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Wood Preservation and Its Corrosive Effects on Metal Fasteners

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November 6, 2017

OUTLINE

- Brief History of Wood Preservation
- General Corrosion of Embedded Metal Fasteners
- Effect of Moisture in Wood
- Effects of Wood, Preservatives, Coatings and Other Factors on Metal Fasteners
- Corrosion of Metal Fasteners Other Than Steel
- Summary and Conclusion

History of Wood Preservation

Early 18th to19th century: Zinc chloride and oil-based treatments (Creosote and Pentachloraphenol)

1938: Chromated Copper Arsenate (CCA)

CCA	Copper (wt% as CuO)	Chromium (wt% as CrO3)	Arsenate (wt% as As2O5)
A	18.1	65.5	16.4
B	19.6	35.3	45.1
C	18.5	47.5	34

AWPA standardized formulations of CCA

Later modifications: ACA and ACZA

History of Wood Preservation

- December 31, 2003: US Environmental Protection Agency phased out use of CCA
- Substitute wood treatments emerged:
  - ACQ, CA and CuHDO (CN)
- Boron treatments: sodium borate
- Future
  - Non-biocidal preservation methods
  - Chemical modified wood
  - Wood-plastic composites
  - Use of heartwood

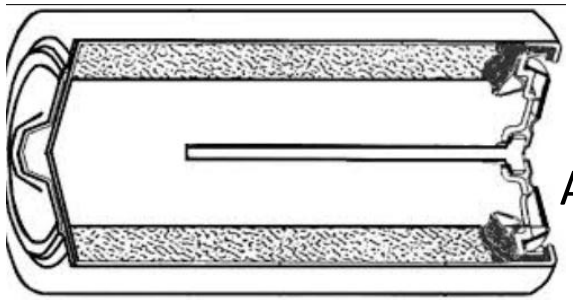
General Corrosion of Embedded Metal Fasteners

Corrosion of metals can be viewed as similar to a dry cell (e.g. alkaline battery) that generates voltage

Cathode

Anode

Cathode



Anode

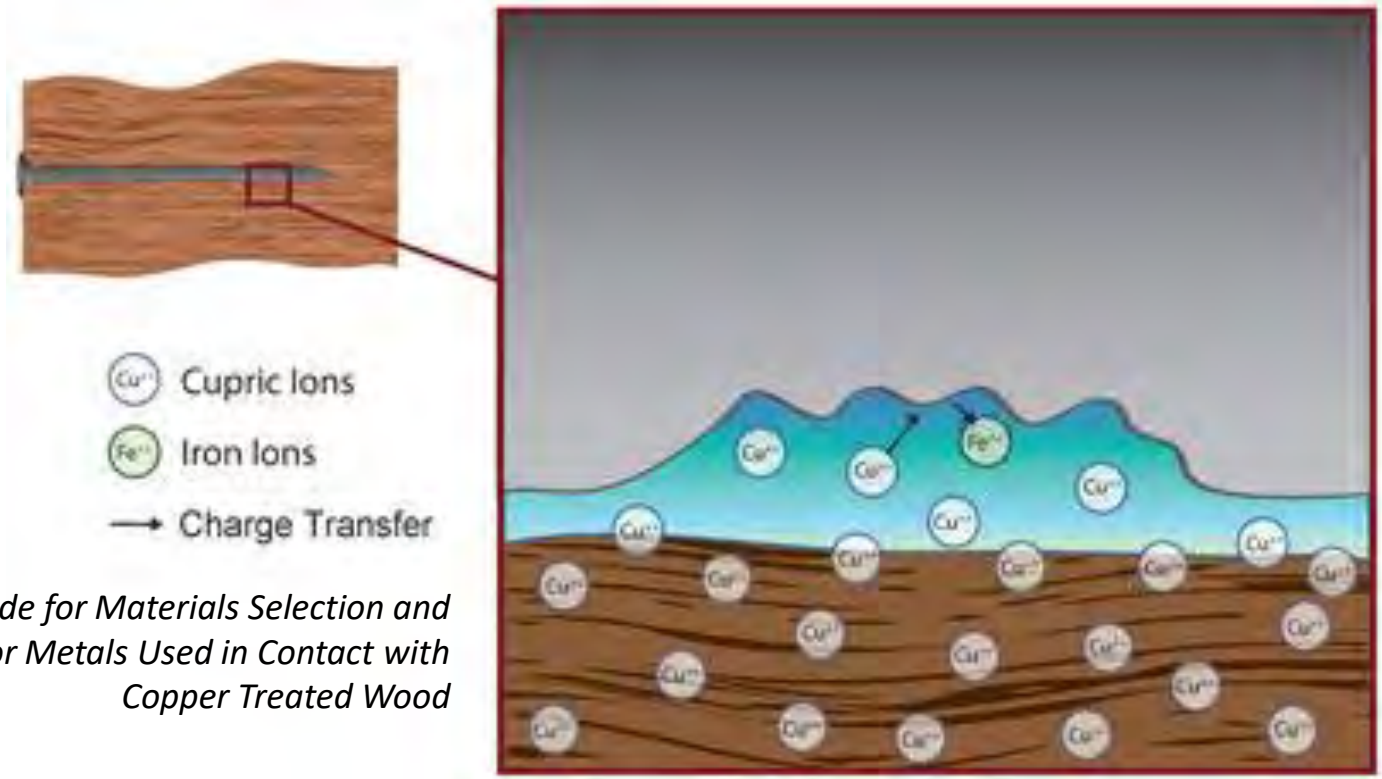
Electrolyte: ammonium chloride paste (battery) and water (fastener)

