line with the greater mass loss exhibited by the hot dipped galvanized nails compared to the hot galvanized nails.

As shown in figure 11, the nail type fasteners attached to lumber treated with the ACQ-D system experienced greater mass loss, on average, over those nails attached to CA-B treated wood three out of the four exposure periods. This correlation is similar to the correlation between mass loss and treatment type seen for the coupon specimens. Only during the 12-month exposure period did the CA-B attached nails suffer greater mass loss on average, and then only by approximately 0.002 grams compared to an average of 0.046 grams less weight loss compared to ACQ-D over the previous three exposure periods.

Figure 11 also shows significant difference in weight loss between nail coating types, with the hot dipped galvanized nails losing 0.068 more grams on average compared to the hot galvanized nails. The hot dipped galvanized nails exhibited surface corrosion in the form of white and red rust over the entire shank of the nails (see Figure 16). The hot galvanized nails exhibited only localized red rust in the areas where the coating had been removed, presumably during installation (see Figure 16).

Hot galvanized nail Hot dipped galvanized nail

Figure 16 – Corrosion of nails after 12 months of exposure (before cleaning)

After removal of the zinc coating, the hot dipped galvanized nails showed little to no damage of the base metal. The hot galvanized nails, however, showed some minor pitting of the base metal after 12 months of exposure and removal of the zinc coating. Figure 17 shows the most severe example of pitting on a hot galvanized nail (nail had attached a G90 coupon to ACQ-D wood).

Figure 17 – Pitting of hot galvanized nail (zinc coating removed) after 12 months of exposure

CONCLUSIONS

Based on the results of this study, the following observations regarding the performance of galvanized steel coupons and galvanized zinc coated nails in contact with preservative treated wood can be made:

1. Coupon specimens that were attached directly to preservative treated wood exhibited between four to six times greater mass loss on average than specimens not attached to preservative treated wood.
2. Coupon specimens attached to ACQ-D preservative treated wood exhibited 1.4 times greater mass loss on average than specimens attached to CA-B treated wood.
3. Coupon specimens that were attached using hot dipped galvanized coated nails exhibited greater mass loss on average than specimens attached with hot galvanized nails.
4. Less than 9% of all coupon specimens tested showed damage to the base metal.
5. Nail specimens tested in ACQ-D preservative treated wood exhibited greater mass loss than nails tested in CA-B treated wood in three out of the four exposure periods.
6. Nail specimens coated by the hot dipped galvanizing process exhibited greater mass loss on average than nails coated by the hot galvanized process.
7. Hot galvanized coated nails after 12 months of exposure were the only nail specimens to exhibit visible damage to the base metal. When damage was present, it was in the form of minor pitting.

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APPENDIX

3 Month Retrieval Results – Coupon Specimens

Sample Name	Initial Weight (g)	First Clean Weight (g)	Weight Loss (g)	Avg. Weight Loss (g)
CABG90HG1	51.0896	51.0616	0.0280	
CABG90HG2	50.9158	50.8448	0.0710	0.0571
CABG90HG3	51.1078	51.0354	0.0724	
CABG90HDG1	50.7518	50.6252	0.1266	
CABG90HDG2	50.5300	50.4976	0.0324	0.0731
CABG90HDG3	50.3254	50.2650	0.0604	
CABG185HG1	85.7220	85.6938	0.0282	
CABG185HG2	85.7552	85.6338	0.1214	0.0920
CABG185HG3	84.9546	84.8282	0.1264	
CABG185HDG1	86.7050	86.3380	0.3670	
CABG185HDG2	87.1824	86.7708	0.4116	0.3893
CABG185HDG3	84.4548	85.8604	---	
ACQG90HG1	52.0312	51.8514	0.1798	
ACQG90HG2	50.1654	50.0338	0.1316	0.1635
ACQH90HG3	49.8154	49.6362	0.1792	
ACQG90HDG1	50.0120	49.8252	0.1868	
ACQG90HDG2	50.9476	50.7340	0.2136	0.1981
ACQG90HDG3	50.6350	50.4410	0.1940	
ACQG185HG1	84.7864	84.5908	0.1956	
ACQG185HG2	86.5902	86.3532	0.2370	0.3321
ACQG185HG3	85.3818	84.8180	0.5638	
ACQG185HDG1	84.5442	84.2022	0.3420	
ACQG185HDG2	85.6096	85.3278	0.2818	0.3387
ACQG185HDG3	83.9962	83.6038	0.3924	
Controls - Out				
G90-1	52.1410	52.1240	0.0170	
G90-2	50.4884	50.4710	0.0174	0.0177
G90-3	51.1388	51.1200	0.0188	
G185-1	86.5212	86.5018	0.0194	
G185-2	85.3058	85.2896	0.0162	0.0184
G185-3	86.5756	86.5560	0.0196	
Controls - In				
G90-1	50.6884	50.6792	0.0092	
G90-2	50.2688	50.2542	0.0146	0.0055
G90-3	50.7448	50.7520	-0.0072	
G185-1	85.7590	85.7480	0.0110	
G185-2	86.2032	86.1894	0.0138	0.0127
G185-3	86.7986	86.7854	0.0132	

