

Corrosion of Metals in Contact with Preservative Treated Wood

An Update

June 2006

Contains technical report
*Current Status Regarding the Corrosion of Metals
in Contact with Preservative-Treated Wood*
by David E. Hendrix, P.E.

Foreword

The conversion from copper chromated arsenate (CCA) to the alternative pressure treated wood chemistries, copper azole (CA) and alkaline copper quaternary (ACQ), has caused much anxiety over hardware corrosion issues. Following is a paper prepared by David Hendrix, P.E., specialist in corrosion engineering and an independent third party observer, who reviewed testing done by various laboratories in accordance with AWPA E12-94 test standards. Mr. Hendrix's conclusions are stated at the end of his report but they basically point out testing deficiencies, deviations and non-real-life scenarios. A series of excerpts from the paper is included after this foreword.

Not covered in the Hendrix paper is a 2005 study conducted by G

Kear, MS Jones and PW Haberecht of Branz (an independent testing laboratory), based in Porirua City, New Zealand. The significance of this study is that the authors tested CCA, copper azole and ACQ in the same environments, using the same fasteners (mild steel, hot dipped galvanized and 316 stainless steel) and the same wood (radiata pine). The complete paper is available at no charge at www.branz.co.nz. Go to Free Information, Publications, CP (Conference paper) No. 114.

To better understand the conclusions and results of the review by Mr. Hendrix and the test done by Branz, a definition of a mil and the ratings for levels of mil penetration (i.e. loss) per year (mpy) are set forth below.

Definition

Mil – a unit of linear measure equivalent to 0.0254 mm or one one-thousandth of an inch¹

Table A – Comparison of mils penetration (i.e., loss) per year (mpy)¹
Relative Corrosion Resistance

| Rating | mpy |
|--------------|--------|
| Outstanding | < 1 |
| Excellent | 1-5 |
| Good | 5-20 |
| Fair | 20-50 |
| Poor | 50-200 |
| Unacceptable | 200+ |

¹ Schweitzer, Philip A., P.E., *Corrosion Engineering Handbook*, copyright 1996 by Marcel Dekker, Inc.

Table 1 in the Hendrix report and Figure III (below) from the Branz test show that corrosion rates for CA and ACQ fall into the “excellent” range for both metals and all retention levels tested. At the levels of mil loss per year based on the tests, differences in the results are statistically insignificant.

Figure III² (A)

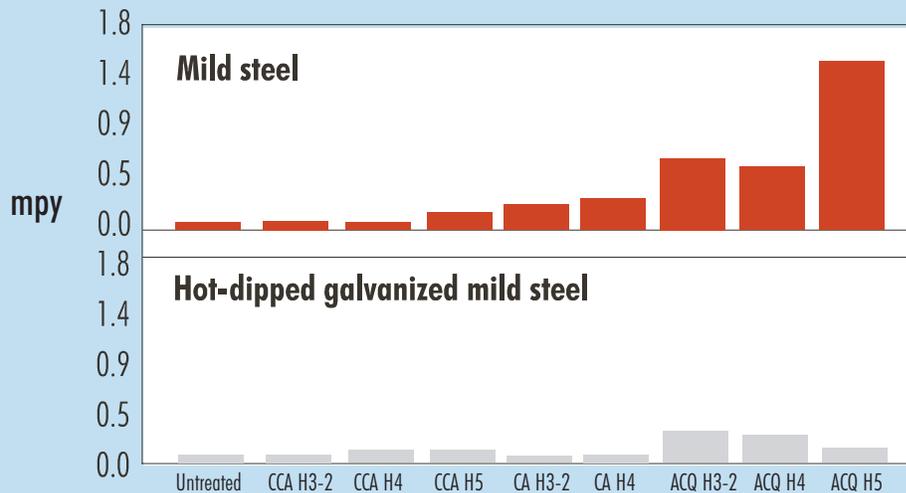


Figure III² (B)

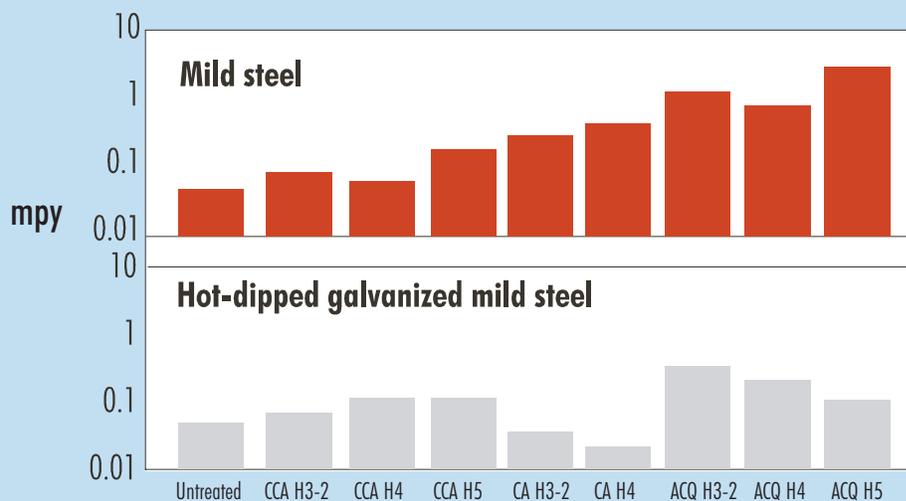


Figure III. (A) Linear and (B) logarithmic mean thickness losses of the mild steel and hot-dipped galvanized steel coupons post-exposure under conditions specified in AWPA E12-94