$$Fe \longrightarrow Fe^{2+} + 2e$$ Anode

$$O_2 + 2H_2O + 4e \longrightarrow 4OH^-$$ Cathode

General Corrosion of Embedded Metal Fasteners

Migration of soluble copper ions

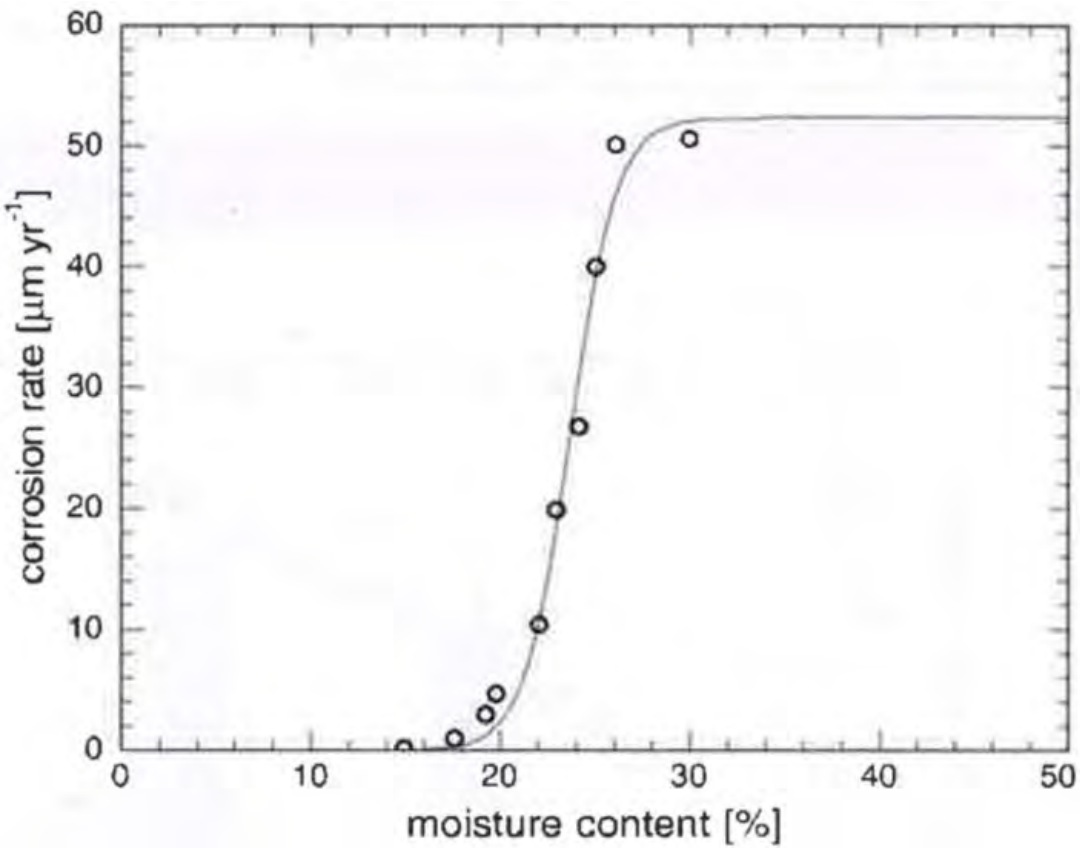


Zelinka, Guide for Materials Selection and Design for Metals Used in Contact with Copper Treated Wood

Cupric ions are reduced as fastener is oxidized

Effect of Moisture in Wood

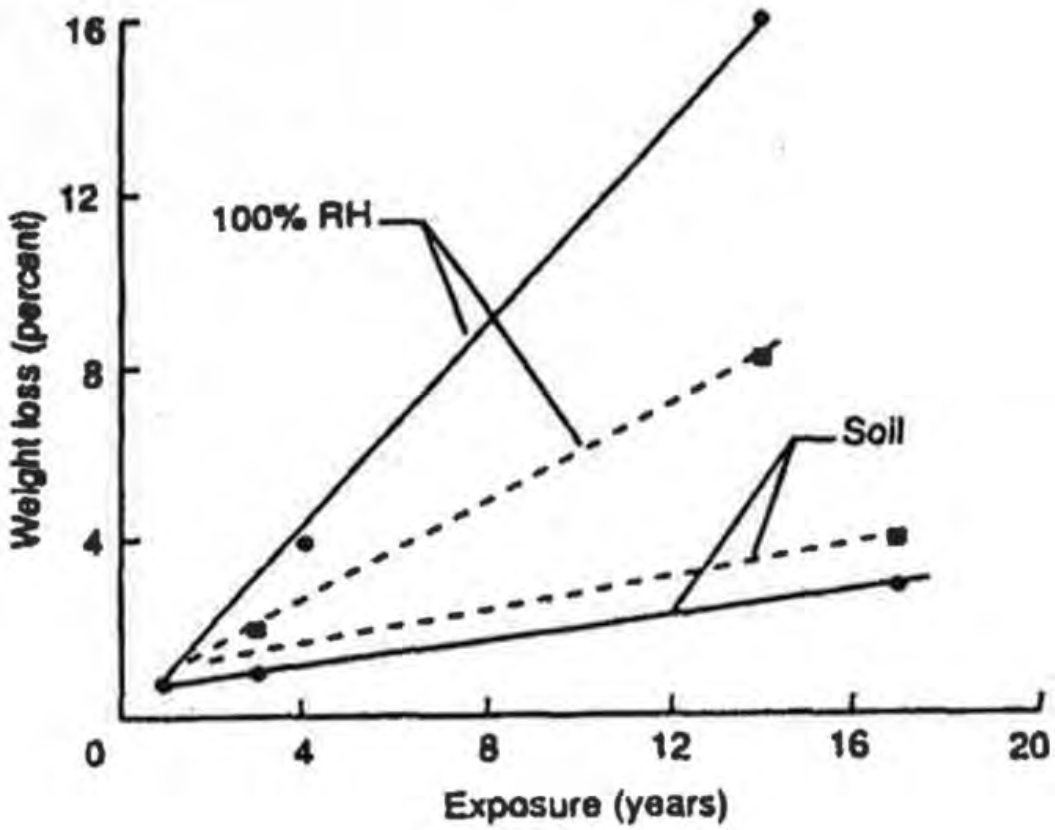
Corrosion cannot take place without moisture.



Zelinka et al. 2012

Effect of Moisture in Wood

High atmospheric humidity compared to being buried in soil



Baker, 1992

Effect of Moisture in Wood

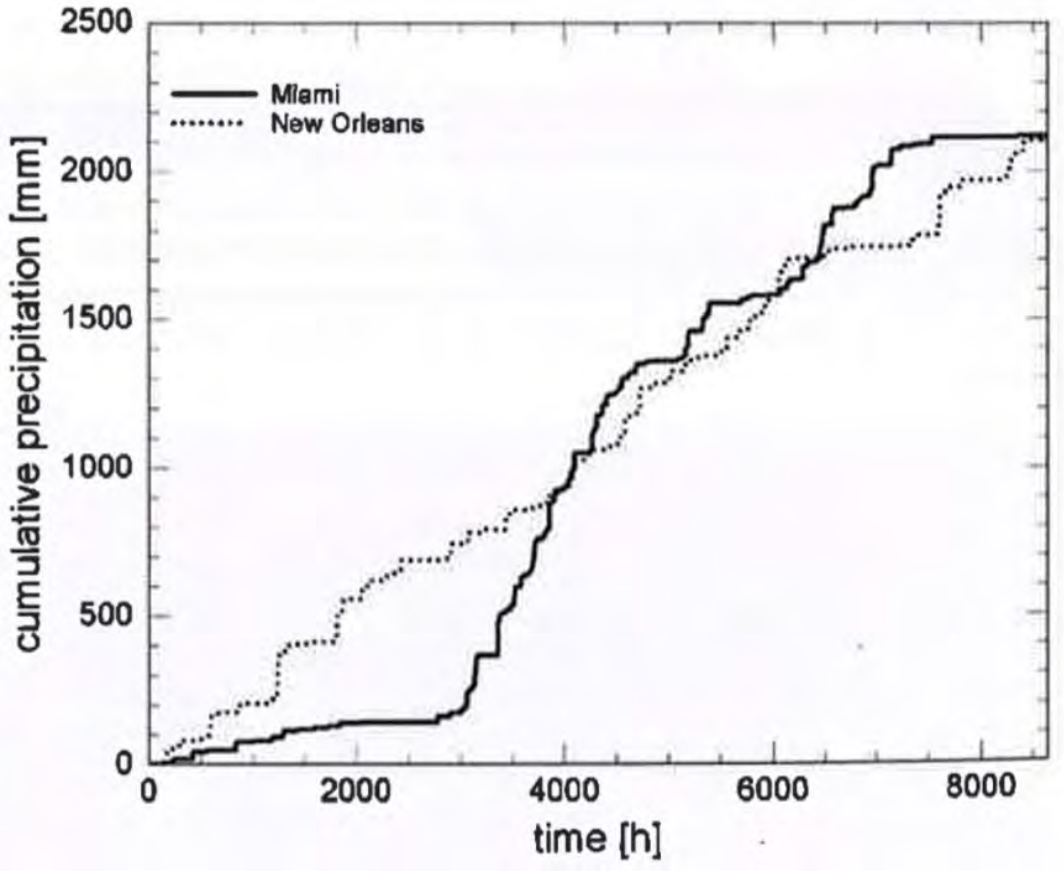
What weather factors affect corrosion?

