Fastener Corrosion in Treated Lumber

by Laurence Claus

紧固件在防腐处理木材的腐蚀现象

Fasteners, whether they are nails, screws, anchors, or metal connectors play a critical and important role in wood/timber construction. In essence, these products are critical in joining materials together and either carrying or helping distribute structural loads. In many instances these fasteners are installed in corrosive environments or brought into contact with corrosive materials. Common examples of these conditions include exposure to constant moist or humid conditions, coastal conditions or salt infused air, preservative-treated lumber, and contact with dissimilar metals. Any one or a combination of several of these factors can conspire to corrode a poorly specified fastener resulting in loss of the load carrying capacity of the joint, either by degradation of the fastener, the surrounding wood, or both. Therefore, the specifier of the fastener must be knowledgeable about the service conditions and make prudent selections of the fastener coating or raw material to minimize these risks.

In December of 2003 the American wood preservative industry voluntarily stopped producing chromated copper arsenate (CCA) treated lumber products for residential uses. Although this product had been on the market for many years, the health risks related to the potential for some of this product's constituents to leach out were deemed too great. In particular, this wood treatment contained arsenic, a known poison and hexavalent chromium, a suspected carcinogen. CCA lumber, although retained for certain commercial uses, was replaced with a variety of new products for residential and common use.

Although bans like this are the right thing to do for our protection and that of the environment, they do raise challenges when the replacement alternatives do not provide equivalent performance or result in unintended consequences. Anyone that has been in the fastener industry for some time can attest to the challenges that arose and remain today with both the reduced usage of cadmium plating and the elimination of plating and coating processes that employed hexavalent chromium constituents.

One of the unexpected consequences of the alternate wood preservatives was their increased corrosivity to fasteners, anchors, and metal connectors. In fact, many of

紧固件产品，无论是钉子、螺丝、锚或是金属连接器，在木质/木材结构都扮演关键性重要的角色。从本质上说，这些产品的关键性在于材料的接合、承担或辅助分散结构荷载。在许多应用案例，这些紧固件安装在腐蚀性环境，或与腐蚀性物质接触。这种情形常见例子包括：暴露在经常潮湿或含水气的环境、处于沿海地带或是饱含盐份的大气中、经过防腐处理的木材，或与性质相异金属接触。这些因素任何一种或其中几种的组合都可能腐蚀不符规格的紧固件，使紧固件、周围木材或两者造成接合荷载功能丧失。因此，采购人在规格上对于紧固件应用环境必须具有相当的认识，并且谨慎选择紧固件的涂装或基材原料，使这些风险降到最低。

美国木材防腐产业2003年12月自愿性停止生产住宅用途以铬化砷酸铜处理（chromated copper arsenate，简称CCA）的木材产品。虽然这种产品在市场已销售多年，有些产品成分的可能流失所引发的潜在健康风险更是钜大。特别是，这种木材处理含有已知有毒元素砷和疑似致癌物质六价铬。现在，住宅和一般用途都已改用各种新产品来替代，仅有某些特定商业用途还保留铬化砷酸铜（CCA）处理的木材。

这样的禁令虽是为了保护我们和环境而该做的事，但是替代方案若是无法提供同等性能，反而可能产生意外的后果，这就形成多面向的挑战。任何在紧固件产业服务一段时间的人，都可证明当时衍生，且至今依然存在的两个主要挑战：其一，降低电镀镉的使用；其二，排除使用含有六价铬成分的电镀和涂装制程。

木材防腐替代品的意外后果之一是防腐剂对于紧固件、锚以及金属连接器产生的腐蚀增加。实际上，相较于铬化砷酸铜（CCA）防腐木材，这些新替代品已经证实具有两到三倍以上的腐蚀性。尽管这并不排除金属紧固件在这些材料应用的可能，却表示在选择指定且正确的紧固件变得更复杂，更具挑战，并且更具关键性。

Figure 1: Zinc Plated Fastener Example in Alternate Treated Lumber After Several Years Exposure
图1、镀锌紧固件曝露于经处理后替代性木材数年后的实例

these new alternatives have proven to be two to three times more corrosive than CCA preserved wood. Even though this does not eliminate the possibility of using metal fasteners in these materials, it does mean that the choice of specifying the right fastener has become more complex, challenging, and critical.

