CWPA Proceedings, 2008, pp 124-137

INVESTIGATION OF FACTORS AFFECTING CORROSION OF FASTENERS IN PRESERVATIVE TREATED WOOD

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Summary

Variables affecting corrosion of screw and plate fasteners in preservative treated wood were evaluated. Four preservative systems were compared: Chromated copper arsenate (CCA), Alkaline copper quaternary (chloride based – ACQ ADBAC), Alkaline copper quaternary (carbonate based – ACQ DDACb), and an all-organic system. For the first three preservative systems, the effects of preservative retention and fixation temperature were evaluated. A number of different commercial screw types and plates were compared for extent of corrosion. Exposure conditions included both high temperature and humidity (50C and 90%RH) and natural exposure for about 1 year in Toronto, Ontario.

1. Introduction

New alkaline copper based preservatives for residential exterior appearance applications have been reported to be more corrosive than CCA and oil based preservatives (American Wood Council 2005, Ruddick 2006). While it is evident that corrosion of fasteners on these materials is often related to improper selection of fasteners or other improper practices (Ruddick 2006), it is also clear based on field observations, that corrosion can be a serious problem with these treatments. This can result in complaints and call-backs, especially for products like stapled lattice work, joist and stringer hangers, post supports, deck boards secured with deck screws and nailed fencing and cladding. Corrosion of fasteners in treated wood may limit applications, reduce consumer satisfaction and lead to costly returns or increased fastener costs if stainless steel or other costly fasteners are specified to avoid future problems. This could price wood out of the market for some applications.

There are several potential approaches to reducing this adverse effect but the relative importance of factors contributing to corrosion is not known. The objective of this study was to investigate the effects of fastener type and preservative processing factors on the corrosivity of screw and plate fasteners and connectors on treated wood. Effects of different pre-treatment, treatment and post-treatment conditions on reducing corrosivity of treated wood in exterior appearance products treated with alkaline copper preservatives were investigated.

Identification of processing factors that can mitigate the corrosion effect would allow chemical suppliers to make recommendations to wood treaters regarding appropriate processes and to end users regarding appropriate fasteners for different applications. This will eventually provide users and specifiers with more confidence in value added treated wood products helping to protect the market for these products against alternatives such as plastic lumber.

Corrosion of fasteners in treated wood is usually an electrochemical reaction resulting from formation of galvanic cells between dissimilar metals in the wood. It requires anodic and cathodic materials where redox reactions occur, connected by an electrically conductive pathway (moisture in wood) according to the series:

Anodic Zn..Al..Fe..Sn..Cu Cathodic

The reaction is accelerated by:

- Higher ion conductivity (higher moisture content and the presence of soluble electrolytes)
- Availability of oxygen and variations in oxygen content
- Higher concentrations of electrolytes
- Presence of dissimilar metals
- Stress (Pinion 1970)

The more noble metal becomes the cathode and the less noble metal the anode where corrosion occurs at the anode. Oxidation at the anode (fastener) depends on the presence of oxygen and water and these can be limited by excluding oxygen and water through coatings such as grease or barrier coatings.

For example, when iron fasteners are placed in contact with wood containing soluble copper, anodic iron is oxidized to red iron oxide (Fe_2O_3) and cathodic copper is reduced and precipitated, usually on the fastener.

$$Fe \longrightarrow Fe^{++} + 2\,e^{-}$$
$$Cu^{++} + 2e^{-} \longrightarrow Cu \text{ metal}$$

Sacrificial coatings such as zinc are preferentially oxidized to iron, resulting in deposition of white zinc oxide on the fastener which helps protect the underlying metal.

The type of preservative can affect the corrosive properties in several ways. Generally corrosion is higher in preservatives

- with higher free copper and other metal cations content (Ruddick et al 2005),
- with free ammonia present (such as ACA, (Baker, 1980, Barnes et al. 1984) ACZA (Kang and Morrell 2000) and ACQ-B).
- with free counterions, especially halogen, phosphate, sulphate or other acidic ions, such as zinc chloride, fire retardant formulations, chloride based quaternary ammonium compounds and IPBC (Barnes et al. 1984). Carbonate formulations produce CO_2 rather than soluble salts so they tend to be less corrosive (Baker 1980).

Corrosion may be reduced in systems with additives such as chromate and borate (Barnes et al. 1984) or by protection from polymer and other coatings.

The observed higher corrosion in copper amine systems compared to CCA is attributed to the higher free copper content, and perhaps to the higher alkalinity and presence of chloride ion in some formulations.

2. Methodology

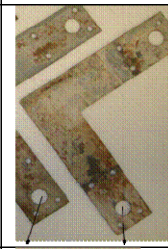
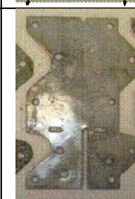
Development of corrosion on screws and plate connectors of different metals and with different metal coatings was evaluated on red pine 4” X 4” (89 X 89 mm) timbers (thick sapwood) treated with the four preservative systems (Fig. 1). Some SPF 2” X 6” (38 X 140mm) samples were also treated to evaluate effects in shallow penetration treatments.