Zone	City	State	Year	Maximum predicted corrosion depth µm (mil)	Yearly Mean Temperature °C (°F)	Yearly Total Rainfall m (ft)	Total number of hours with T > 0°C (32°F)	Total number of hours with Rain
1	Hilo	HI	1990	45(1.8)	23.0 (73)	5.36 (17.5)	8760	2213
1	Miami	FL	1968	12(.47)	23.4 (74)	2.12 (6.96)	8760	588
2a	New Orleans	LA	1961	20(.79)	19.6 (67)	2.12 (6.96)	8715	593
2b	Phoenix	AZ	1978	5(.20)	23.3 (74)	0.39 (1.28)	8734	284
3a	Atlanta	GA	1975	17(.67)	15.9 (61)	1.68 (5.51)	8440	699
4a	Baltimore	MD	1989	16 (.63)	12.6 (55)	1.32 (4.33)	8127	794
4c	Seattle	WA	1971	26 (1.0)	10.1 (50)	1.10 (3.61)	8422	1205
5a	Chicago	IL	1983	11 (.43)	9.7 (49)	1.25 (4.10)	6691	739
6a	Minneapolis	MN	1983	12 (.47)	7.8 (46)	0.99 (3.25)	6217	731

Zelinka et al. (2011).

Effect of Moisture in Wood

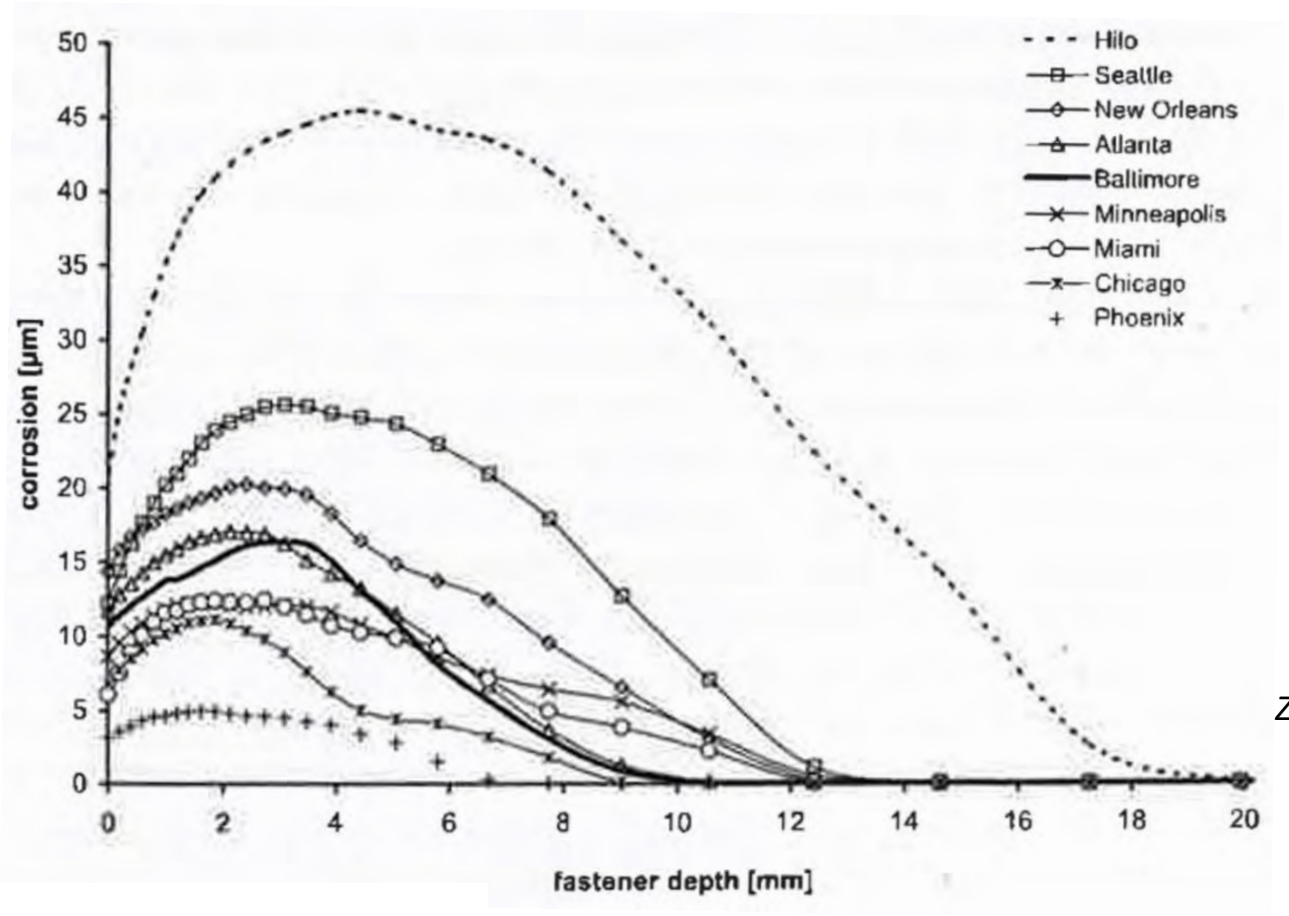
Not only is total annual rainfall a factor but so time and frequency of rain events



Zelinka et al. 2011

Effect of Moisture in Wood

Maximum corrosion occurs not a the wood surface but a short distance below it



Zelinka et al. 2011

Effect of Wood on Metal Fasteners

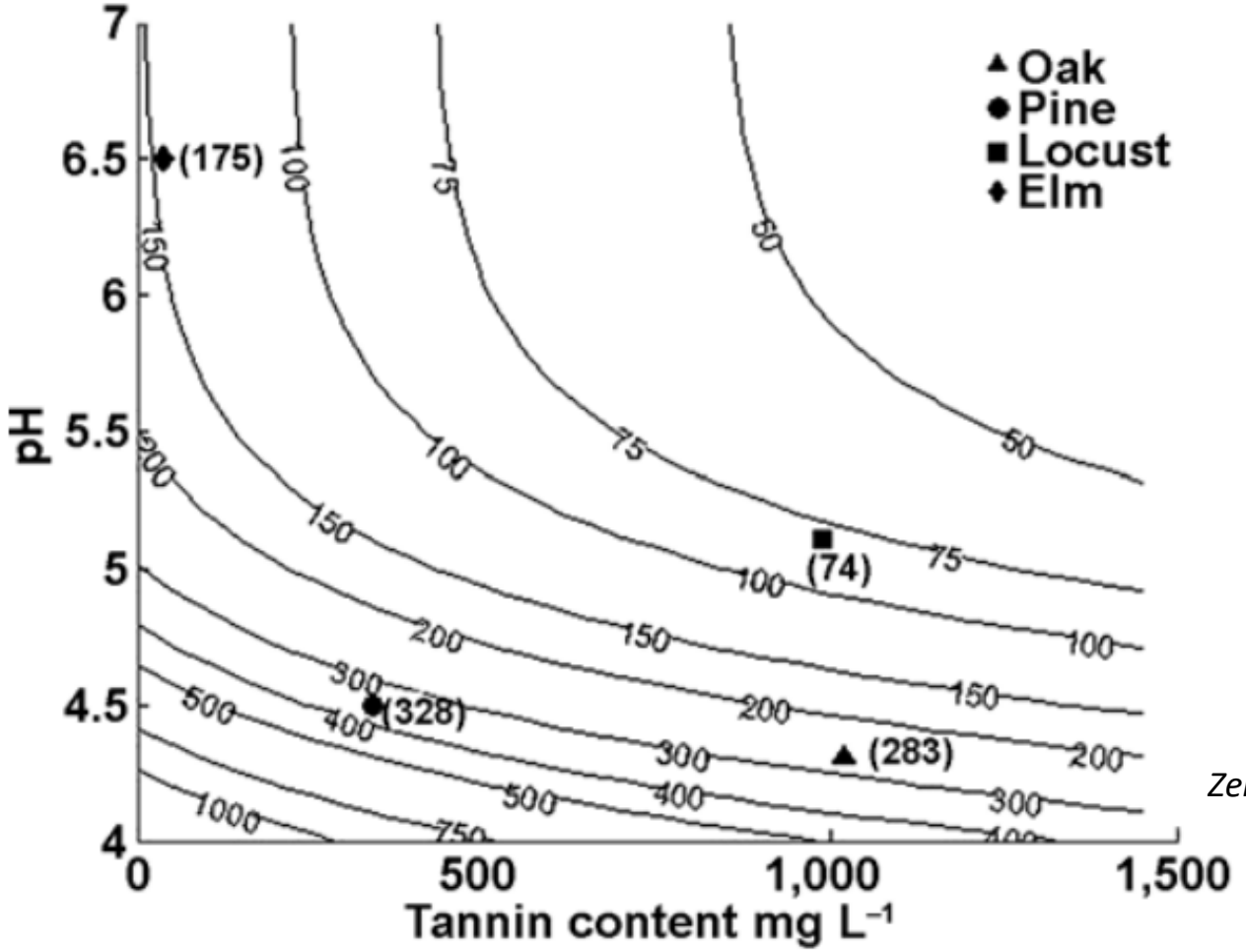
Wood is inherently acidic (acetic acid):

