EVALUATION OF METAL FASTENERS CORRODED FROM CONTACT WITH PRESERVATIVE TREATED WOOD

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ABSTRACT
This report will summarize work that was jointly funded by SPRI, the RCI Foundation and the National Roofing Contractors Association. The objective of this research program was to determine the potential corrosive effects of new wood preservatives on metal fasteners used in low-slope commercial roofing systems, specifically those used to hold the assembly to wood nailers and to hold the wood nailers in place.

Due to environmental and regulatory concerns the wood industry began using new preservative chemicals. Concern has been expressed that some of these new chemicals may cause corrosion of certain types of metal fasteners. This has been observed in some instances. The report will provide the following information:

1. Background on the potential issues of corrosion of metal fasteners in treated wood.

2. Data developed in various laboratories that identify critical variables that initiate corrosion of metal fasteners in contact with wood using various types of preservatives, along with theories as to why this reaction is occurring.

3. Field data from the wood nailer location of low-slope roofing systems located in various regions of the country to determine if the critical parameters necessary to initiate corrosion are present.

4. Recommendations as to the proper combination of fasteners and wood nailers that should be used to prevent corrosion.

INTRODUCTION

Preservatives are used to reduce the potential for insect infestation and rotting of wood products to extend the service life of these materials. Historically the most prevalent preservative used was Chromated Copper Arsenate (CCA). Effective January 2004 the Environmental Protection Agency (EPA) banned the use of this preservative for

residential use due to health and environmental concerns. While the use of CCA was still allowed for certain applications it was more cost effective for producers to switch too more widely accepted preservatives. (Wieland, et al 2004)

Two of the more common substitutes for CCA that emerged were:

- Alkaline Copper Quartenary (ACQ)
- Copper Boron Azole (CA-B)

These materials rely on high levels of dissolved copper to provide resistance to insects and fungi-induced rot. Standard industry tests for compatibility indicted that metal exposed to these new preservatives had a higher level of corrosion as compared to CCA preservative.

Third generation wood preservatives which rely on finely ground copper in suspension, resulted in less free copper ions are being produced. These new formulations include:

- Dispersed copper azole (uCA-C)
- Micronized copper azole (MCA)
- Micronized copper quaternary (MCQ)

These new formulations claim reduced corrosion rates compared to copper solution treatments.

In addition to these copper based wood preservatives there are also borate-based products available. Borate is reported to be no more toxic to humans than common table salt. However, borate is very water-soluble, therefore wood treated with borate-based preservatives is not suitable for outdoor use.

The increased corrosion rate associated with ACQ and CA-B preservatives has the potential of being problematic for the low slope commercial roof industry. Preservative treated lumber is used as nailers for securement of roof membranes and roof edge products. The nailers are attached to the building structure with metallic fasteners, which would then be in direct contact with the preservative treated lumber. In many applications the wood nailer would also be in direct contact with a steel roof deck. If corrosion of the metallic fasteners were to occur and weaken the attachment of the edge securement system, the entire roof assembly would be more susceptible to damage during high wind events.

Post hurricane investigations conducted by the Roofing Industry Committee on Weather Issues (RICOWI) has consistently shown that in many cases damage to a low slope roof system during high wind events begins when the edge of the assembly becomes disengaged from the building structure. Once this occurs, the components of the roof system (membrane, insulation, etc.) are exposed. Damage then propagates across the entire roof system by peeling of the roof membrane, insulation, or a combination of the two. (see Figure 1)

Figure 1 – Large retail building, Punta Gorda, FL, Hurricane Charley
Photo courtesy of RICOWI

For this reason a research project was initiated by SPRI to determine if corrosion of metal fasteners in contact with ACQ and other new wood preservatives was an issue in low-slope commercial roofing applications. This report summarizes the work completed to make this determination, which included laboratory studies to identify the critical temperature and humidity conditions necessary to initiate the corrosion process with various wood preservatives and fastener types. The study also involved determining the temperature and humidity conditions that exist in the wood nailer in various climate zones. This data is then compared, and conclusions are provided regarding potential corrosion of fasteners in wood nailers in low slope roofing applications.

LABORATORY STUDIES

DURO-LAST ROOFING STUDY

Galvanic corrosion occurs when a metal corrodes preferentially when in electrical contact with a different type of metal and both metals are immersed in an electrolyte. The extent or rate of corrosion is a function of each metal's electrochemical potential and the efficacy of the electrolyte as a media for ionic transport.

When two or more different sorts of metal come into contact in the presence of an electrolyte, a galvanic couple is formed. The electrolyte provides a means for ion migration whereby metallic ions can move from the anode to the cathode.

Gravimetric studies were conducted at Duro-Last Roofing, Saginaw, MI, to assess corrosion product weight growth as a function of time of exposure to different test environments.

CORROSION TESTS

The two experimental phases were based on the American Wood-Preservers Association (AWPA Standard E12-94).

The first phase was an accelerated test looking at corrosion of stainless steel and e-coated carbon steel fasteners, and determining their response in a controlled environment in various lumber treatments. The environment was extremely harsh and likely unrealistic, however, was designed to maximize sensitivity to corrosion rates.

The second phase was to assess rates of corrosion at various temperatures and relative humidity (RH) conditions.

TEST PROTOCOL

- 1022 carbon steel e-coated fasteners were used for the experiments.
- The e-coated fasteners were weighed before and after the coating process to eliminate the weight of coating in the final results.
- Lumber with various treatments were equilibrated in their relative test environments until less then 1% weight change was observed (to allow moisture absorption equilibration).
- Four each of 5" X 5" X 1.5" blocks of ACQ, CA-B, SBX (Borate Oxide) and CCA lumber were prepared. Three e-coated carbon steel fasteners (as prepared above) were drilled into each wood block. All fasteners were drilled until the tip was observed to break through the backside of the board. The treated lumber blocks with installed fasteners were then placed into the following environments:

  Phase 1:

  1) Kesternich cabinet at 120 °F with a RH of 90 ± 3 %

  Phase 2:

  2) Kesternich cabinet at 140 °F with a RH of 90 ± 3 %.
  3) Kesternich cabinet at 75 °F with a RH of 90 ± 3 %.

  4) Environmental oven at 120 °F with a relative humidity of 60 ± 5 %.
  5) Ambient conditions in room at 75 °F and a RH of 30 ± 5%.

