FASTENER CORROSION IN ACQ AND OTHER "NEXT-GENERATION" TREATED LUMBER

A New Analysis

BY HEINZ WIELAND

This paper was originally presented by Gary Martini, then of SFS Intec, at the RCI 20th International Convention & Trade Show in Miami Beach, Florida, in April 2005, but has been substantially updated with newly discovered scientific information by its author, Heinz Wieland.

PROBLEM DEFINITION

Building materials, including roofing products, accessory attachments, and gutters, are often connected to pressure-treated lumber by metallic fasteners such as nails or screws. Like most metal-based components, these connectors and fasteners are susceptible to corrosion.

Corrosion is a time- and environment-dependent process. Unfortunately, corrosion is also an extremely complex process. It is common for the causes of corrosion, and thus the methods of corrosion prevention, to be misunderstood and thereby misapplied. The very nature of the supply chain for components to the building construction industry often feeds this trail of misinformation. This leads to well-intentioned applicators installing components that are doomed to service lives far short of written warranties or implied system life. Fastener manufacturers offer only comparative information based upon experiences in like materials. Lumber treaters transfer the onus for knowledge to the applicators. Accessory or membrane manufacturers rely on the knowledge and experience of fastener manufacturers. As a result, in practice, proper science is seldom applied by any party to back up guarantees implied to building owners.

The very reason that lumber is preservative pressure treated is to avoid premature failure due to insect infestation and rot deterioration. To prevent failure of a lumber or timber structure, both the wood material and the connection devices have to be stable over the intended period of service. Wood-preservative treatment is an old process, and there is significant practical experience with the behavior of metal fasteners in treated lumber.

The reason for the renewed debate is a change in lumber and timber preservative materials mandated by the Environmental Protection Agency (EPA). The traditional preservative, CCA, has been replaced to a great extent due to health and environmental concerns. CCA is an abbreviation for chromated copper arsenate (*Figure 1*).

Chromium and arsenic are harmful both to human health and to the environment. For purposes of this discussion, this is stipulated, even though when properly applied and installed, the composite CCA has a rather low potential for harm. Key to this point is the proper allowance for time and/or process to thoroughly dry these materials. In defense of the U.S. EPA regulations, we must acknowledge the fact that such time and treatment prior to application are the exceptions in the fast-paced manufacture-to-market cycle now in place in the U.S.

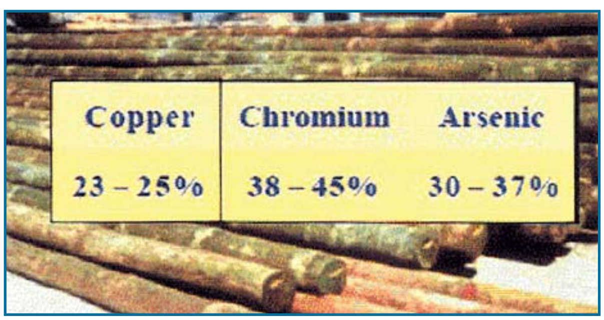

Figure 1

Beginning with materials produced in January 2004, the EPA banned CCA for residential use, while some commercial use was still permitted. The practical problem is that pressure treaters serve large markets and gain certain economies of scale by producing only a single, more broadly accepted treatment type. Since CCA is not acceptable for all applications, it is simply more cost effective for producers to tool their manufacturing facilities for the exclusive production of the new, broadly permissible ACQ-type material.

There are several trade substitutes for CCA. The most common are:

- ACQ – Alkaline copper quaternary (often dubbed "quat")
- CA or CBA (-A), CA-B – copper (boron) azole
- SBX – Sodium borate (not recommended for all applications)

The compositions of these new preservatives are roughly as follows:

- ACQ solution: 49% copper oxide, 33% quaternary ammonium
- Copper azole (CBA-A): 49% copper oxide, 49% boric acid, 2% tebuconazol

There are various qualities of ACQ in the market; nevertheless, the copper contents in both ACQ and CA are substantially higher than in CCA. Conclusions based on simplified theoretical corrosion analyses and tests indicate that fasteners corrode more rapidly in lumber treated with the new CCA substitutes.

Primarily as a result of the higher copper contents, these new wood preservatives are more expensive than older CCA. This means that besides the technical problem of corrosion, there is a potential economic problem. Treated lumber is likely to become more expensive than it was prior to 2004, resulting in a longer return-on-investment period. This could have the effect of necessitating that the fasteners perform with intended values for a longer time than before, despite the increased corrosion risk. This concept should add to the immediacy and concern for this problem.

