CANADIAN WOOD PRESERVATION ASSOCIATION

PROCEEDINGS

34TH ANNUAL MEETING
OCTOBER 2013

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SAPSTAIN CONTROL UPDATE

Avtar Sidhu

Introduction

Antisapstain industry pertains to application of chemical treatments for the prevention of discolorations on lumber that appear as a result of microbial (fungal infestations) as well as non-microbial (chemical) factors. Wood, being composed of celluloses, hemicelluloses and lignin, as well as wood sugars, starches, proteins, lipids and fatty acids is an excellent nutritional source for fungal growth. Prior to harvesting, the bark of the tree serves as a protective skin against fungal infestations. In most cases, once the bark is removed the tree becomes susceptible to fungal growth. Once the logs are cut into their respective dimensions, the exposed lumber becomes extremely susceptible to mold and stain fungi. Unless this lumber is kiln dried (KD) or treated with prophylactic fungicides within 24 hours, it will become discolored and result in significant economic losses for the specific seller. While kiln-drying is presumed to render the wood immune to fungal attack, the lumber is still susceptible if it becomes wet during storage and/or transport (N. Melencion N., Morrell, J. J.). Overall, the stain and mold fungi can cause serious damage to wood and wood products, resulting in significant economic losses for the whole wood products industry. The wood discolorations that appear as a result of fungal infestation cause a cosmetic and surface damage but because the surface is the visible part of the wood such discolorations can have an immediate impact on a customer. Discolorations can develop in both hardwoods and softwoods but light-colored woods (whitewoods) of both types are particularly prone to this problem. With the move towards value-added products and with higher quality product specifications discolorations have become an important economic problem. Increase in the use of second-growth timbers which contain greater amounts of sapwood also exacerbates this problem.

The main driving factors for clean and mold free lumber are: (1) Economics – clean lumber means higher value. The customer expects mold and stain free lumber. (2) Huge financial claims and rejection of shipments. (3) Litigation – people exhibiting health problems as a result of moldy lumber in buildings. Since wood predominates in low-rise buildings in North America, it is scrutinized more closely than other materials and it can be perceived as a major substrate for, and source of, mold growth. (Uzunovic, A, Byrne, T).

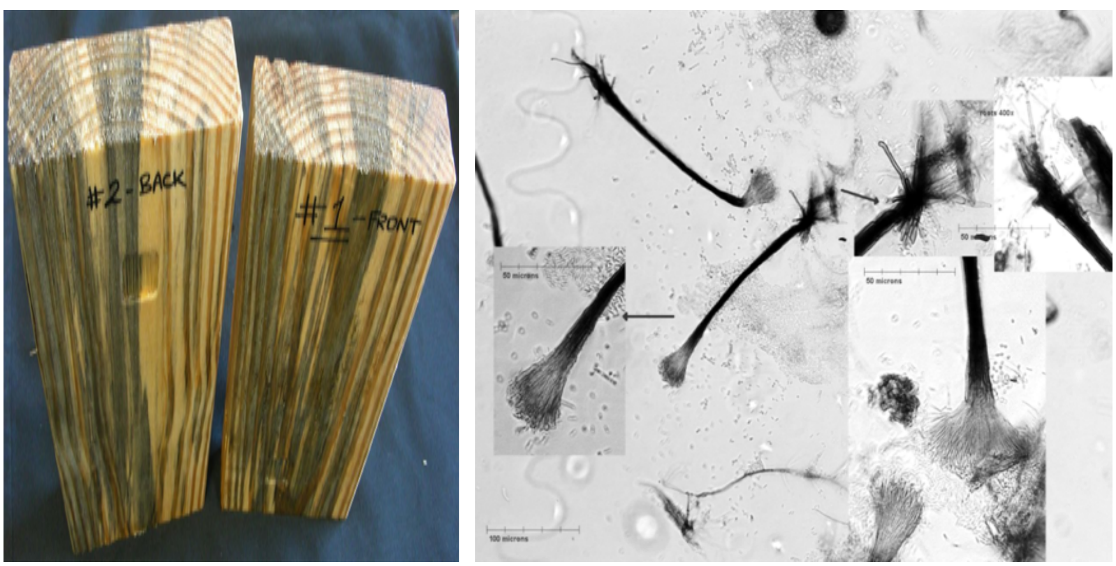
KD lumber in weak market conditions, where the lumber inventory sits stagnant for unusually long periods, has higher chance of picking up excessive moisture and getting rewet. As a result, the likelihood of the lumber becoming infected with mold is extremely high. Many suppliers of