3 Month Retrieval Results – Nail Specimens

Sample Name	Initial Weight (g)	First Clean Weight (g)	Weight Loss (g)	Avg. Weight Loss (g)
NCABG90HG1-1	3.5166	3.5154	0.0012	0.0015
NCABG90HG1-2	3.4226	3.4188	0.0038	
NCABG90HG2-1	3.3064	3.3058	0.0006	
NCABG90HG2-2	3.4998	3.4994	0.0004	
NCABG90HG3-1	3.5432	3.4090	---	
NCABG90HG3-2	3.5808	3.6186	---	
NCABG90HDG1-1	3.6456	3.6250	0.0206	0.0098
NCABG90HDG1-2	3.5380	3.5322	0.0058	
NCABG90HDG2-1	3.7520	3.7486	0.0034	
NCABG90HDG2-2	3.7210	3.7000	0.0210	
NCABG90HDG3-1	3.5630	3.5592	0.0038	
NCABG90HDG3-2	3.5540	3.5500	0.0040	
NCABG185HG1-1	3.5980	3.5974	0.0006	0.0005
NCABG185HG1-2	3.3648	3.3644	0.0004	
NCABG185HG2-1	3.6660	3.6656	0.0004	
NCABG185HG2-2	3.5906	3.5900	0.0006	
HCABG185HG3-1	3.4162	3.4158	0.0004	
HCABG185HG3-2	3.6686	3.6680	0.0006	
NCABG185HDG1-1	3.5624	3.5494	0.0130	0.0284
NCABG185HDG1-2	3.5920	3.5580	0.0340	
NCABG185HDG2-1	3.9604	3.9456	0.0148	
NCABG185HDG2-2	3.7446	3.7092	0.0354	
NCABG185HDG3-1	3.8532	3.8300	0.0232	
NCABG185HDG3-2	3.6052	3.5554	0.0498	
NACQG90HG1-1	3.4406	3.4390	0.0016	0.0006
NACQG90HG1-2	3.4242	3.4246	-0.0004	
NACQG90HG2-1	3.3980	3.3964	0.0016	
NACQG90HG2-2	3.5758	3.5770	-0.0012	
NACQG90HG3-1	3.5852	3.5836	0.0016	
NACQG90HG3-2	3.4136	3.4132	0.0004	
NACQG90HDG1-1	3.4648	3.4586	0.0062	0.0478
NACQG90HDG1-2	3.6714	3.5974	0.0740	
NACQG90HDG2-1	3.5658	3.5506	0.0152	
NACQG90HDG2-2	3.6276	3.5584	0.0692	
NACQG90HDG3-1	3.6602	3.5960	0.0642	
NACQG90HDG3-2	3.8756	3.8178	0.0578	
NACQG185HG1-1	3.5374	3.5358	0.0016	0.0014
NACQG185HG1-2	3.4912	3.4882	0.0030	
NACQG185HG2-1	3.4650	3.4648	0.0002	
NACQG185HG2-2	3.4486	3.4472	0.0014	
NACQG185HG3-1	3.5248	3.5244	0.0004	
NACQG185HG3-2	3.5316	3.5298	0.0018	
NACQG185HDG1-1	3.5818	3.5130	0.0688	0.0752
NCAQG185HDG1-2	3.6492	3.5928	0.0564	
NACQG185HDG2-1	3.8134	3.6828	0.1306	
NACQG185HDG2-2	3.7134	3.6136	0.0998	
NACQG185HDG3-1	3.7404	3.6470	0.0934	
NACQG185HDG3-2	3.5266	3.5246	0.0020	