For purposes of this discussion, we refer to these "next-generation" pressure treatments simply as "ACQ," as has become the industry terminology, even though CA is also a widely used material.

UNDERSTANDING CORROSION

Regardless of how corrosion is defined – galvanic, atmospheric erosion, or intergranular-stress corrosion – there is one thing that is certain: corrosion is a bad thing. It must be staved off or delayed using all available knowledge and methods. This is only possible when a scientific approach is taken to the corrosion issues at play in a given situation. Appropriate remedies must be applied to a problem. To do this, an understanding of the corrosive nature of the ACQ-treated lumber as well as the materials or coatings available for use in fastening requirements is necessary.

There are several practical questions that must be answered in order to apply some certainty to a material or coating solution.

1. What level of corrosion tolerance does the application call for? Is a fastener effectively corroded if surface rust occurs or the substrate or exposed surface is stained?
2. What is the application environment to which the coupling of lumber and fasteners will be exposed? Will it be closed, sheltered, or exposed to clean air, salt spray, coastal, industrial, hazardous, or acidic conditions?
3. What type and concentration of preservative will be used?

The approach to a solution for this complex fastener corrosion problem is critical. Seeking the lowest cost solution while trying to cover each of the parameters at play can lead to minor misjudgments that, in fact, can result in total system failure. Material specifiers should keep this in mind when confronted with information from fastener producers claiming effectiveness against one particular aspect of ACQ-related corrosion.

As clearly stated above, corrosion is a very complex problem; the above-cited parameters are still only part of the puzzle. When seeking answers to specific potentially corrosive application questions, it is common to receive a simple answer like: "Understanding the galvanic series scale will tell you if you have a potential problem. Simply seek materials that are electrochemically similar, and you won't have any problem." But be very careful. This simple approach is very basic, and while true under certain circumstances, it is impossible with limited information such as knowledge of materials specified for a particular project to make this claim. The results, depending on other conditions, can be completely the opposite of what is anticipated. In fact, with such limited information, a specifier might as well simply select the lowest-cost materials and hope for the best.

So what is the galvanic series, and how is it useful?

Each metal material has a specific electrochemical potential. This potential is generally thought of in the materials's most basic application, such as pure water from clean rain, absent acid rain or salt spray. But most people using these materials don't truly understand how significantly these potentials can change under very real, everyday conditions.

The electrochemical potential of the metals listed in the adjacent table is measured in a cell that consists of the metal strip submerged into a solution containing its dissolved ions and a platinum electrode submerged in an aqueous solution containing hydrogen ions. Voltage is measured between these two elements. This sounds very theoretical – and it is. Such a standard

Practical Electrochemical Series in Water pH 6.0		Electrochemical Series for Theoretical Elements (standard potentials)		Practical Electrochemical Series in Seawater pH 7.5	
Metal	**E°mV**	**Metal**	**E°mV**	**Metal**	**E°mV**
Silver	195	Silver	799	Silver	149
Copper	140	Copper	345	Nickel	46
Nickel	118	Lead	-130	Copper	10
Aluminum	-169	Tin	-140	Lead	-259
Tin	-175	Nickel	-230	Zinc (Zn 8.5)	-284
Lead	-283	Cadmium	400	Steel	-335
Steel	-350	Iron	440	Cadmium	-519
Cadmium	-574	Zinc (Zn 8.5)	-760	Aluminum	-667
Zinc (Zn 8.5)	-823	Aluminum	-1660	Tin	-809

Potentials compared to a standard hydrogen electrode E°mV = Electrochemical potential in millivolts

Figure 2

scale is limited to pure metals. It excludes metal alloys. Pure metals are very rarely used in construction applications. For more practical use, potential is measured in the same predefined aqueous solution for all metals – alloys included. (See *Figure 2*.)

Among these three solutions, not only the potentials, but also the sequences are very different. Look, for example, at steel versus zinc. In the pH 6.0 water series in the left two columns, zinc has a much lower potential than steel. In the pH 7.5 seawater series on the right two columns, the opposite is true. This is the reason that hot-dipped galvanized components are not found on ocean-going vessels. Therefore, if confronted with a suggested corrosion application solution using only the potential scales, ask the supplier in which aqueous solution the scale was established.

In the case of ACQ, if the proposed corrosion-resistance approach is measured in an ACQ solution with a limited predefined concentration, it may help to learn about the interaction between copper and a stainless steel part. But one will still not be able to determine the expected effect on a zinc-coated carbon steel fastener in an ACQ-treated piece of lumber.