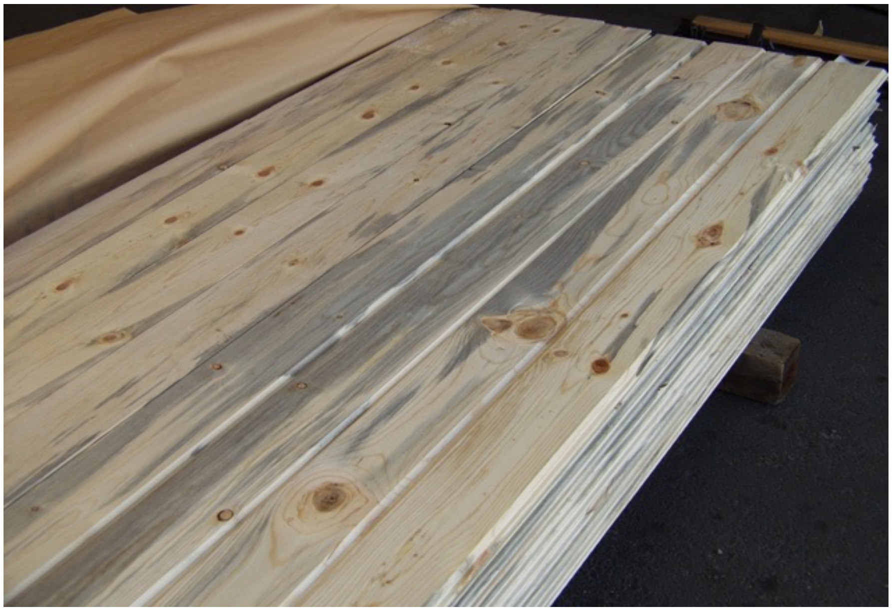
KD lumber have begun applying supplemental antifungal treatments to provide added protection in the time between production and installation.

Wood Discoloration Factors

Wood discolorations appear on lumber as a result of microbial and non-microbial factors. Microbial factors that cause discoloration on wood include sapstaining fungi, mold fungi and incipient decay fungi. Since the antisapstain industry deals with the control of molds and stain fungi, no details of decay fungi will be provided. Sapstain fungi infect the entire sapwood and cause bluish, greyish or black coloration to the wood (Figure 1). Sapstain fungi contain pigmented hyphae that penetrate the cells below the wood surface and cause permanent discoloration that cannot be reversed (Kreber B).

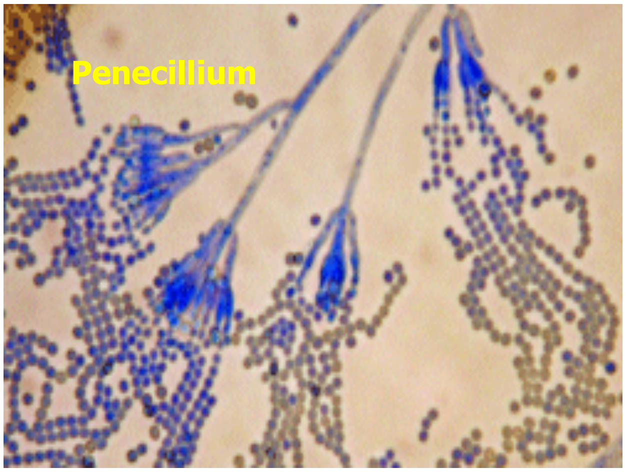
Figure 1. Example of Sapstain in lumber x-section as well as on the surface of finished lumber and microscopic structures of *Ophiostoma* fungal species.