Softwoods	pH	Heartwoods	pH
Spruce	4.0 - 5.5	Chestnut	3.6
Pine	3.8	Oak (Europe and US)	3.3 - 3.9
Douglas Fir	3.1 - 4.4		
Western Red Cedar (US)	2.9 - 4.0		

- Corrosion is prolific < 4.3 pH and significantly decreases > 5 pH
- Density of wood is a factor
- Consider the source of the wood

Effect of Wood on Metal Fasteners

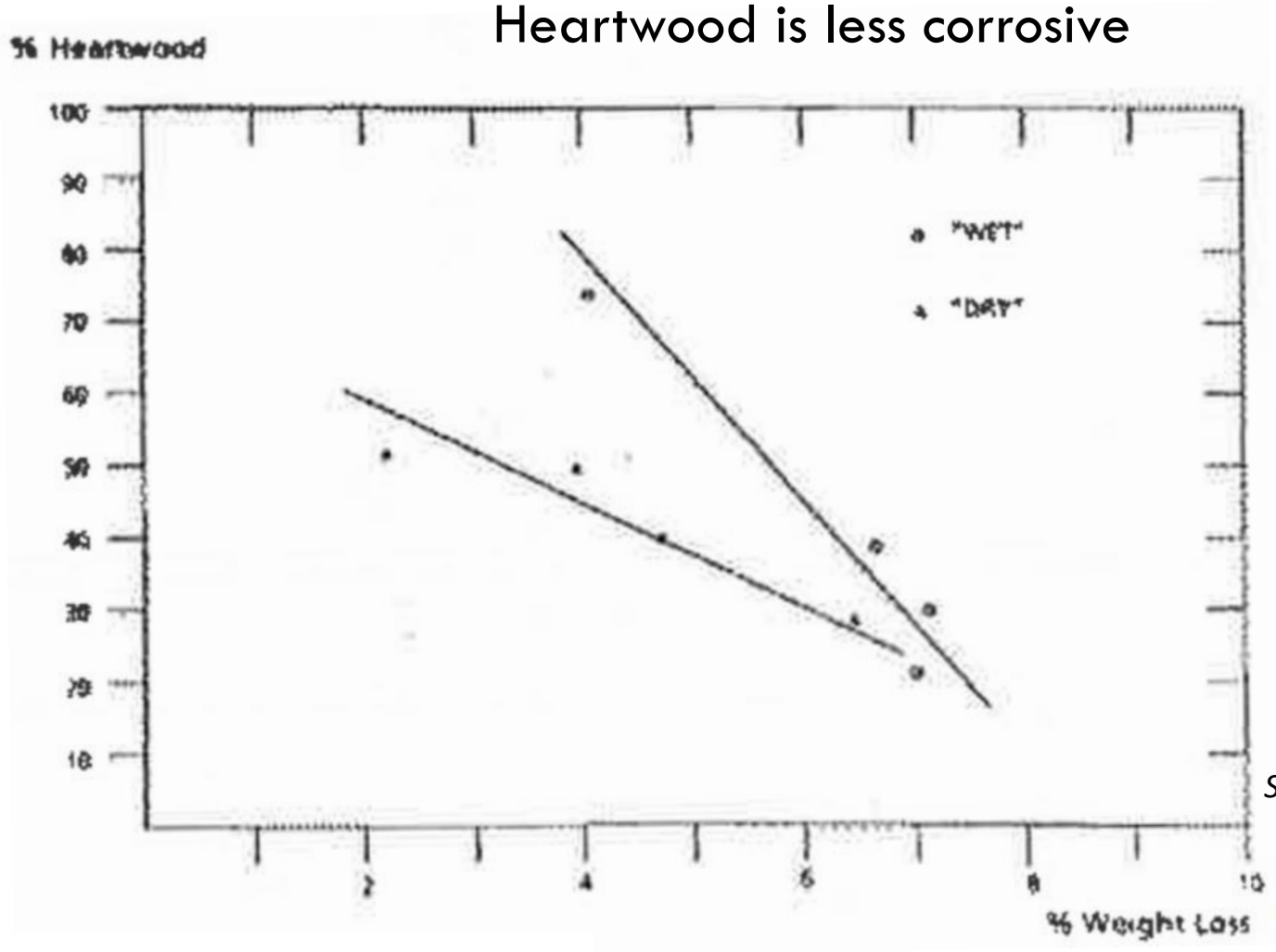
Corrosion Rate Isotherm In Wood Extracts As a Function of pH and Tannin Content



