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Synthesis of Published and Unpublished Corrosion Data From Long Term Tests of Fasteners Embedded in Wood: Calculation of Corrosion Rates and the Effect of Corrosion on Lateral Joint Strength

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ABSTRACT

In the past 5 years, several accelerated test methods have been developed to measure the corrosion of metals in contact with wood. It is desirable to contrast these accelerated results against those of long term exposure tests. While there have been several published long-term exposure tests performed on metals in treated wood, the data from these studies could not be used as a comparative baseline because the formulations and retentions of the preservatives were not reported or the amount corrosion was presented as percent mass loss instead of a true corrosion rate because the surface areas of the fasteners were unknown. This work reexamines four reports (two unpublished) that measured the corrosion of metals in treated wood. Where possible, the composition of the preservatives are reported from the original laboratory notebooks. In all cases, the percent mass loss data are presented in terms of a true corrosion rate by calculating the surface areas of the fasteners. The second part of this paper uses the long term corrosion rates to calculate the reduction in capacity of the joint using the yield theory equations from the National Design Specification for Wood Construction. Specific examples illustrate the loss of capacity with time using measured corrosion rates for wood treated with chromated copper arsenate and alkaline copper quaternary.

Key words: preservative treated wood, corrosion, yield theory, chromate copper arsenate (CCA), alkaline copper quaternary (ACQ)

INTRODUCTION

In the past five years, there have been numerous studies on corrosion of metals in treated wood (e.g. [1-7]). These studies were focused on determining the corrosiveness of new wood preservatives that have become widely used since chromated copper arsenate (CCA) was voluntarily withdrawn for residential

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use in the United States on January 31, 2003. These studies have shown that wood treated with new preservatives such as alkaline copper quaternary (ACQ) and copper azole (CuAz) are more corrosive than CCA treated wood by a factor of between 2 and 19 depending on the metal and the environment[1,8].

CCA treated wood has been successfully used for many years with few corrosion problems[9] however the original research on CCA treated wood never measured corrosion rates, nor was the effect of corrosion on joint strength analyzed. In other words, while CCA treated wood may present an "acceptable" level of corrosion, this level is not well characterized. Furthermore, even if it were well characterized, knowing the difference in corrosion rates between ACQ and CCA lacks meaning unless it can be put into the context of mechanical performance.

To answer these questions, a review of 2 papers that measured long term corrosion rates (14-20 years) was conducted. The goal was to convert the data, which were originally published as a percent weight loss into corrosion rate so that it could be compared with current work on newer wood preservatives. On conducting this investigation, 2 additional unpublished reports on fastener corrosion were found in the archives at the US Forest Service, Forest Products Laboratory (FPL). While these reports predate the use of CCA as a preservative, they contain valuable information about the mechanism of corrosion in treated wood: one report examines the effect of copper on the corrosion rate, and the other examines combining copper with arsenates and chromates individually (the building blocks of CCA). All four of these reports, with pertinent experimental details, are summarized here along with the data, which we transformed from the originally reported percent weight loss to a corrosion rate. The conversion was accomplished by finding archived photographs, and using a novel method to calculate the surface area of the fastener from a photograph[10,11]. To give a common basis to compare different treatments, the concentration of copper is presented as kilograms of copper per cubic meter of dry wood is included along with the more traditional "retention" of the preservative.

The second part of this paper explores how corrosion, through a reduction in fastener diameter, affects the lateral strength of nailed connections. The reduction in capacity is calculated from yield theory equations given in the National Design Specifications for Wood Construction (NDS). Specific examples are shown comparing the reduction in capacity as a function of time for corrosion rates measured for ACQ and CCA treated wood.

PART I: SYNTHESIS OF PUBLISHED AND UNPUBLISHED DATA

Corrosion of Nails in CCA- and ACA-Treated Wood in Two Environments[12]

Significance and Overview.

Baker conducted the most recent long-term corrosion study on metal fasteners in preservative treatments. This work has special significance as it strongly influenced the International Building Code's statements on corrosion of metals in treated wood[13]. Despite its widespread use implications for design codes and building practices, data from this report were only presented in the form of percent weight loss. The original laboratory notebook, which contained photographs of the fasteners, was used to calculate a corrosion rate in µm yr^{-1}. In going through the laboratory notebook unpublished experimental details such as the exact compositions of the preservatives used were discovered. Additionally, uncorroded galvanized fasteners from the original study were found which have now been analyzed to obtain the coating thickness and elemental composition. We first present a brief summary of the test details, followed by the new information on the preservative treatment and galvanized fasteners, before finishing with the transformation of percent weight loss data to corrosion rates.