The preservative treatments evaluated extensively included CCA-C, ACQ-C (amine copper + alkyl dibenzyl ammonium chloride or ADBAC) and ACD-D (amine copper + didecyl dimethyl ammonium carbonate or DDACb); limited comparisons were made with wood treated with a pigmented all-organic preservative. Wood was treated with either a 1.2% or 1.9% solution strength (CCA and ACQ treatments) by a full cell treating process which resulted in retentions in the red pine of approximately 6.0 and 9.0 kg/ m^3 respectively. The treated wood was subjected to post treatment conditioning, either at ambient temperature (22°C wrapped in plastic to prevent drying) or 50°C and 95% RH until the copper stabilized. Effects of these treatments on treated wood free copper content were evaluated.

Screw (5 replicates per assembly X 2 assemblies each accelerated and outdoor exposure) and L-plate or flat plate connectors (3 replicates per assembly X 2 assemblies) of different metals or treatments (Table 1) were applied to assemblies of the treated timbers. Generally fasteners were electro-galvanized (construction screws), hot dip galvanized (G-90 0.9 ounces/ square foot i.e 0.45 oz. per side; or G-185, 1.85 oz./ft^2) or “Goldcoat barrier coated which was a combination of zinc galvanizing and organic barrier coat.
Assemblies were exposed to accelerated conditions (up to three 39 day cycles at 50°C and 90% RH or exterior exposure for 11 months in Toronto, ON). Corrosion of different fasteners was evaluated by fastener appearance (ASTM D610-01; 0 to 10 with 10 the best condition and a rating of 5 means 50% rust coverage) and mass loss as appropriate after being subjected to either accelerated laboratory or natural field exposure conditions.

Figure 1: Example of fastener configuration on red pine 4” X 4” timbers

Table 1: Summary of fastener types evaluated

Fastener	Finish				Photo
L-plate	G-90	G-185	Goldcoat		
Flat plate	G-90	G-185	Goldcoat		
Deck screw	Construction	Duradized brown	Duradized green		
Lag screw	Construction	Goldcoat			

3. Results and Discussion

3.1 Extent of fixation and free copper content

The stabilization treatments resulted in different levels of free copper for the different preservatives and retention levels (Table 2). Soluble copper levels were very low for CCA, especially when fixed at the higher temperature. For ACQ, they were higher for the ADBAC formulation than the DDACb formulation. As expected, the free copper content was normally higher for the higher retention treatments and for samples conditioned at the lower fixation temperature. The fixation levels in Table 2 reflect these differences.

3.2 Corrosion in screws – accelerated exposure

Most of the observed corrosion occurred during the first 39 day cycle. Based on mass loss comparisons, the Goldcoat finished screws had the least degradation, followed by the duradized screws and the construction screws (Figure 2). For all screw types, corrosion was least in the CCA treated wood by a large factor. While there were some exceptions, corrosion mass loss was generally considerably lower for the DDACb formulation (ACD-D) than for the chloride based ACQ-C. Higher retention treatments usually resulted in more corrosion than low retention treatments for ACQ formulations but for CCA, the higher retentions often had less corrosion mass loss. This suggests a strong relationship between free soluble copper content in the wood and extent of corrosion. Also, although again there are exceptions, in most cases, wood that was stabilized at higher temperature resulted in less corrosion than wood stabilized at room temperature. These results suggest that corrosion in deck screws in ACQ treated wood can be mitigated to some extent by ensuring that the wood is not over treated and by using higher temperature conditioning to more completely stabilize the copper in ACQ formulations. Use of the carbonate formulation also reduces corrosion in screws.

Table 2: Fixation conditions and extent of fixation after conditioning

Preservative	Fixation T °C	Preservative concentration (%)	Free copper concentration in wood cells (%)	% stabilized
CCA	22	1.2	0.011	100 (CrVI)
		1.9	0.013	100 (CrVI)
	50	1.2	0.002	100 (CrVI)
		1.9	0.002	100 (CrVI)
ACQ ADBAC	22	1.3	0.20	85 (Cu)
		1.9	0.33	74 (Cu)
	50	1.3	0.22	83 (Cu)
		1.9	0.20	84 (Cu)
ACQ Carb.	22	1.3	0.11	92 (Cu)
		1.9	0.17	86 (Cu)
	50	1.3	0.04	97 (Cu)
		1.9	0.09	93 (Cu)

3.3 Corrosion in plates – accelerated exposure

Corrosion of the L-plates and the flat plates were similar and only the L-plates are discussed here. It is clear that the G-90 galvanizing was not adequate to protect the plates applied to the two ACQ formulations for 3 cycles of accelerated corrosion exposure (Fig. 3a). These plates were almost completely covered with red iron rust (ASTM rating close to 0) and had significant mass loss of 10-40%. However, corrosion levels were moderate in CCA and low in the organic preservative treated wood. Mass losses were insignificant in both cases and visible corrosion products relatively low.