6 Month Retrieval Results – Coupon Specimens

Sample Name	Initial Weight (g)	First Clean Weight (g)	Weight Loss (g)	Avg. Weight Loss (g)
CABG90HG4	50.0520	49.9522	0.0998	0.0775
CABG90HG5	51.5246	51.4542	0.0704	
CABG90HG6	52.9702	52.9080	0.0622	
CABG90HDG4	50.9046	50.7486	0.1560	0.1226
CABG90HDG5	51.5594	51.4136	0.1458	
CABG90HDG6	50.9500	50.8840	0.0660	
CABG185HG4	85.8196	85.6060	0.2136	0.2301
CABG185HG5	85.8610	85.5930	0.2680	
CABG185HG6	85.2540	85.0454	0.2086	
CABG185HDG4	85.8854	85.3516	0.5338	0.4220
CABG185HDG5	84.0982	83.6500	0.4482	
CABG185HGD6	85.8100	85.5260	0.2840	
ACQG90HG4	51.0680	50.7494	0.3186	0.2758
ACQG90HG5	51.5264	51.2440	0.2824	
ACQG90HG6	49.8422	49.6158	0.2264	
ACQG90HDG4	51.1518	50.7162	0.4356	0.3284
ACQG90HDG5	50.5014	50.0916	0.4098	
ACQG90HDG6	50.8434	50.7036	0.1398	
ACQG185HG4	84.5840	84.2392	0.3448	0.3588
ACQG185HG5	87.3140	87.0900	0.2240	
ACQG185HG6	85.4756	84.9680	0.5076	
ACQG185HDG4	86.4354	85.8904	0.5450	0.6397
ACQG185HDG5	87.7116	86.9186	0.7930	
ACQG185HDG6	85.1380	84.5568	0.5812	
Controls - Out				
G90-4	50.4314	50.3982	0.0332	0.0349
G90-5	51.1758	51.1424	0.0334	
G90-6	50.9032	50.8652	0.0380	
G185-4	87.3880	87.3452	0.0428	0.0383
G185-5	86.4294	86.0403	---	
G185-6	87.6846	87.6508	0.0338	
Controls - In				
G90-4	50.4434	50.4258	0.0176	0.0171
G90-5	50.8888	50.8740	0.0148	
G90-6	51.3880	51.3692	0.0188	
G185-4	85.4238	85.4122	0.0116	0.0129
G185-5	86.7420	86.7302	0.0118	
G185-6	87.1024	87.0870	0.0154	

6 Month Retrieval Results – Nail Specimens

Sample Name	Initial Weight (g)	First Clean Weight (g)	Weight Loss (g)	Avg. Weight Loss (g)
NCABG90HG4-1	3.4098	3.5432	---	
NCABG90HG4-2	3.5740	3.5746	-0.0006	
NCABG90HG5-1	3.5538	3.5570	-0.0032	-0.0005
NCABG90HG5-2	3.5214	3.5210	0.0004	
NCABG90HG6-1	3.3794	3.3792	0.0002	
NCABG90HG6-2	3.5032	3.5026	0.0006	
NCABG90HDG4-1	3.6456	3.6360	0.0096	
NCABG90HDG4-2	3.6832	3.6576	0.0256	
NCABG90HDG5-1	3.6338	3.6250	0.0088	0.0221
NCABG90HDG5-2	3.7646	3.7346	0.0300	
NCABG90HDG6-1	3.5372	3.5234	0.0138	
NCABG90HDG6-2	3.7266	3.6818	0.0448	
NCABG185HG4-1	3.3956	3.3950	0.0006	
NCABG185HG4-2	3.5884	3.5882	0.0002	
NCABG185HG5-1	3.5762	3.5750	0.0012	0.0007
NCABG185HG5-2	3.5930	3.5926	0.0004	
HCABG185HG6-1	3.6202	3.6198	0.0004	
HCABG185HG6-2	3.6102	3.6090	0.0012	
NCABG185HDG4-1	3.6558	3.6314	0.0244	
NCABG185HDG4-2	3.6578	3.6178	0.0400	
NCABG185HDG5-1	3.5420	3.5262	0.0158	0.0255
NCABG185HDG5-2	3.7484	3.7202	0.0282	
NCABG185HDG6-1	3.6402	3.6152	0.0250	
NCABG185HDG6-2	3.7010	3.6812	0.0198	
NACQG90HG4-1	3.4432	3.4444	-0.0012	
NACQG90HG4-2	3.6700	3.6030	0.0670	
NACQG90HG5-1	3.2086	3.2098	-0.0012	0.0104
NACQG90HG5-2	3.5986	3.5968	0.0018	
NACQG90HG6-1	3.5624	3.5618	0.0006	
NACQG90HG6-2	3.4980	3.5024	-0.0044	
NACQG90HDG4-1	3.5766	3.5676	0.0090	
NACQG90HDG4-2	3.7952	3.7372	0.0580	
NACQG90HDG5-1	3.5660	3.5456	0.0204	0.0678
NACQG90HDG5-2	3.7284	3.5304	0.1980	
NACQG90HDG6-1	3.5540	3.4526	0.1014	
NACQG90HDG6-2	3.5604	3.5406	0.0198	
NACQG185HG4-1	3.6340	3.6332	0.0008	
NACQG185HG4-2	3.6096	3.6074	0.0022	
NACQG185HG5-1	3.6252	3.6242	0.0010	0.0008
NACQG185HG5-2	3.5012	3.5004	0.0008	
NACQG185HG6-1	3.6168	3.6156	0.0012	
NACQG185HG6-2	3.5224	3.5238	-0.0014	
NACQG185HDG4-1	3.7506	3.5198	0.2308	
NCAQG185HDG4-2	3.7612	3.6128	0.1484	
NACQG185HDG5-1	3.7416	3.6260	0.1156	0.1331
NACQG185HDG5-2	3.6518	3.5792	0.0726	
NACQG185HDG6-1	3.7852	3.7018	0.0834	
NACQG185HDG6-2	3.7044	3.5568	0.1476	