² G Kear, MS Jones & PW Haberecht- Branz, Porirua City, New Zealand; Conference paper No. 114, 2005

Building Code Fastener Requirements

The International Residential Code (IRC) (§R319.3) and the International Building Code (IBC) (§2304.9.5) have similar requirements for fasteners used with treated wood. Both codes require fasteners to be made from hot-dipped galvanized steel meeting ASTM A 153, stainless steel, silicone-bronze or copper. The IRC provides an exception that permits non-galvanized

½” and larger anchor bolts. The codes also require that steel used to manufacture connectors (e.g., joist hangers) be hot-dipped galvanized to meet ASTM A 653. Manufacturers of these connectors (e.g. U.S.P., Simpson Strong-Tie), recommend a coating weight of G185 (1.85 oz. zinc/sf) for use with all copper alternative preservatives.

Building codes require the specifications listed above for exterior applications regardless of the wood preservative treatment.

Quotes

from David Hendrix, Corrosion Engineer

GENERAL COMMENTS & ISSUES

“...there is not a good or generally accepted test standard that can accurately predict the service life of different hardware in contact with treated wood.”

“Further complicating the decision of which hardware to use are the number of potential alloy and coating combinations, the proprietary nature of coating technologies used on fasteners and connectors, a lack of industry standard quality assurance requirements for these products, and the lack of traceability from the manufacturers.”

“...the thickness of zinc on hot dip galvanized fasteners and connectors used with CCA treated wood has never been specified.”

“Electroplated galvanized steel and aluminum [have] never been recommended for use in contact with treated wood.”

“...the significant variability in wood, even within the same species, contributes to the difficulty in evaluating the comparative performance of metals in contact with wood in laboratory corrosion tests.”

MISLEADING & CONFUSING MARKET INFORMATION

“...there are conflicting and often misleading claims circulating throughout the industry as to how copper azole compares to the various ACQ preservatives regarding fastener corrosion. The information is generally presented as technical data but is used as marketing material.”

“The different test methods and data presentation formats make it difficult to compare one test result against another.”

“[The conflicting market information] makes it difficult for the consumer to make informed decisions about which treated wood and hardware to specify for a specific environmental need.”

“The issue as to which preservative is the most corrosive begs clarification.”

ACCELERATED TESTING ISSUES

“Some reports on accelerated laboratory tests suggest that the new generation wood preservatives are more corrosive than CCA. What is not clear, however, is the reliability of accelerated test data and how the greater measured corrosion rates may correlate to service life prediction for fasteners.”

“Accelerating test methods provide relatively quick results. However, the accelerating process may change corrosion mechanisms from a diffusion-controlled process to an activation-controlled one or vice versa.”

“The accelerating process also makes it difficult to compare test results with real life conditions in attempting to make service life predictions.”

“...it is difficult to explain why in these accelerated test environments the corrosion of some metals such as aluminum generally is minimal, but its performance in actual use is poor compared with other metals/alloys.”

“...none of the standardized test methods provides guidance for the interpretation of results. For example, what is the meaning of a result of 3 mpy? Is it a meaningful result? Is it statistically significant?”

“The rate of corrosion in the accelerated test is anticipated to be much faster than the rate in a service application. A good example of this is the use of hot dipped galvanized nails in CCA treated wood. Test results for galvanized materials have been reported to be as high as 24.4 mpy...However, hot dipped galvanized nails have been successfully used in CCA treated lumber for over 30 years.”

AWPA STANDARD E12 ISSUES

"[The AWPA] E12 standard can, and has been, modified to suit individual preferences, and the 'looseness' of the language in the standard can result in significant scatter in the corrosion rates of metals among different laboratories and for repeated tests in the same lab."

"The [AWPA E12] method is not representative of common exterior corrosion environments and does not reflect or predict corrosion rates for specific conditions such as coastal, heavy industrial or arid environments."

"...the [AWPA E12] standard does not provide a method for interpretation of test results, i.e., is 3 mpy an acceptable result? Is 3 mpy difference between treatments significant?"

"...the inherent susceptibility to scatter in the [AWPA] E12 test results, and deviations from the standard in presenting test results, present opportunities for misleading reports in marketing and company promotional materials."

"A review of AWPA E12 test data from different published papers and internet sources reveals that the test results are difficult to interpret and are apparently being used, where favorable, to promote individual interests."

"...corrosion data presented from AWPA E12 test results in marketing material as "Technical Bulletins" should be used with caution. This is based on...sources of errors and scatter, plus other intentional or unintentional omissions in the marketing materials.

Omissions include:

1. Specific solutions used in the test are not reported (e.g., "ACQ" can mean one of several different formulations, which can vary in performance),
2. Results reported as "2x, 3x, 4x, . . . more or less corrosive" instead of mils per year (mpy) as specified in the E12 method,
3. Wood type and moisture content (especially at time of first contact with the metal) not reported,
4. Test times not reported,
5. Sample sizes not large enough to account for scatter, and
6. Cleaning methods not reported."

"The current AWPA E12 standard needs to be revised to address its shortcomings with respect to reproducibility of corrosion rate data."