- The Phase 1 fasteners were exposed for 0.07, 0.17, and 0.29 years in condition 1 above to assess a worst case environment.
- The Phase 2 fasteners were exposed for 0.1, 0.17, 0.34, and 0.46 years.
- In all samples, at the conclusion of their allotted time, the wood was split and the fasteners removed, cleaned and weighed.
- The corrosion was removed from each fastener by gentle scrubbing and immersion in a 20 wt % ammonium citrate solution.
- A secondary corrosion removal step was accomplished with a 2 minute immersion in a 100% HCl bath followed by gentle scrubbing.
- Complete removal of corrosion was verified using optical microscopy.
- The samples were weighed and the corrosion products gravimetrically determined by difference.
- The data from both experimental phases were recorded, plotted and modeled using JMP v. 5.0 statistical analysis software. Parabolic rate functions were determined from the gravimetric data for predictive modeling.

TEST RESULTS

Figure 2 illustrates the gravimetric profiles of the treatments tested over time, reflecting a parabolic rate mechanism for the corrosion observed in all treatments studied (ACQ, CA-B, and CCA).

1) Figure 3 illustrates the differences observed in the various treatments used in Phase 1 for extent of corrosion with stainless steel, e-coated carbon steel and uncoated carbon steel. The stainless steel fasteners exhibited no corrosion in any of the lumber treatments tested, and thus were eliminated from further studies. Further, little or no corrosion was observed in the untreated or SBX treated lumber.
2) Corrosion was observed in the fasteners emplaced in CCA, ACQ, and CA-B treated lumber.

3) Where corrosion was observed (only on samples exposed to 90% RF), the weight loss data from the e-coated carbon steel fasteners fit parabolic rate models with correlation coefficients (R-squared values) ranging from 0.87 to 0.99 (indicating good fits). The Arrhenius-like relationship was found to be:

$$y = y_0 + k_p (t)^{0.5} \qquad (1)$$

Where:

y is the oxide mass gain due to oxidation
t is time of exposure
k_p is the rate constant, directly proportional to the diffusivity of the ionic species which are rate controlling
y_0 is a constant.

4) Parabolic rate mechanisms are commonly observed for lower temperature corrosion kinetics and suggest an ion species-diffusion limited rate mechanism driven by temperature and humidity.

5) The temperature appears to be the key driver in the extent of corrosion. Though, a sustained presence of moisture within the wood is also required for corrosion to occur. It appears that the absorbed moisture becomes the medium (electrolyte) for electron transfer.

6) The data additionally suggested that the relative permeability of the e-coat was sufficient to allow the passage of moisture to create the galvanic circuit.

7) Figures 4 through 6 illustrate the various responses with increasing exposure time for the different treatments tested. Only those environments held at 90% relative humidity indicated corrosion.

8) Figures 7 and 8, respectively illustrate the response for those treatments held at 90% RH.

9) Corrosion was only observed for those conditions where the relative humidity was held at 90 % RH and at 140 and 75 degrees respectively. No corrosion was observed for samples held at 120 °F and 60 % RH, or for those held at 75 °F and 30% RH (Figures 9 and 10). The relative humidity has to be sustained at high levels approaching 90 % in order for the wood to retain sufficient moisture for a galvanic cell to be functional, thus, is a requirement for corrosion to occur.

10) At typical ambient conditions, the responses observed for the treated lumbers are comparable to those observed with CCA type treatments.

11) After the tests, the corrosion was observed to occur in areas where e-coating was lost in the initial drilling. Further, there was evidence of corrosion on e-coated portions of the fasteners with no evidence of coating loss suggesting diffusion of ionic species through the e-coat.

12) The mechanisms for corrosion for CCA lumber is the same as that for the ACQ and the CA-B. The ACQ and CA-B demonstrate higher rates of corrosion if sufficient moisture is present. It is suggested that the lumber needs to maintain saturation in order for corrosion to occur.

13) For conditions typical of a roof, the typical ambient temperature and typical levels of moisture saturation required to generate corrosion are not problematic.

14) In four years Duro-Last has seen no indication that roof-top conditions are sufficient to cause accelerated fastener corrosion in ACQ or CA-B treated lumber.

15) For the temperature and moisture conditions observed in the field study, no corrosion issues would be expected.

LSU WOOD DURABILITY LAB (WDL) STUDY, T.F. Shupe, et al

OBJECTIVES

The objective of this study was to evaluate the corrosion effects of ACQ type D ground contact treated lumber on 4-inch and 5-inch hot dipped galvanized (HDG) metal fasteners 4", and two e-coated metal fasteners, also 4-inch and 5-inch. The test included 10 fasteners for each metal tested. The wood samples were cut from a treated ACQ ground contact 4in. x 6in. x 8 ft. board. A total of 40 metal fasteners were used in this test. Each unit contained one e-coated sample and one HDG coated sample. Therefore, two fasteners were in each sample unit for a total of 20 samples units (wood and fasteners).

PROCEDURE

SYP treated 4x6 ACQ type D treated material were locally purchased from Lowes and milled at the WDL on a table saw into samples measuring 3in. x 3in. x 6in.. The test was started on 04/24/09 and concluded on 06/22/09. The test sample units consisted of 2 fasteners imbedded in a 3in. x 3in. x 6in. piece of SYP ACQ treated 4x6. Fasteners were driven into the sample units using an electric drill. The fasteners were spaced at 12 times their respective diameter within the sample unit. Each sample unit contained one coated and one HDG fastener. After 60 days of exposure at 90º F and 90% RH, the fasteners were removed from the wood by splitting the wood with a wood-chisel. The samples were visually rated and weighed. The samples were then cleaned with Evapo Rust to remove corrosion materials, then oven dried in a force draft oven and reweighed. Diameter measurements of the fastener were taken with a digital caliper to determine the amount of local rusting.

RESULTS

Fastener weight loss was minimal for the e-coated fasteners losing 0.01 grams when exposed to accelerated conditions inside ACQ type D ground contact treated wood. Fastener weight loss was greater for HDG 4" losing 0.48 grams and HDG 5" losing 0.53 grams when exposed to accelerated conditions inside ACQ type D ground contact treated wood. Diameter loss values for the e-coated fasteners were unchanged for the 4-inch sample and 0.001 cm for the 5-inch sample. Diameter loss values for the HDG 4" was 0.007 cm and loss for HDG 5" was 0.010 cm. Rusting was found to be very minor on all fasteners tested.

CONCLUSIONS

1. Weight loss and diameter loss for the HDG 4, and HDG 5" were greater than that of the e-coated fasteners while exposed in a accelerated condition chamber when set in ACQ type D ground contact treated wood.
2. Rusting was very minor on all fasteners tested with some minor spots found on the heads, shafts, and shanks.
3. Rust was not present on the HDG fasteners below the head of the fasteners;

however most of the coatings were removed and fixed to the wood surfaces.

4. There was minor coating loss on the shanks of the e-coated sample.

VISUAL TEST

One of the early evaluations conducted was a very straightforward one that provided the ability to visually evaluate the corrosion potential of ACQ treated lumber in contact with metal fasteners. This test started in March of 2004.