9 Month Retrieval Results – Coupon Specimens

Sample Name	Initial Weight (g)	First Clean Weight (g)	Weight Loss (g)	Avg. Weight Loss (g)
CABG90HG7	50.6350	50.5520	0.0830	
CABG90HG8	51.8146	51.6466	0.1680	0.1425
CABG90HG9	50.3304	50.1540	0.1764	
CABG90HDG7	50.3018	50.1504	0.1514	
CABG90HDG8	50.3944	50.0790	0.3154	0.3356
CABG90HDG9	50.6548	50.1148	0.5400	
CABG185HG7	87.5316	87.4434	0.0882	
CABG185HG8	84.7624	84.4490	0.3134	0.2527
CABG185HG9	83.7766	83.4200	0.3566	
CABG185HDG7	85.8880	85.2726	0.6154	
CABG185HDG8	87.4446	87.1734	0.2712	0.3924
CABG185HGD9	85.6990	85.4084	0.2906	
ACQG90HG7	50.7886	50.5230	0.2656	
ACQG90HG8	51.3202	50.9572	0.3630	0.2951
ACQG90HG9	51.8660	51.6094	0.2566	
ACQG90HDG7	51.3210	50.9358	0.3852	
ACQG90HDG8	51.7248	51.3434	0.3814	0.3988
ACQG90HDG9	50.3174	49.8876	0.4298	
ACQG185HG7	86.4478	86.2634	0.1844	
ACQG185HG8	85.4756	85.2160	0.2596	0.3402
ACQG185HG9	85.7926	85.2160	0.5766	
ACQG185HDG7	85.7630	85.2200	0.5430	
ACQG185HDG8	86.0424	85.5136	0.5288	0.5029
ACQG185HDG9	87.2340	86.7972	0.4368	
Controls - Out				
G90-7	50.6864	50.6226	0.0638	
G90-8	50.6904	50.6090	0.0814	0.0759
G90-9	51.7219	51.6394	0.0825	
G185-7	85.6372	85.5482	0.0890	
G185-8	85.7198	85.6268	0.0930	0.0941
G185-9	85.4004	85.3002	0.1002	
Controls - In				
G90-7	50.6240	50.5914	0.0326	
G90-8	50.8456	50.8088	0.0368	0.0317
G90-9	50.8212	50.7956	0.0256	
G185-7	85.9580	85.9196	0.0384	
G185-8	83.8962	83.8348	0.0614	0.0519
G185-9	85.1444	85.0884	0.0560	