Readers may have also noticed in the table that, in the standard potential scale, steel is missing. This is because steel is actually an alloy of iron and carbon. Alloys are not part of the standard potential scale., but nearly all metallic parts in contact with treated lumber are alloys.

Even the more elaborate graph in *Figure 3*, showing the corrosion potential in flowing seawater at 10 to 27˚C (50 to 80˚F) in volts vs. standard hydrogen (upper scale), saturated $Cu/CuSO_4$ (middle scale), and saturated calomel (Hg/HgCl lower scale) is of little help, because most lumber is probably not intended to be used in flowing seawater.

In reality, one hardly has an anode/cathode situation when connecting treated lumber with fasteners as the situation in which the values above are measured. An anode/cathode situation means that a metal with a higher electrochemical potential and one with a lower electrochemical potential are electrically connected by an aqueous solution. In the above example, the seawater was the aqueous solution. In a typical anode/cathode situation, the anode (low electrochemical potential – e.g., zinc) dissolves and the cathode (high electrochemical potential – e.g., copper) grows in mass as it is plated with the dissolved metallic ions in the aqueous solution. This principle is precisely the method used to intentionally electrically deposit metals such as chromium or zinc on steel components (plating). In practice, this phenomenon is also dependent upon the surface ratio of the two electrodes, the conductivity of the aqueous solution, and the external contact of the electrodes.

Often, there is substantial real-world variation from the theoretical expected corrosion of metals. This is due to the dramatic variability of environmental conditions as described above. As a result, we must rely on simulation tests to approximate the true, reasonably expected behavior of fasteners in ACQ-treated lumber. Yet there is a serious problem with corrosion tests as well. It may take years for results to appear from realistic tests, and accelerated tests lack standardization. One might suggest that if tests take years for corrosion to appear, then this is in effect a good sign for the material being tested. This is very far from the truth. In fact, the only truly perfect test for simulated corrosion testing is an exact replica of materials being tested under the exact application environment for the full expected life of a connection.

This means that a 20-year roof would have to be simulated for 20 full years. Reasonable shorter-cycle comparisons may be made, but the nature of corrosion of protection-coated materials (such as zinc-plated or epoxy e-coated) is such that though the period prior to surface breech may be extended, the effect of the corrosive compound on the eventually unprotected steel may be dramatic and extremely rapid. Accelerated tests such as salt spray will produce interesting results if a project is planned for a coastal area or northern urban area where road salt is commonly applied. But how would this compare with test results of a noncyclic, high-humidity test in a Kesternich cabinet? The latter test would make sense in an industrialized zone. Unfortunately, there is a temptation to use one or the other test methods for a special brand of fastener or surface coat that gives the most advantageous results compared with those of a competitor.

Still, such noncyclic humidity test results, as shown in *Figure 4*, may give some indications about the probable behavior of zinc-coated fasteners in wood treated with the different preservatives. But one should be aware that zinc coatings vary in type and technique of manufacture.