Zelinka and Stone, 2013

Effect of Wood on Metal Fasteners

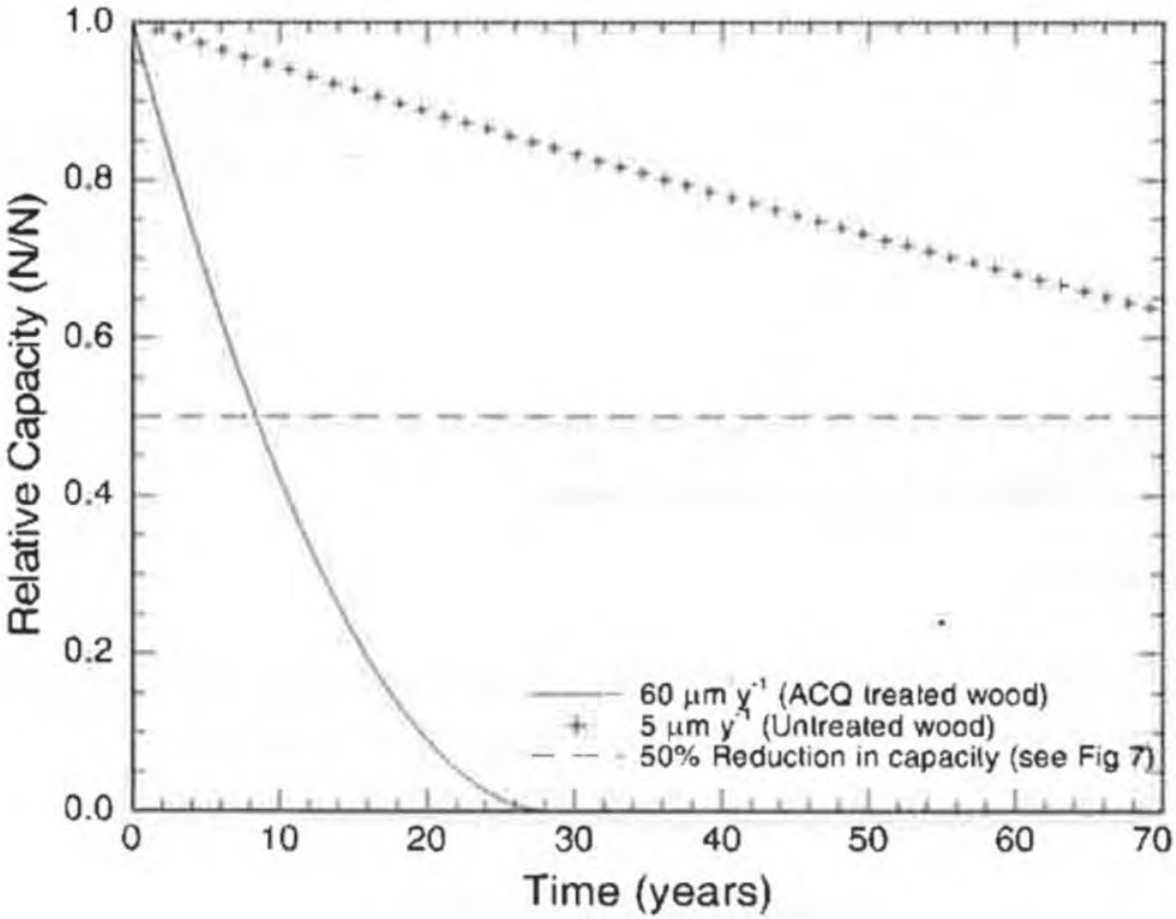
Heartwood is less corrosive



Simm and Button, 1985

Effect of Preservatives on Metal Fasteners

ACQ's Reduction of Strength Capacity

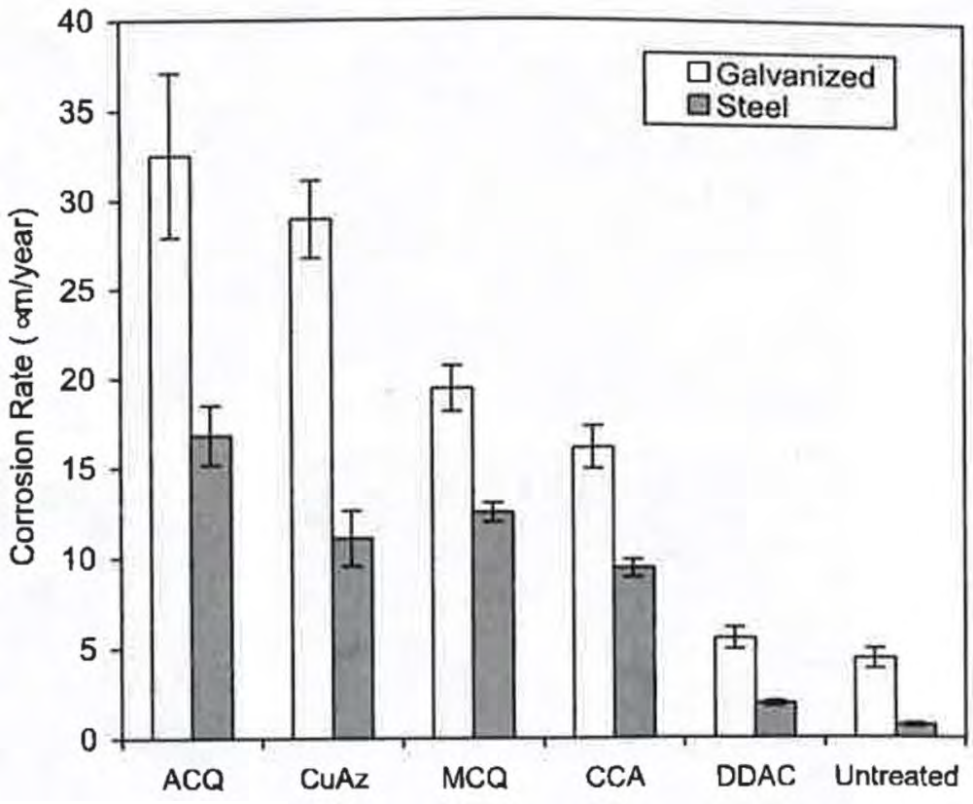


Baker, 1992

Effect of Preservatives on Metal Fasteners

Oil based preservatives: OK

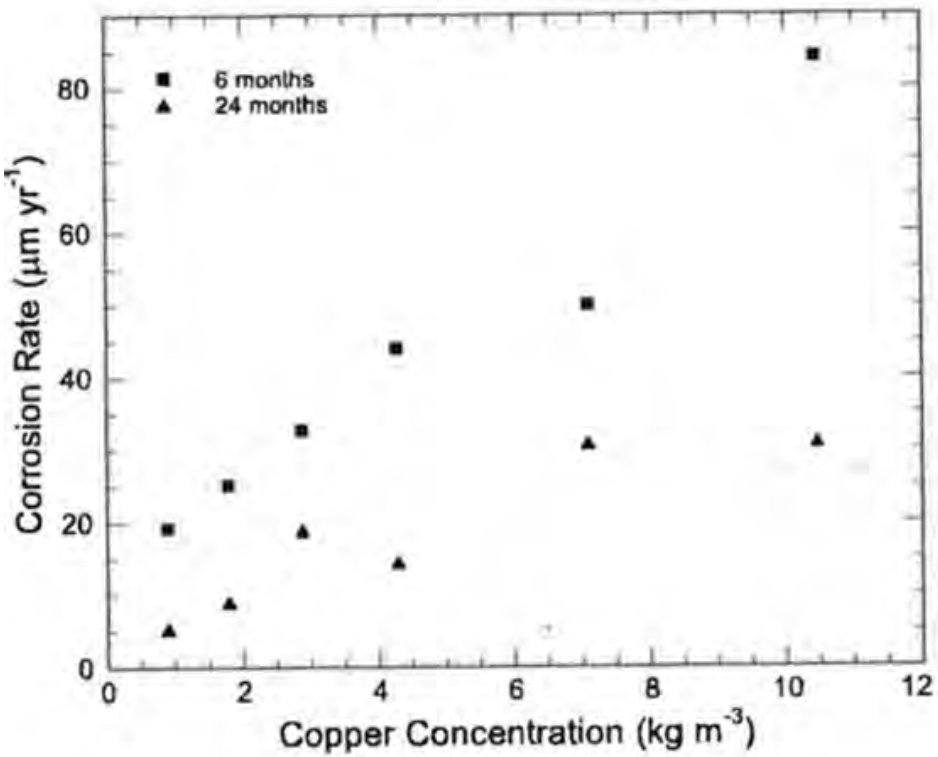
Waterborne preservatives: Depends on composition



Zelinka et al. 2010

Effect of Preservatives on Metal Fasteners

Corrosion by water borne preservatives are largely governed by composition in the following order of importance: Cu, Cr, As.