9 Month Retrieval Results – Nail Specimens

Sample Name	Initial Weight (g)	First Clean Weight (g)	Weight Loss (g)	Avg. Weight Loss (g)
NCABG90HG7-1	3.458	3.4950	-0.0370	
NCABG90HG7-2	3.6368	3.6310	0.0058	
NCABG90HG8-1	3.5908	3.4576	0.1332	0.0173
NCABG90HG8-2	3.4392	3.4394	-0.0002	
NCABG90HG9-1	3.5908	3.5900	0.0008	
NCABG90HG9-2	3.5150	3.5140	0.0010	
NCABG90HDG7-1	3.6054	3.4984	0.1070	
NCABG90HDG7-2	3.8868	3.7412	0.1456	
NCABG90HDG8-1	3.7710	3.6508	0.1202	0.1172
NCABG90HDG8-2	3.6026	3.5114	0.0912	
NCABG90HDG9-1	3.7690	3.6416	0.1274	
NCABG90HDG9-2	3.4928	3.3810	0.1118	
NCABG185HG7-1	3.7980	3.6788	0.1192	
NCABG185HG7-2	3.4538	3.4536	0.0002	
NCABG185HG8-1	3.5516	3.5504	0.0012	0.0207
NCABG185HG8-2	3.5308	3.5298	0.0010	
HCABG185HG9-1	3.6038	3.6032	0.0006	
HCABG185HG9-2	3.5502	3.5482	0.0020	
NCABG185HDG7-1	3.6444	3.6296	0.0148	
NCABG185HDG7-2	3.7300	3.7156	0.0144	
NCABG185HDG8-1	3.6410	3.5568	0.0842	0.0753
NCABG185HDG8-2	3.6250	3.5252	0.0998	
NCABG185HDG9-1	3.5248	3.4372	0.0876	
NCABG185HDG9-2	3.8082	3.6570	0.1512	
NACQG90HG7-1	3.4346	3.4354	-0.0008	
NACQG90HG7-2	3.4260	3.4282	-0.0022	
NACQG90HG8-1	3.6164	3.6166	-0.0002	-0.0015
NACQG90HG8-2	3.5824	3.5846	-0.0022	
NACQG90HG9-1	3.5072	3.5070	0.0002	
NACQG90HG9-2	3.5396	3.5436	-0.0040	
NACQG90HDG7-1	3.6052	3.5606	0.0446	
NACQG90HDG7-2	3.6102	3.6966	-0.0864	
NACQG90HDG8-1	3.6232	3.6466	-0.0234	0.0648
NACQG90HDG8-2	3.5238	3.4978	0.0260	
NACQG90HDG9-1	3.7346	3.6282	0.1064	
NACQG90HDG9-2	3.6840	3.3622	0.3218	
NACQG185HG7-1	3.3264	3.3262	0.0002	
NACQG185HG7-2	3.5684	3.5690	-0.0006	
NACQG185HG8-1	3.5452	3.5458	-0.0006	-0.0004
NACQG185HG8-2	3.4890	3.4888	0.0002	
NACQG185HG9-1	3.6066	3.6072	-0.0006	
NACQG185HG9-2	3.4002	3.4012	-0.0010	
NACQG185HDG7-1	3.6452	3.4990	0.1462	
NCAQG185HDG7-2	3.7700	3.4978	0.2722	
NACQG185HDG8-1	3.7202	3.5468	0.1734	0.1184
NACQG185HDG8-2	3.5724	3.4242	0.1482	
NACQG185HDG9-1	3.4144	3.5938	-0.1794	
NACQG185HDG9-2	3.6956	3.5456	0.1500	

12 Month Retrieval Results – Coupon Specimens

Sample Name	Initial Weight (g)	First Clean Weight (g)	Weight Loss (g)	Avg. Weight Loss (g)
CABG90HG10	50.4304	50.3156	0.1148	
CABG90HG11	50.0388	49.9132	0.1256	0.1295
CABG90HG12	50.6144	50.4664	0.1480	
CABG90HDG10	50.2662	49.9128	0.3534	
CABG90HDG11	50.9188	50.6282	0.2906	0.3117
CABG90HDG12	52.4334	52.1424	0.2910	
CABG185HG10	87.0742	86.8616	0.2126	
CABG185HG11	87.7686	87.2818	0.4868	0.4009
CABG185HG12	84.4022	83.8988	0.5034	
CABG185HDG10	85.1804	84.6776	0.5028	
CABG185HDG11	85.7048	85.5092	0.1956	0.4556
CABG185HGD12	87.0696	86.4012	0.6684	
ACQG90HG10	50.2606	50.0028	0.2578	
ACQG90HG11	51.1556	50.8802	0.2754	0.2691
ACQG90HG12	50.6524	50.3784	0.2740	
ACQG90HDG10	51.2596	50.8112	0.4484	
ACQG90HDG11	50.9366	50.5970	0.3396	0.3807
ACQG90HDG12	51.2730	50.9188	0.3542	
ACQG185HG10	86.1212	85.8846	0.2366	
ACQG185HG11	86.1530	85.7122	0.4408	0.2777
ACQG185HG12	85.7164	85.5606	0.1558	
ACQG185HDG10	86.0580	85.5674	0.4906	
ACQG185HDG11	85.9302	85.4050	0.5252	0.4475
ACQG185HDG12	86.4508	86.1240	0.3268	
Controls - Out				
G90-10	52.4702	52.3828	0.0874	
G90-11	50.7974	50.7138	0.0836	0.0868
G90-12	50.0996	50.0102	0.0894	
G185-10	86.0662	85.9480	0.1182	
G185-11	86.0178	85.9230	0.0948	0.1029
G185-12	85.5934	85.4978	0.0956	
	86.0662			
Controls - In				
G90-10	50.5278	50.5030	0.0248	
G90-11	51.1284	51.1032	0.0252	0.0281
G90-12	51.0346	51.0002	0.0344	
G185-10	85.5618	85.5406	0.0212	
G185-11	87.0820	87.0564	0.0256	0.0237
G185-12	86.2022	86.1780	0.0242	