TEST PROTOCOL

- Epoxy coated screws were installed into three 1 foot long pieces of ACQ treated 2" x 4"s
- One sample was left as received, a second sample was soaked for 24 hours in a bucket of water simulating rain on the nailer during construction, and the 3rd sample has been soaked in a bucket of water for 24 hours the 1st business day of every month (64 months) which represents a very extreme condition.
- An aluminum term bar was also installed on each piece since aluminum is reported to be very susceptible to corrosion in contact with ACQ. (see Figure 1)

TEST RESULTS

1. The screws show no evidence of accelerated corrosion. There was a very small amount of corrosion present in the recess from contact with the bit during installation. This would be observed with any screw that is soaked in water for 24 hours every month.
2. No unusual corrosion was observed on aluminum term bar.

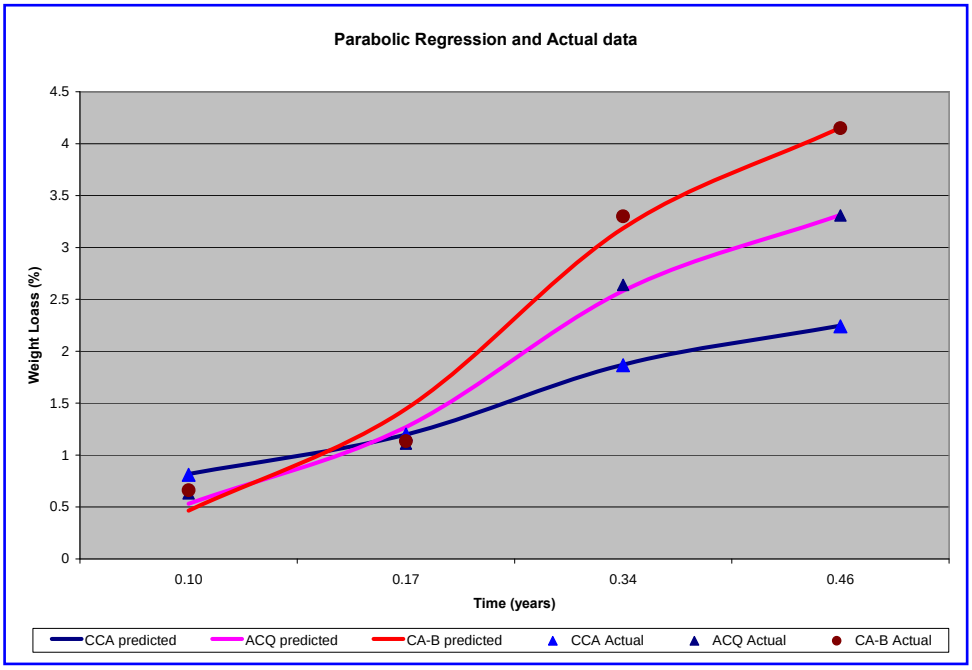

Figure 2- Parabolic Rate Corrosion Growth vs Actual Measurements

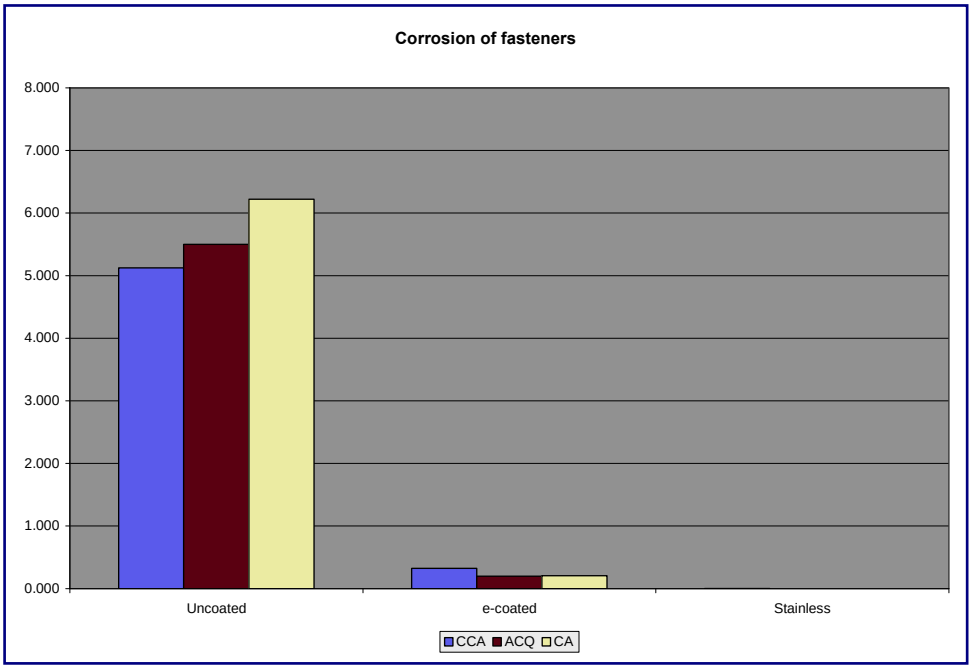

Figure 3- Extent of corrosion up to 2528 hours at 140 ˚F and 90% RH for uncoated 1022 steel, e-coated 1022 steel, and stainless steel fasteners

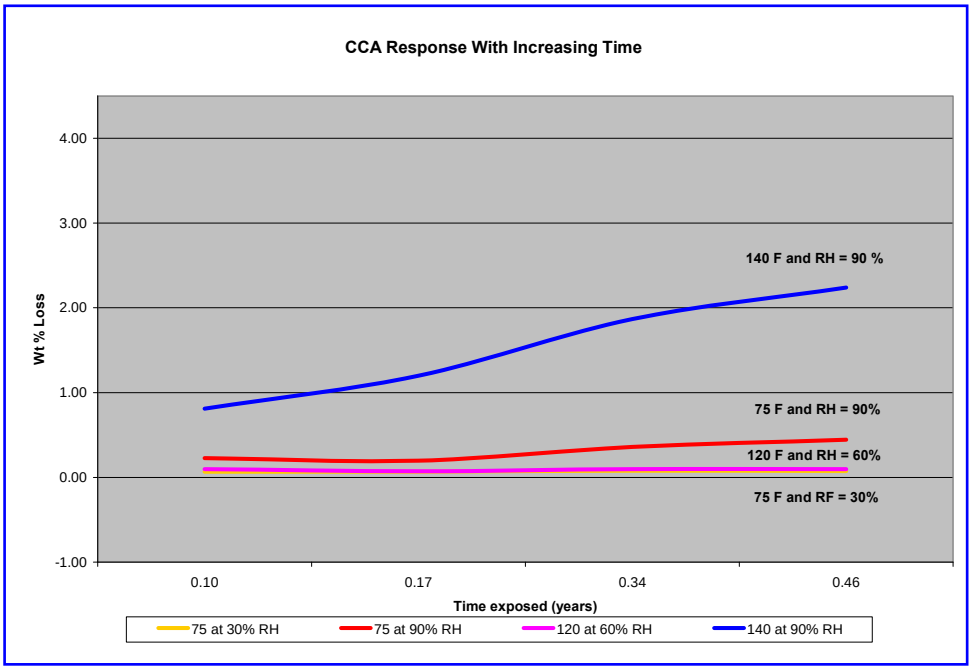

Figure 4- Response curves for e-coated fasteners in CCA treated lumber in the various environments tested.