Wood preservatives have been available and used commercially for over seventy years since Dr. Karl Wolman invented a process that employed high pressure to force wood preservative deep into wood products. The most successful of these products was CCA which is a water-borne solution of chromium trioxide, copper oxide, and arsenic pentoxide. There are three standard formulations, Types A, B, and C, but Type C or CCA-C is the one almost exclusively employed today because of its resistance to leaching and overall performance track record.

CCA has been replaced by a variety of different treatments. In the United States the most common alternate treatments are Alkaline Copper Quaternary (ACQ), Copper Azole (CBA and CA), Sodium Borate (SBX), and Micronized Copper Quaternary (MCQ). ACQ is a combination of about 2/3rd copper oxide and 1/3 quaternary ammonium compound. Like CCA, there are several different standards that exist for ACQ, Types B, C, and D. ACQ-B is the most prevalent treatment in the United States because of its improved ability to penetrate certain western species of US pines. CA-B or copper azole type B is used in the United States and is a waterborne solution of 96% copper and 4% tebuconazole. SBX or borate treatments are generally reserved for timbers being treated for termite or other insect infestation hazards. Most borate treatments use disodium octaborate tetrahydrate because of its excellent water solubility which facilitates the application of more concentrated solutions. Their lack of copper constituents generally makes them unsuitable for prolonged wet conditions and so they are usually used in "dry" applications. Finally, MCQ utilizes micro-sized particles of solid copper rather than aqueous copper like its close cousin, ACQ.

With the exception of the SBX treatments, experience has shown that the alternate treatments, ACQ, CA, and MCQ all are much more corrosive to metallic fastening elements than the CCA treatment. Although the actual mechanism of corrosion is still unknown, it is theorized that the greater concentration of copper and absence of hexavalent chromium in these alternates is a significant contributing factor. Hexavalent chromium is a proven corrosion blocker and was an integral part of many corrosion protection systems up until about fifteen years ago when it was deemed a hazardous substance.

自从卡尔·沃尔曼博士（Dr. Karl Wolman）发明以高压方法使防腐剂深入木质以来，木材防腐处理已在市场上流通超过七十年。这些产品最成功的就是铬化砷酸铜（CCA），它是三氧化铬、氧化铜以及五氧化二砷组成的水性溶液。有三种标准配方，A型、B型和C型，但是C型，或简称CCA-C型，以其抗流失和整体追踪记录性能，是现今几乎唯一采用的木材防腐系统。

铬化砷酸铜（CCA）目前已被各种不同的处理方法取代。美国最常见的替代处理是铜烷基铵（Alkaline Copper Quaternary，简称ACQ）、铜唑（Copper Azole，简称CBA和CA）、硼酸钠（Sodium Borate，简称SBX）和微米化铜烷基铵（Micronized Copper Quaternary，简称MCQ）。铜烷基铵或ACQ是大约2/3氧化铜和1/3的四元铵化合物的组合。和铬化砷酸铜（CCA）一样，铜烷基铵（ACQ）也存在有几个不同标准，有B型、C型和D型。ACQ-B型在美国最普遍，因为这个处理方式对于某些西部品种的美国松的穿透性带来显着改善。CA-B或铜唑类B型使用在美国，是96%铜和4%戊唑醇组合的水性溶液。SBX或硼酸钠盐通常特别用于白蚁或其他昆虫危害的木材处理。大多数的硼酸处理使用二钠水合八硼酸，以其优异的水溶解度，因此有利于浓度较高溶液的应用。硼酸处理因为缺乏铜成分，一般而言，较不适合长时间潮湿的环境，所以通常是"干式"应用。最后，微米化铜烷基铵或MCQ，利用实心铜微米化颗粒，而不像它的近亲铜烷基铵ACQ利用含铜水溶液。