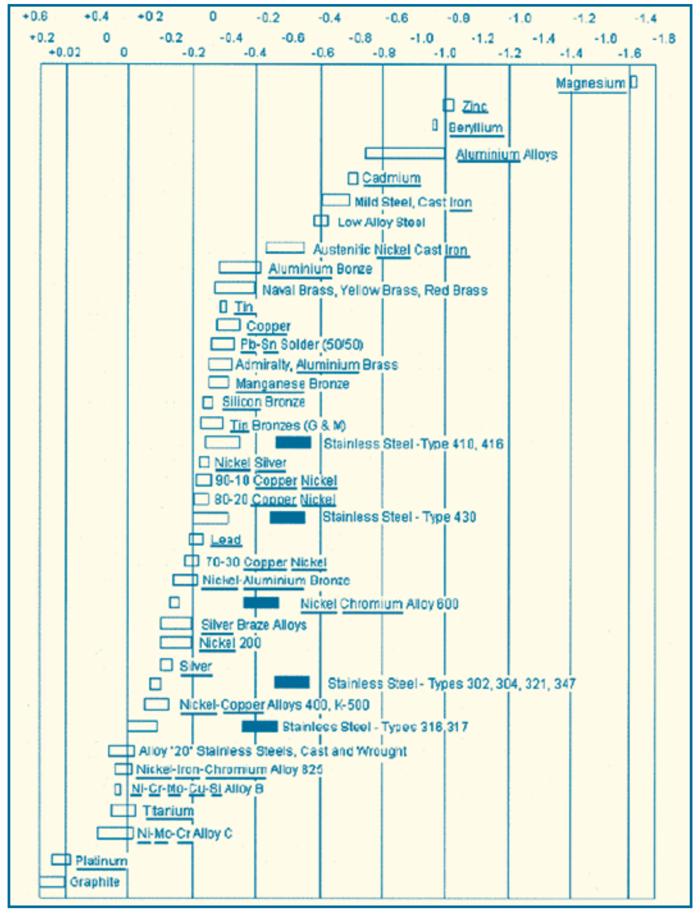

Figure 3

Figure 4 reflects the results of actual tests performed at SFS Intec labs in Heerbrugg, Switzerland. It shows the corrosive rates of zinc-plated fasteners in lumber with the listed treatment types, relative to the base process – untreated pine lumber.

Nevertheless, results of a comprehensive series of tests of noncyclic, high-humidity Kesternich tests do allow for a better understanding of what happens to fasteners in ACQ-treated timber.

First, the test series proves that, in general, corrosion of metallic parts in ACQ-treated lumber is stronger than in CCA-treated timber. This is a key point. Regardless of what else we are able to determine, and absent any long-term real-life experience, we should be alarmed by this fact immediately. Most specifiers would be hesitant to make assurances about service-life expectation for a product known to be of lesser corrosion resistance, with nothing more definitive to establish an opinion.

Second, all types of zinc-plated fasteners begin corroding by producing white rust – a popular name for zinc oxide. Therefore, zinc does not simply dissolve, but also oxidizes. At about the same rate, stainless-steel fasteners – 300 and 400 series – become copper-plated, while carbon-steel-based fasteners begin to corrode. This

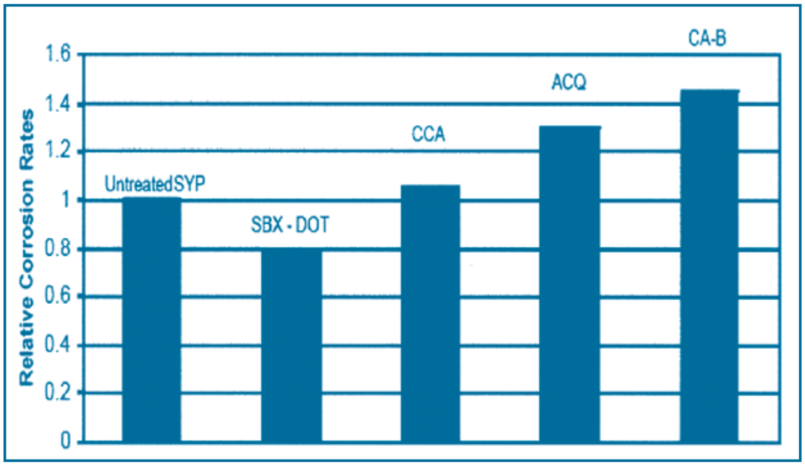

Figure 4

means that the copper in ACQ, which is in the form of copper oxide, gets reduced to pure copper and plates the stainless-steel fastener, which acts as a cathode. This has no adverse effect on the corrosion resistance of the stainless material. At the same time, however, the zinc coating on the carbon-steel fastener oxidizes and no longer provides the necessary protective layer for the steel. The theoretical effect is that the carbon steel begins to corrode, producing red rust or iron oxides. This is precisely what is observed in lab tests. Needless to say, no copper plating occurs on the stainless steel in untreated lumber, and only minimal copper plating occurs on the stainless in CCA-treated lumber. (See *Figure 5*.)

The tests, therefore, help us to better understand what happens in treated lumber. The process is not the same as with screws in metal structures. Here, the main corrosion effect is not of galvanic type, but of oxygen type, also known as general corrosion. The galvanic mechanism occurs to a smaller extent, depending upon the materials being used.