12 Month Retrieval Results – Nail Specimens

Sample Name	Initial Weight (g)	First Clean Weight (g)	Weight Loss (g)	Avg. Weight Loss (g)
NCABG90HG10-1	3.5198	3.5196	0.0002	0.0005
NCABG90HG10-2	3.6000	3.6032	-0.0032	
NCABG90HG11-1	3.5966	3.5940	0.0026	
NCABG90HG11-2	3.5888	3.5864	0.0024	
NCABG90HG12-1	3.5236	3.5228	0.0008	
NCABG90HG12-2	3.4994	3.4990	0.0004	
NCABG90HDG10-1	3.6182	3.5838	0.0344	0.0655
NCABG90HDG10-2	3.7254	3.6282	0.0972	
NCABG90HDG11-1	3.5792	3.5314	0.0478	
NCABG90HDG11-2	3.6494	3.5662	0.0832	
NCABG90HDG12-1	3.6624	3.6234	0.0390	
NCABG90HDG12-2	3.9278	3.8362	0.0916	
NCABG185HG10-1	3.6034	3.6030	0.0004	0.0024
NCABG185HG10-2	3.3560	3.3546	0.0014	
NCABG185HG11-1	3.5098	3.5084	0.0014	
NCABG185HG11-2	3.5708	3.5670	0.0038	
HCABG185HG12-1	3.4594	3.4584	0.0010	
HCABG185HG12-2	3.4738	3.4676	0.0062	
NCABG185HDG10-1	3.7762	3.6886	0.0876	0.0767
NCABG185HDG10-2	3.5432	3.4594	0.0838	
NCABG185HDG11-1	3.7324	3.6678	0.0646	
NCABG185HDG11-2	3.3188	3.2482	0.0706	
NCABG185HDG12-1	3.6084	3.5280	0.0804	
NCABG185HDG12-2	3.6340	3.5606	0.0734	
NACQG90HG10-1	3.5290	3.5274	0.0016	0.0013
NACQG90HG10-2	3.4398	3.4390	0.0008	
NACQG90HG11-1	3.5712	3.5694	0.0018	
NACQG90HG11-2	3.4916	3.4922	-0.0006	
NACQG90HG12-1	3.5580	3.5558	0.0022	
NACQG90HG12-2	3.7590	3.7570	0.0020	
NACQG90HDG10-1	3.8716	3.7826	0.0890	0.0948
NACQG90HDG10-2	3.6486	3.4614	0.1872	
NACQG90HDG11-1	3.7472	3.6630	0.0842	
NACQG90HDG11-2	3.5734	3.5470	0.0264	
NACQG90HDG12-1	3.6276	3.5462	0.0814	
NACQG90HDG12-2	3.6904	3.5900	0.1004	
NACQG185HG10-1	3.5290	3.5272	0.0018	0.0020
NACQG185HG10-2	3.6284	3.6238	0.0046	
NACQG185HG11-1	3.2160	3.2156	0.0004	
NACQG185HG11-2	3.4756	3.4726	0.0030	
NACQG185HG12-1	3.6002	3.5990	0.0012	
NACQG185HG12-2	3.5346	3.5336	0.0010	
NACQG185HDG10-1	3.7430	3.6902	0.0528	0.0621
NCAQG185HDG10-2	3.5892	3.5102	0.0790	
NACQG185HDG11-1	3.6180	3.5618	0.0562	
NACQG185HDG11-2	3.4208	3.3566	0.0642	
NACQG185HDG12-1	3.6984	3.6470	0.0514	
NACQG185HDG12-2	3.7698	3.7010	0.0688	