The G-185 treated plates performed much better with low mass losses even in the ACQ treated wood and moderate levels of surface rust (Figure 3b). The barrier coating (Fig. 3c) performed very well on all preservative types. For the G-90 plates, wood treated with the carboquat based ACQ formulation generally had less corrosion than the wood treated with the chloride based ACQ formulation. There was no apparent difference for the better protected G-185 and Goldcoat finished plates. Unlike for the screws, there were no appreciable differences resulting from preservative loading and temperature of stabilization.

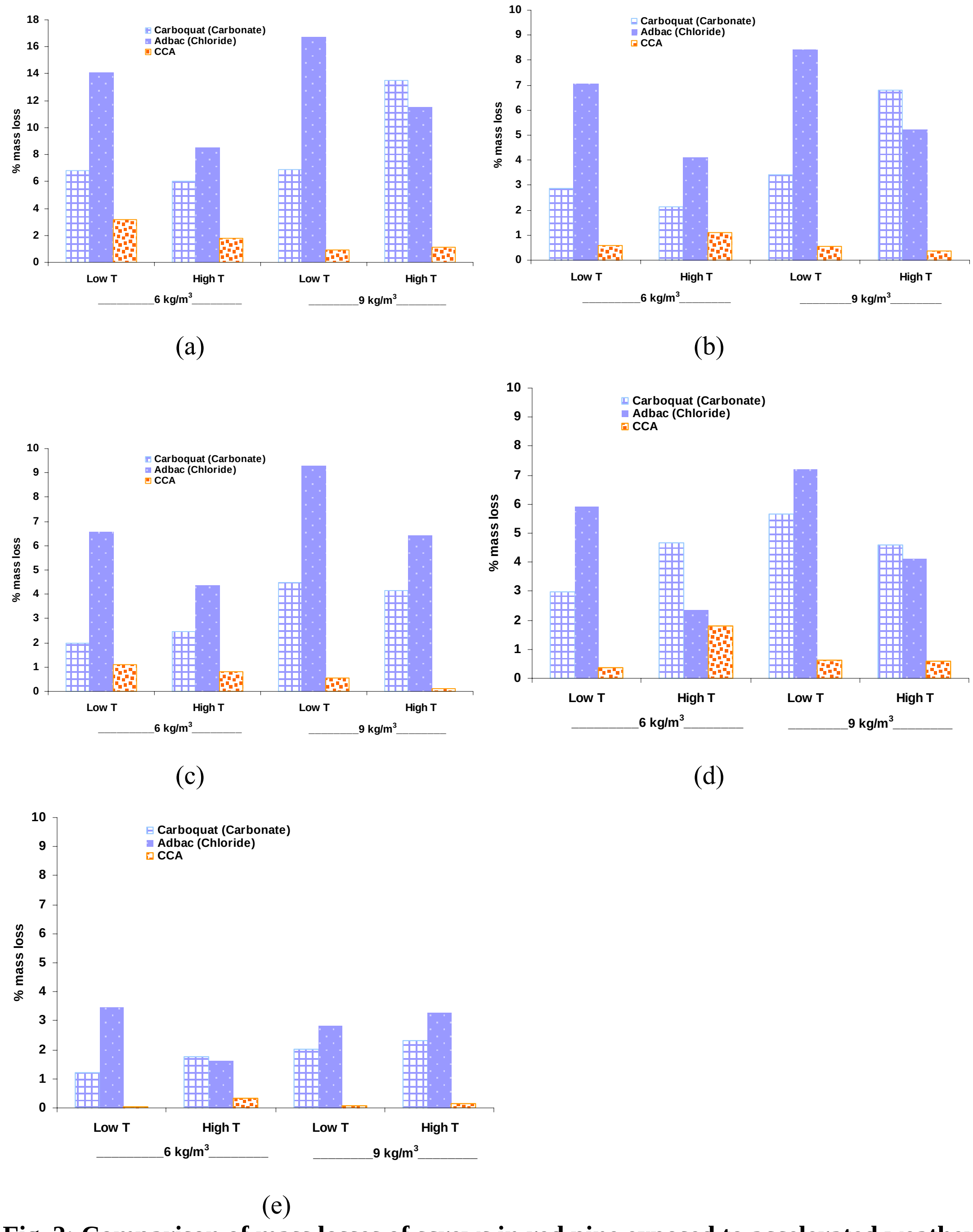
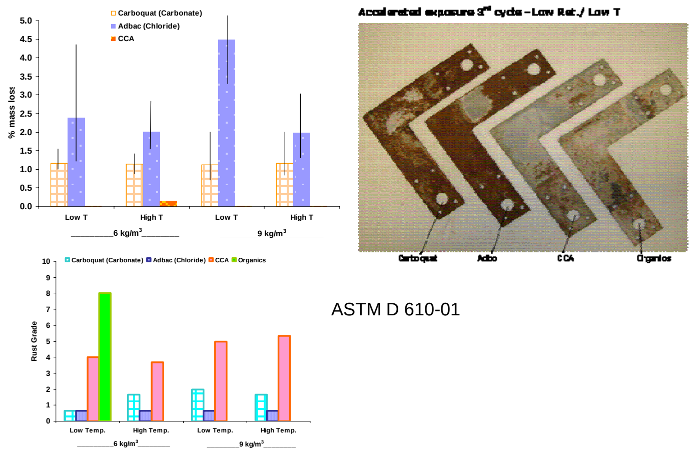