	Cu metal concentration (kg m^{-3})	Corrosion Rate (µm yr^{-1})
Untreated	-	5
Cu+Cr "light"	2.0	5
Cu+Cr "heavy"	4.4	9
Cu+As "light"	2.0	20
Cu+As "heavy"	5.6	20

Left - Zelinka, 2011
Right - Zelinka and Rammer, 2011

Effect of Preservatives on Metal Fasteners

Typical preservative compositions

	Retention ($kg\ m^{-3}$)	Copper as CuO (%)	Chromium as CrO_3 (%)	Arsenic as As_2O_5 (%)	DDAC[a] (%)
ACQ	2.4[b]	67	—	—	33
CCA-I	2.9[c]	18	65	16	—
CCA-II	2.9[c]	20	35	45	—
ACA	2.9[c]	50	—	50	—

The increase in copper (soluble copper ions) and lack of chromate inhibitors are the primary factors in the corrosive nature of ACQ.

Effect of Preservatives on Metal Fasteners

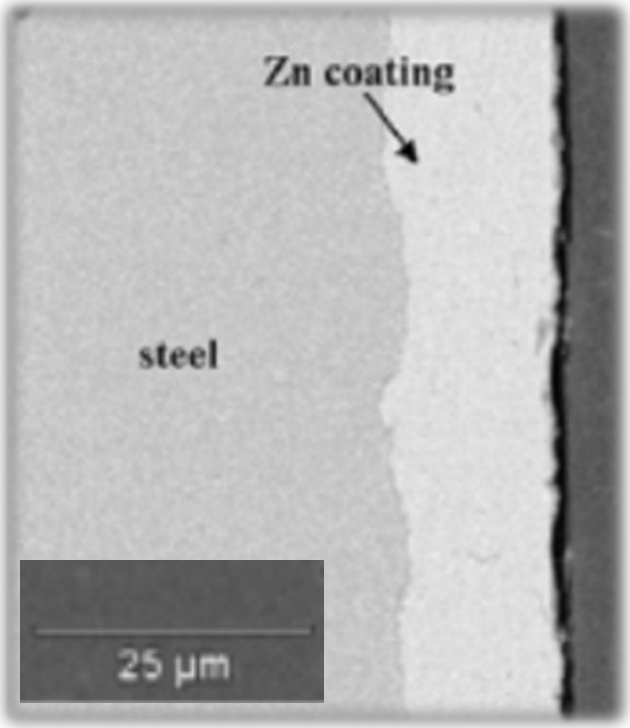
Waterborne Wood Preservatives and Above Ground Retentions

Preservative	Composition	Above ground retention (kg of preservative per m^3 of wood)	Copper concentration (g of copper per m^3 of wood)
CCA	47.5% chromium trioxide 34.0% chromium trioxide 18.5% copper as copper oxide	4	591
ACQ	67% copper as copper oxide 33% DDAC	4	2,141
CA-B	96.1% amine copper as Cu 3.9% tebuconazole	1.7	1,634
CA-C	96.1% amine copper as Cu 1.95% tebuconazole 1.95% propiconazole	1.0	961
ESR-1721 (MCA-B)	96.1% amine copper as Cu 3.9% tebuconazole	1.0	961
ESR-1721 (MCA-C)	96.1% amine copper as Cu 1.95% tebuconazole 1.95% propiconazole	0.8	769
ESR-1980	67% copper as copper oxide 33% DDAC	2.4	1,285
ESR-2240	25/26 copper particles 1/26 tebuconazole	1.0	961

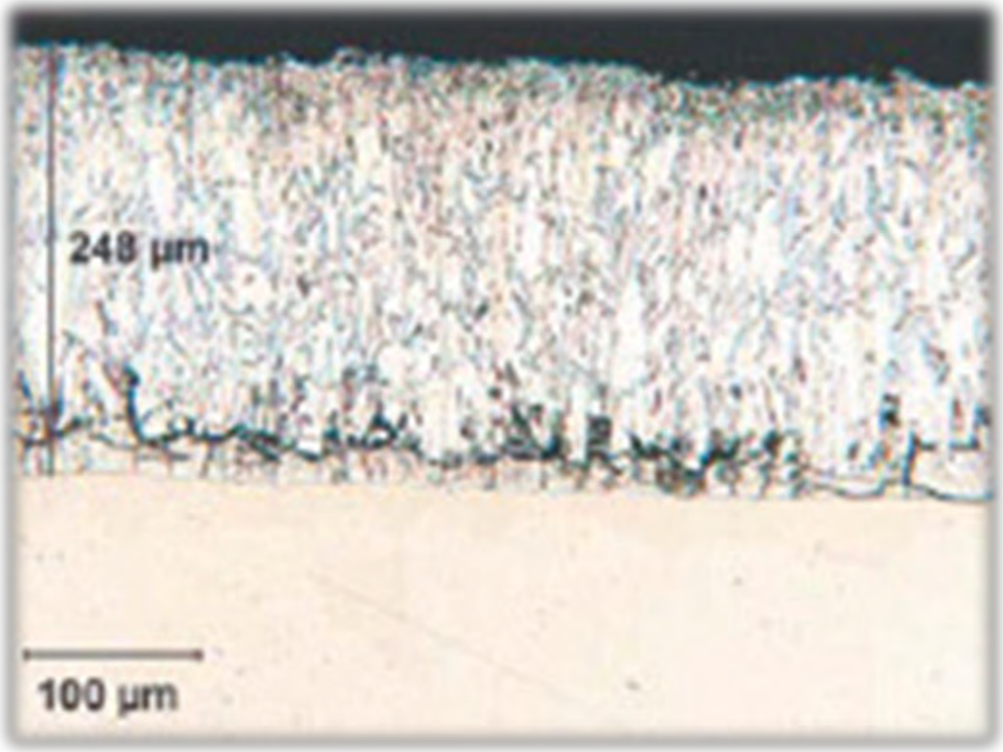
Anon (2007b), Lebow (2010)