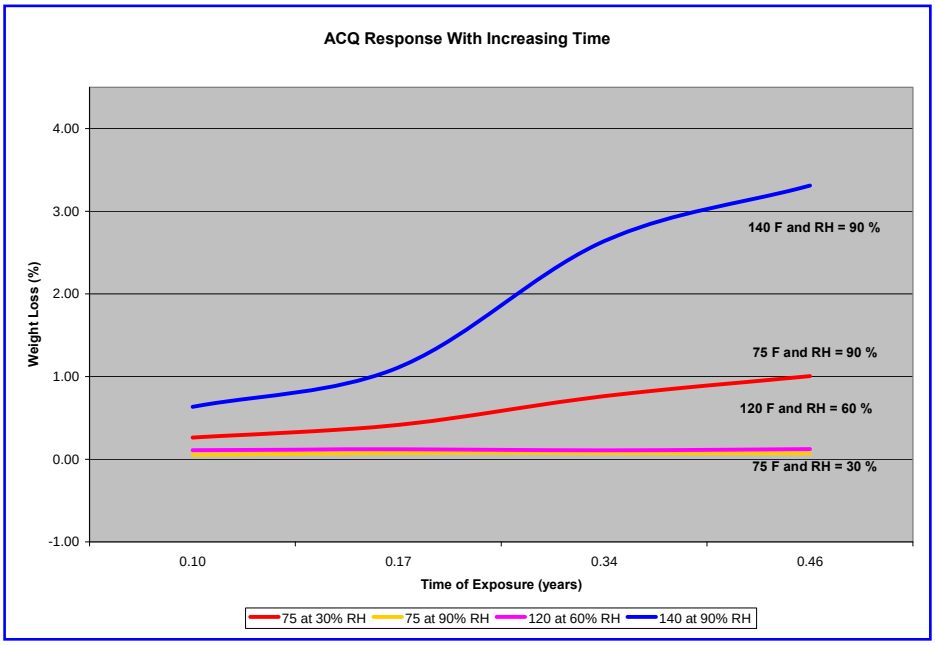

Figure 5- Response curves for e-coated fasteners in ACQ treated lumber in the various environments tested.

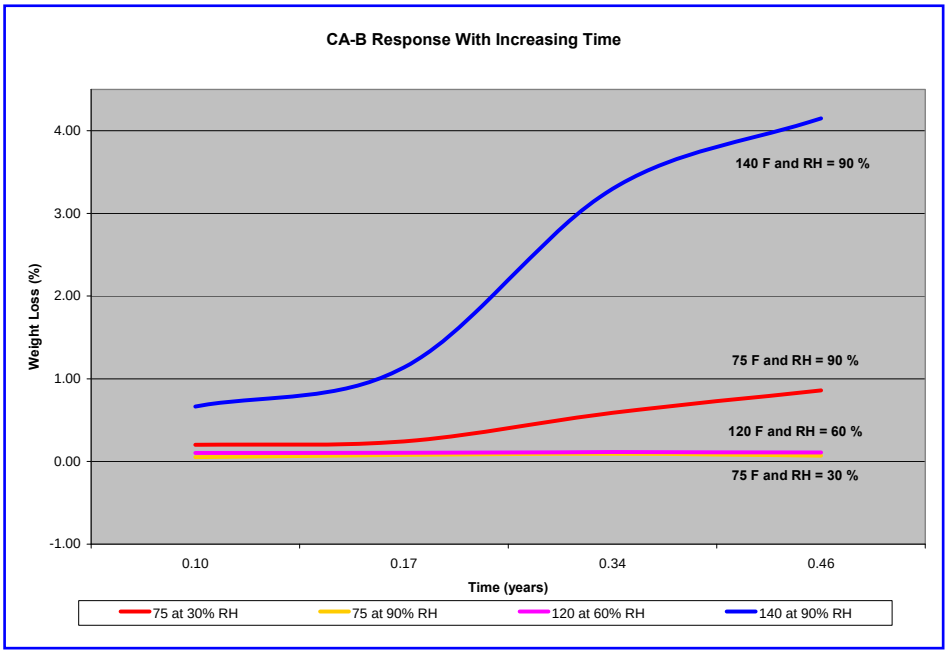

Figure 6- Response curves for e-coated fasteners in CA-B treated lumber in the various environments tested.