From this we can draw several conclusions. First, standard zinc coatings are of little use. Thick zinc coats, such as heavy, hot-dip galvanizing, may help for a limited time. Epoxy-barrier coatings such as commonly used roofing screw e-coat (electromagnetic coatings) will have the same minimal effect. Other improved zinc coats may also show a slowed corrosion rate, but zinc-oxide corrosion seems to be unavoidable, and with it, the fast degradation of zinc. Zinc layers exposed to the humidity of the atmosphere will corrode as well, but the corrosion product is a zinc carbonate (due to the carbon dioxide in the air) – a strong, nonabrasive, protective layer that slows corrosion to a large extent. Zinc oxide or white rust, has no such effect. Again, tests support this theoretical expectation. Fasteners that were unscrewed for periodic inspection exhibited much more rapid corrosion than fasteners left in place. The zinc oxide was abraded and lost. Although it offered only a minimal protection function, its degradation resulted in accelerated fastener corrosion. While this oxide-removal process accelerates corrosion, it does not promote it, and therefore we can accept the observations of these fasteners as a prediction of the inevitable increased corrosion of the undisturbed test fasteners.

Under an industry test, fasteners were left for 154 days in a Kesternich cabinet with pure water humidity at a temperature around 104°F. *Figures 6A* and *6B* show car-

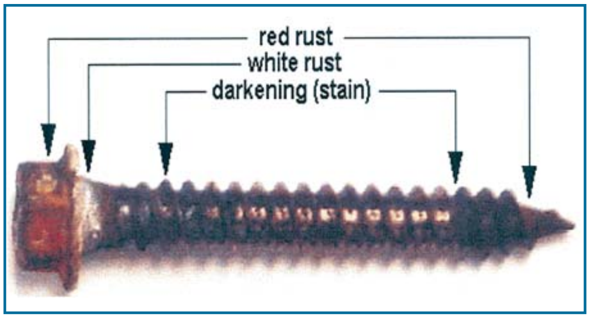

Figure 5 – Standard zinc-plated carbon steel fastener after 154 hours in ACQ lumber chamber.

bon-steel and austenitic stainless-steel fasteners after the simulation. Whereas the carbon-steel fasteners were heavily corroded to a condition where structural safety would be compromised, the austenitic stainless-steel series 300 fasteners showed very little corrosion. The head of the stainless fastener exhibited some white rust caused by the zinc coat that is applied for installation lubricity, and the carbon-steel tip exhibited some stain and red rust. This tip is designed and expected to fail over time, and the head and shank are protected, as they are composed of stainless steel under the thin zinc coating. Corrosion, therefore, is limited to zones where it produces no harm.

The conclusion is that austenitic (300 Series) stainless steel fasteners are virtually unaffected by the wood preservative. If they are plated with a thin zinc layer, it will only serve to provide lubricity for installation rather than to improve corrosion resistance. After installation, the zinc has no function and may corrode away, leaving the austenitic stainless steel to fend off the corrosive effects of ACQ on its own, which it will do quite effectively.

MARTENSITIC (400 SERIES) STAINLESS STEEL

In terms of true surface corrosion, neither martensitic 400 Series nor austenitic 300 Series (304 and 316) fasteners showed visible degradation in industry ACQ tests. But the 400 series (martensitic) fasteners produced some stain on the surface. This is to be expected and will naturally be a problem where fastener heads are visible on the structure surface. Staining may produce clearly visible spots that dissipate into the lumber, leaving the appearance that something is wrong with the fastener.

There are two types of stress corrosion cracking to be considered. Hydrogen-induced stress corrosion cracking is called hydrogen embrittlement. This occurs if normal carbon-steel fasteners or 400 Series stainless-steel fasteners are thermally hardened and zinc-plated in a galvanic process. In the galvanic process, hydrogen is produced, infiltrates the hardened shell of the fastener, and produces hydrogen embrittlement. The hydrogen may be driven out of the hardened shell of the fastener by storing it at 200°C for 24 to 48 hours (opinions differ). This process, however, is not totally reliable. Sometimes the effect does not take place as intended, and the entire lot of screws remains embrittled – an unacceptable situation for structurally loaded fasteners. Therefore, structurally loaded fasteners should not be galvanically zinc-plated. Other coatings (even zinc) are acceptable – but not in ACQ-treated lumber.

The second type is chlorine-induced stress corrosion cracking, which may occur under certain conditions at ambient temperature under a chlorine atmosphere and if acidic water is condensed on the surface of the screw. Chlorine is in our atmosphere – near the ocean or on streets where road salt is commonly applied. Acidic environments are possible with lumber; just one extreme example is fresh oak lumber.

It is here that 400 Series stainless steel has its strong point: it is not at all susceptible to such corrosion, whereas 300 Series stainless steel is susceptible to chlorine-induced stress corrosion cracking (304 more than 316). But failure, alas, is failure. There have been very serious accidents in the past two decades due to that type of corrosion. The reason for such corrosion, by the way, is the nickel content of the steel alloy. This type of corrosion may not be detected by visual inspection and is therefore extremely dangerous.