Effects of Fastener Coatings

Electroplated Coatings



Matéria (Rio J.) vol.12 no.4 Rio de Janeiro Dec. 2007

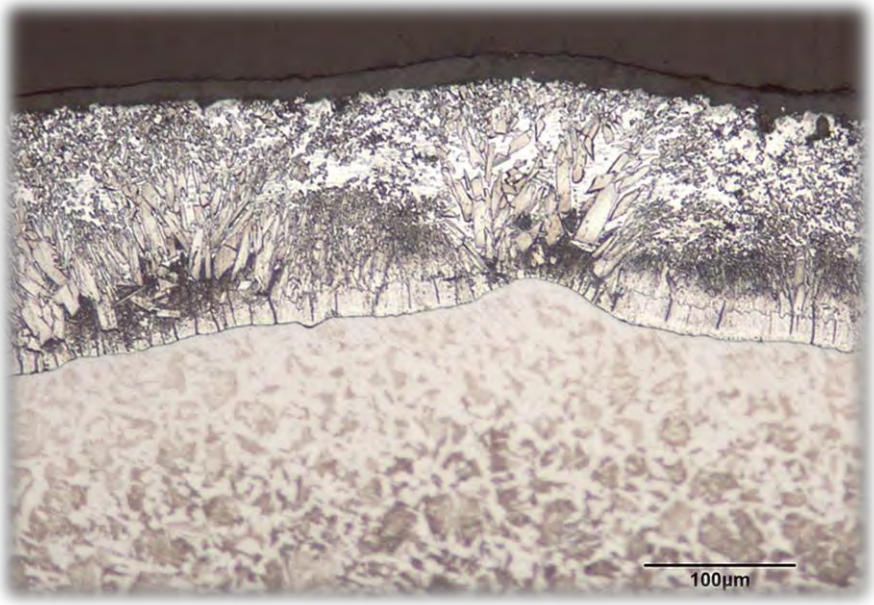


Industrial Galvanizers, Specifiers Manual

Effects of Fastener Coatings

Hot Dipped Galvanized Coatings

Wesley Narciso, Bacon Donaldson, sometime between 2002 and 2007



Effects of Fastener Coatings

Hot Dipped Galvanized Coatings

American Galvanizers Association

Other Factors Effecting Corrosion

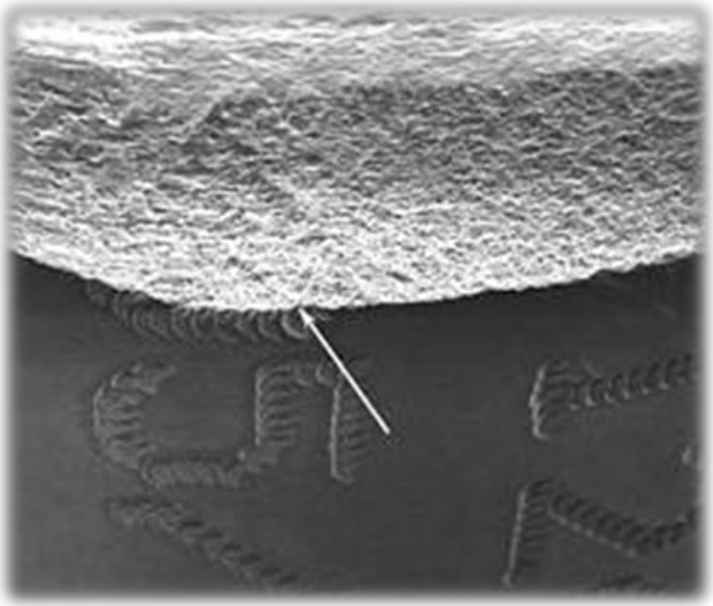
Fixation Time

Fire Retardant Chemicals

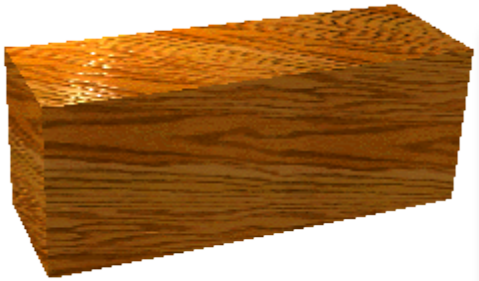
Temperature

Other Factors Effecting Corrosion

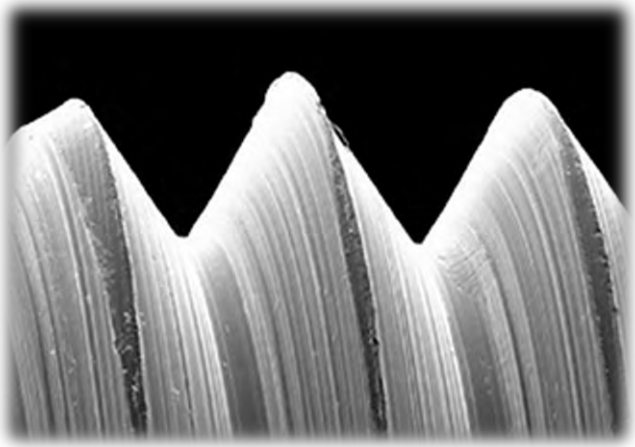
Residual Stresses



Grain Angle

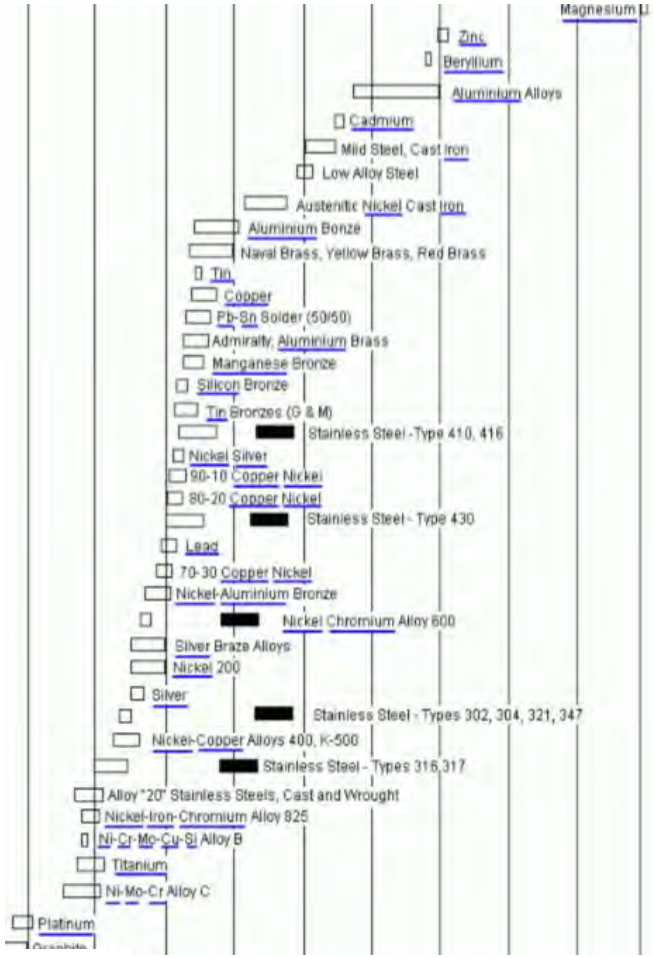


Metallurgical Characteristics



Corrosion of Non-Steel Fasteners

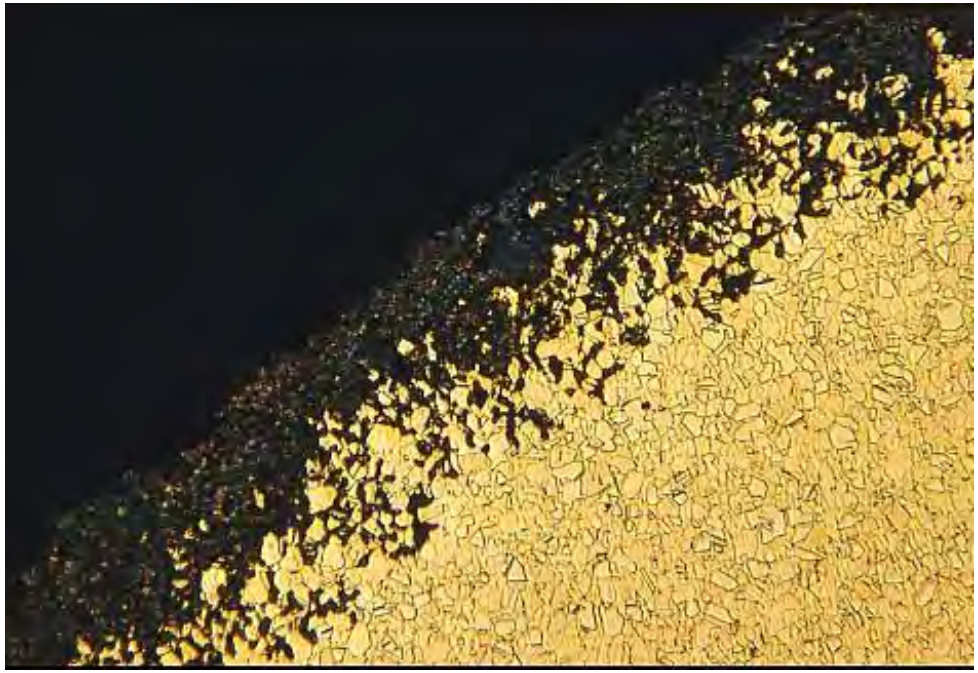
Corrosion is generally governed by the galvanic series table