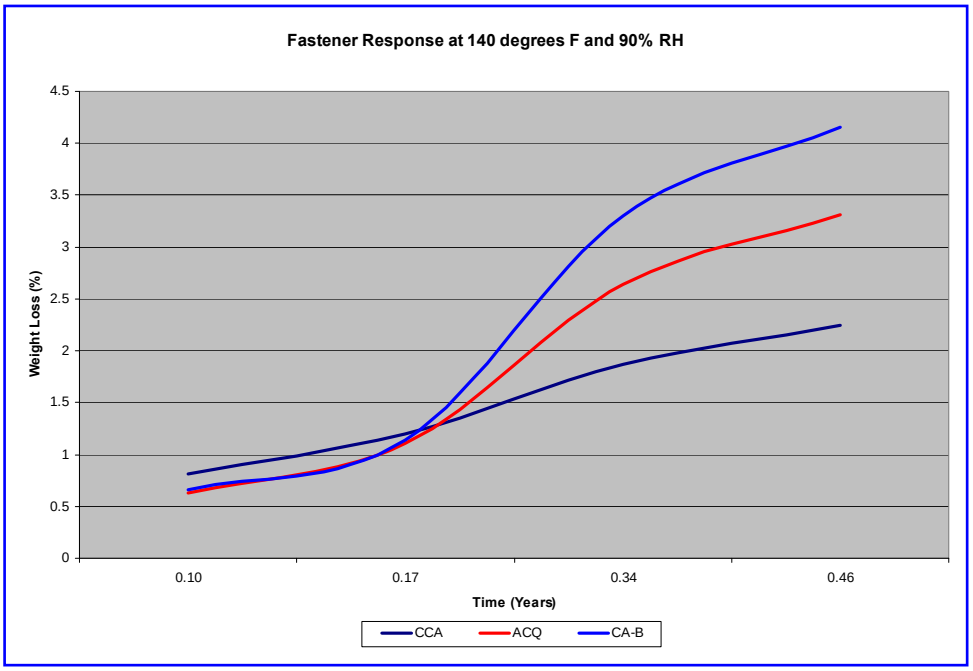

Figure 7- Fastener Responses for Different treatments at 140 °F and 90 % RH

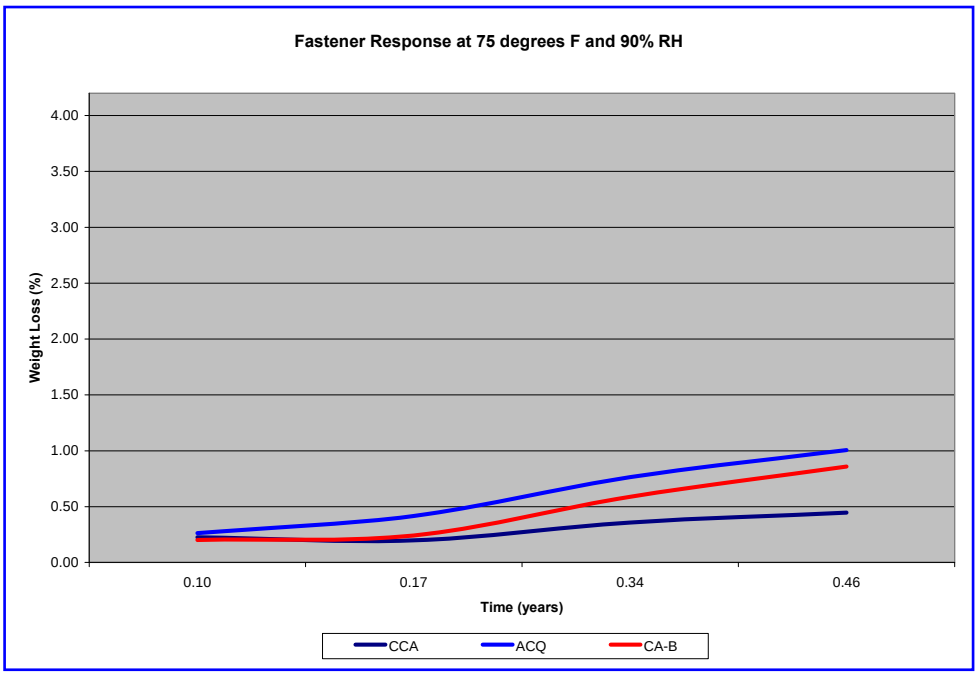

Figure 8- Fastener Responses for Different treatments at 75 °F and 90 % RH.

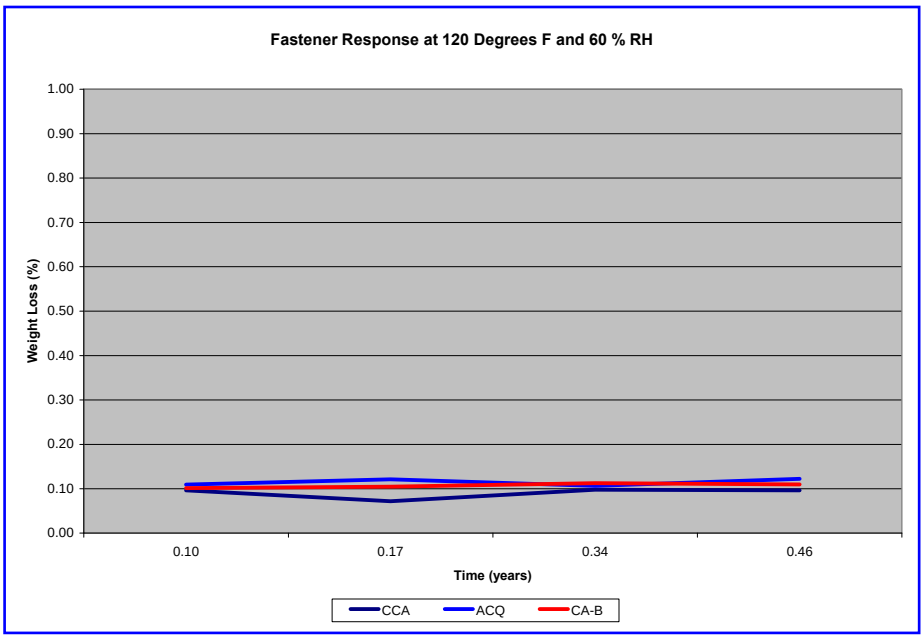

Figure 9- Fastener Responses for Different treatments at 120 °F and 60 % RH.

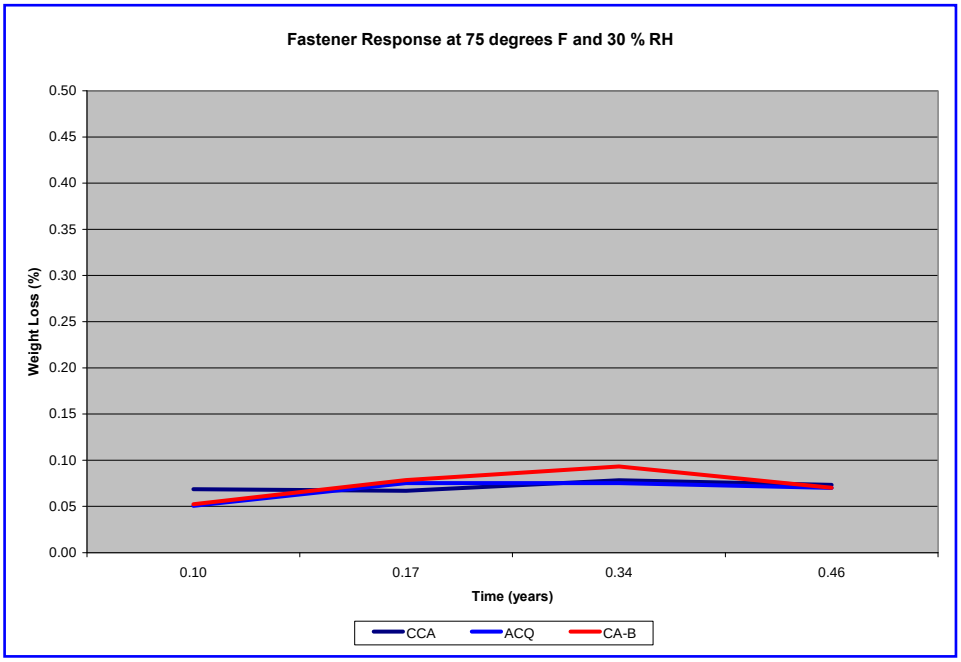

Figure 10- Fastener Responses for Different treatments at 75 ˚F and 30 % RH.