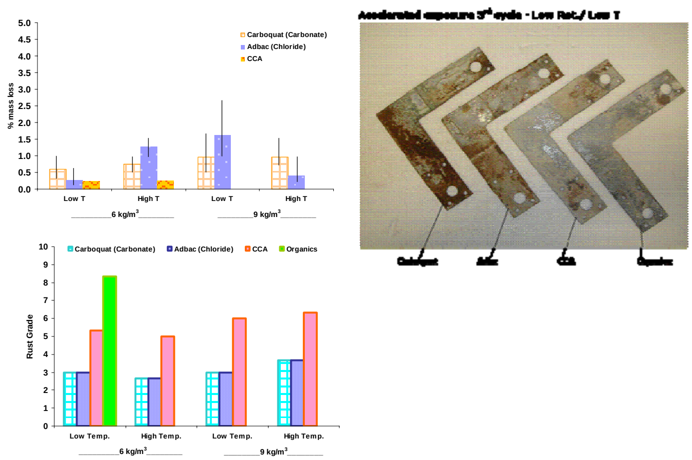
Fig. 2: Comparison of mass losses of screws in red pine exposed to accelerated weathering exposure (a) construction deck screw; (b) duradized green screw; (c) Duradized brown screw; (d) construction lag screw; (e) Goldcoat lag screw

L6 L-plate (G90)



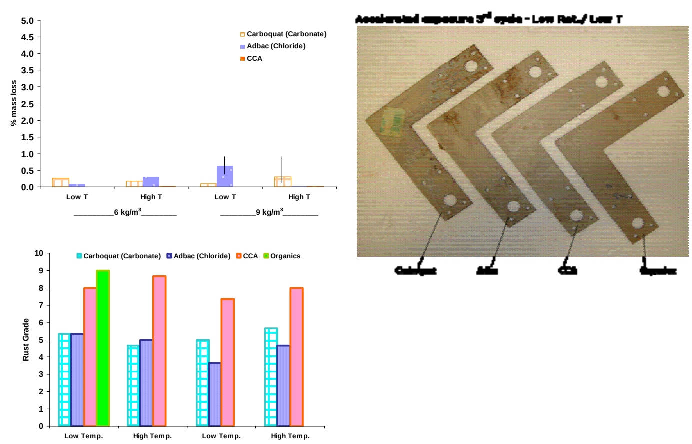
(a)

L6 Triple zinc (G185)



(b)

L6 Gold Coat

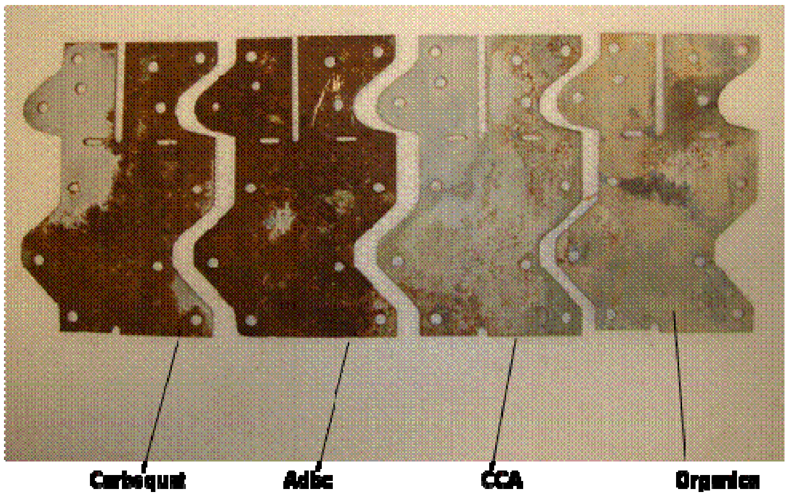


(c)