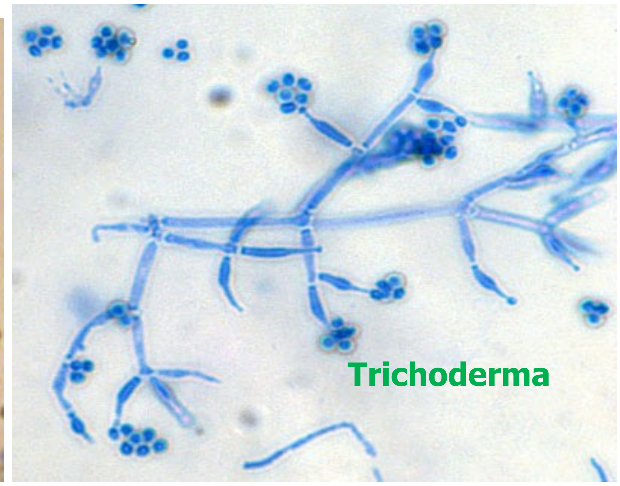




Molds, on the other hand, exhibit colorless hyphae but colored spores. These masses of colored spores appear on the surface and can be brushed or planed off. The molds may appear in many different colors, such as, green, grey, brown, orange and many other shades (Figure 2). Discolorations caused by stain/mold fungi will have a significant impact on lumber economically at the point of sale.

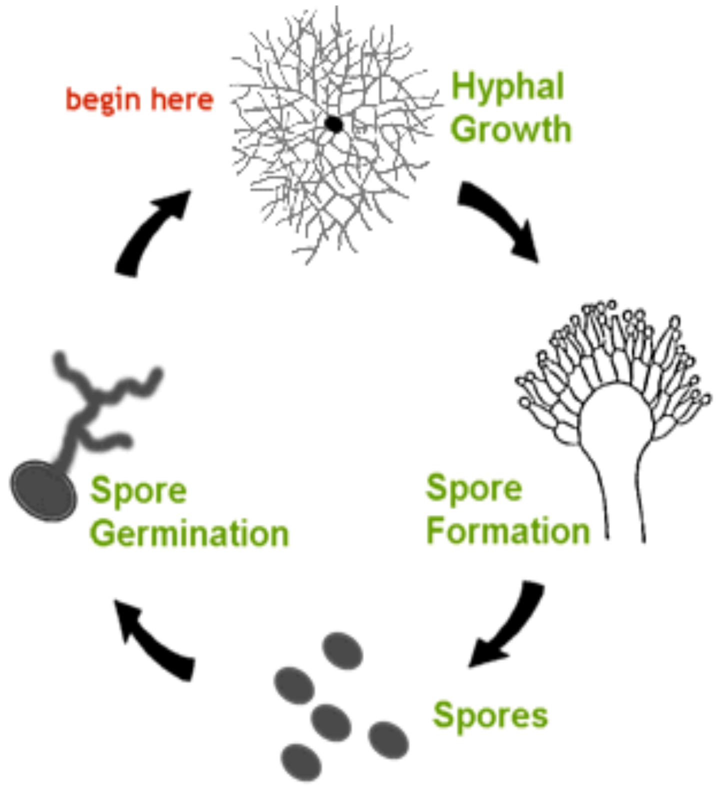
Figure 2. Example of unsightly mold on treated lumber (top). Example of *Penecillium* (bottom, left) and *Trichoderma* (bottom, right) genus at microscopic levels.





Both the stain and mold fungi require several growth requirements. They need oxygen, nutrients, water and a favorable temperature. Without any one these requirements, the fungal growth becomes arrested. The sapwood of freshly felled logs or freshly cut lumber contains abundant oxygen, nutrients and water that can support growth of stain and mold fungi. The optimal temperature for growth of sapstain and mold fungi ranges between 15 – 30%. When the appropriate conditions for growth exist: presence of moisture, nutrients, temperature, etc, mold begins to reproduce via its life cycle (Figure 3): (1) Hyphael Growth: Hyphae are the thread-like filamentous cells that release enzymes which degrade and absorb nutrients from a substrate (ie. organic debris, cellulose, wood, almost any carbon containing material including human skin). Upon obtaining its nutrition, the hyphae will grow into a mycelium, the main body of the fungus which is also the visible portion. (2) Spore Formation: Spores form on the ends of some hyphael cells. The formation of spores is dependent on a variety of environmental factors including light, oxygen levels, temperature, and nutrient availability. (3) Spore Dispersal: After the spores are formed, they are released into the air and carried elsewhere to begin the process of germination and growth all over again. Mold spores are highly resistant and durable. They can remain dormant for years in even hot and dry environments. (4) Spore Germination: Once the spore is dispersed to a new area and when the appropriate conditions exist, moisture and nutrient availability, the spore will begin to germinate into a new hyphael cell (Power Vac America, inc.).

Figure 3. Mold/stain fungi Life Cycle.