Experimental Details.

Southern pine (*Pinus spp.*) was treated to a retention of 9.7 kg/m^3 (0.6 lb/ft^3) with one of three different preservatives: "CCA-I" , "CCA-II" or ammoniacal copper arsenate (ACA) (Table 1). The resulting copper concentrations for CCA-I and II were 1.39 and 1.50 kg m^{-3}, respectively. Nails were driven through two pieces of preservative-treated wood to simulate how nails are used in service. There was a 0.8-mm (1/32-in.) spacer between the two pieces of wood so that all test replicates had the same availability of water and oxygen. Specimens were either buried underground at a test site near Madison, Wisconsin or exposed to a constant 27°C (80°F), 95% relative humidity environment; replicates were removed at 1, 3, and 17 years for the underground exposure, and at 1,3, and 14 years for the humidity chamber exposure. Eleven different fasteners were tested which included 6 different materials (copper, silicon bronze, two stainless steels- UNS S30400 and S30160, a nickel alloy-UNS 04400, and an aluminum alloy- UNS A95056) and five different types of coated steel (hot-dip galvanized, mechanically galvanized, electroplated galvanized, cadmium coated steel, and a tin-cadmium alloy coated steel).

Treating Statistics.

Official correspondence* found in Baker's study file contained detailed information on the preservative treatments used in the study and are given in Table 1. It is instructive to compare these formulations to the standardized CCA formulations[14], also summarized in Table 1. The standardized formulations vary in the ratio of copper, chromium, and arsenic with the current formulation referred to as CCA-C. It is clear from the table that the composition of Baker's CCA-II is the same as the formerly standardized CCA-B. It also appears that Baker's CCA-I is similar to the formerly standardized CCA-A. However, it should be noted that the preservatives that Baker used were made from the "salt" formulation of chromic acid and arsenic acid, which is forbidden in the current AWPA standard[14]. It has been suggested that the salt formulations of preservatives may be more corrosive than currently used oxide formulations[15], although this has not been rigorously tested.

Table 1: AWPA Standardized formulations of CCA (A-C)[14] as well as the formulations used by Baker[12].

	Copper (wt.% as CuO)	Chromium (wt.% as CrO_3)	Arsenate (wt.% as As_2O_5)
CCA-A	18.1	65.5	16.4
CCA-B	19.6	35.3	45.1
CCA-C	18.5	47.5	34.0
CCA-I (a)	17	61	22
CCA-II(a)	20	35	45

(a) compositions used in Baker[12]

Recent work on corrosion in treated wood has used CCA-C as a baseline preservative. Therefore, it is instructive to have a short discussion on the differences in these preservatives and how these differences may affect corrosion. It has been shown that the corrosion mechanism in wood involves the reduction of cupric ions[2] and that the higher the copper concentration in the treated wood, the higher the corrosion rate[1]. On the other hand, hexavalent chromium is widely known as a corrosion inhibitor and it has been speculated that the arsenates in CCA may also act as inhibitors[5]. From this information, we would expect CCA-B, with the highest copper concentration and the lowest chromate concentration to be the most corrosive, and CCA-A with the lowest amount of copper and the greatest amount of chromates to be the least corrosive. In fact, however, the opposite was observed; based on percent weight loss, CCA-II was less corrosive than CCA-I. Regardless, CCA-I and CCA-II should give lower and upper bounds on the corrosiveness of the CCA-C used in modern experiments because the composition of CCA-C lies between these two extremes.

* Letter from Andrew Baker to Ray Lindberg of Reynolds Metal Company (Richmond, VA) dated December 13, 1973.

Galvanized Fastener Details.

A hot-dip galvanized nail with the same stock number as those used in the experimental work was found in the study file. To determine the galvanized coating thickness the fastener was cross sectioned, polished and viewed in an SEM. The coating thickness was measured at several locations and the average coating thickness was 24 µm (Figure 1). Additionally, EDS was used to detect the composition of the galvanized coating (Figure 2). Chromium was found on the fastener which suggests that a chromate conversion coating was applied to the fastener post-galvanizing.