ACQ SPECIFIC

"Aggressive ions such as chlorides (present in some ACQ preservatives) tend to prevent formation of protective oxide films on the metal surface and thus increase corrosion."

"Chlorides...can be present in significant levels in some of the ACQ preservative systems. Chlorides are particularly harmful as they are mobile and migrate to the anodic corrosion sites in crevices, hydrolyzing to form hydrochloric acid."

Current Status Regarding the Corrosion of Metals in Contact with Preservative-Treated Wood

April 2006

David E. Hendrix, P.E.

Executive Summary

A critical review has been conducted regarding corrosion and corrosion evaluation issues associated with the transition from chromated copper arsenate (CCA) to new generation preservatives for treated wood, including the waterborne compounds alkaline copper quaternary (ACQ) and copper azole (CA). The review considered available scholarly, trade association, and promotional literature. This paper covers the basics of corrosion science as it relates to treated wood and describes problems with current test methods: imprecision of protocols and inconsistency of test results, lack of correlation between accelerated test conditions and in-service applications, and lack of guidance for interpreting test results.

Background

Historically, chromated copper arsenate (CCA) has been the most commonly used preservative to treat wood for resistance to decay. However, for non-industrial uses, wood is now being preserved with other waterborne compounds such as alkaline copper quaternary (ACQ types B, C and D) and copper azole. There has been some question among chemical and hardware suppliers regarding what metals and alloys to use in contact with the newer types of treated wood for different applications or exposure conditions. One of the reasons for this is that there is not a good or generally accepted test standard that can accurately predict the service life of different hardware in contact with treated wood. Another reason is the lack of an acceptable level of corrosion that can be predicted from the existing test methodologies. Also, the effects of different treatment formulations, retention levels, and additives such as moldicides and water repellents are not clearly understood. Further complicating the decision of which hardware to use are the number of potential alloy and coating combinations, the proprietary nature of coating technologies used on fasteners and connectors, a lack of industry standard quality assurance requirements for these products, and the lack of traceability from the manufacturers.

Hot dipped galvanized steel, types 304 or 316 stainless steel fasteners (nails and screws) and copper have always been recommended by the industry for use with treated wood; however, the thickness of the zinc on hot dip galvanized fasteners and connectors used with CCA treated wood has never been specified. Zinc coatings conforming to ASTM A 653 G-60 and G-90 grade were commonly used for connectors such as joist hangers and truss plates. However, all manufacturers are now recommending G-185 grade galvanizing. Electroplated galvanized steel and aluminum had never been recommended for use in contact with treated wood.

The following are current recommendations for fastener and connector materials, and reflect recommendations by both the treated wood and fastener and connector industries:

1. Hot-dipped galvanized fasteners meeting ASTM Standard A153 and connectors meeting ASTM Standard A653 Class G-185 are minimum requirements for hardware in contact with treated wood for outdoor exposure.
2. While hot-dipped galvanized fasteners and connectors are also preferred for indoor exposure, the use of non-galvanized fasteners and connectors is acceptable for sill plate application provided that the wood will remain dry and protected from weather and water.
3. For below-grade use with treated wood, or for other severe uses such as swimming pools or seawater service, types 304 and 316 stainless steel are recommended.
4. Aluminum is not recommended for use as fasteners or connectors in contact with treated wood.

Corrosion Theory

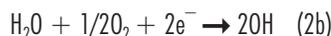
With a few exceptions, metals are unstable in ordinary aqueous environments. Metals are usually extracted from ores through the application of a considerable amount of energy. Unfortunately, as soon as the pure metal is given the chance to recombine with the environment, i.e. oxygen, and become a metal compound (i.e., an oxide) again, it will do so. Certain environments offer opportunities for metals to combine chemically with elements in the environment to form compounds and return to their naturally lower energy levels. This process is commonly called "corrosion".

Corrosion specifically refers to any process involving the deterioration or degradation of metal components by a reaction with the environment. Most metals will corrode on contact with water (and moisture in the air), and other solutions containing water, including acids, bases, salts, oils, etc. A well known example of corrosion is the rusting of steel.

Virtually all corrosion reactions are electrochemical in nature; that is, they involve chemical reactions and the transport of electrons. At anodic sites on the

surface, the metal (iron) goes into solution as ferrous ions, this constituting the anodic reaction. As iron atoms undergo oxidation to ions they release electrons whose negative charge would quickly build up in the metal and prevent further anodic reaction, or corrosion. Thus this dissolution will only continue if the electrons released can pass to a site on the metal surface where a cathodic reaction is possible. At a cathodic site the electrons react with some reducible component of the electrolyte and are removed from the metal. The rates of the anodic and cathodic reactions must be equivalent according to Faraday's Law, being determined by the total flow of electrons from anodes to cathodes, which is called the "corrosion current".

The most common and important electrochemical reactions in the corrosion of iron are:



Reaction 2a is most common in acids, and above approximately 5 pH, the most important reaction is oxygen reduction (equation 2b). In this latter case corrosion is usually accompanied by the formation of solid corrosion products from the reaction between the anodic and cathodic products. If solid corrosion products are produced directly on the surface, as a result of anodic oxidation, they may provide a protective surface film that retards further corrosion. The surface is then said to be "passive".