The non-microbial factors that can discolor the lumber result from chemical changes in the wood, producing colored wood extractives which are deposited in the lumen of wood cells (Figure 4). Whereas the microbial based discolorations only occur in sapwood, the non-microbial discolorations can occur in both sapwood and heartwood. These non-microbial factors that cause discolorations include; (1) Photochemical – changes in wood color as a result of exposure to light (visible and UV). (2) Biochemical – oxidation of extractives following felling of trees or sawing of lumber. This is analogous to browning reactions in freshly cut fruit. (3) Chemical – intense discoloration development in green lumber upon contact with iron. Oak, Western Hemlock and Western Red Cedar are well known to produce such discolorations called "tannin stains". (4) Brownstain – brown discolorations in western softwoods. The causes of these stains are very poorly understood.

It is important to remember that although these discolorations do not compromise INTEGRITY of lumber they do result in: DOWNGRADE and in huge REVENUE LOSS.

Figure 4. Examples of Non-microbial discolorations: Photochemical (top, left), Enzymatic (top, right), Chemical (middle) and Brownstain (bottom).

Antisapstain Treatment Alternatives

As mentioned in the introduction, kiln drying lumber immediately after processing of logs to bring the moisture content of lumber below 19% will most likely prevent the development of any mold and stains. There are two caveats to KD lumber being totally immune to mold and stain fungal infection. During the lumber drying process, moisture content of lumber follows a normal (Gaussian) statistical distribution around the target moisture content expected. Therefore, some of the lumber will result in being over-dried and a fraction of lumber will be under-dried. Some of the under-dried lumber will be susceptible to fungal infection if it is kept tightly banded and paper wrapped. The paper wrap around partially dried lumber will act as an incubator and allow some of this mold to proliferate within the package (Figure 5). Any neighboring lumber to the under-dried pieces may also be somewhat discolored.

Figure 5. Improperly dried and improperly stored lumber showing mold/stain/decay development.

Although there are some important advantages to kiln drying lumber, there are many disadvantages that have to be weighed respectively (Table 1). The lumber drying costs are much higher than the antisapstain treatment costs. Improper drying can lead to lumber degrade (lumber checking and casehardening) and the under-dried (<19% m.c.) lumber is still susceptible to mold if it is kept banded and wrapped (Clark, J. E). For these reasons, many lumber manufacturers have begun using supplemental antisapstain treatments on lumber which has already gone through the lumber drying process and has been freshly planed. These supplemental treatments prevent the mold from growing on under-dried lumber (>19% m.c.) which is packaged and stored (Figure 6).

Tabel 1 – Advantages and disadvantages of KD lumber.

<table>
<tr><th>Advantages of KD Lumber</th><th>Disadvantages of KD Lumber</th></tr>
<tr><td>Achieve m.c. < 19%</td><td>Cost(Capital, Energy)</td></tr>
<tr><td>Decrease in transportation costs</td><td>Lumber quality degrade(due to improper drying</td></tr>
<tr><td>Inventory Reduction</td><td>Under-dried lumber still susceptible to mold</td></tr>
<tr><td colspan="2">Kiln Drying Cost: - $25 – 100/MBft</td></tr>
<tr><td colspan="2">Antisapstain Treatment Cost: - $1 – 10/MBft</td></tr>
<tr><td colspan="2">Lumber Cost: - $150 – 400/MBft</td></tr>
<tr><td colspan="2">Lumber degrade lost (due to mold/stain): - up to 50%</td></tr>
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Figure 6. An example of sixteen-month old wrapped KD lumber that has been treated with antisapstain.

