Fastener Corrosion: Testing, Research, and Design Considerations

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Summary

In 2004, the voluntary removal of chromated copper arsenate (CCA) from residential wood construction raised concern about corrosion of metal fasteners in wood treated with replacement preservatives. Replacement preservatives contain more copper, which may increase corrosion, and do not contain chromates or arsenates, which are known corrosion inhibitors. This paper is an overview of activities related to standardizing or acceptance testing, research, and design considerations related to corrosion performance of fasteners in treated wood.

1. Introduction

1.1 Problem

In almost every timber engineering application, wood is in direct contact with metal. Metallic fasteners embedded in wood are subject to corrosion because water and oxygen are present in the cellular structure of wood. Corrosion of fasteners in wood is a coupled phenomenon: corrosion products of the metal locally accelerate degradation of wood around the fastener (Baker, 1978).

1.2 Formulation Changes

Since the 2004 voluntary removal of chromated copper arsenate (CCA) from the residential construction marketplace, many designers are choosing to use wood treated with alternatives to CCA, including alkaline copper quaternary (ACQ) and copper azole (CuAz). Published research on the effect of these alkaline preservatives on corrosion rate is limited, although ACQ and other new preservatives are believed to be much more corrosive than CCA because of the increased percentage of copper in the preservatives. In addition, CCA contains hexavalent chromium and arsenic, both of which typically act as corrosion inhibitors. In contrast, ACQ and other new preservatives do not contain such inhibitors, and some formulations of ACQ contain chlorides, which can increase the conductivity of the wood, increase corrosion rate, and cause pitting corrosion. Unfortunately, a procedure to quantitatively measure the change of corrosion rate with these alternative preservatives is not readily available. Zelinka and Rammer (2005a) provide further information about the effect of new wood preservatives on corrosion and review test methods used to measure corrosion in wood.

2. Corrosion Testing Procedures

2.1 AWPA E-12

To the authors' knowledge, only one standard, AWPA E12 (AWPA, 2004), attempts to rapidly assess the corrosion of metal in wood. This standard, developed by the American Wood Preservers' Association, accelerates corrosion by placing a metal coupon between two pieces of preservative-treated wood. This wood/metal assembly is then placed in a conditioning chamber at 49°C ± 1°C, 90% ± 1% relative humidity for a minimum of 240 h. Although this test gives rapid results, how measured corrosion rates relate to performance at ambient temperatures and humidities encountered in service is unclear.

2.2 ICC-ES Acceptance Criteria

As of March 1, 2006, the International Code Council–Evaluation Service *Acceptance criteria, proprietary wood preservative systems—common requirements for treatment process, test methods, and performance, AC326* (ICC-ES, 2005) became effective. Within section 4.6 of AC326 are provisions for visually evaluating corrosion of fasteners in treated wood. For evaluation, a minimum of 10 replicates per metal fastener are driven into treated wood and tested according to E12 procedure. After fasteners have been exposed for the minimum time requirement, they are removed from the wood sample, cleaned, and visually inspected for signs of surface corrosion. Surface condition is ranked according to the following criteria: (1) no corrosion to minor corrosion (less than 5% of surface area); (2) partial (5% to 25% surface corrosion); (3) moderate (25% to 50% surface corrosion); (4) severe (50% to 75% surface corrosion); and (5) very severe (75% to 100% surface corrosion). An average visual inspection ranking ≤ 2 is deemed acceptable.

This approach and AWPA E12 are limited and subjective—limited because no criteria link test results to performance and subjective because surface area is not well defined for some fastener types (namely, threaded fasteners). In addition, section 4.6.2 requires that fasteners be cleaned prior to visual inspection, which is problematic. Once the corrosion products have been removed, there is no way to estimate the amount of surface area that had corroded, which will lead to a better ranking.

2.3 ASTM Activities

As a result of many uncoordinated activities to assess the corrosiveness of treated wood towards metal fasteners, a section—"Corrosion of Metal in Treated Lumber"—was formed within the ASTM G01 Corrosion of Metal Technical Committee in May 2005. The section's first action, which took several months, was to collect and disseminate information related to corrosion testing of fasteners in contact with treated wood. After this was completed, the committee decided to develop a testing procedure to evaluate the effects of preservatives on the corrosion behavior of metal. Because some members of the group had participated in an International Nail and Staple Tool Association–American Wood Preservers' Association activity to develop a testing procedure, their proposal became a logical starting point. All activity since has focused on refining this standard.