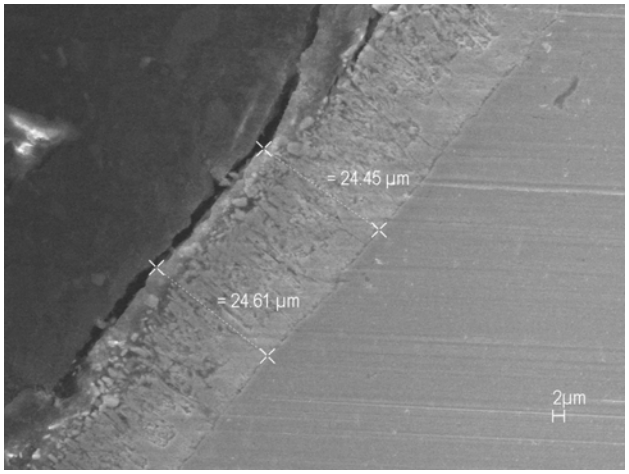

Figure 1: SEM image showing measurements of the coating thickness of a galvanized fastener found in the study file of Baker.

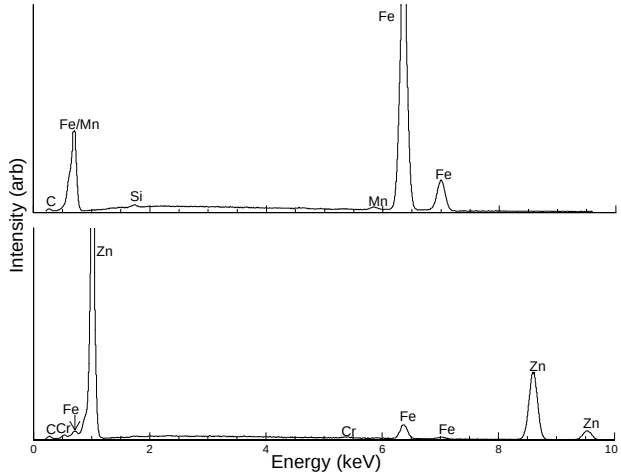

Figure 2: Composition of the inner core (top) and coating (bottom) of the galvanized coating as determined by EDS.

Corrosion rates.

The study file contained several different pictures that were suitable for calculating the surface areas of the fasteners (for example, Figure 3). However, since the photographs were not taken with a scale marker in the picture, an approximation was needed to convert the surface area (in pixels) to physical units. The image was calibrated by setting the width of the UNS30160 stainless steel fastener in Figure 3 to its standardized width. Combined with the starting and final masses recorded in the laboratory notebook, we were then able to calculate a corrosion rate for Baker's data. The results for galvanized steel and aluminum exposed in a humidity room are shown graphically in Figure 4; it was found that the corrosion rates for stainless steel and the nickel alloy were negligible given the uncertainties in the measurements. Baker found a linear relationship between percent weight loss and time between 1 and 17 years Given this constant corrosion rate 1-year corrosion rate data should be sufficient for extrapolation of long term corrosion performance.

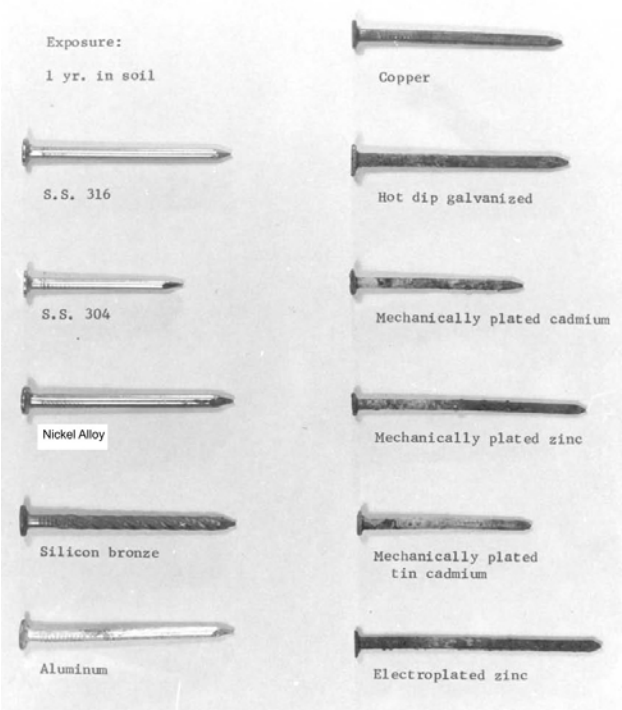

Figure 3: Photograph of the fasteners tested by Baker after 1 year exposure to soil. Several similar photographs were found and used to calculate the surface areas of fasteners tested to get a true corrosion rate.