Certain factors tend to accelerate the action of a corrosion cell. These include:

- (a) Establishment of well-defined locations on the surface for the anodic and cathodic reactions. An example of this is a single, deep pit in a strong electrolyte, where the resulting high anodic corrosion current acts to protect the area surrounding the pit. This results in high pitting penetration rates.
- (b) Stimulation of the anodic or cathodic reaction. Aggressive ions such as chlorides (present in some ACQ preservatives) tend to prevent the formation of protective oxide films on the metal surface and thus increase corrosion.
- (c) Increasing temperature increases the corrosion kinetics. Although simplistic, a rule of thumb is that an increase in temperature of 10°C doubles the corrosion rate.

The rate at which corrosion occurs is of prime importance and is usually expressed in one of two ways:

- (1) Weight loss per unit area per unit time, usually expressed as mdd (milligrams per square decimetre per day)
- (2) A rate of penetration, i.e. the thickness of metal lost. This may be expressed in American units, mpy (mils per year, a mil being a thousandth of an inch) or in metric units, mmpy (millimetres per year).

Galvanic Corrosion

Galvanic corrosion occurs when a metal or alloy is electrically coupled to another metal in a common electrolyte. Three essential components are needed for galvanic corrosion to occur:

- (1) Metals or alloys possessing different surface potentials,
- (2) A common electrolyte,
- (3) A common electrical path.

A mixed-metal system in a common electrolyte, where the metals are electrically isolated, will not experience galvanic corrosion regardless of the proximity of the metals or the magnitude of the potential difference between the metals.

During galvanic coupling, corrosion of the more anodic metal increases and corrosion of the more cathodic metal decreases. The extent of accelerated corrosion resulting from galvanic coupling is affected by the following factors:

- A. The potential difference between the metals or alloys,
- B. The nature of the environment,
- C. The polarization behavior of the metals or alloys,
- D. The geometric relationship of the metals or alloys.

When one needs to know which materials in a system are candidates for galvanically accelerated corrosion, this information can be obtained from a galvanic series. A galvanic series is a list of freely corroding potentials of the materials in the environment of interest, arranged in order of potential. The material with the most negative, or anodic, corrosion potential has the tendency to suffer accelerated corrosion when electrically connected to a material with more positive, or cathodic, potential. One such common galvanic series is the galvanic series of metals exposed to seawater, shown in Figure 1.

Figure 1 – GALVANIC SERIES OF METALS EXPOSED TO SEAWATER

| | |
|--------------------------------|--|
| ACTIVE END (-) | Magnesium |
| | Magnesium Alloys |
| | Zinc |
| | Galvanized Steel |
| | Aluminum 1100 |
| | Aluminum 6053 |
| | Alclad |
| | Cadmium |
| | Aluminum 2024 (4.5 Cu, 1.5 Mg, 0.6 Mn) |
| | Mild Steel |
| | Wrought Iron |
| | Cast Iron |
| | 13% Chromium Stainless Steel |
| | Type 410 (Active) |
| | 18-8 Stainless Steel |
| | Type 304 (Active) |
| | 18-12-3 Stainless Steel |
| | Type 316 (Active) |
| | Lead |
| | Tin |
| | Manganese Bronze |
| | Naval Brass |
| | Nickel (Active) |
| | 76 Ni-16 Cr-7 Fe Alloy (Active) |
| | 60 Ni-30 Mo-6 Fe-1 Mn |
| | Yellow Brass |
| | Admiralty Brass |
| | Aluminum Brass |
| | Red Brass |
| | Copper |
| | Silicon Bronze |
| | 70:30 Cupro Nickel |
| | G-Bronze |
| | M-Bronze |
| | Silver Solder |
| | Nickel (Passive) |
| | 76 Ni-16 Cr-7 Fe |
| | Alloy (Passive) |
| | 67 Ni-33 Cu Alloy (Monel) |
| | 13% Chromium Stainless Steel |
| | Type 410 (Passive) |
| | Titanium |
| | 18-8 Stainless Steel |
| | Type 304 (Passive) |
| | 18-12-3 Stainless Steel |
| | Type 316 (passive) |
| (+) Noble or passive end | Silver |
| | Graphite |
| | Gold |
| | Platinum |

It should be noted that predicting galvanic corrosion can be difficult since small changes in the electrolyte can cause changes in the relative potentials between two metals or alloys. Also metallurgical and environmental factors such as heat treatment, surface preparation, mill scale, flow rate and temperature can influence galvanic potentials. Some of these are demonstrated in the galvanic series in Figure 2 which depicts metals in soil. Therefore, the relative potential between two metals or alloys is dependent on the external environment (corrosive species). What may be the anodic half cell (corroding metal) in a coupled metal or alloy in one environment, may be the cathodic (non-corroding) half cell in another environment. The closer to each other the coupled metals are in the series, the more potential for them to change in relative order.

