

Minimizing Corrosive Action in Timber Bridges Treated With Waterborne Preservatives

Authors:

Samuel L. Zelinka, U.S.D.A. Forest Products Laboratory, 1 Gifford Pinchot Drive, Madison, WI, szelinka@fs.fed.us
Douglas R. Rammer, U.S.D.A. Forest Products Laboratory, 1 Gifford Pinchot Drive, Madison, WI, drammer@fs.fed.us
James P. Wacker, U.S.D.A. Forest Products Laboratory, 1 Gifford Pinchot Drive, Madison, WI, jwacker@fs.fed.us

INTRODUCTION

Wood preservatives are required by AASHTO specifications in bridge applications [1] to extend the service life of the wood members. The only exception is for naturally durable species, which are significantly more expensive. While the majority of wood used in bridge applications is treated with oil-type preservatives, wood treated with waterborne preservatives has been used in timber bridge applications. Many design engineers are choosing waterborne preservatives due to oil-type exudation concerns [2].

As of January, 2004, the most common waterborne preservative of the past thirty years, Chromated Copper Arsenate (CCA), was voluntarily withdrawn from use in residential applications. While this withdrawal does not directly affect bridge applications, some designers are choosing to use alternative treatments to CCA, such as Alkaline Copper Quaternary (ACQ), Copper Azole (CuAz).

It is believed that these preservatives are more corrosive towards metal than CCA because CCA contains hexavalent chromium and arsenic, both of which typically act as corrosion inhibitors, and are not contained in the CCA alternatives. In addition, these preservatives contain more copper than CCA, and the mechanism of corrosion of metals in contact with treated wood is believed to be related to the free copper within the wood [3]. Unfortunately, there has been very little published research on the corrosiveness of wood treated with these preservatives because of the difficulties of measuring the corrosion rate in these environments.

This work will briefly review published literature and current research activities on the corrosion of metals in contact with wood treated with waterborne alternatives to CCA. In addition, recommendations to minimize these corrosive effects in timber bridges will be discussed.

REVIEW OF CORROSION DATA

One of the first to conduct laboratory investigations into the corrosion behavior of wood in contact with ACQ and other preservatives was Simpson Strong-Tie (Dublin, California). Most of their work centered on the AWPA E12 testing procedures and focused on accelerated tests [4,5].

They have tested more than 1,800 specimens using the AWPA E-12 standard and more than 3,000 specimens using a modified E12 test procedure. Simpson Strong-Tie tested fasteners (nails, lag screws, bolts, connectors) in several wood preservatives, including CCA-C, borates, ACQ-D, CuAz-B, and ammoniacal copper zinc arsenate (ACZA). Metal connector coating included various thicknesses of continuous galvanized, hot-dipped galvanized, paint, and stainless steel; fasteners tested included uncoated, mechanically galvanized, and hot-dipped galvanized. Their results showed qualitatively that ACQ-D, CuAz-B, and sodium borate (with $NaSiO_2$) is more than twice as corrosive as CCA-C for the average of G90 and G185 hot-dipped galvanized samples.

The authors of this paper have collected corrosion rate data on nails and screws exposed to wood treated with ACQ to a retention of 4 kg m^{-3} in a 27ºC, 100% relative humidity (RH) environment for one year. It was found that the corrosion rates (in um/year) were 44, 70, and 22 for a bright steel nail, hot-dip galvanized nail, and aluminum nail respectively [6]. The 27ºC, 100% RH environment was chosen because it has been used by several researchers to evaluate the corrosiveness of CCA-treated wood [7,8].

CURRENT RESEARCH

Most research activity at the USDA Forest Products Laboratory (FPL) has focused on the development of rapid electrochemical-based corrosion procedures and exposure studies to validate these electrochemical procedures. The advantages of electrochemical testing, as opposed to gravimetric (weight-loss) methods include ability to maintain moisture content and temperature at conditions encountered in service; ability to measure corrosion rate even if the reaction is diffusion controlled; ability to design a cell that simulates actual fastener placement; ability to test preservative- and fire-retardant-treated wood without polarizing the preservative salts; and, most importantly, the ability to create an equivalent circuit that models the corrosion process both in the experiment and in real-life wood service conditions.