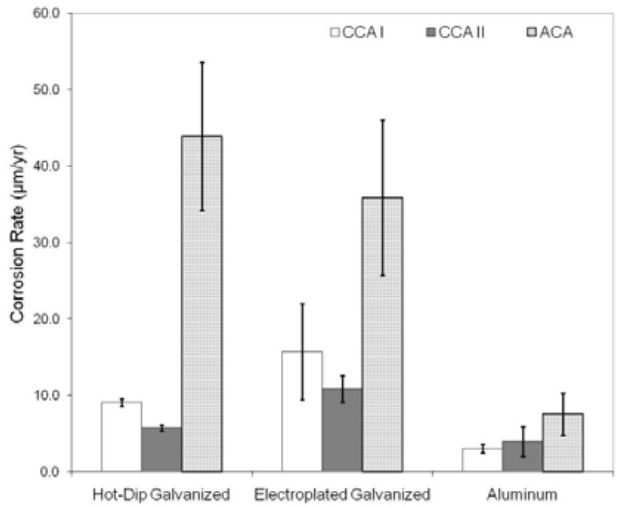

Figure 4: Corrosion rates (in µm yr^{-1}) measured by Baker in a 27°C, 95% relative humidity environment. Error bars represent the uncertainties in the mean.

Corrosion of Metal Fastenings In Zinc Chloride-Treated-Wood After Twenty Years[16]

Significance and Overview.

Baechler conducted the longest known study on the effect of chemical treatments on the corrosion of metal fasteners. This work is significant in two regards: (1) it contains the only long-term (> 1 year) corrosion data on untreated wood and (2) it measures the corrosion rate at several moisture contents. It is well known that the corrosion rate depends strongly on wood moisture content, although the only quantitative observations of this dependence used polarization resistance in solid wood[17]- but these measurements fail to take into account that the resistivity of solid wood changes by several orders of magnitude in this moisture content regime[18]. As with the work of Baker, additional unpublished photographs were discovered in the study file. These photographs are included, as well as the corrosion rates based off of the weight loss measurements and surface areas calculated from the photographs. We present a brief description of the experimental testing before presenting the corrosion rate data. Since the two unpublished studies used the same fasteners and same methods for removing the corrosion products as this study, these details are highlighted in more thoroughly in this summary.

Experimental Details.

Baechler measured the weight loss of three different fasteners in contact with treated and untreated ponderosa pine (*Pinus ponderosa*) exposed to four different environmental conditions. The treatments consisted of four different levels of zinc-chloride preservative and an untreated control. Two treatments, one with a net retention of 22.6 kg m^{-3} of dry zinc-chloride and the other with a net retention of 11.8 kg m^{-3} were applied and then allowed to return to their original moisture content prior to the corrosion tests. The time it took for the specimens to return to their pretreatment moisture content was approximately six months. Two other treatments were applied shortly before the corrosion test and were not allowed to dry. The first of these treatments had a net retention of 24.2 kg m^{-3} zinc chloride

and the second treatment was a mixture of two parts zinc chloride to one part sodium dichromate by weight, with a net retention of 24.2 kg m^{-3} of total salt. Untreated pine was also tested.

Three different fasteners were tested: a No. 4 common wire nail, a No. 6 brass screw, and a 38 mm long galvanized steel nail. The mass loss of the galvanized fasteners was not recorded, although visual observations were recorded. The corrosion products were removed by immersing the fasteners in a solution of 10% ammonium citrate in water. This procedure was found to reduce the mass of uncorroded nails in an ancillary experiment by 0.25% (a 0.04 g change on 10 fasteners with an original weight of 16.16 g). We have accounted for extra mass loss due to cleaning in the corrosion rate calculations.

The outdoor exposure took place on a fence at Madison, Wisconsin. It is unclear whether the test pieces were exposed parallel or perpendicular to the ground but it was stated the specimens had a southern exposure. Photographs of FPL during this time frame show test fences on the second floor roofs, and we believe that the Bachler's corrosion specimens may have been exposed on these racks. In addition to running outdoor exposure experiments, sets of similar specimens were exposed to a constant temperature of 27°C, (80°F) and a constant relative humidity of 30%, 60%, or 90% for twenty years. The estimated equilibrium moisture contents associated with those conditions are 6%, 12%, and 20% [19].

Corrosion Rates.

A photograph of the fasteners after the exposure test (Figure 3) was found in Baechler's study file and used to calculate the surface area of the fasteners. Since no scale bar was included in the photograph, it was assumed that the width of the carbon steel fastener was equal to its standardized width when calculating the surface area. The resulting corrosion rates for carbon steel nails are given in Table 2; the corrosion rates for the brass screws were smaller than the uncertainties in the calculations for all conditions. The uncertainties in the measurement are large because the balance used by Bachler could only measure to the nearest 0.01 g. Corrosion rates for times less than 10 years are not presented for the same reason. While measurements were taken at several moisture contents, the trend in corrosion rate with moisture content cannot be inferred from the data because the corrosion rates are so low. The difference between the seasoned and unseasoned results most likely occurred because of a high initial corrosion rate during the first six months as the boards dried from a completely saturated condition. From the 20 year study a baseline corrosion rate for untreated wood in a 20% moisture content environment is 6 µm/yr while the 6%, 12%, and exposed test fence indicated little or no corrosion.