Figure 2 - GALVANIC SERIES OF METALS EXPOSED TO SOIL

| | |
|-------------|----------------------------|
| ACTIVE END | Pure Magnesium |
| (-) | Magnesium Alloy |
| | Zinc |
| | Aluminum Alloy |
| | Pure Aluminum |
| | Mild Steel (Clean & Shiny) |
| | Mild Steel (Rusted) |
| | Cast Iron |
| | Lead |
| | Mild Steel in Concrete |
| | Copper, Brass, Bronze |
| | Mill Scale on Steel |
| (+) | High Silicon Cast Iron |
| NOBLE OR | Carbon, Graphite, Coke |
| PASSIVE END | |

Corrosion of Zinc

In a normal atmosphere, zinc forms a basic zinc carbonate film that greatly retards its corrosion rate. This is similar to the oxide film that forms on aluminum, resulting in its low corrosion rate. Zinc, when connected with metals below it in the electrochemical series, will sacrificially protect that metal, which accounts for its wide usage in the galvanized steel industry.

As with atmospheric corrosion, the corrosion resistance of zinc exposed to water depends on its initial ability to form a protective layer by reacting with the environment. The corrosion of zinc in waters is largely controlled by impurities present in the water. Naturally occurring waters are seldom pure. Even rainwater, which is distilled by nature, contains nitrogen, oxygen, CO₂, and other gases, as well as entrained dust and smoke particles. Water that runs over the ground carries with it eroded soil, decaying vegetation, living microorganisms, dissolved salts, and colloidal and suspended matter. Water that seeps through soil contains dissolved CO₂ and becomes acidic. Groundwater also contains salts of calcium, magnesium, iron, and manganese. All of these foreign substances in natural waters affect the structure and composition of the resulting films and corrosion products on the surface, which in turn control the corrosion of zinc. In addition to these substances, such factors as pH, time of exposure, temperature, motion, and fluid agitation influence the aqueous corrosion of zinc.

The degree of scale generated by water depends principally on three factors: its hydrogen ion concentration (pH value), the total calcium content and the total alkalinity. If the pH value is below that at which the water would be in equilibrium with calcium carbonate (CaCO₃), the water will tend to dissolve rather than to deposit scale. Waters with high content of free CO₂ also tend to be aggressive toward zinc.

Zinc is not used in contact with acid and strong alkaline solutions, because it corrodes rapidly in such media. Very dilute concentrations of acids accelerate corrosion rates beyond the point of usefulness. Alkaline solutions of moderate strength are much less corrosive than corresponding concentrations of acid, but are still corrosive enough to impair the usefulness of zinc.

Corrosion of Metals in Wood

Under the correct conditions, metal in contact with wood will corrode; interestingly, the products of corrosion can also result in the deterioration of wood. The corrosion of metals and alloys in wood is fundamentally similar to the corrosion of metals in other aqueous systems, i.e., it is an electrochemical process. The rate and amount of corrosion depends on the metal, the conductivity of the wood, and the time and temperature of exposure. Factors influencing corrosion specific to wood include the wood moisture content, natural constituents of the wood, and the presence of modifiers added to chemically enhance the properties of the wood such as preservatives.

The amount of available moisture in the wood is perhaps the most important factor. Wood naturally contains some moisture as a result of its function in a living tree. In addition, wood is hygroscopic; that is, it can absorb moisture from its environment and will eventually reach a steady state moisture level or equilibrium moisture content. Wood may also contain moisture as a result of manufacturing processes or from the environment in which it is exposed. When the moisture content is below 15 to 25 percent of the dry weight of wood, the water is bound to the wood constituents and not available as free moisture for ionic transport. Several sources suggest that if the moisture content of wood is below approximately 18 %, the corrosion rate of metals is very low.

The principle constituent of wood is cellulose, a polysaccharide, i.e., a polymer made of sugar molecules joined in long chains. The sugar units contain mildly basic hydroxyl radicals, some of which are combined with acetylated radicals. The acetyl radical comprises approximately 1 to 6 % by weight of dry wood, with more in hardwoods than in softwoods. Most woods are slightly acidic, with a pH of 3 to 6. Acetic acid from acetyl groups is the most prevalent acid in

wood, but other organic acids, including formic, propionic and butyric acids can also contribute to acidic conditions. Different woods vary in the ease with which the acetyl is hydrolyzed to acetic acid. Therefore, depending on the type of wood and the initial acid and moisture contents, woods can vary appreciably in their corrosivity to metals. In a given wood, the rate of formation of acetic acid depends on the temperature and moisture content of the wood. Wood also contains 0.2 to 1.0 percent of inorganic components. These include primarily calcium, potassium and magnesium. These materials may accelerate corrosion, but possibly more significant are the interactions with zinc and other protective coatings. The role of these inorganic components is not understood, but they too may be a source of variation seen in accelerated corrosion tests. In summary, the significant variability in wood, even within the same species, contributes to the difficulty in evaluating the comparative performance of metals in contact with wood in laboratory corrosion tests.

Wood preservatives are the most common chemical modifiers added to wood. Preservatives in treated wood can influence the corrosion of metals and alloys primarily based on the chemistry used to formulate the preservative. For example, the traditional preservative, CCA, could be formulated from either a mixture of potassium dichromate, copper sulfate and arsenic acid or from a mixture of chromium trioxide, copper oxide and arsenic acid. The potassium dichromate formulation has higher conductivity than CCA made with chromium trioxide by virtue of the formation of potassium sulfate making it more corrosive. In addition to the formulating materials, the preservative actives themselves may enhance corrosion. Chromium had been shown to passify steel, but copper is cathodic to carbon steel and zinc and can plate out on those materials during the corrosion reaction. The formation of many cathodic sites promotes galvanic corrosion. Conversely, copper and the austenitic stainless steels, i.e., 304SS and 316SS, are very close in the galvanic series, thus the galvanic effect of copper on those metals is minimal. Chlorides are another constituent of some preservatives and can be present in significant levels in some of the ACQ preservative systems. Chlorides are particularly harmful as they are mobile and migrate to the anodic corrosion sites in crevices, hydrolyzing to form hydrochloric acid.