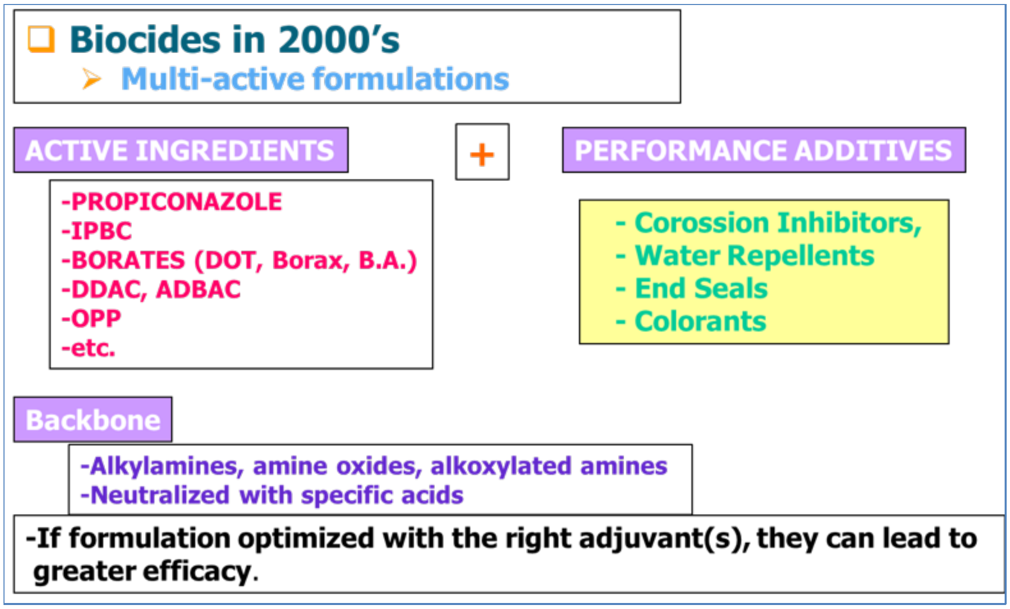
Types of Antisapstains

The antisapstain treatment programs have evolved over the years from containing a single active ingredient to containing multi-active ingredients. Additionally, the types of active ingredients used nowadays are much more environmentally friendly and pose a much lower health risk to workers that are in contact with these products on a daily basis. Today's lumber contains substantially more sapwood than that produced 20 years ago – a consequence of changing timber resources. Chemistries and application technology have evolved with the change – but the dominant influencers have been regulatory (intolerance of inadequate/incomplete data), occupational (risk reduction) and environmental (persistence, bioaccumulation, microcontaminants). These have led to the "strategic objective" of specificity, and a clear trend forward: that actives will originate in the agricultural and pharmaceutical sectors, such that risk assessment is so thoroughly documented as efficacy before introduction to the forestry sector. Propiconazole represents the first such innovation registered for use throughout Canada and USA.

Essentially, a good active ingredient (mold inhibitor) ought to: Deter germination of incipient spores from natural fallout; Inhibit proliferation of superficial fungal hyphae; Attract no regulatory consequences for the treated article and; Cost a mere fraction of the value protection conferred…thus helping to protect pristine lumber safely and economically. A mold inhibitor cannot, at reasonable doses: Reverse infection after-the-fact (i.e. pre-infected lumber) and; Reverse aesthetic damage after-the-fact. At the concentrations employed, most antisapstain agents "last" a long time – that is, they are indefinitely analytically detectable. However, the starting concentration gradients are compromised by leaching and diffusion as time passes, among other mechanisms. A challenge will "fail" once superficial concentrations fall below the threshold of toxicity to a particular inoculant.

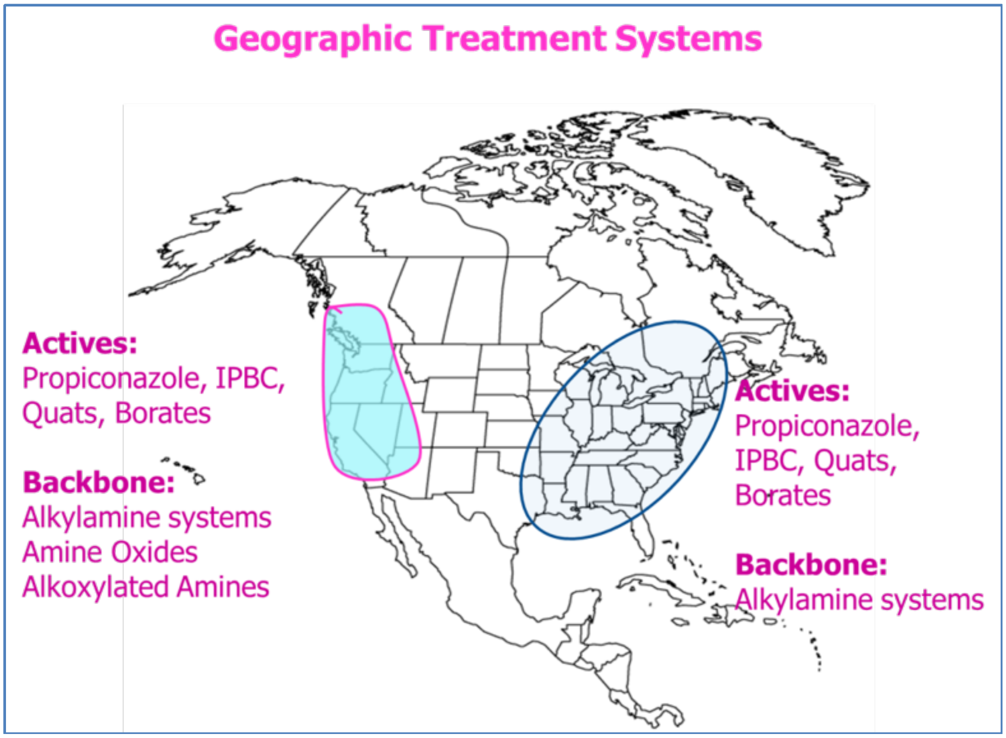
The currently used antisapstain formulations are based on using multiple actives that exhibit synergy when used in specific combinations. This not only provides a wider spectrum of inhibition against numerous fungi but also lead to very cost effective formulations. More importantly the synergistic use of these actives lowers the total environmental impact. The various active ingredients that may be used in any specific antifungal formulation are shown in Figure 7. The economic sapstain/mold control requires a cellulose-substantive cationic formulation. The cationic emulsion system may be based upon either quaternary cotoxicants (which are exploited as adjuvants not actives, as they are present at marginally efficacious deposit levels), or upon alkylamine soaps (precursors to such quaternaries). These cationic emulsions actually creates what's termed as the "backbone" for the formulation containing one or more actives. Just prior to use, these formulations are usually diluted to specified concentrations and then used in conjunction with other additives such as, corrosion inhibitors, water repellents, end seals and colorants.