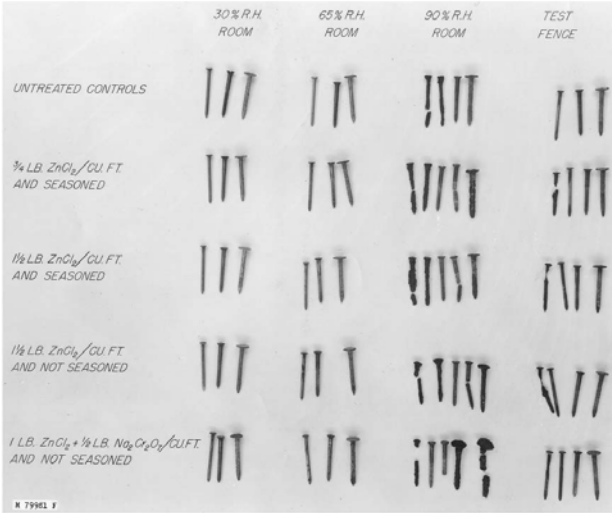

Figure 5: Photographs of fasteners tested by Baechler after 20 years of exposure[16]. The "Untreated Control" fasteners at 30% RH were used to calculate the surface area of the fasteners.

Table 2: Corrosion rates measured by Baechler after 20 years of exposure[16] for carbon steel. The "—" indicates that the corrosion rate was much smaller than the uncertainty in the measurement. Measurements at a specified RH were taken at 27°C.

Treatment	Corrosion rate (μm/yr) 30% RH	65% RH	90% RH	Test Fence
Untreated	—	—	6	<1
11.3 kg m^{-3} ZnCl (s)	—	—	17	1
22.6 kg m^{-3} ZnCl (s)	—	—	18	<1
22.6 kg m^{-3} ZnCl (ns)	<1	1	21	1
ZnCl + $Na_2Cr_2O_7$ (ns)	<1	1	21	2

(s)= seasoned (allowed to dry) after treatment
(ns) = not seasoned

Tests on Stakes Treated With Copper Arsenate and Copper Chromate By the Double Diffusion Process[†]

Significance and Overview.

The purpose of this study was to evaluate wood treated with copper arsenate and copper chromate. In addition to the corrosion tests, which will be presented in detail, the treated wood was also examined for decay and termite attack. One significant aspect of this work is that it is possible, in a limited sense, to evaluate the effects of chromates and arsenates separately. It has been hypothesized that both the chromates and arsenates were acting as corrosion inhibitors in CCA[5], although no published studies have examined the role of the individual components on fastener corrosion.

Experimental Details.

In addition to untreated controls, Southern pine (*Pinus spp.*) was treated with one of 2 different preservative combinations; each combination was tested at two retentions (Table 3). The first combination contained copper sulfate and sodium arsenate, with a copper sulfate retention of 5 kg m^{-3}(light) or 11 kg m^{-3} (heavy) and a sodium arsenate concentration of 3 kg m^{-3} (light) 12 kg m^{-3} (heavy). The other combination contained copper sulfate with a retention of 5 kg m^{-3}(light) or 14 kg m^{-3} (heavy) and sodium chromate with a retention of 8 kg m^{-3}(light) or 25 kg m^{-3} (heavy).

Specimens were then placed outdoors in Saucier, MS, and Madison, WI, although no data are reported from the specimens located at Madison, WI. Specimens were exposed for 2 years.

[†] Unpublished FPL Report: *R.H. Baechler, "Tests on stakes treated with copper arsenate and copper chromate by the double diffusion process: inspection of stakes and metallic fastenings after two years' exposure" filed March 13 1944.*

Three types of fasteners, nominally the same as those in the 20 year study[16], were tested: a No. 4 common wire nail, No. 6 brass screw and a 38 mm long galvanized steel nail. The same cleaning methods that were described earlier were used in this study. Weight loss was only determined for the carbon steel nails. All fasteners were graded qualitatively on a four point scale from "perfect condition" to "very rusty". For the fasteners where weight loss was measured, individual measurements were not taken because the balance had a precision of only 0.01 g, and the average mass of an uncorroded steel fastener was ~ 1.5 g. Instead, to decrease the uncertainties in the mass loss measurements, the entire group of 5 fasteners was weighed before and after exposure to get an average percent weight loss. Using the surface areas calculated from the 20 year study, we have converted these to a corrosion rate.