Figure 2: Typical ACQ Treated Timber
图2、典型的铜烷基铵 ACQ 防腐木材

除了SBX硼酸钠盐，经验证明ACQ铜烷基铵，CA铜唑和MCQ微米化铜烷基铵这些替代处理，对于金属紧固元件的腐蚀性比CCA铬化砷酸铜高出许多。虽然腐蚀的实际机制仍然未知，学说指出，这些替代品较高的铜含量以及不存在的六价铬是影响腐蚀显着的因素。六价铬经过证实是个腐蚀的阻滞剂，在过去向来是许多腐蚀防护系统的组成成分，直到大约十五年前被认为是有害物质。

为了要理解这种现象，已开发几种加速测试方法，用来研究这些替代防腐处理对于金属接触以及不同涂层的影响。这并不是唯一的加速试验方法，最常用的可能是美国木材防腐协会标准E12-94"防腐处理木材中金属腐蚀的判定标准方法"。在这试验中，紧固件先测重量，然后，根据标准将紧固件精确的旋入，固定到研究防腐处理的木块。这个「测试木块」然后放置在120°F和90%湿度的环境室，持续进行指定时间的测试。紧固件从测试木块移除、清洗并重新测重。与紧固件原始状态相比，减少的重量代表测试过程中发生的腐蚀，以恒等式可以确定所求的腐蚀速率。然而，像大多数加速腐蚀试验一样，这些结果只能用来作比较，并不能预测或说明实际使用条件下紧固件或接合的实际寿命与腐蚀之间的相关性。

In an effort to understand this phenomenon several accelerated test methods have been developed to study the effects of metal contact and different coatings with these alternate preservative treatments. Although it is not the only accelerated test method, the most commonly used may be the American Wood-Preservers Association Standard E12-94, "Standard Method of Determining Corrosion of Metal in Contact With Treated Wood." In this test, fasteners are weighed and then precisely fastened according to the standard into wood blocks treated with the preservative being studied. The "test block" is then placed in an environmental chamber held at 120° F and 90% humidity for the duration specified in the test. The fasteners are removed from the test block, cleaned, and re-weighed. The resulting loss of weight from their original condition represents the corrosion that occurred during the test and an equation can be used to determine the expected corrosion rate. Like most accelerated corrosion tests, however, these results can only be used for comparative purposes and do not predict or correlate to the actual life expectancy of the fasteners or joint under actual service conditions.

Simpson Strong-Tie conducted this test on many parts, both on several thousand coupons and fasteners. Assigning CCA-C a baseline value of 1.0, they determined that ACQ and CA were greater than twice as corrosive, ACZA (Ammoniacal Copper Zinc Arsenate), another arsenic containing treatment commonly used in the US in non-residential applications, was over three times more corrosive and MCQ was just a little lower than ACQ or just under two times. An even more extensive study by the New Zealand Building Research Levy (BRANZ) supported these findings. In section 1.2.1 the authors of this test report state, "BRANZ also tested the comparative aggressivity of timbers treated with CCA, CuAz[CA] and ACQ towards mild steel, hot dip galvanized steel and austenitic stainless steel according to AWPA E12-94 [Kear et al. 2006a]. The corrosion rates derived from mass loss measurements indicated that timbers treated with ACQ and CuAz [CA] could be more corrosive than those treated with CCA under identical testing conditions."