Wood can absorb materials from its environment. Marine environments are of particular concern because of tidal fluctuations, wave action, and salt spray. Another source of absorbed salt is on the wood decking of bridges, walkways and patios receiving de-icing materials in the winter.

Commercial Wood Preservatives

CCA, or chromated copper arsenate, has been the wood preservative of choice for many years. After the voluntary elimination of CCA-treated wood for residential applications, preservative formulations based on amine copper plus organic fungicides have become predominant.

The common generic names for American Wood-Preservers' Association (AWPA) listed copper-based treatments available today are copper azole (CA: chemical tradename — Wolman[®] E) and alkaline, ammoniacal or amine copper quaternary (ACQ). There are two variations of copper azole, but today only CA type B is sold commercially in North America. For ACQ, AWPA lists ACQ-A, ACQ-B, ACQ-C, and ACQ-D. These formulations vary by the type and quantity of quaternary compound in the formula as well the use of an amine or ammonia solvent. ACQ types A, B, and D use didecyl dimethyl ammonium chloride (DDAC) as the quat and now allow substitution of DDAC with carbonate anion (carbo-quat). ACQ type C specifies alkyl benzyl dimethyl ammonium chloride as the quat. The only formulation in use in Canada today is ACQ type C.

Some reports on accelerated laboratory tests suggest that the new generation wood preservatives are more corrosive than CCA. What is not clear, however, is the reliability of accelerated test data and how the greater measured corrosion rates may correlate to service life prediction for fasteners. Moreover, there are conflicting and often misleading claims circulating throughout the industry as to how copper azole compares to the various ACQ preservatives regarding fastener corrosion. The information is generally presented as technical data but is used as marketing material. The next section of this paper attempts to shed some light on these issues.

A Critical Review of Preservative and Treated Wood Corrosion Test Data

Test methods to evaluate the resistance of metals and alloys to corrosion in aqueous environments can be broadly divided into accelerated, or laboratory, and non-accelerated, or field, methods. Accelerating test methods provides relatively quick results. However, the accelerating process may change corrosion mechanisms from a diffusion-controlled process to an activation-controlled one or vice versa. They may also bias the types of corrosion products. The accelerating process also makes it difficult to compare test results with real life conditions in attempting to make service life predictions.

Field tests provide results more representative of real life conditions; however, they tend to require prolonged periods of time to develop useful data. Tests conducted in one geographical location cannot be compared with results from another location. Also, local test conditions can change over time during the test duration. The long field test times makes it impractical to commercialize a product.

A review of the available published and private literature relating to the corrosion of metals and alloys in treated wood¹⁻³² shows that many different test methodologies and data presentation formats have been used. Reference 17 provides an excellent overview of historical test methods and provides a good summary of the process leading up to the current widely used AWPA E 12 test method. Other sparsely used and reported on standardized test methods have included the American Society for Testing and Materials (ASTM) Standards B 117, G 59, and G 85 and the military Standard MIL L 19140 E. The different test methods and data presentation formats make it difficult to compare one test result against another.

Present day test methods for preservative treating solutions, especially those used for submission to AWPA, tend to be based on complete or partial immersion testing of metal coupons in solutions of interest using procedures specified in NACE TM 0179, ASTM G 31 or AWPA E 17. The three procedures share similarities in that they are based on laboratory immersion testing, but are different or contain flexibility with respect to test parameters, such as solution volume to coupon

surface area ratio, exposure time, exposure temperature, agitation, pre- and post-exposure coupon preparation, and cleaning methods.

The most widely used method to generate test data on the corrosion rate of metals and alloys in contact with treated wood is AWWA E 12-94, "Standard Method of Determining Corrosion of Metal in Contact with Treated Wood". Standard E 12 is based on sandwiching metal samples between treated wood wafers under set conditions and expressing the corrosion rate in mils per year. This standard is useful since it allows within test comparisons between wood – metal treatments. Unfortunately, it has several limiting aspects. As will be discussed, the E 12 standard can, and has been, modified to suit individual preferences, and the "looseness" of the language in the standard can result in significant scatter in the corrosion rates of metals among different laboratories and for repeated tests in the same lab. The method is not representative of common exterior corrosion environments and does not reflect or predict corrosion rates for specific conditions such as coastal, heavy industrial or arid environments. Additionally, the standard does not provide a method for interpretation of test results, i.e., is 3 mpy an acceptable result? Is a 3 mpy difference between treatments significant?