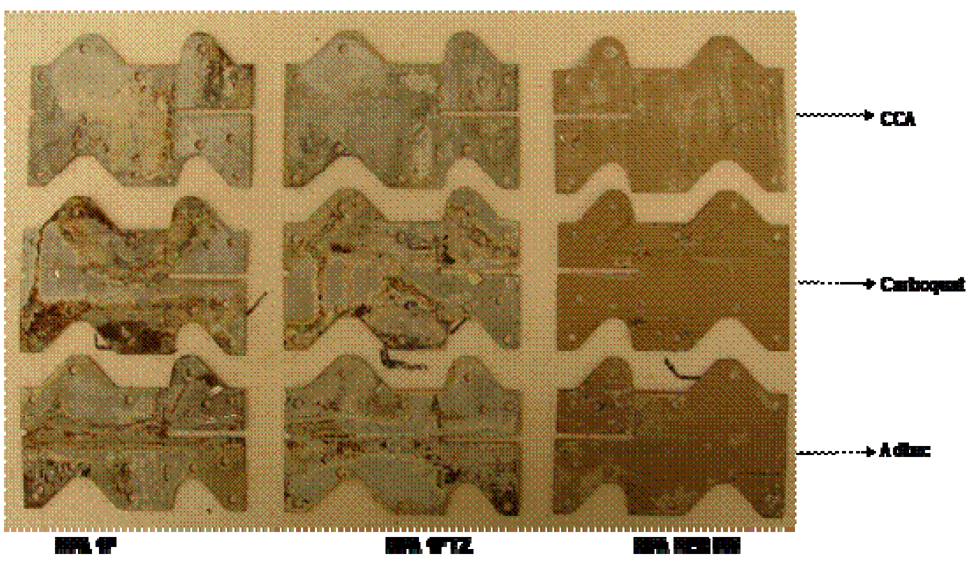
Fig. 3: Comparison of mass losses and visual rating of L-plates in red pine exposed to accelerated weathering exposure (a) G-90 galvanized (b) G-185 (c) Goldcoat barrier

3.4 Effect of wood species

The shallow penetration of the spruce boards resulted in very little corrosion of screws as might be expected. Somewhat surprisingly, the plate corrosion was also much less in the spruce than the red pine. Thus it is apparent that the shallow penetration does not result in a high concentration of free copper near the surface. As seen in Figure 4, for the worst case G-90 connector, the extent of corrosion on the surface next to the wood is considerably lower in spruce than red pine.



(a)



(b)

Figure 4: Comparison of plate corrosion in red pine (G-90 only) (a) and spruce (G-90, G-185 and Goldcoat (b) exposed to accelerated weathering exposure

3.5 Corrosion under natural exposure for 11 months in Toronto, Ontario

The corrosion under natural weathering conditions was considerably less than for the accelerated exposure; in fact there was little corrosion visible on the upper surfaces of the plates. However, the screw heads were showing signs of rust in the ACQ treated wood (Fig. 5) and there was significant visible rust on the underside of the plates (Fig. 6) for both ACQ treatments after 11 months.