Although electrochemical methods are well established for corrosion in aqueous environments, little has been published on the effectiveness of these techniques to measure corrosion rates of metals in contact with wood. For these reasons, several different electrochemical methods are being pursued at FPL. Electrochemical Impedance Spectroscopy (EIS) allows modeling of corrosion reaction with an equivalent circuit model. This mechanistic circuit model can then be used to predict how changes in the environment or other parameters will affect corrosion rate. Although several researchers [9,10] have published data from EIS corrosion experiments in wood, no one has offered a physical interpretation of the data in terms of corrosion reactions because of the complexities of electrical transport in wood. While EIS data collected from experiments in wood give information about the corrosion reaction on the surface of the metal, this information is convoluted with information about electrical and ionic transport through the wood to the other electrode(s). Before EIS can be a viable experimental technique for corrosion of metals in wood, a thorough understanding of the electrical properties of wood and wood–metal interfaces is needed. Research at FPL is focusing on understanding the electrical properties of wood and developing an equivalent circuit model.

Because wood is a complex and variable material, a qualitative test that mimics the corrosion effects of treated-wood conditions on the metal fastener without using wood specimens would be of great value in rapidly evaluating the corrosiveness of new wood preservatives. Direct-current

Linear Polarization Resistance (LPR) testing has been run on solutions that have been made to imitate the treated-wood environment. The first of such tests was run by placing metals in dilute solutions of wood preservatives, and it was found that the results from these tests did not correlate well with what is known about corrosion of metals in wood [11]. Current research is focusing on finding a solution that better imitates the corrosive treated-wood environment.

DESIGN CONSIDERATIONS TO MINIMIZE CORROSION

Current AASHTO bridge specifications requires all iron steel bridge components to be hot-dip galvanized in accordance with the AASHTO material specification M111 (products) and M232 (hardware) [12]. The zinc coatings should be smooth and relatively uniform in thickness. In general, the required galvanizing coating thickness increases as the thickness of the base metal gets larger. Zinc-coated components are to be free from uncoated areas, blisters, flux deposits, dross inclusions, and other types of projections that would interfere with their intended use.

In general, there are two major strategies that are taken to minimize corrosion action, the first is to isolate a common steel component from the environment using a non-metallic coating or barrier, the second is to replace (or coat) the common steel component with a material with a better corrosion performance in that environment. These methods will be discussed below.

Non-Metallic Coatings

Ceramic and organic coatings and barriers try to completely isolate the substrate from the corrosive environment (Figures 1 and 2). The effectiveness of these coatings depends on their ability to provide and maintain a defect-free, dry environment on the surface of the fastener. Organic coatings range from common alkyd paints to epoxy resins to various rubbers, although they all work upon the same principle of isolation. This wide range of materials allows for a certain degree of optimization of the coating to the environment and use. Ceramic linings, although more porous than their organic counterparts, have a higher hardness, which is important because any damage that occurs to the coating during insertion will give the corrosive environment a path to the substrate, and pitting and/or crevice corrosion may occur at these sites.

Metallic/Galvanized Coatings

Metallic coatings, of which galvanizing (zinc plating) is a specific example, work by applying a metal that corrodes at a slower rate in a certain environment over a metal that corrodes faster. It is important, at this point, to stress that the lower corrosion rate of the coating is what gives improved service life, and corrosion rate of the coating is independent of its ranking on the galvanic series. Although it is widely believed that the effectiveness of a metallic coating is directly correlated to the coating metal's position on the galvanic series, this is just one of many factors that affect durability of the coated fastener. For example, zinc coatings perform better than do cadmium coatings in industrial environments, but cadmium performs better than zinc in marine environments because the corrosion products of zinc are not as stable as cadmium in this environment [13].

Metallic coatings can be further subdivided into two categories, depending on the relative

positions of the coating to the substrate on the galvanic series. If the coating is more active (anodic) than the substrate, then the coating will corrode at the expense of the substrate; that is, the coating galvanically protects the substrate. The advantage of anodic coatings is that the substrate is protected from defects in the coating, such as pores and cracks, because of the galvanic protection. Common examples of anodic coatings are zinc or cadmium applied to steel. Cathodic (noble) coatings, on the other hand, act solely as a barrier between the substrate and the environment. In this respect, cathodic coatings are similar to ceramic or organic coatings because the substrate is susceptible to pitting corrosion at defects in the coating. Common examples of cathodic coatings are chromium, nickel, and tin. Increasing the thickness of these cathodic coatings can increase the corrosion performance because it provides a thicker barrier with a lower chance of defects extending through to the substrate.

FIGURE 1
PVC TUBING SEPARATING ACQ TREATMENT FROM GALVANIZED HIGH-STRENGTH STEEL BARS WITHIN A STRESS-LAMINATED DECK DECK. NOTICE THE WHITE CORROSION PRODUCTS.