The BRANZ team did not, however, stop there. They set out to determine if the results of the AWPA E12-94 and other accelerated testing they performed would be confirmed with actual field exposure test results. To do this they set up a test field at two locations in New Zealand, one in a moderate and protected environment and one only several meters away from the ocean surf. In each case untreated timbers and those with preservative treatments of CCA, ACQ, and CA were tested with a combination of nails, screws, and flashing plates of unprotected mild steel, mechanically zinc plated steel, hot dip galvanized steel, and stainless steel. Their study confirmed the findings of the lab testing that ACQ and CA treated timbers generally accelerated the corrosion rates of the uncoated mild steel , mechanically plated zinc steel and the hot dipped galvanized

Simpson Strong-Tie公司曾经以数千支紧固件进行这项测试。以CCA-C铬化砷酸C型的基线值设定为1.0，他们发现ACQ铜烷基铵和CA铜唑的腐蚀性超过两倍，另一种含砷、常用在美国非住宅应用的氨铜锌砷酸 ACZA（Ammoniacal Copper Zinc Arsenate）的腐蚀性却超过三倍，MCQ微米化铜烷基铵比ACQ铜烷基铵稍微低些，不到两倍。另外，纽西兰建筑研究所（BRANZ）所作一个更广泛的研究支持了这些发现。这个测试报告1.2.1节中，作者这么叙述：「BRANZ研究团队依据美国木材保护协会(AWPA) 标准 E12-94 [Kear及其他，2006a] 测试了CCA，CuAz [CA]和ACQ木材对低碳软钢、热浸镀锌钢和奥氏体不锈钢的腐蚀性。从质量损失测得的腐蚀速率显示，ACQ铜烷基铵和CuAz [CA]铜唑处理的木材腐蚀性，相较于那些CCA铬化砷酸处理的木材，在相同的测试条件下可能更高。」

BRANZ的研究并不仅只于此。他们进一步研究是否AWPA E12-94标准所得出的结果，以及他们所执行其他加速试验的结果，可以从现场实际暴露的试验结果得到证实。为此，他们在纽西兰两个地方建立了一个测试场，一个在温和并受保护的环境，一个距离大海冲浪场只有几公尺。每一个实验中，未经处理的木材以及那些CCA铬化砷酸、ACQ铜烷基铵和CA铜唑防腐处理木材，都以钉子、螺丝、未保护软钢的厚金属片、机械镀锌钢、热浸镀锌钢以及不锈钢的组合进行测试。他们的研究证实了实验室的测试结果，证明ACQ铜烷基铵和CA铜唑处理木材，一般而言，对于未涂装软钢、机械镀锌钢和热浸镀锌钢，相较于以CCA铬化砷酸处理或未处理木材，会加速金属的腐蚀速率。如同Simpson-Strong-Tie，他们并得出结论，奥氏体不锈钢、304和316不锈钢材质的紧固件显示测试中无显着降解。虽然热镀锌样品确实出现劣化，但是不像机械锌或未保护软钢样品那么显着。

以锌镀层厚度为基准，热浸镀锌紧固件可能表现不同的腐蚀速率，以及测试后不同的腐蚀程度。其结果，辛普森·史丛泰（Simpson-Strong-Tie）建议暴露于某些环境或与研究中替代处理木材接触的热镀锌金属连接器最好增加厚度。除了热浸镀锌紧固件，他们也推荐使用奥氏体不锈钢，但警告说，最好的做法是不要混用异种材料。换言之，如果连接器使用热镀锌材质，紧固件也应热镀锌处理，不锈钢连接器则应使用不锈钢紧固件。

Figure 3: Hot Dipped Galvanized Fastener Example in Treated Landscape Timber after Several Years Exposure
图3、热镀锌紧固件曝露于处理的景观木材数年后的实例

steel as compared to both untreated and CCA treated timbers. Additionally, they concluded, as did the Simpson Strong-Tie testing that austenitic grades, 304 and 316 stainless steel, fasteners showed no appreciable degradation in the testing. Although the hot dip galvanized samples did exhibit deterioration, it was not as significant as the mechanical zinc or unprotected mild steel samples.