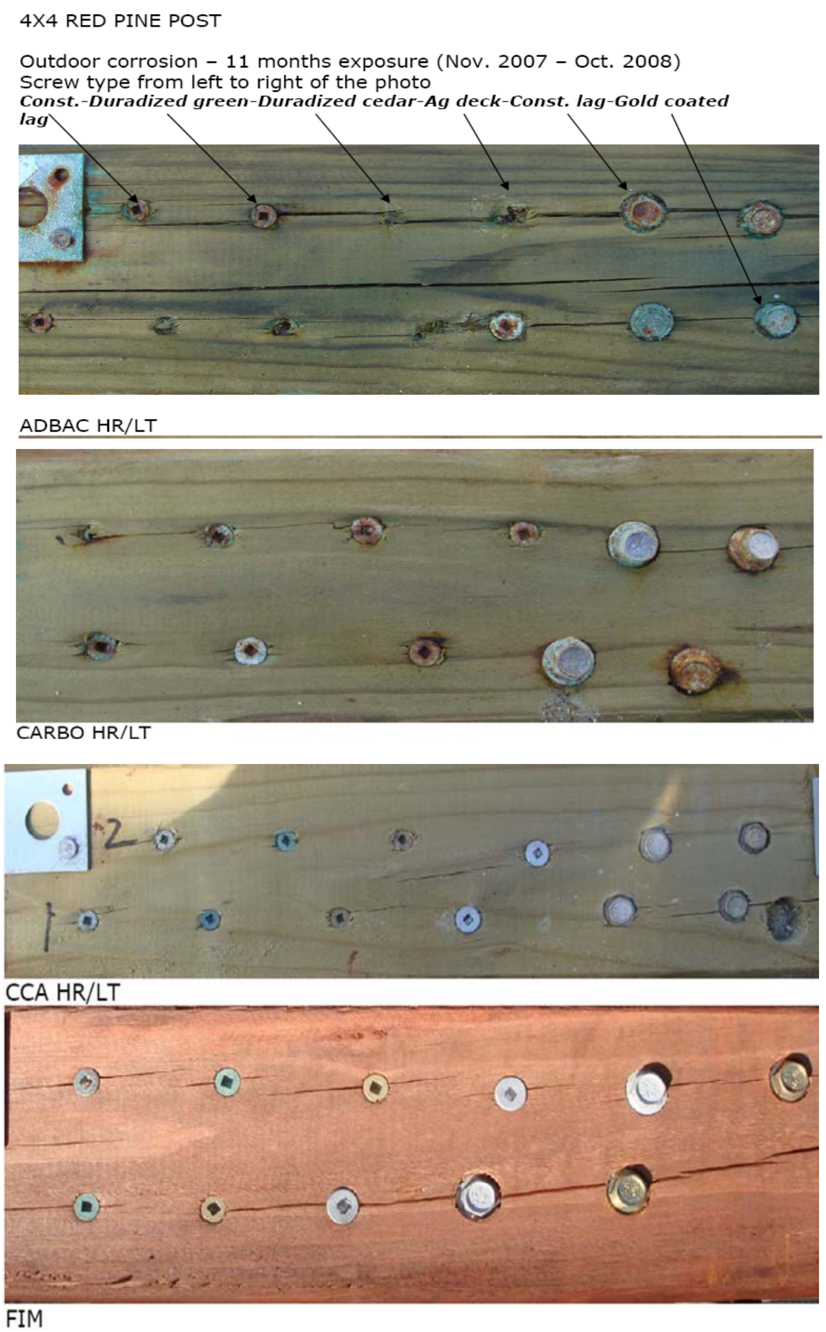
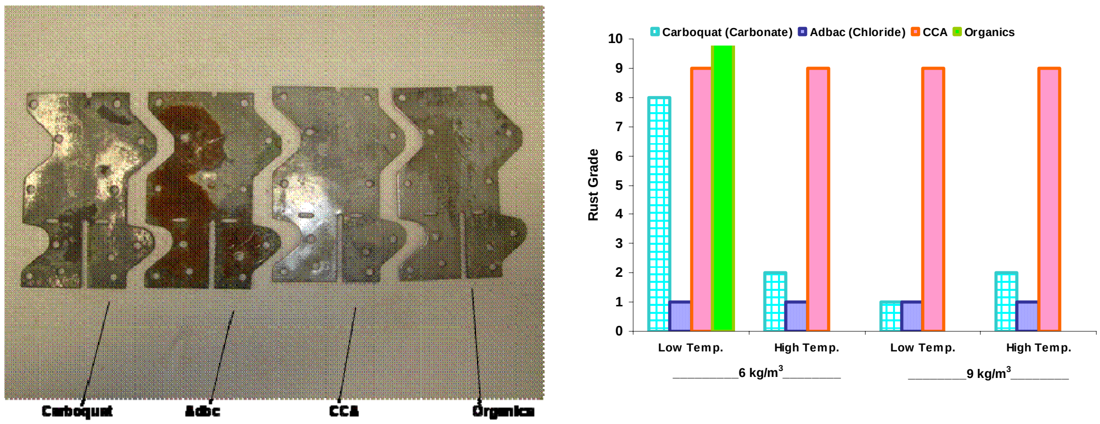
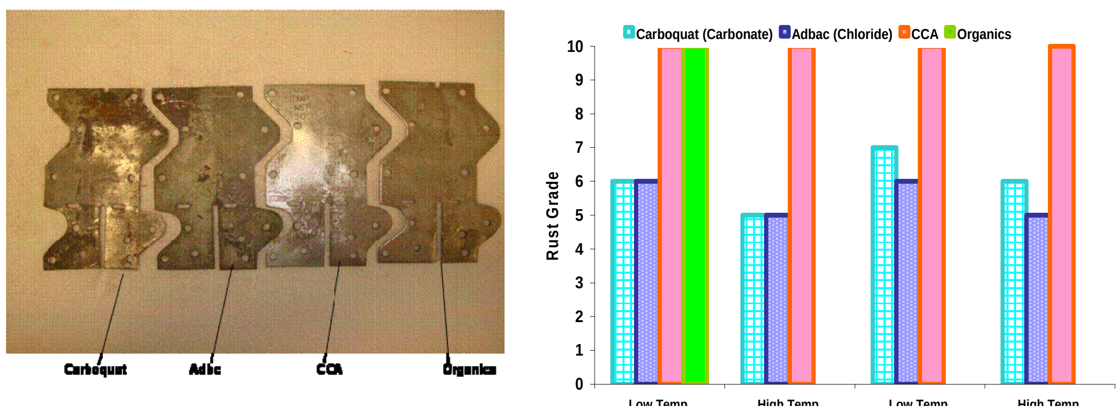


