Metal corrosion in wood joint products and structures: a review

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Abstract

Nails and screws are relatively small parts connecting wood items into construction products ranging from simple ones, such as a drawer, to large structures, such as houses and bridges. Metal nails and screws will corrode both outside and inside the wood. The wood around the nail or bolt will also deteriorate. Metal corrosion and wood deterioration are the basis for researchers to publish the corrosion rate of nails and screws, the composition of metal elements, and wood extractives that affect the corrosion rate. These publications need to be compiled into a review to obtain a complete set of various perspectives concerning nail and screw corrosion in wood. The chemical elements of nails and bolts, such as iron, carbon, zinc, and other chemical elements, play an important role. The wood extractives that comprise phenolic compounds, organic acids, and other wood chemical compounds affect the corrosion rate. The occurrence of corrosion processes and interactions with wood cause damage to wood and wood deterioration that can cause damage to wooden structures. Prevention of corrosion and wood damage can be done by coating nails and bolts and improving the quality of wood. This step will result in a wooden structure connected using nails and screws over a long period for human safety and conserving wood-producing trees in the nature.

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1. Introduction

Citizens in various countries still choose wood as a structural and building material because it has multiple advantages [1]. Wood is a renewable resource that is widely used in construction and buildings [2]. Wood also has high mechanical properties and great thermal insulation [3]. Wooden houses account for 50% of extracted materials, 35% of total greenhouse gas emissions, 42% of total energy consumption, and 30% of water consumption [4].

While metals require more complicated processes to be used in construction and buildings [5], they are used as complementary material in the form of construction connectors in wooden structures. Metal as a fastener in a wood construction must be able to support the wooden structure [6]. Egyptians used nails for wooden materials starting from 3400 BC [7], while screws were patented in 1902 [8].

Metal corrosion can occur due to direct contact of a metal with water and the effect of air humidity around the metal [9]. Metal corrosion in wood is very specific because various factors affect corrosion in wood, for example, wood moisture content, extractives and additives [10].

Corrosion of metal connections in wood has been widely published. There is a significant gap in research on the deterioration of wood affected by metal corrosion of wood joints [11]. Therefore, it is necessary to study metal corrosion and the resulting wood damage to get an idea of its application in the field of wood structures in the present and in the future.

2. Wood as outdoor constructions

Outdoor round timber constructions include playground equipment, pedestrian and non-pedestrian bridges, and watchtowers [12]. Outdoor constructions from sawn timber include houses, buildings, docks, bridges, and others. Wooden houses provide comfortable atmosphere in the house [3] and tend to be lightweight and resistant to earthquakes [2]. Wooden houses give the foremost common, practical, and economical arrangement for development [13]. People can build wooden houses from sawn timber and wood-derived products such as Laminated Veneer Lumber (LVL), Cross Laminated Timber (CLT), and Glued Laminated Timber (GLT).

Today, wooden houses in Indonesia are still found in various forms and names. Wooden houses in Java are known as Joglo [14], Batak Karo wooden houses in North Sumatra are known as Siwaluh Jabu [15], and several types of wooden houses in other areas. In Kalimantan, the wooden house of the Dayak Bidayuh is known as Baruk [16], and the wooden house of the Dayak Ngaju is known as Betang [17]. An example of a wooden house in Kalimantan can be seen in the following picture.

One of outdoor wood constructions commonly found in East Kalimantan is a wooden tower that supports a water tank above it. The metal bolts on the wooden tower significantly contribute to its construction strength [18].

Bridges can be made of wood at a lower cost [19]. The bridge construction has a wooden foundation that is connected to the ground [20] and there are parts that become the base for vehicles that pass through it. To connect parts together, one should use screws because there is a dynamic load that causes the connection to loosen. When the connection becomes loose, the screw can be re-tightened.

Figure 1. Wooden house in Samarinda, East Kalimantan. The wooden walls are nailed, and the support poles are screwed.

Outdoor wood constructions tend to be larger, thus requiring more joints. The higher the specific gravity of the wood, the more bolts that need to be attached to the wooden construction [21].

Beside permanent buildings, there are temporary constructions using Gelam (*Melaleuca cajuputi*) wood [22, 23]. Gelam wood structures are arranged when helping workers to cast or construct buildings and to reach higher locations. Nails are used for connecting Gelam wood because they are more practical to use [24].

3. Wood as indoor constructions

Indoor wooden constructions tend to be smaller with lighter loads. Various indoor furniture is made of wood, such as tables, chairs, cabinets, and others. Door connections in the cabinets use bolts [25]. The drawer runners are connected to the cabinet walls using bolts [26].