The objective of the proposed ASTM method is to produce relative corrosion information among different fasteners of interest by using two different environments. The first (static) environment consists of a 90% ± 3% relative humidity, 49°C ± 1°C chamber for a period of 120 days. The second (cyclic fog) environment consists of repeated cycles: 48 h of fog followed by 72 h of drying, repeated for120 days. During the fog cycle, conditions are defined as 24°C ±3°C and <75% relative humidity; during the drying period, temperature is maintained at 35°C ± 1.5°C. The fasteners of interest are compared against three control fasteners made of bright steel, 304 stainless steel, and hot-dipped galvanized material. The effect of corrosion may be quantified by two methods: (1) visual grading of the percentage of surface corrosion according to ASTM D 610 (ASTM, 2005) or (2) measurement of the reduction of cross section at the most corroded location. Details of the draft standard are located on the ASTM website within the G01 Technical Committee section.

2.5 Comments

Current testing activities have focused on AWPA E12 tests or AWPA E12 tests with slight modification. The current ASTM proposal uses AWPA E12 tests as a basis for the static environment tests but has added a cyclic fog test to simulate changing conditions that may be encountered in service. In all cases, these accelerated test procedures are not in any manner linked to fastener performance with in-service environmental conditions.

3. Research Activities

3.1 Simpson Strong-Tie

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 (Simpson Strong-Tie, 2006). 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. The modified procedure, which focused on how actual fasteners performed in treated wood, consisted of driving six clean and weighed fasteners into the narrow face of a standard 38- by 89-mm pressure-treated block 150 to 230 mm long. This composite specimen was placed in an environmental chamber held at 49°C and 90% relative humidity for 240 h. Fasteners were chiseled from the wood, cleaned, and weighed, and an average percentage weight loss was calculated from six fasteners.

Simpson Strong-Tie tested fasteners (nails, lag screws, bolts, connectors) in several wood preservatives, including CCA-C, borates, ACQ-D, copper azole-B (CA-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, CA-B, and sodium borate (SBX) with $NaSiO_2$ is more than twice as corrosive as CCA-C for the average of G90 and G185 hot-dipped galvanized samples. In addition to testing the effect of different preservatives, Simpson Strong-Tie also examined the effect of different metals and galvanizing treatments, from which a fastener selection guideline chart was developed. This chart recommends the connector coating thickness or metal fastener type as a function of both environmental condition and preservative type.

3.2 USDA Forest Products Laboratory

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.

3.2.1 Electrochemical Methods

Although electrochemical methods are well established for corrosion in aqueous environment, little has been published on the effectiveness of these techniques to measure corrosion rate 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 (Zelinka and Rammer, 2005b; Jack and Smedley, 1987) 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. Current research is focusing on finding a solution that better imitates the corrosive treated-wood environment.

3.2.2 Exposure Methods

Because electrochemical methods are not well established for corrosion of metals in wood, they need to be validated by exposure tests where fasteners are placed in treated wood. The authors 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. The 27ºC, 100% RH environment was chosen because it has been used by several researchers to evaluate the corrosiveness of CCA-treated wood (Baker, 1992; Simm and Button, 1985).

To convert gravimetric data to corrosion rate, the surface area of the fastener must be calculated accurately. To this end, the authors have developed an algorithm to accurately calculate the surface area of threaded and unthreaded fasteners.

3.3 Future Research Activities

Three important items are needed for a better fundamental understanding of the corrosive behavior of treated wood towards fasteners: (1) a method to determine the surface area of threaded fasteners used in corrosion experiments so that corrosion rates can be computed and compared between different fastener geometries, (2) accelerated testing procedures to rapidly evaluate the effectiveness of new coatings in a corrosive wood environment, and (3) a long-term exposure study of fasteners in both treated and untreated wood with which rapid or accelerated tests can be compared or correlated.

3.3.1 Surface Area of Threaded Fasteners

Many fasteners used in an outdoor environment contain some type of thread to increase structural performance. However, the surface area of threaded fasteners, which is needed to calculate a corrosion rate, is difficult to obtain from caliper measurements. A better measurement technique is needed to measure the surface area of threaded fasteners before quantitative corrosion measurements can be taken.