Hot dip galvanized fasteners can exhibit different rates and subsequent levels of corrosion based in the thickness of the zinc layer. As a result, Simpson Strong-Tie recommends a thicker version of hot dipped galvanized metal connector when exposed to certain environments or contacting the alternate treated wood addressed in these studies. In addition to hot dipped galvanized fasteners they also recommend austenitic stainless steel, but caution that best practice dictates not mixing dissimilar materials. In other words, if using hot dip galvanized connectors, the fasteners should also be hot dip galvanized and stainless connectors should use stainless fasteners.

The BRANZ study also goes on to recommend that when specifying the fastener one must consider the entire joint holistically. The report points out that, "Deterioration of metallic fasteners not only weakens the fastener itself, but the chemical reactions involved in corrosion can also weaken the timber surrounding the fastener." They refer to this as "Nail Sickness" and, as a result, suggest that the fastener and timber be considered as a system to minimize any risks in structural safety or longevity.

In a related fashion, it has long been known that zinc plated fasteners often result in a blueish gray staining over time in cedar or redwood. Woods, like cedar, that are high in tannins react to iron to produce this blueish stain. This "iron staining" is particularly unsightly on a deck, fence, or other exposed structure and occurs when the fastener coating breaks down and exposes the underlying base steel. Austenitic stainless steel fasteners do not exhibit this phenomenon and are generally regarded as the best recommendation for exposed use with cedar.

There is a lot yet to be discovered about corrosion of fasteners in timber. It is clear, however, that understanding even a few basic principles and pairing the fastener with the lumber type will go a long way to assuring a long-term, sustainable joint and structure. This is particularly important when choosing the right fastener for use with wood preservative treatments that are an alternative to CCA-C treated lumber.

BRANZ研究团队进一步建议，指定紧固件时，必须从整体上考虑整个接合。该报告指出：「金属紧固件的劣化不仅削弱紧固件本身，腐蚀所涉及的化学反应也可能会削弱紧固件周围的木材。」他们将这种现象称作为「钉子疾病」，并建议紧固件和木材两者应该被看作是一个系统，以尽量减少任何有关结构安全或使用寿命的风险。

Figure 4: Example of "Nail Sickness"
图4、钉子疾病的例子

以同样相关角度可看出一个已知事实，镀锌紧固件置放于雪松或红杉一段时间，经常会出现一种蓝灰色的渍染现象。含单宁酸的木材，例如雪松，会与铁反应，产生这种青蓝色的渍点。这种「含铁质的渍染」在阳台甲板、栏干或其他暴露结构尤其不容易看出来，但是当紧固件的涂装崩解，露出底下的钢基材，这种现象就会发生。奥氏体不锈钢紧固件并没有出现这一现象，所以通常被视为雪松暴露应用的最佳建议。

有关紧固件在木材应用的腐蚀，有许多知识尚未发现。不过，要了解几个基本原则，甚至于知道紧固件与木材类型的配对，还是很明显需要很长的时间，才可以确保长期永续的接合和结构。这一点，在选择适合防腐处理木材应用的紧固件的时候，因为这些木材防腐处理必须足以作为CCA-C铜烷基铵C型的替代方案，尤其显得重要 。

Reference/参考文献：

- Alonzy， Jerry.2014. 'Pressure-Treated Wood- Its Uses， Limitations and Safety Considerations'. Natural Handyman's Home Repair Articles. www.naturalhandyman.com.
- Groenier， James， and Lebow， Stan. 2006， 'Preservative-Treated Wood and Alternate Products in the Forest Service'. Technical Paper 0677-2809P-MTDC. United States Forest Service. Washington DC.
- Li SW， Marsten NJ and Jones MS. 2011. 'Corrosion of Fasteners in Treated Timber'. BRANZ Study Report 241. BRANZ Ltd， Judgeford， New Zealand.
- Simpson Strong-Tie Technical Bulletin T-PTWOOD08-R. 'Preservative Treated Wood'. Simpson Strong-Tie Company Inc. Pleasanton CA.
- Truini， Joseph.2013. 'Your Guide to Working With Pressure-Treated Lumber'. Hearst Communications， Inc. www.popularmechanics.com.