Fasteners after 154 days in noncyclic Kesternich high-humidity chamber, with periodic removal for inspection:

Figure 6A – Zinc plated carbon steel.

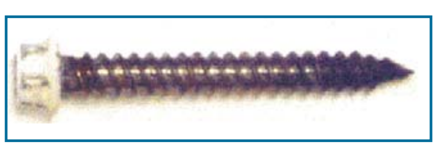

Figure 6B – 304 Stainless steel with carbon tip.

BUILDING ENVELOPE KNOWLEDGE ASSESSMENT

Test your knowledge of building envelope consulting with the following questions developed by Donald E. Bush Sr., RRC, FRCI, PE, chairman of RCI's RRC Examination Development Subcommittee.

1. **When working with metal buildings or roofs, what is the meaning of auxiliary loads?**
2. **When working with metal buildings or roofs, what is the meaning of axial force?**
3. **What is the meaning of camber?**
4. **What is a cantilever beam?**
5. **What is a collateral load?**
6. **What is deflection?**
7. **What is drift?**
8. **What is an end bay?**
9. **What is a girder?**
10. **What is a girt?**

Answers on page 14

BUILDING ENVELOPE KNOWLEDGE ASSESSMENT

Answers to questions from page 13:

1. **Dynamic live loads such as those induced by cranes and material handling systems.**
2. **A force tending to elongate or shorten a member.**
3. **Curvature of a flexural member in the plane of its web before loading.**
4. **A beam supported only at one end, having a free end and a fixed end.**
5. **The weight of additional permanent materials (othere than the building system) required by the contract, such as sprinklers, mechanical and electrical systems, partitions, and ceilings.**
6. **The displacement of a structural member relative to its supports due to applied loads. (Deflection should not be confused with "drift.")**
7. **Horizontal displacement at the top of a vertical element due to lateral loads.**
8. **The bays adjacent to the end walls of a building. Usually the distance from the end wall to the first interior main frame measured normal to the end wall.**
9. **A main horizontal or near horizontal structural member that supports vertical loads. It may consist of several pieces.**
10. **A horizontal structural member that is attached to side-wall or end-wall columns and supports paneling.**

Reference: ***Metal Building Systems Manual***

RECOMMENDATIONS

We have noted that ACQ- or CA-treated wood may be more expensive than the traditional CCA-treated lumber. Logically, the payback period is longer, and the service life of fasteners may be expected to be longer. For zinc-coated carbon-steel fasteners, the opposite applies. They corrode faster in ACQ- or CA-treated wood. The already-existing disparity between the expected service lives of lumber and carbon-steel fasteners increases – not in favor of the fasteners.

For structural fastening, the use of 400 Series fasteners is recommended unless chlorine-induced stress corrosion cracking can be safely excluded. The building owner should be informed about the possibility of stain spots. For nonstructurally loaded fastenings, but where aesthetic appearance is important, use 300 Series fasteners.

Zinc-coated carbon-steel fasteners are not susceptible to chlorine-induced stress corrosion cracking, but to hydrogen embrittlement if galvanically zinc-coated. They still are not recommended for use in ACQ-treated lumber, due to the short-term degradation of the zinc coat.

Timber connections using a screw base with a thread the whole length of the shaft produce a significant commercial advantage if used properly. As the screw thread is used for anchoring the timber on both sides, much higher structural loads can be transmitted. The very small head, required only for driving the screw in, may cause it to be driven below the surface, thus avoiding aesthetic deterioration of 400 Series stainless steel screws. Here, the above-cited recommendations are even more important. It should be noted that these fasteners require proper application but produce highly efficient and cost-saving solutions. Today, such modern fasteners are available and should be implemented.

CONCLUSION

ACQ/CA pressure treatments are proven to be more corrosive than traditional CCA wood treatments. Galvanic and oxygen-related corrosion occur in these materials. Because of the variable environments in application as well as the condition of wood material at delivery (moisture-content variability), corrosion prevention cannot be accomplished through improved workmanship or care. Further, due to high variability in materials and conditions, existing coatings such as zinc and epoxy e-coats are likely to be of little long-term effect in reliably preventing this corrosion. Certainty can only be gained through the use of martensitic and austenitic stainless steels for fastening these materials.

Specifiers must be cautious and mindful of available industry information that is clearly designed to support proprietary products and treatments. Extensive studies and data must be insisted upon. As discussed herein, there are no simple answers to complex corrosion issues such as ACQ.

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