Figure 7. The composition of a "Multi-active Formulation".



Geographically, the treatment systems may vary depending on the types of wood species being treated and the typical weather patterns that are prevalent in the specific treatment regions. For example, majority of the lumber treated in the West Coast is Hemlock and Douglas Fir and some Pine species. In the East (Canada and US) there is mix of softwoods including Eastern White Pine, Red pine, Eastern Hemlock. Hardwoods include Red Maple, Red Oak. In the Southeast of USA, there is Southern Yellow Pine species. The collective term "Southern Yellow Pine" or "Southern Pine" includes principally longleaf, shortleaf, loblolly and slash pines growing in the Southern States from Virginia to Texas. The treatment systems consist of similar active ingredients and backbones and are custom tailored for each individual customer and/or region (Figure 8). There are distinct differences in the type of antisapstain treatments that are required for each of these geographic regions and one treatment does not fit all. Therefore, the design of treatment for each region and species of wood often takes extensive experimentation and trials to find the most effective treatment.

Figure 8. Geographic Treatment Systems.



Antisapstain Treatment Application Systems

The antisapstain treatment application systems mainly consist of dip tanks and spray systems. The dip tanks are preferred method of treatment for smaller, lower production lumber mills. Dipping is the only way to insure uniform contact of the treating solution with all surfaces of the wood. The lumber units can be assembled, banded, trimmed and even paper capped before treatment. The units are handled entirely by chains, rollers and forklifts, eliminating personnel exposure to chemically treated lumber. Automated in-feed, dipping and out-feed systems are capable of handling high throughput (Figure 9). Some of the disadvantages of dip tanks include the excessive sludge build-up in the dip tank overtime and greater amount of drippings from lumber packages. At one time it was believed that the lumber for export be treated by dip treatment only since the export requirements are more critical, where lumber is containerized and subject to extended holding time under severe staining conditions, dip treatment provides the best insurance against claims.

Figure 9. Automated dip-tank for antisapstain treatment application.

There are usually two types of Spray Systems, Lineal and Transverse, that are used in the antisapstain industry (Figure 10). Both types of Spray Systems use spray nozzles that are used at varying pressures to provide uniform lumber coverage. These Spray Systems are fitted with mist-eliminator systems that control the mist build-up in the spray boxes. In the past high nozzle pressures were used to apply the antisapstain chemical and it was thought that the greater pressures lead to more uniform lumber coverage. The moderate to low pressure systems (20-60 psi) are now known to provide the better lumber coverage. The biggest benefit of Spray Systems is the throughput they provide. Some of the lumber mills using spray systems today have throughputs of greater than 2MM bdft/day.

Figure 10. Lineal Spray System (left) and Transverse Spray System (right).