It may be tempting to evaluate the results of gravimetric corrosion tests on threaded fasteners in terms of percentage weight loss, which does not require surface area calculations, as opposed to corrosion rate, which does require surface area calculations. The total amount of corrosion depends on surface area and density. Therefore, percentage weight loss measurements, which are a measure of the total amount of corrosion, tend to favor certain materials and geometries and therefore could lead to biased results.

3.3.2 Accelerated Testing Procedures

Perceived corrosion risks associated with ACQ have led to the development of new corrosion-resistant coatings. In addition, preservative manufacturers are constantly changing preservative formulations. A new testing procedure to evaluate the corrosion potential of these coated fasteners in various preservative formulations is critical.

Some companies have relied on the use of salt-spray tests to predict long-term performance of fasteners in treated wood. It cannot be stressed enough that the corrosion rate is sensitive to the type and concentration of chemicals in the environment, and any correlation between a salt-spray test and corrosion performance of fasteners in treated wood is coincidental, at best.

An ideal accelerated test would provide a method to measure localized corrosion, a method to evaluate damage to the coated fastener when driven into wood, and a method to evaluate damage to the coated surface when driven through a hard surface, such as a deck hanger.

3.3.3 Long-Term Exposure Studies

Accelerated tests have little value unless they can be related to in-service performance, which requires validation with long-term exposure data. Fortunately, previous researchers have run corrosion experiments in wood for times up to 20 years. Baker (1992) conducted a long-term study on fasteners in treated wood exposed to two conditions: buried underground and a 27ºC, 95% RH environment. Baechler (1949) conducted a 20-year study of two types of metal fasteners exposed to four controlled conditions and on an outdoor test fence in Madison, Wisconsin. However, these studies were not developed to be a baseline for future corrosion experiments; all the data are reported in percentage weight loss. To convert these data for use in a quantitative comparison, surface areas of the fasteners must be estimated from archived pictures.

4. Design Considerations

4.1 Protective Coatings

Overall corrosion performance of a coated fastener depends not only on the properties of the coating but also on the size and quantity of defects in the coating and on adhesion between the coating and the fastener. Furthermore, coatings that do well in certain environments do very poorly in other environments. 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 (Mooney, 2003). Although coatings may be a cost-effective way of increasing corrosion performance of fasteners in treated wood, care should be taken in evaluating the corrosion rate of coated fasteners. Fasteners must be tested in the treated wood so that results are not erroneously applied to building design (Mooney, 2003).

4.1.1 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. Position of the substrate on the galvanic series also plays an important role. A large disparity between the substrate and the coating metal on the galvanic series could actually accelerate corrosion of the underlying fastener if the coating is cathodic to the substrate and develops microcracks or pores (Mooney, 2003).

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.

4.1.2 Ceramic and Organic Coatings

Ceramic and organic coatings try to completely isolate the substrate from the corrosive environment. 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 to which it will be put. Ceramic linings, although more porous than their organic counterparts, have a higher hardness, which is important for fasteners that are driven into the wood in a violent fashion. 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 will occur at these sites.

4.2 Dissimilar Metals

Recently 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. Figure 1 shows one of the aluminum sign that suffered extensive corrosion damage near the point of attachment, which ultimately led to failure.

This is an example of galvanic corrosion, which occurs when dissimilar metals are placed in electrical contact 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.

Figure1: Failure of an aluminum traffic sign that was attached to ACQ-treated wood with a stainless steel fastener. Photo courtesy of WISDOT.

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 (Elliott, 2003).

5. Conclusions

Since the voluntary removal of chromated copper arsenic (CCA) from residential wood construction, concerns have been raised about the possibility of corrosion of metal fasteners in wood treated with replacement preservatives. These concerns have led to the development of new acceptance criteria and standardization activity to develop new testing procedures for corrosion of metal fasteners in treated wood.

Designers should be aware of capabilities and limitations of protective coatings and of the potential corrosive effect of dissimilar metals in electrical contact.

Finally, for a better understanding of the corrosive effects of treated wood on metal and coated metal fasteners, three activities need development: methods to determine the surface area of threaded fasteners, new or improved testing procedures for coated fasteners, and long-term exposure data to link accelerated testing and in-service performance.

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