FIGURE 2
ROOF SHINGLE MATERIAL SEPARATING A STEEL BEARING PLATE FROM CCA-TREATED WOOD DECK.

In applications where two different metals may be used, it is important to recognize that galvanic corrosion may also occur and the less noble metal corrodes at the expense of the more noble metal. Although galvanic corrosion is often used to protect structures and ships via a sacrificial anode, if not accounted for in design practices, it can lead to failures in service. Even if the metals are protected by paint or another barrier, galvanic corrosion can occur through defects in the barrier. The anodic (less noble) metal should never be coated, because defects in the coating exacerbate the effect of galvanic corrosion by localizing it to a small surface area [14].

An example of galvanic corrosion in highway structures recently occurred in the state of Wisconsin. Aluminum road signs were to be attached to ACQ-treated posts. Hearing concerns about new preservatives and corrosion of fasteners, engineers specified stainless steel lags screws for attaching the signs to the posts. After a short time, several signs failed at points of attachment, a failure never previously observed. The aluminum signs suffered extensive corrosion damage near the point of attachment, which ultimately led to failure.

CONCLUSIONS

This work briefly summarized the results of corrosion tests that have been performed on metal in contact with wood treated with waterborne alternatives to CCA, as well as highlighted new test methods that are being developed to better understand this phenomenon.

Designers should be aware of capabilities and limitations of protective coatings and of the potential corrosive effect of galvanic corrosion. Inspection engineers should look for visual signs of corrosion on metal components on timber bridges, especially in areas where water tends to remain.

REFERENCES

[1] Anon. 2002. Standard specifications for highway bridges. AASTHO American Association of State Highway and Transportation Office. 17th ed. Washington, DC.

[2] Wacker, J.P., Crawford, D.M., Eriksson, M.O. 2003. Creosote retention levels of timber highway bridge superstructures in Michigan's lower peninsula. Res. Note FPL-RN-0289. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 17 p.

[3] Baker, A.J. 1978. Corrosion of metal in wood products. In: Durability of building materials and components; Ottawa, Canada. West Conshohocken, PA: American Society for Testing and Materials.

[4] Anon. 2004. Standard method of determining corrosion of metal in contact with treated wood. American Wood Preservers. Association AWPA E12-94. Selma, AL: American Wood Preservers. Association.

[5] Anon. 2006. Corrosion Fact Sheet. Simpson Strong-Tie Technical Bulletin TPTWOOD06. Available electronically at http://www.strongtie.com/ftp/bulletins/TPTWOOD06.pdf

[6] Zelinka, S.L. 2007. Uncertainties in corrosion rate measurements of fasteners exposed to treated wood at 100 % relative humidity. ASTM Journal of Testing and Evaluation. 35(1).

[7] Baker, A.J. 1992. Corrosion of nails in CCA and ACA treated wood in two environments. Forest Products J. 42(9):39-41.

[8] Simm, D., Button, H. 1985. Corrosion behaviour of certain materials in CCA-treated timber. Environmental tests at 100% relative humidity. Corrosion Prevention & Control. 32(2):25-35.

[9] Zelinka, S.L., Rammer, D.R. 2005. The Use of Electrochemical Impedance Spectroscopy (EIS) to Measure the Corrosion of Metals in Contact with Wood. TMS Letters 2(1):15-16.

[10] Jack, E., Smedley S. 1987. Electrochemical study of the corrosion of metals in contact with preservative treated wood. National Association of Corrosion Engineers 43(5):266-275.

[11] Zelinka, S.L., Rammer, D.R., Stone, D.S., Gilbertson, J.T. 2007. Direct current testing to measure corrosiveness of wood preservatives. Corrosion Science 49(3):1673–1685.

[12] Anon. 2002. Standard specifications for transportation materials and methods of sampling and testing. Standards M111-02 and M232-02. AASTHO American Association of State Highway and Transportation Office. 17th ed. Washington, DC.

[13] Mooney, T. 2003. Electroplated Coatings. In: ASM Handbook Volume 13A Corrosion: Fundamentals, Testing, and Protection. Materials Park, OH. ASM International

[14] Elliott, P. 2003. Designing to Minimize Corrosion. In: ASM Handbook Volume 13A Corrosion: Fundamentals, Testing, and Protection. Materials Park, OH. ASM International

Zelinka, Samuel L. ; Rammer, Douglas R. ; Wacker, James P. 2007. Minimizing corrosive action in timber bridges treated with waterborne preservatives. IN: Lyons, Robert, ed. Proceedings of the 2007 Structures Congress: New horizons and better practices; 2007 May 16-19; Long Beach, CA. Proceedings published on CD.