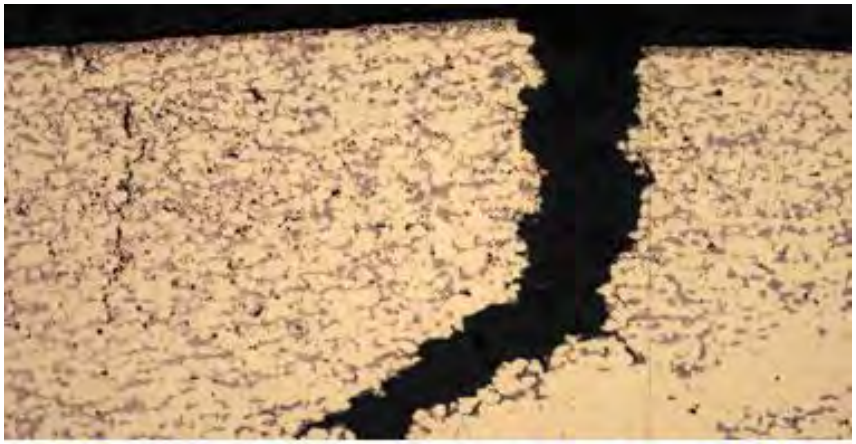
www.corrosionsource.com

Corrosion of Non-Steel Fasteners

Dezincification



George Langford, Sc.D., Massachusetts Institute of Technology, Cambridge, MA, 1966

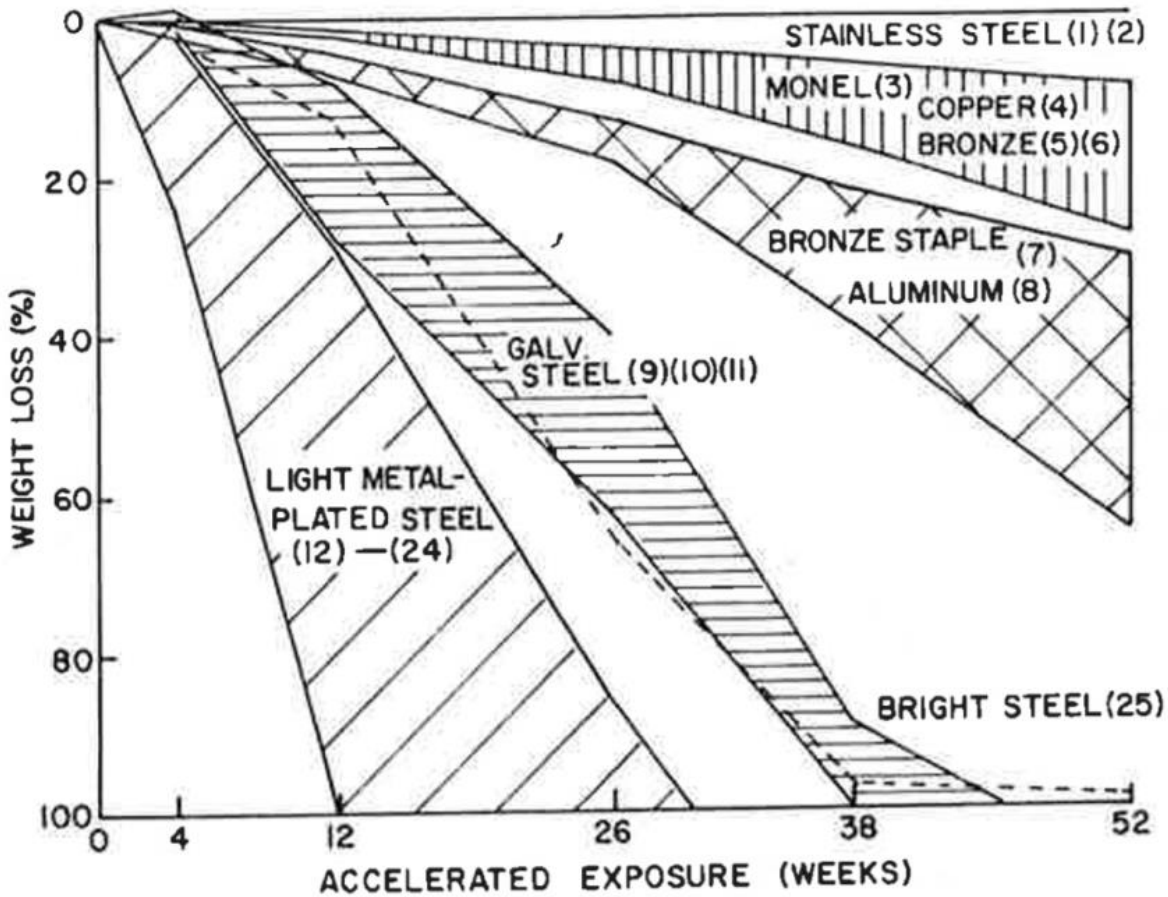


Gross dezincification of yellow brass fitting. 100X

Corrosion and Materials Consultancy Inc.

Corrosion of Non-Steel Fasteners

When in doubt, use stainless steel (with some exceptions)



Bengelsdorf, 1983

Summary and Conclusion

Generally more corrosion resistent fastener material →

(with exception of brass, copper and silicon bronze when exposed to chlorides)

Treatment	Bare Steel	Coated/Plated Steel (Zn or Ni)	HDG Steel	Al	Brass	Copper	Silicon Bronze	304 SS	Monel (Cu-Ni alloy)	316 SS
Untreated	2	3	4	4	4	4	4	4	4	4
Penta	3	4	4	4	4	4	4	4	4	4
Creosote	3	4	4	4	4	4	4	4	4	4
ZnCl	1	2	4	4	4	4	4	4	4	4
CCA (Type C)	2	3	4	2	4	4	4	4	4	4
ACA	1	1	2	2	4	4	4	4	4	4
ACZA	1	2	3	3	4	4	4	4	4	4
ACQ	1	1	2	1	3	3	3	4	4	4
MCQ	1	2	3	3	4	4	4	4	4	4
CA	1	1	2	2	3	3	3	4	4	4
Borate	2	3	4	4	4	4	4	4	4	4

In the shaded areas, the author has interpolated and extrapolated based on a lack of past literature/testing.

Notes: The summary assumes Pacific Northwest conditions and generally for metal fasteners that are not completely exposed (e.g. fasteners securing strapping or wall cladding). ZnCl has not been used in North America for over 50 years, ACA for over 20 years and MCQ hardly ever. Performance with Al is mixed - this depends on its coating, location and intimacy with treated wood. Borate is easily leached and its use is therefore limited in completely exposed conditions.

Rating	Description
4	Permitted in almost all situations
3	Permiited in most situations
2	Permitted in some situations
1	Permitted in very few situations

Corrosivity: ACQ > CA > MCQ > CCA > DDAC > untreated

Please keep in mind the following factors:

- Atmospheric humidity
- Temperature of substrate
- Frequency, quantity and type of stresses (dyanamic, static and residual)
- Type of wood
- Macro location (proximity to seawater, altitude)
- Micro location (behind cladding, buried in soil, at pool)
- Type of fastener (nail, staple, screw, bolt)

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QUESTIONS?