Indoor wood constructions are not only made of solid wood but also use other processed wood products such as plywood [27] and expansion of MDF [28]. Wood construction materials affect the type of connection used, for example, plywood and MDF tend to use screw connections, while solid wood tends to use nails. On plywood and MDF, the type of adhesive will determine the corrosion rate at the joint [29]. Phenol-formaldehyde besides being useful as an adhesive also functions as an anti-corrosion coating [30].

4. Metal as wood constructions connector

Screwed joints have lower quality and solidness than nailed joints [31]. The wood is drilled beforehand so the bolts can be screwed fixedly to the wood and minimize the wood damage [32]. Screws are used for the connection of large parts of wood and various other wood-derived products, such as CLT expansion [33]. Based on various types of screws, stainless steel has good corrosion resistance as screws on wood but tends to be easily detached when used [34]. Screw installation in the radial direction on the CLT has a higher strength than the tangential direction [35]. The installation of several bolts on wooden joints requires a certain distance to obtain maximum strength [36].

Nails are used widely and traditionally on small-sized wood items [33]. Nails can be attached directly to wood or the wood pre-drilled and then nailed using a larger diameter than the drill hole [37]. The nailed joints appear way better bendable and scattering than screwed joints [31]. Nails can connect a beam-column with high strength mechanical performance [38]. CLT is an innovative panel product joined by nails together for lightweight structures [39]. Nails not only join several wood panels together but can also prevent wood densification swelling [7].

5. Effect of metal chemical elements on metal corrosion rate

Bolts with iron (Fe) as the main component have the disadvantage of being easily corrodible [40], so they are made of metal alloys with chemical elements such as molybdenum (Mo), silicon (Si), and cadmium (Cd) as coating materials [41]. Bolts with 8–16 mm diameter contain aluminum (Al), steel (Stl), bronze (Brz), cast iron (CI), copper (Cu) and brass (Br) [42]. Aluminum alloy screw AA130 is made of 0.157 Fe, 0.058 Si, 0.022 Zn, 0.013 Cu, 0.006 V, 0.004 Ni, 0.002 Ti, 0.001 Mn, and 99.1 Al [43]. Combinations of aluminum (Al), chrome (Cr), and zinc (Zn) were detected in bolts [44]. Electroplated galvanized screw corrosion rate is up to 60 μm/year [29].

Iron (Fe), tin (Sn), silver (Cu), lead (Pb), arsenic (As), silver (Ag), antimony (Sb) elements were detected in aged bronze nails [45]. Nail corrosion rate ranges from 0.042–0.171 mpy [46]. Nail corrosion rate depends on the constituent material: the average corrosion rate of carbon steel nails is 45 μm/year, that of 5056 aluminum nails is 20 μm/year, and that of hot-dip galvanized nails is 75 μm/year [29].

The zinc element in the metal will corrode first to protect the iron element from being corroded [47]. The higher the carbon element in the metal, the higher the corrosion rate in the metal [48]. A small nickel concentration in steel screw can reduce the corrosion rate [49]. The presence of the Cr element is stronger as inhibiting metal corrosion rate than the Sn element [50].

6. Effect of wood chemical components on the metal corrosion rate

The content of natural acids within the wood of tree species ranges within 0.21–1.08% [51]. The type of wood determines its extractive acidity. Elm (*Ulmus*) wood is an example of wood that has extractives that are weakly acidic, while oak (*Quercus*) wood has extractives that are acidic and corrosive [52]. Organisms that live on wood, such as stain molds, affect the extractive acidity of wood. Molds (*Aspergillus niger*, *A. flavus*, *Alternaria tenuissima*, *Fusarium culmorum*, and *Trichoderma harzianum*) have various concentrations of organic acids (oxalic, citric, tartaric, succinic, glutaric, acetic, propionic, and butyric) in the wood extractives [53]. The lower the pH of the wood, the faster the metal corrosion rate in the wood connection [54].

Wood extractives may contain fatty acids such as heptadecanoic acid, which are lipophilic [55]. Fatty acids are formed when trees grow and can be stored in wood for a long time [56]. Fatty acid groups such as sterols, lipopeptides, lactones, amides and pyrroles function as antifouling agents on metal surfaces to prevent metal corrosion [57].