FIELD STUDIES

TEST OBJECTIVES

The objectives of the field studies were:

1. Determine how long wood nailers stay wet if saturated with water prior to installation.
2. Gather field data in various climates and measure wood nailer moisture content.
3. Use the data to develop a model to predict drying times in various climate zones.
4. Compare collected data to the critical temperature/humidity levels identified in the laboratory test procedures that are required to initiate severe corrosion of metal.

TEST PROCEDURE

To satisfy the objectives of this test program the following test protocol was developed:

Three test sites were chosen for this experiment. All test sites were located at SPRI member facilities so that any problems with the test equipment could be corrected quickly. Agawam, MA was chosen as a test location representing a cold climate zone. Jackson, MS was chosen as a hot and humid climate zone, and Grants Pass, OR was chosen as a mild and humid climate zone. These sites were chosen because the climate conditions present would provide a variety of temperature and humidity levels.

Nominal 2" x 4" x 2' wood sections were saturated by submerging them in water for 30-days. After the submersion period the samples were wrapped in plastic wrap to keep the moisture in place and were shipped to the test location.

Once at the test location the test samples were unwrapped and instrumented with temperature and moisture content sensors. Figure 11 is a schematic representation of the instrumentation used in this study. Figure 12 shows the actual test samples used in the experiment. Insulation was cut and removed so that the test samples could be installed directly on the roof deck. (See Figure 13)

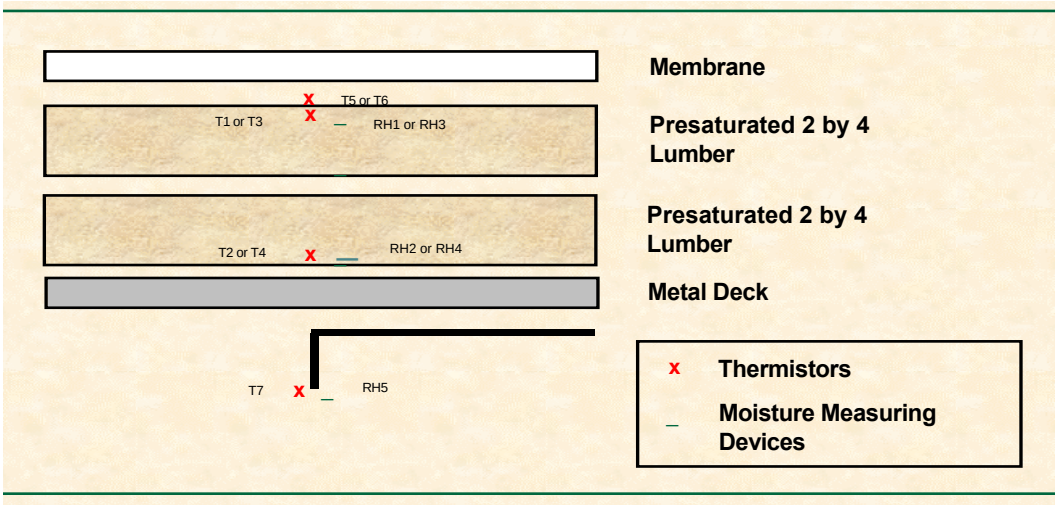

Figure 11

Figure 12 – Installed instrumentation

Figure 13 – Simulated wood nailers installed on roof deck

The temperature and moisture content sensors were connected to a data acquisition system to allow for continuous monitoring of the information. The data was remotely downloaded once per week and maintained by Oak Ridge National Laboratory. In addition to monitoring the instrumentation connected to the test samples, the interior temperature and relative humidity near the roof cut were also monitored.

The initial installation of the saturated wood samples occurred on November 13, 2007 in Agawam, MA. Installing the test samples at the Jackson, MS location on January 15, 2008, followed this. It was determined that the instrumentation in these initial tests was not adequately sensitive to gather the desired information. Test samples and instrumentation were re-installed at the Jackson, MS location on June 5, 2008 and at the Agawam, MA location on July 24, 2008. After it was determined that the instrumentation was working properly samples were installed at Grants Pass on September 24, 2008.

TEST RESULTS

The average daily temperatures within the wood nailers were highest at the Jackson, MS test location. At this location temperatures remained above 70F for the first 100 days of exposure (test was initiated June 5, 2008). Temperatures ranged from 40F to 70F for the next 205 days of exposure. The relative humidity within the wood nailer at this location ranged from 85% to 100% at the start of the test and dropped to a range of 60% to 70% after 120 days (except for the 200 to 22 days time period). See Figures 14 and 15 for a summary of this data.

At the Agawam, MA location the temperature within the wood nailer ranged from 70F to 80F for the first 50 days of the test (test started on July 24, 2008), dropped to a range of 50F to 70F for the next 60 days, and then dropped to a range of 35F to 50F for the next 90 days before beginning to increase again. The relative humidity within the simulated wood nailers for this location started at 90% to 100% and dropped to a maximum of 60% after 80 days for the remainder of the test period (310 days). See Figures 16 and 17 for a summary of this test data.

At the Grants Pass, OR test site the test temperatures within the simulated wood nailers ranged fro 30F to 60F for the duration of the test. At this location the moisture content sensors in one of the test samples malfunctioned, however the moisture content sensors in the duplicate sample performed well. The relative humidity at this location started at approximately 90% and dropped to a range of 45% to 55% after 70 days where it remained for the duration of the test. See Figures 18 and 19 for a summary of this test data.

The maximum temperatures and relative humilities were observed at the Jackson, MS test site. Previous studies have indicated that temperature and humidity are key drivers for the corrosion process when metal fasteners are in contact with treated lumber. Since this is

the case, the Jackson, MS location would represent the most likely location for corrosion to occur.