Majority of the antisapstain treatment on the West Coast is carried out using Spray Systems, both Lineal and Transverse. Depending on the space available for Spray System installation together with the throughput requirements and the capital expense allocated, appropriate Spray Systems are selected to meet the customers' needs. In the East coast of Canada and US most of the antisapstain treaters are the small mom-and-pop type of operations that use predominantly Dip Tank Treatment Systems and only a small number use Lineal Spray Systems. Majority of the lumber that is treated in this region is hardwood lumber including Maple, Birch, Red Oak, White Oak, Poplar, Ash and Red Pine. In the US SE, the Southern Yellow Pines, including Slash Pine, Loblolly Pine and Long-leaf Pine are predominantly treated using Lineal Spray Systems.

Monitoring Chemical Retention on Lumber

Traditionally the monitoring of chemical treatment on lumber is carried out by taking retention samples (1"x1") from the treated wood surface. The retention samples are then sent to the lab where the active ingredients are extracted from the samples and then analyzed by Gas or Liquid Chromatograph (Figure 11). Although the retentions of actives obtained by this method are accurate and provides valuable data for monitoring the consistency of treatments from week-to-week, the lag period after treatment is 2-3 days before the results are obtained. This may pose problems in catching any application system failures where the lumber is inadequately treated. Of course, there are other cautions placed in the spray systems to catch such failures.

Figure 11. Retention sample extraction from lumber (left). Gas Chromatograph (right).

Some of the more advanced lumber mills are using more advanced chemical retention monitoring systems that provide real-time chemical application data. The actual chemical use and all the spray system parameters can be remotely displayed and made available to mill managers in their offices (Figure 12).

Figure 11. Chemical retention monitoring automated.

Summary

With changing timber resource from utilizing “old growth” trees to utilizing second growth trees, lumber contains substantially more sapwood and therefore the chemistries and application technology have evolved with the change. Most of the mold species that cause sapstain in the Pacific Northwest belong to the genera Ophiostoma, Aureobasidium and Penecillium. Countless other species do occur, some under predictable conditions (e.g. insect vector population), some associated with particular processes (e.g. heat treatment for export) and others owing to unpredictable outbreaks or marginal treatment levels. The antisapstain industry provides solutions for the lumber manufacturers to prevent microbial and non-microbial stains. Although, the antisapstain industry has evolved into utilizing much more environmentally acceptable formulations, the best protective practices have lagged. The lumber industry is so cost-conscious that the quality of incoming stock is ignored and the more often than not the lumber gets under treated. To mitigate the problem of lumber containing higher levels of sapwood and slow seasons where lumber inventory moves at a much slower rate, “multi-active” formulations have been created. These formulations not only provide cost-effective solutions but provide a greater spectrum of inhibition against mold and stain fungi. The antisaptain treatments are designed to fit treatments for specific wood species in a specific region of N.A. In certain regions of N.A. mould fungi are more prevalent and in other regions, sapstain fungi are more prevalent. Certain

types of treatments are more effective against moulds and the others are more effective sapstainers. One type of treatment does not fit all.

The antisapstain application systems have also evolved into using more automated monitoring systems. These automated monitoring systems were created to catch any problems during the lumber treatment process. Additionally, these monitoring systems are capable of assessing how much chemical is being deposited on lumber at the point of treatment. This provides confidence to the customer that "insurance" levels of protection is provided for all the treated lumber.

Literature

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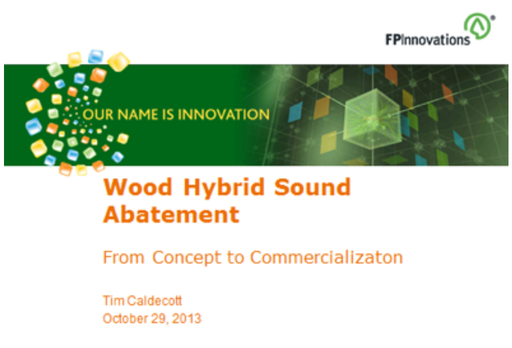
Morrell, J.J., C.S. Love, and C.M. Freitag. 2002. Preventing discoloration of unseasoned hem-fir and Douglas-fir lumber with selected fungicide formulations. Forest Prod. J. 52(2):53-61.