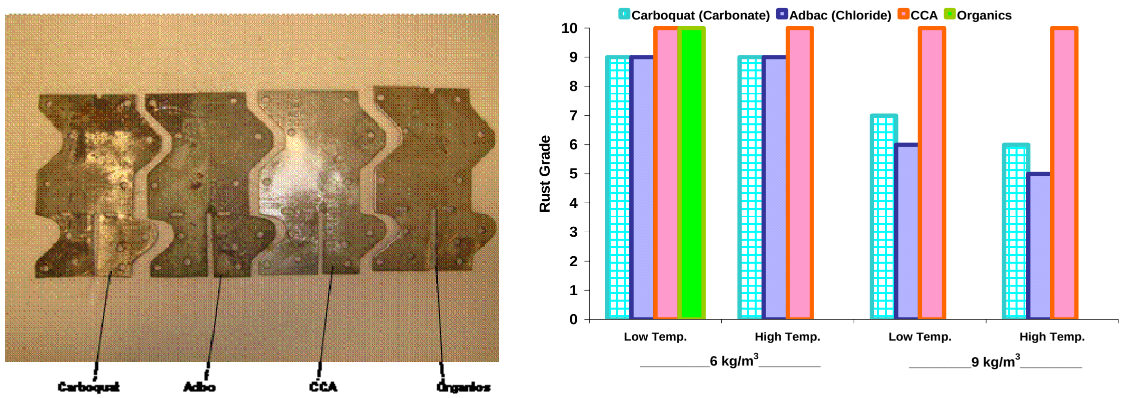
Figure 5: Comparison of screw head corrosion in red pine exposed to natural weathering for 11 months



(a)

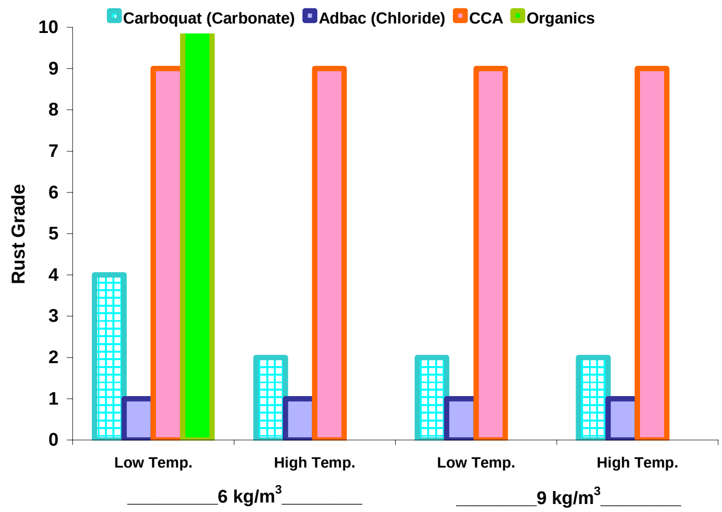


(b)

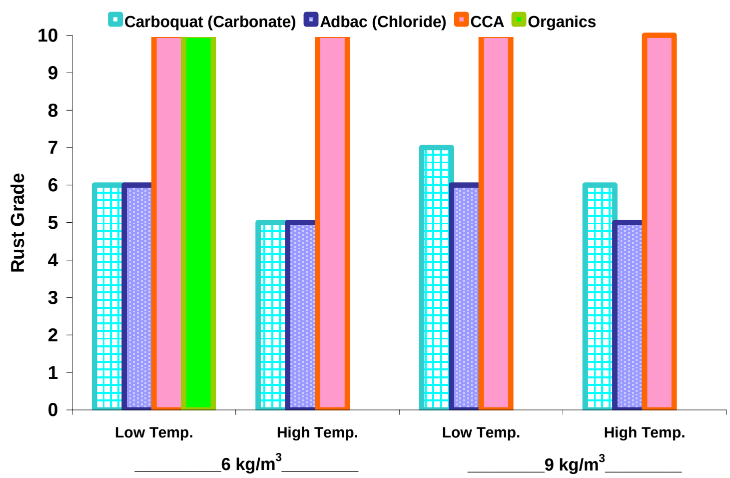


(c)

Figure 6: Comparison of plate corrosion in red pine exposed to natural weathering for 11 months G-90 (a), G-185(b) and Goldcoat (c)



MPA 1F



3.6 Discussion

As hypothesized, there was some indication that the presence of chloride vs. carbonate in the ACQ formulation, higher ACQ retentions and lower stabilization temperatures resulted in somewhat higher corrosion, especially in screw fasteners and G-90 plate connectors. The higher temperature fixation results in both a lower pH (higher H^+ concentration) and lower Cu^{++} concentration in the free solution in the wood (Ung and Cooper 2005). It has also been shown that the speciation of the copper amine complex changes with pH (Davies and Patel 1968), changing from an uncharged complex at high pH to a monovalent, then divalent species at lower pH values characteristic of stabilized ACQ. These factors may offset each other to some extent: the effects of the lower pH (higher hydrogen ion concentration) and charged copper species to increase the electrical conductivity of the wood, accelerating corrosion is balanced by the lower copper and amine concentration in high temperature fixed wood. This is supported by our observation that as copper stabilization progresses, the electrical conductivity of the free solution in wood increases, which could help cancel the benefits of lower free copper concentration with more completely fixed wood conditioned at higher temperature.