Results.

The corrosion rate data are given in Table 3**.** While none of these formulations are currently used as wood preservatives, they represent subcomponents of CCA. For this reason, it is interesting to look at differences between the preservatives with only chromates and those with only arsenates to better understand the corrosiveness of CCA treated wood. For the treatments with the light copper retention, the corrosion rate of the treatment with chromate was roughly the same as that of the untreated wood, whereas the corrosion rate was 4 times larger with the arsenates. Similar trends were also seen in the data with a higher amount of copper. From this data it appears that the chromates are primarily responsible for mitigating the corrosiveness of CCA. Previously, it had been speculated that arsenates my also play a role in inhibition but these data suggest that at best it is secondary to the effect of chromates.

Table 3: Corrosion rates for stakes treated with copper arsenate and copper chromate; exact treatment details are given in the text.

	Cu metal concentration (kg m^{-3})	Corrosion Rate (μm yr^{-1})
Untreated	-	5
Cu+Cr "light"	2.0	5
Cu+Cr "heavy"	4.4	9
Cu+As "light"	2.0	20
Cu+As "heavy"	5.6	20

The Corrosion of Wire Nails in Wood Treated With Copper Sulphate[‡]

Significance and Overview.

The purpose of this study was to evaluate an experimental method for wood preservation where the preservatives are injected into a living tree. Corrosion tests were performed on shortleaf pine (*Pinus echinata*) specimens that had been injected with copper sulfate prior to felling. Because of the unusual treating method, each group of fasteners was exposed to a different amount of copper. The actual copper concentration in the wood near each group of fasteners was measured in a separate experiment. No untreated controls were included.

Experimental Details.

Trees were injected with copper sulphate and then felled. Sections along the length of tree were then cut. The nails were driven directly into these sections around the circumference. No. 4 common wire nails, nominally the same as those used in previous studies[16], were used in this study and the corrosion

[‡] Unpublished FPL Report: *E. Bateman, R.H. Baechler "Corrosion of wire nails in wood treated with copper sulphate" filed September 28, 1938.*

products were removed with the same methods described previously. The wood/metal assemblies were exposed to one of two constant temperature, constant humidity conditions: 27°C 30% RH or 27°C 75% RH and removed at intervals between 3 and 24 months. It is not clear from the study documents whether the wood was conditioned prior to the test. However, from the data it appears that the wood must have been green when the fasteners were driven; the corrosion rate decreases with exposure time, and even fasteners exposed to the 30% relative humidity condition have a high corrosion rate-(10-47 µm yr^{-1}), contrasted with the negligible corrosion rates found for the same conditions in Table 2. The report includes the actual copper retentions in each section of wood, but the method used to measure the retention is not given.

Experimental Results.

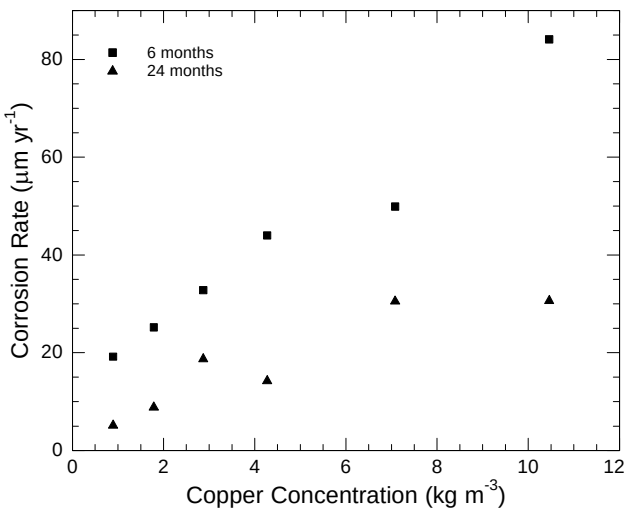

Figure 6: Corrosion rate of carbon steel nails as a function of copper concentration at 6 and 24 months of exposure at 27°C, 75% RH.

Selected data from the 75% relative humidity condition are shown in Figure 6. Two major trends can be seen in the data. The same trends appear in the remainder of the data, which was removed from the figure for clarity. The first trend is that the corrosion rate increases with increasing copper concentration. For example, between the extreme points on the curve, the copper concentration changes by a factor of ~12 and the corrosion rate changes by a factor of ~5. This ratio remains constant over all exposure times. The second trend is that the corrosion rate decreases with time. There are two possibilities to explain this decrease. The first is that the nails were driven in the green condition and the specimen was drying during the exposure period. An alternate explanation is that protective corrosion products were formed during this period that reduced the corrosion rate. However, since the corrosion rates are so high for this environment, we believe the former explanation is the correct one.