In this writer's opinion, the inherent susceptibility to scatter in the E 12 test results, and deviations from the standard in presenting test results, present opportunities for misleading reports in marketing and company promotional materials. Potential sources of scatter and error in the AWWA E 12 standard are many and include the following test parameters:

1. Metal Samples — There is no requirement for traceability of samples or quality control steps in their preparation. For example hot dipped galvanized steel, have had different coating thicknesses and surface appearances.
2. Wood Type — E 12 does not specify the type of wood to be used for testing. Different woods have different equilibrium moisture contents and different levels of acidity. The influence of wood type has been shown to affect the corrosion rates of metals²⁴.
3. Wood Surface Preparation — Often wood contains irregular surfaces due to differential swelling of spring- and summer-wood and from planing and other preparation steps.
4. Clamping Force — In the E 12 test, the metal coupons are clamped between two pieces of wood with nylon bolts. The clamping force is specified as "tighten until the threads strip." Stripping is not good because the assembly may then become loose and can not be subsequently tightened. This affects the exposure of the coupons to the humid environment.
5. Exposure Geometry — E 12 standard does not specify how to position the sandwiched wood samples in the test chamber. Whether the wood wafers are horizontal in the chamber or positioned on edge can potentially influence the exposure of the metal coupons to condensed, standing water, thus, accelerating corrosion rates.
6. Exposure Time — E 12 specifies a minimum of 240 hours exposure time, but says that longer periods such as 366 hours may be more convenient to the experimenter. A review of the available published literature shows that test periods can vary widely, from the minimum of 240 hours to a maximum of 2728 hours²⁰. Corrosion rate results have not always been consistent for the same metal at different exposure periods nor for the relative corrosion rate between different metals at different exposure periods.
7. Post-exposure Cleaning Methods — Metal coupons exposed in the E 12 test typically contain hard to remove corrosion products at the end of the test. The effectiveness of corrosion product removal and/or aggressiveness in the removal of corrosion products if pursued can significantly affect measured corrosion rates. Typically, the results of corrosion tests that this writer has seen have not included definite procedures for the removal of corrosion during cleaning.
8. Equipment Capacity — The exposure conditions of 49 °C and 90 % RH are very strenuous for environmental chambers and if maintained for extended periods, could result in chamber failure. Once the chamber stops, the RH reaches 100 % and condensate forms on the samples. This will further accelerate corrosion.

The above sources of errors and scatter in AWWA E 12 test results can be seen in Tables 1 and 2. Table 1 details corrosion rate test results for different treatment solutions conducted by different experimenters, as noted by the references column. More data is available for the CCA-C solution, as it is used as a comparison in most tests; however, one can see the wide scatter in the reported mpy results for the same solution. The test results have been normalized as mils per year; however, different exposure times can contribute to scatter, if the corrosion rate exhibits a parabolic shape vs.time All results are believed to be for the same solution type, except where noted.

The data in Table 1 are interesting in several aspects. Notable is the large difference in corrosion rates between G-90 and G-185 galvanized coupons, (Ref. 22). The difference is not easily explained without knowing details of the test, i.e, the quality of the zinc coating, if the galvanized coating thicknesses were verified or if the galvanized coating was breached, with the carbon steel substrate contributing to the corrosion. Also, several reported corrosion rates for carbon and galvanized steel in the CCA-C solution are as high or higher than in the new generation treatment solutions that replaced CCA-C (References 8, 28 and 31). This is puzzling, as newer generation solutions have been presented as being inherently more corrosive than CCA-C, based on their increased copper contents. One can also find no clear trends or differences in the corrosion rates of the quaternary based solutions (ACQ-B and D) vs. the azole-based solution (CA-B), which is contrary to some published literature suggesting that the azoles are more corrosive than the quaternary based solutions.

Table 1 — AWWA E-12 Test Results Conducted by Various Laboratories (mpy)

Table 2 shows the results of round robin testing between three different laboratories using reportedly the same CCA solution composition (Reference 12). The test

| CCA-C | | ACQ-B | | ACQ-C | | ACQ-D | | | | CA-B | | | | |
|--------------------|--------------------|-----------------------------|-------|-------|-------|------------------------|-------|-------------------|--------------------|------|-------|-------|-------|------|
| CS | Galv. | CS | Galv. | CS | Galv. | CS | Galv. | G-90 | G-185 | CS | Galv. | G-90 | G-185 | Ref. |
| 2.25 | 2.60 | | | | | | | | | | | | | 24 |
| | | | | | | | | | | 2.30 | 1.80 | | | 25 |
| 1.41 | 0.72 | | | | | 6.83 | 0.84 | | | | | | | 26 |
| 3.70 | 5.20 | | | | | | | | | | | | | 27 |
| 19.51 ¹ | 24.40 ¹ | | | | | | | | | | | | | 28 |
| 4.97 | 3.06 | | | | | 19.87 | 6.47 | | | | | | | 29 |
| 26.30 | 15.15 | | | | | 5.42 | 0.12 | | | | | | | 8 |
| | | | | | | | | 8.62 ² | 12.28 ² | | | 18.78 | 13.75 | 22 |
| 19.50 | 24.40 | 50.60 | 45.50 | | | | | | | | | | | 31 |
| | 13.65 | | 37.24 | | | | | | | | | | | 31 |
| | 5* | 23* | 28* | | | | | | | | | | | 31 |
| 4.97 | 3.06 | | | 19.90 | 6.01 | | | | | | | | | 32 |
| (1) oxide | | (2) ACQ type not identified | | | | * Estimate from graphs | | | | | | | | |

results show large scatter, as detailed by the statistical min.-max. range and standard deviation columns. Of interest are the low corrosion rates of aluminum in CCA while aluminum has consistently been not recommended for use in contact with preservative treated wood. The galvanized coupons show particularly high standard deviation results, suggesting that some unexplained variable in the galvanizing may be contributing to large scatter in corrosion rate test results.