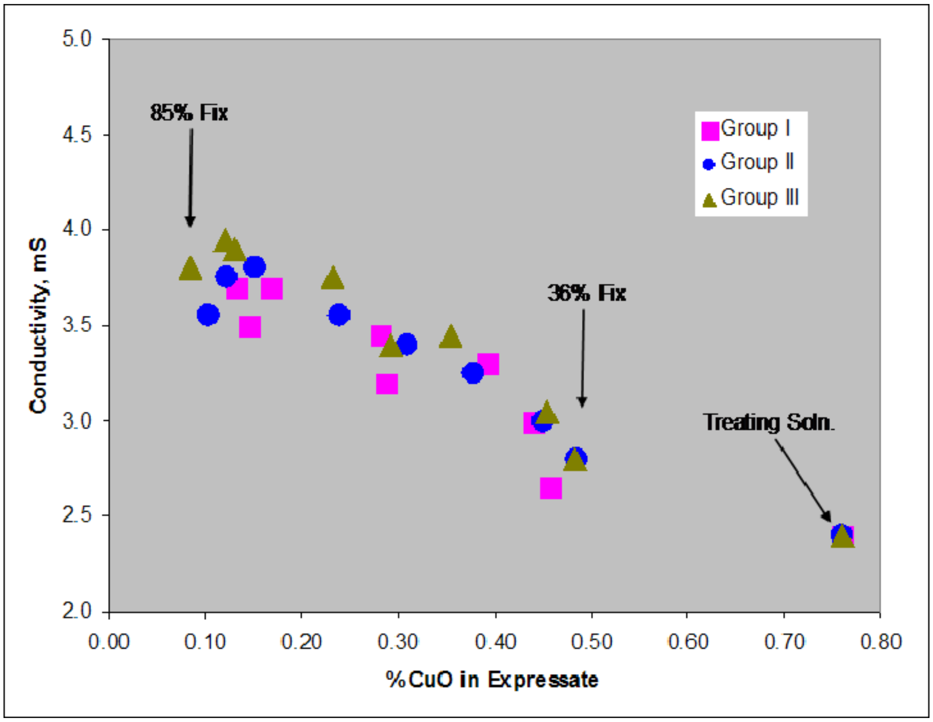


Figure 7: Effect of fixation status in ACQ on the electrical conductivity of the solution in wood

4. Conclusions

1. Fastener corrosion is greater in ACQ treated wood than in CCA treated wood or in wood treated with an organic wood preservative;
2. Wood treated to lower retentions is generally less corrosive than that treated to high retentions and this effect was greater for the screws than for the plates;
3. Wood treated with ACQ formulated with a carbonate based quat results in less corrosion than that treated with the conventional chloride based quat, especially for the screws.
4. ACQ treated wood stabilized before use at high temperature is slightly less corrosive than wood stabilized at room temperature.
5. Corrosion under natural weathering conditions for 11 months was relatively minor, especially on the visible surfaces, while accelerated aging for 39 days weeks resulted in heavy corrosion in some fasteners.
6. The barrier coated screws and plates performed very well on all preservative treatments. As expected, the G185 plates performed relatively well in all cases, while the G90 plates did not.

5. Literature

1. ASTM. Standard A653 Standard specification for steel sheet, zinc coated (galvanized) or zinc-iron-alloy coated (galvanealed) by the hot-dip process. Standard ASTM A153 Standard specification for zinc coating) hot-dip) on iron and steel hardware.
2. Davies, C.W. and B.N. Patel. 1968. Complexes of the cupric ion with mono-, di- and tri-ethanolamine. J. Chem. Soc. (A) Inorg. Phys. Theor.1824-1828.
3. ISANTA 2005 Draft standard "Standard method of determining the relative corrosion performance of fasteners in contact with treated lumber 8-3-05 Draft
4. Kang, S.-M.; Morrell, J. J. 2000. Effect of humidity and temperature on fastener withdrawal resistance from CCA and ACZA treated Douglas-fir Document No: IRG/WP 00-20209
5. Ruddick, J.N.R., N. Ashari and S. Solodkin. 2004. Fastener corrosion and ACQ treated wood. Proc. AWPA. 100:156-157.
6. Ruddick, J.N.R. 2006. Field investigations on the application of ACQ treated wood and use of metal fasteners and connectors in residential construction. Report prepared for Homeowner Protection Office, Vancouver. B.C. www.hpo.bc.ca/research
7. Schneider, P. 2004. Corrosion issues. Proc. AWPA. 100:124-126.
8. Ung, Y.T. and P. A. Cooper 2005. Copper stabilization in ACQ treated wood – retention, temperature and species effects. Holz als Roh-und Werkstoff, 63:186-191.