PART II: EFFECT OF CORROSION ON THE LATERAL JOINT STRENGTH

The single-fastener connection performance is dependent on the joint geometry (thickness of main and side members), fastener diameter, dowel bending-yield strength, dowel-bearing strength, and direction of load to the grain. Yield expressions relating these parameters were developed by Johansen[20] using a static analysis that assumes the wood and the metal dowel fastener are both perfectly plastic. After nearly a decade of development, the yield model became the standard for dowel connection design in the 1991 NDS and is applicable to all types of dowel fasteners-nails, lag screws, and bolts[21-26]. The yield model theory selects the worst case of yield modes based on different possibilities of wood bearing and nail bending. Mode I is a wood-bearing failure in either the main or side member; mode II is a rotation of the fastener in the joint without bending; modes III and IV are a combination of wood-bearing failure and one or more plastic hinge yield formations in the fastener. For a two member nailed joint, the lateral design load Z (N) of a joint is determined by the minimum of the following yield expressions:

$$Z = \min \begin{cases} \dfrac{Dt_s F_{es}}{2.2} & (\text{Mode I}_s) \\ \dfrac{k_2 D l_p F_{em}}{2.2(1+2R_e)} & (\text{Mode III}_m) \\ \dfrac{k_3 D t_s F_{em}}{2.2(2+R_e)} & (\text{Mode III}_s) \\ \dfrac{D^2}{2.2}\sqrt{\dfrac{2F_{em}F_{yb}}{3(1+R_e)}} & (\text{Mode IV}) \end{cases} \quad \text{where} \quad \begin{array}{c} k_2 = -1 + \sqrt{2(1+R_e) + \dfrac{2F_{yb}(1+2R_e)D^2}{3F_{em}l_p^2}} \\ k_3 = -1 + \sqrt{\dfrac{2(1+R_e)}{R_e} + \dfrac{2F_{yb}(2+R_e)D^2}{3F_{em}t_s^2}} \\ \text{and} \\ R_e = F_{em}/F_{es} \end{array}$$

where D is the dowel diameter (mm) $F_{e_}$ is the dowel bearing stress of the main ($_m$) or side ($_s$) member (MPa), F_{yb} is the bending yield stress of the nail (MPa), l_p is the length of penetration in to main member, and t_s is the thickness of the side member. For determining the effect of corrosion on the lateral fastener strength two assumptions are made. The first is that corrosion occurs uniformly along the length of the fastener and the corrosion rate can be treated as a constant reduction in diameter with time. The second assumption deals with the effect of moisture content on the wood dowel bearing strength. It is assumed that the wood moisture content at failure is greater than 19% MC; in this regime, the dowel bearing strength does not depend on moisture content[27]. This is reasonable as it is likely that the moisture content is greater than 19% if corrosion is occurring. Figure 7 illustrates the effect of corrosion on the lateral strength of single shear nailed joint for a hot-dip galvanized 8d nail (3.05 mm) for different wood preservatives using historical CCA data from Baker **(**Figure 4**)** and recent data collected by Zelinka and Rammer on ACQ treated wood (retention of 4 kg m^{-3})[7]. The below analysis assumes a constant corrosion rate with time, even after the galvanized coating has been consumed. Future work could include a change in corrosion rate once the reduction in diameter exceeds the coating thickness. The reduction in capacity depends upon the side member thickness, which, along with the diameter, determines the failure mode.