Table 2 – Round Robin Test Results of Different Laboratories using the AWPA E-12 Test Procedure

| Metal | Wood Treatment | Lab 1 | Lab 2 | Lab 3 | Statistics | | | | |
|------------|----------------|---------|---------|---------|------------|--------|--------|--------|-----------|
| | | Mils/yr | Mils/yr | Mils/yr | n | Max. | Min. | Range | Std. Dev. |
| Aluminum | CCA | 2.250 | 0.520 | 1.213 | 3 | 2.250 | 0.520 | 1.730 | 0.870 |
| Aluminum | None | 0.543 | -0.511 | 0.047 | 3 | 0.543 | -0.511 | 1.054 | 0.527 |
| Brass | CCA | 0.938 | 0.506 | 0.533 | 3 | 0.938 | 0.506 | 0.432 | 0.242 |
| Brass | None | 0.615 | 0.464 | 0.270 | 3 | 0.615 | 0.207 | 0.345 | 0.173 |
| Steel | CCA | 8.284 | 4.600 | 4.490 | 3 | 8.284 | 4.490 | 3.794 | 2.159 |
| Steel | None | 5.699 | 2.709 | 7.023 | 3 | 7.023 | 2.709 | 4.314 | 2.210 |
| Galvanized | CCA | 12.521 | 11.039 | 15.697 | 3 | 15.697 | 11.039 | 4.658 | 2.380 |
| Galvanized | None | 5.057 | 3.086 | 16.890 | 3 | 16.890 | 3.086 | 13.804 | 7.466 |

Reference 30 states, "In order to correctly interpret the results of any corrosion test, a complete pedigree of material information and testing parameters

should accompany the test results.” This writer strongly agrees with that statement and finds that most of the reviewed test data did not meet this scientific premise.

A review of AWPA E 12 test data from different published papers and internet sources reveals that the test results are difficult to interpret and are apparently being used, where favorable, to promote individual interests. Particularly, corrosion data presented from AWPA E 12 test results in marketing material as “Technical Bulletins” should be used with caution. This is based on the previous discussion regarding sources of errors and scatter, plus other intentional or unintentional omissions in the marketing materials. Omissions include:

1. Specific solutions used in the test are not reported (e.g., “ACQ” can mean one of several different formulations, which can vary in performance),
2. Results reported as “2x, 3x, 4x, . . . more or less corrosive” instead of mils per year (mpy) as specified in the E 12 method,
3. Wood type and moisture content (especially at time of first contact with the metal) not reported,
4. Test times not reported,
5. Sample sizes not large enough to account for scatter, and
6. Cleaning methods not reported.

The above makes it difficult for the consumer to make informed decisions about which treated wood and hardware to specify for a specific environmental need.

Another serious deficiency with the existing test methods and data, and one common to most accelerated laboratory test methods, is their deviation from common exposure environments.

Unusually harsh environments are typically used to accelerate corrosion. A temperature of 49 °C and relative humidity of 90% are used in the AWPA Standard E 12. This test does not take into consideration salt that may be present in coastal areas or elevated atmospheric sulfur and nitrogen oxides in industrial environments. Other tests such as ASTM B 117 and G 85 introduce free water and allow for drying periods but the use of cyclic moisture exposures is not typical. In addition, it is difficult to explain why in these accelerated test environments the corrosion of some metals such as aluminum generally is minimal, but its performance in actual use is poor compared with other metals/alloys.

Finally, none of the standardized test methods provides guidance for the interpretation of results. For example, what is the meaning of a result of 3 mpy? Is it a meaningful result? Is it statistically significant? A parallel is needed between the test result and an equivalent result to be expected from a service application, i.e. 3 mpy in an AWPA E 12 test provides 50 years of service in a suburban exterior deck. A common misunderstanding when reviewing test results is that a result of 3 mpy would mean that a coating of 3 mils would only last a single year in service. This is not true. The rate of corrosion in the accelerated test is anticipated to be much faster than the rate in a service application. A good example of this is the use of hot dipped galvanized nails in CCA treated wood. Test results for galvanized materials have been reported to be as high as 24.4 mpy (Table 1). Galvanized nails typically have a zinc coating of from 1 to 2 oz/ft², equating to a thickness of only 0.14 to 0.25 mils. If the test result is used without considering the environment which the nail is exposed to, it would only be expected to last 2 to 4 days. However, hot dipped galvanized nails have been successfully used in CCA treated lumber for over 30 years. Third, data needs to be established to equate the amount of predicted corrosion to specific reductions in strength and/or withdrawal. Further, although design specifications and building codes have safety factors for pressure treated wood, these values must also be established for predicted corrosion.

What’s Next?

The construction industry has been struggling to adapt to the new generation preservatives and treated wood personnel wonder how to address the question, “which preservative is best” and what recommendations to provide to end users. Several issues need to be addressed including:

- a) The current AWPA E 12 standard needs to be revised to address its shortcomings with respect to reproducibility of corrosion rate data;
- b) Studies should be conducted to address how much corrosion is acceptable in actual use and what safety factors exist in treated wood connectors.
- c) Once an acceptable level and reproducible test are established, users need trustworthy hardware and installation recommendations.

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