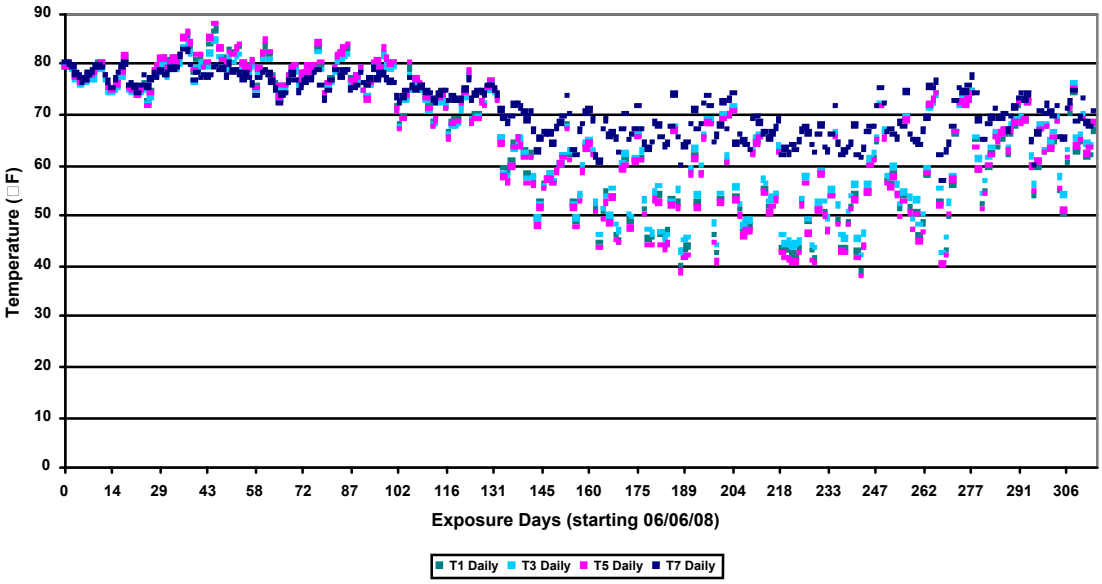

Figure 14
Jackson, MS Average Daily Temperatures

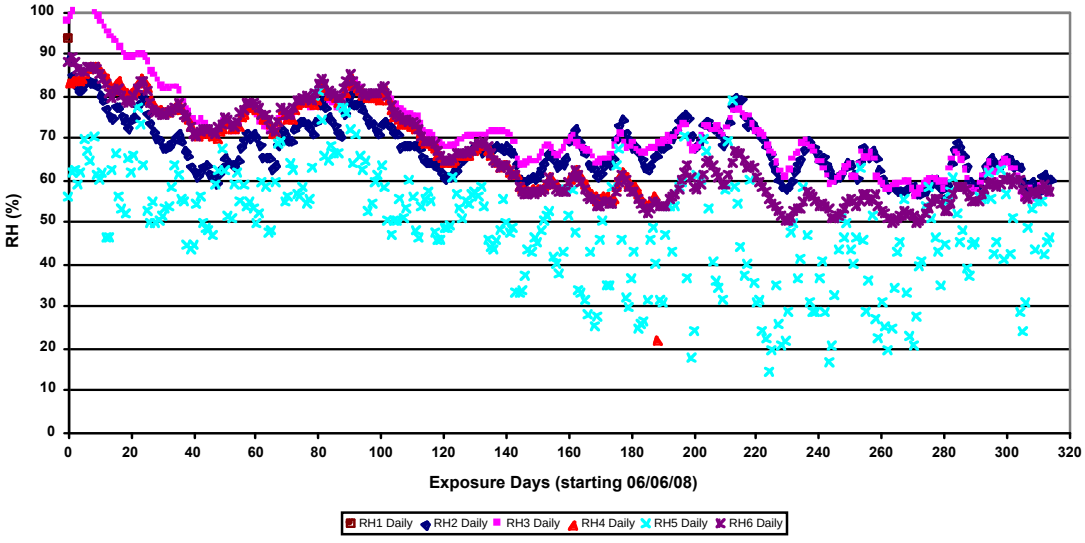

Figure 15
Jackson, MS Average Daily RH

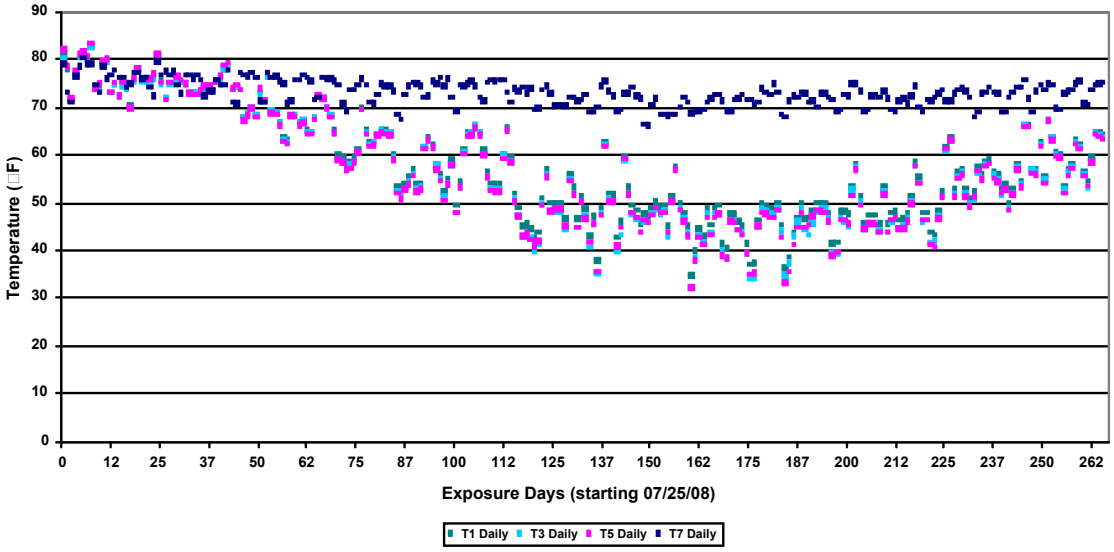

Figure 16
Agawam, MA Average Daily Temperature

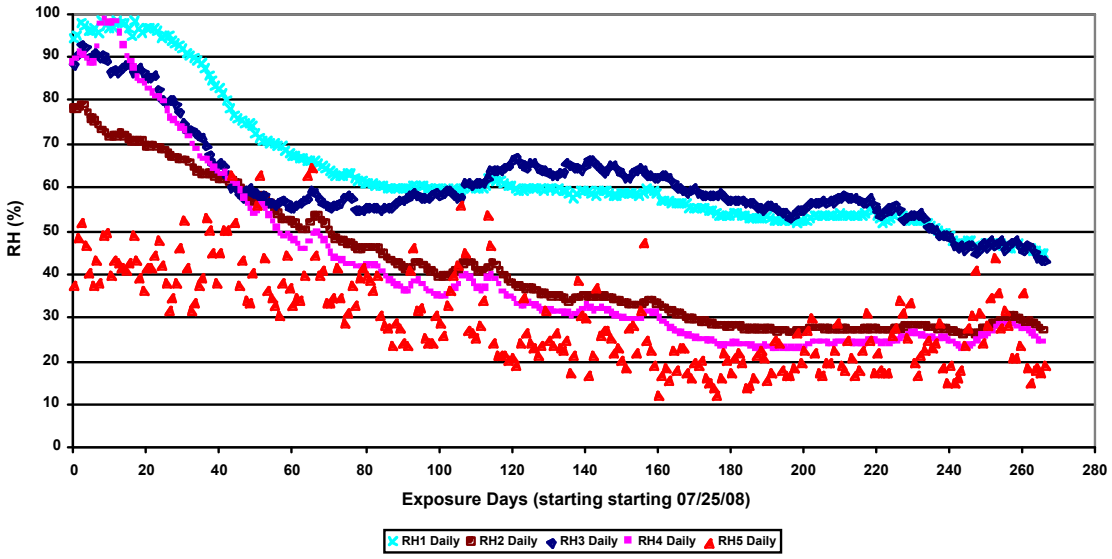

Figure 17
Agawam, MA Average Daily RH

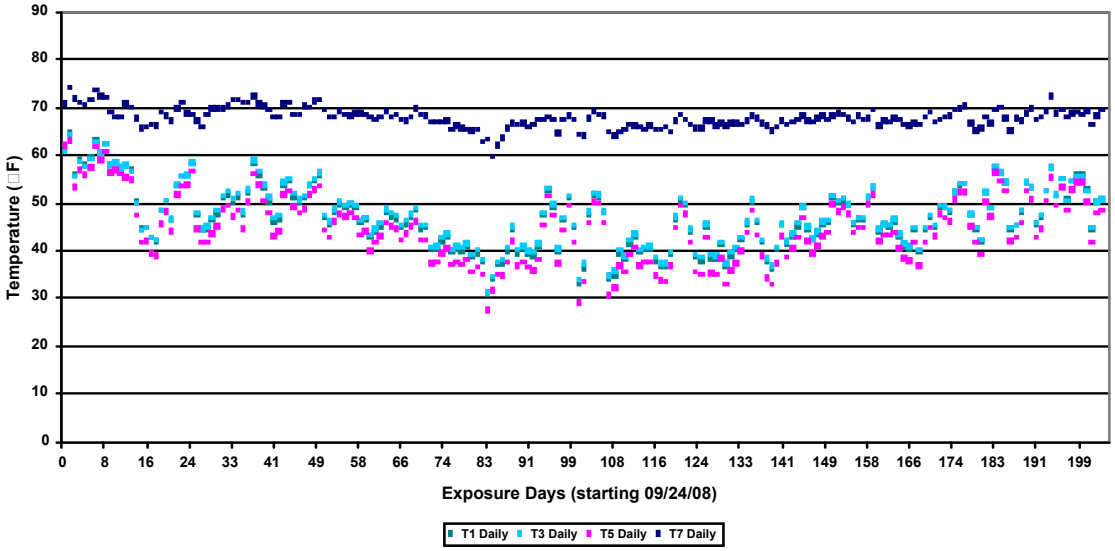

Figure 18
Grants Pass, OR Average Daily Temperatures

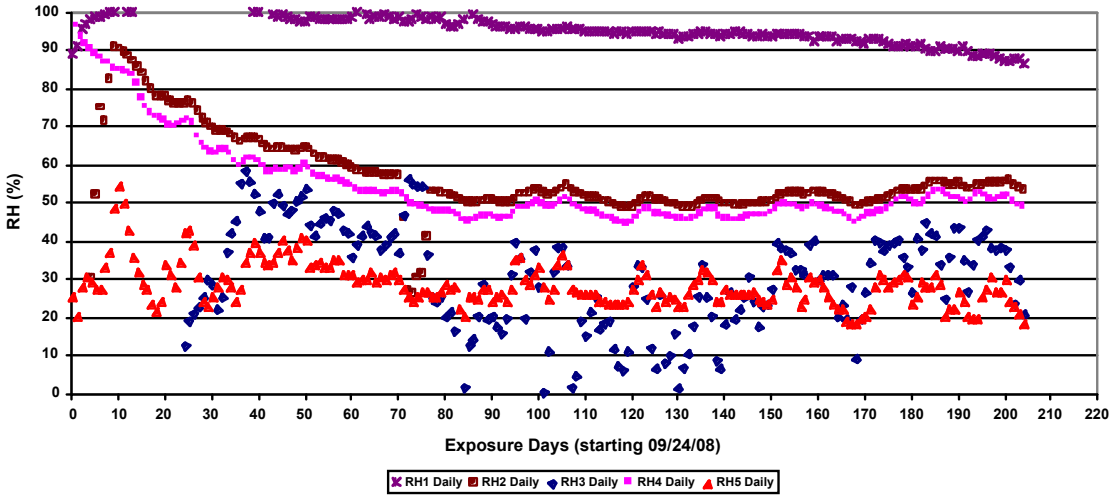

Figure 19
Grants Pass, OR Average Daily RH

Figure 20 – Visual test set-up

CONCLUSIONS

1. The relative humidity has to be sustained at high levels approaching 90 % in order for the wood to retain sufficient moisture for a galvanic cell to be functional, thus, is a requirement for corrosion to occur. This conclusion is based on exposure of 1022 carbon steel e-coated fasteners to wood treated with ACQ, CA-B, CCA.

2. Temperature appears to be the key driver in the extent of corrosion. Though, a sustained presence of moisture within the wood is also required for corrosion to occur.

3. The mechanisms for corrosion for CCA lumber are the same as that for the ACQ and the CA-B. The ACQ and CA-B demonstrate higher rates of corrosion if sufficient moisture is present.

4. No measurable corrosion was noted on stainless steel fasteners during this study.

5. No measurable corrosion was noted on fasteners exposed to SBX treated wood.

6. Field studies demonstrated that the wood nailers dried from a saturated condition to a range of 45% to 65% RH within 6 months of exposure. The highest RH occurred at the Jackson, MS test site.

7. Comparing conditions required for corrosion to occur in the laboratory test program, with the conditions that exists in the nailer corrosion of e-coated or stainless steel fasteners will not be an issue.

8. There have been no reports of excessive fastener corrosion when installed in treated wood nailers, supporting conclusion #7.

RECOMMENDATIONS

1. Use either non-treated or SBX treated wood for the nailers.

2. If treated wood is used either e-coated steel fasteners or stainless steel fasteners should be used.

3. In all cases, a Factory Mutual compliant fastener, or equivalent should be used.

REFERENCES

(AWPA Standard E12-94).

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Cushman T., 2009, "Pressure-Treated Wood: The Next Generation," pp. 3-4, 12-13, April 2009 Journal of Light Construction.

Shupe T.F., Wu Q., Curole J., Voitier M., Ring D. 2009, Wood Durability Lab Louisiana Forest Products Development Center, Report #: WDL-2009-06,School of Renewable Natural Resources LSU Agricultural Center