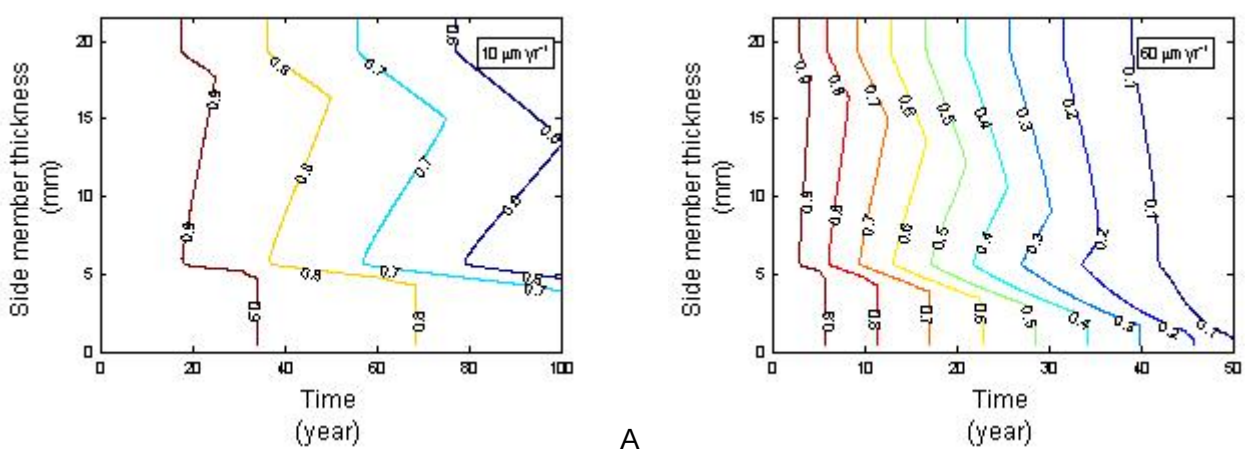

Figure 7: Percent reduction of capacity as a function of time for an 8d (3.05 mm) fastener embedded in wood with an assumed corrosion rate of 10 (A) or 60 (B) µm yr^{-1}, which correspond to corrosion rates measured in hot-dip galvanized steel at 27°C, 100% RH for CCA and ACQ treated wood, respectively[12,7]. Each contour represents a 10% loss in capacity; note the difference in the time axes.

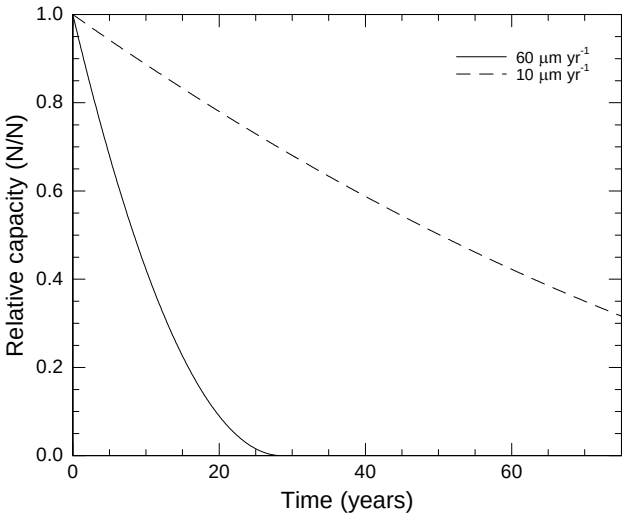

Figure 8: Relative capacity of an 8d decking nail exhibiting a mode IV failure. The 10 and 60 μm yr-1 corrosion rates correspond to corrosion rates measured for hot-dip galvanized fasteners at 27°C, 100% RH in CCA and ACQ treated wood, respectively[7,12].

For narrow side member the reduction is directly related to the reduction of nail diameter due to corrosion. As the side member thickness increases the reduced diameter will affect both the bearing and nail bending performance. For large enough side member thicknesses, the joints will fail in Mode IV, which is independent of the wood thicknesses. Since most of the work on corrosion in wood has examined decking nails, and the most common decking material in the United States of America is "5/4 radial deck board" (25 mm thick), it can be expected that decking nails will exhibit a Mode IV failure- in which case a simpler diagram can be made (Figure 8). In this failure mode, the capacity of the connection is proportional to the square of the fastener diameter.

In all cases, corrosion rates from laboratory experiments were used to calculate the reduction in capacity with time. Wood exposed in outdoor conditions will most likely experience fluctuations in moisture content, and may have higher or lower corrosion rates than those used in these calculations. Recent changes to ACQ formulations and treatment retentions may have also lessened the corrosiveness to treated wood.

SUMMARY AND CONCLUSIONS

This paper reevaluated two classic reports on the corrosion of metals in wood and presented the data as a corrosion rate. Two smaller, unpublished reports were also summarized that give insight into role of the components which comprise CCA. One of these reports highlighted the effect of copper concentration on the corrosion rate of carbon steel. The other report showed that the chromate in CCA acts as a corrosion inhibitor, whereas the arsenate has a smaller if any effect.

From these uniform, constant, corrosion rates, a reduction in diameter with time was calculated, and this in turn was used in the yield theory equations to calculate the reduction in lateral joint strength. For decking materials, the fasteners are expected to exhibit a Mode IV failure where the reduction in joint capacity is related to the square of the diameter. This dependence results in the capacity being quite sensitive to the corrosion rate.

ACKNOWLEDGEMENTS

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