Wood extractives contain some phenolic compounds such as tannins, quinones, flavonoids, terpenoids, and alkaloids [58]. Quinones such as 2-amino-4-[4-(dimethylamino)phenyl]-7-hydroxy-1,4-dihydroquinoline-3-carbonitrile function as a corrosion inhibitors on mild steel under acidic conditions through a cathodic inhibition mechanism [59]. Myricetin and rutin are flavonoids that function as corrosion inhibitors on mild steel and aluminum in 2 M HCl solutions [60].

Tannins are chemical compounds containing polyphenols that are non-toxic and can be degraded naturally [61]. Tannins from tropical woods are dominated by catechin species, while gallic species dominate those from sub-tropical areas [62]. The wood contains 0.83–20.8% tannins [51]. Tannins belong to cathodic corrosion inhibitors that can be used in a neutral pH environment [63].

Other chemical compounds in wood extractives that affect corrosion include nitrogen (N), phosphorus (P), sulphur (S) groups, and combinations with double or triple bonds [64]. Alkaloids are chemical compounds containing a nitrogen group. They are sometimes associated with a heterocyclic carbon group, and their presence in wood extractives is slight, such as taxols, xanthines, quinines, and others [65]. A natural material quinine can inhibit the corrosion of low carbon steel with an efficiency of up to 96% [66].

7. Construction failures

Wood species affect the corrosion rate of nails and screws used as connecting materials. The weight loss of screws mounted in *Ficus nervosa* wood was 6.91–7.23% [67], that in *Melaleuca cajuputi* wood was 5.96% [68], and that in *Castanopsis acuminatissima* wood was 6.89% [69].

When the wood is nailed, the structure of the wood is damaged, and the process of wood deterioration begins [70]. The wood weight loss due to screw installation on *Litsea roxburghii* wood was 16.31% [68], and that on *Castanopsis tunggurut* wood was 7.23% [69]. Threads on bolts cause more severe wood damage if the connection to the wood construction is damaged [71]. The nailing process, especially using an airgun nailing device at a speed of 30 m/s, causes friction of the cell walls, which can degrade lignin in the cell wall [70].

The weight loss of wood due to metal corrosion of nails and bolts as well as chemical damage to wood will cause a decrease in the mechanical properties of wood. The bearing strength of the screw also increases with an increase in the maximum compressive strength parallel to the wood grain [72]. Damage to the wood around a screw can result in damage to the joint due to holding the maximum grain parallel pressure from the screw [73].

8. Technical treatments

The treatment of wood and nails or bolts can prevent corrosion. Wood with a low moisture content dried by kiln-drying has a stronger screw/nail connection and lasts longer than fresh wood [74]. Wood with a moisture content below the EMC tends to have minimal or no corrosion [75].

Treatment of wood, such as the addition of preservatives, can cause changes in the corrosion rate when compared to untreated wood. Acetylated wood does not affect nail corrosion rate [76]. Wood preserved with DDAC (dodecyl dimethyl ammonium carbonate) has a higher corrosion rate than wood preserved with copper-based preservatives such as CCA, ACQ and CuAz [77]. Addition of PEG to wood can function as a corrosion inhibitor [78]. Some fire-retardants can trigger corrosion [79].

Bolted joints with slotted-in steel plates in round timber provided higher mechanical strength with a longer joint life [12]. Coating the surface of bolts and nails can reduce the corrosion rate [44]. The coating process acts as anodic protection in the corrosion inhibition process [50]. Extractives from a natural product containing C, N, O, S, or functional groups such as alkaloids, terpenes, carboxylic acids, polyphenols, quinine, and nicotine can be attached to metal surfaces to form a thin layer that can prevent corrosion [80].

Nails or bolts can be surface thermal diffusion galvanized to reduce corrosion in a more environmentally friendly manner [81]. Wetting and drying tests on galvanised nails did not significantly affect the corrosion rate of nails nailed into wood [82]. The galvanization process can use Zn phosphate, Fe phosphate, duralumin or aluminum bronze to form a metal alloy with high corrosion resistance [83]. By keeping the temperature low, the screw drilling process can inhibit the corrosion process [84].

Conclusion

The widespread utilization of wood in outdoor and indoor construction causes variations in the corrosion of nails and bolts used as wood connectors. The chemical elements of nails and bolts, such as iron, carbon, zinc, and several other chemical elements, play an important role. In comparison, the wood part that affects the corrosion rate is the wood extractives which comprise phenolic compounds, organic acids, and several other wood chemical compounds. The occurrence of corrosion processes and interactions with wood cause damage to wood and wood deterioration which can cause damage to wooden construction structures. Preventing corrosion and wood damage can be done by coating nails and bolts and improving wood quality, such as wood drying and addition of corrosion inhibitor additives.

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