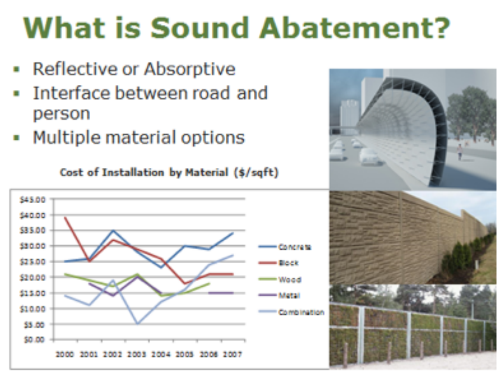
Power Vac America, Inc. (2014): The mold life cycle. http://www.powervacamerica.com/Newsletter/vol4issue2/vol4issue2_article1.htm

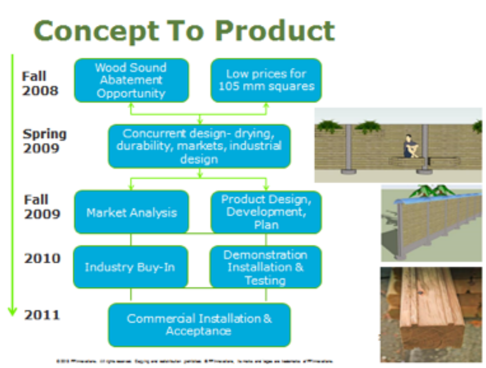
WOOD HYBRID SOUND ABATEMENT - FROM CONCEPT TO COMMERCIALIZATION

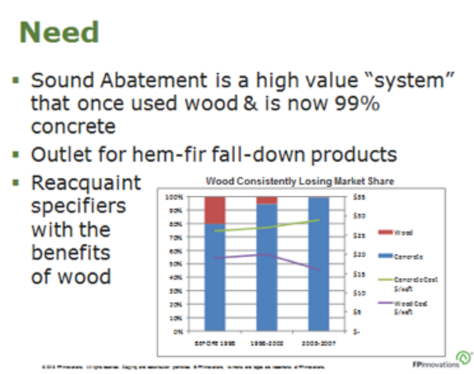
Abstract

Sound abatement is available as either reflective or absorptive and provides an interface between noisy road networks and residential areas. The cost of materials used in sound barriers varies considerably with concrete being among the most expensive and most commonly used, while historically wood has lost its once considerable share of this market. The FPInnovations Wood Hybrid Sound Abatement System was conceived in 2008 to be a potential margin adding outlet for suitable fall-down products. By 2011, the collaborative design process, including technical development and market analysis, yielded a commercialized product that has since been installed on almost four kilometres of road ways in the lower mainland of British Columbia.





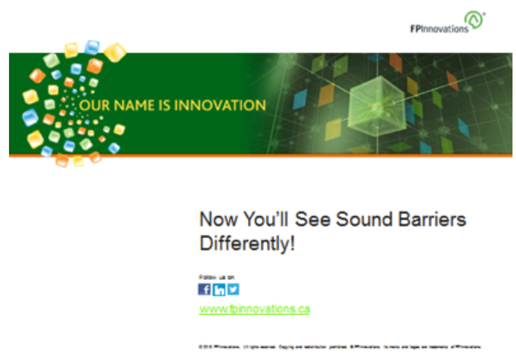





Approach – Market Analysis
Determined large market opportunity for wood
Opportunity on West Coast: = 65,000 mfbm/a
- Mfbm -
80,000
60,000
40,000
20,000
W. Canada Municipal
US Pacific Municipal
W. Canada Hwy
US Pacific Coast Hwy
Annual New
Annual Replacement of Existing
20% Penetration for Wood
Comparative Costing ($/sqft)
FPInnovations Wood/Concrete
Concrete
$-
$20.00
$40.00
Cost of Panel
Installation
Wood product has competitive cost advantage and "green" marketability
Industry interest
FPInnovations


Approach – Product Development
FPInnovations collaborative design team, manufacturer & installer
Installed test & demonstration sites
Tested system against industry requirements (STC)
Achieve Recognized Product Status with BC Ministry of Transport
BRITISH COLUMBIA
FPInnovations


Benefit
Winning competitive bids in BC
– upgrading $0.40/bf into a $2.75/bf system
– 3km to be installed = 500 mbf
– Installed 2x the rate of concrete & up to 50% lower cost than concrete
Accepted to BC Ministry of Transport Recognized Products List
FPInnovations


FPInnovations
OUR NAME IS INNOVATION
Now You'll See Sound Barriers Differently!
www.fpinnovations.ca

UPDATE ON WOOD PRESERVATION CANADA AND CANADIAN STANDARDS ASSOCIATION ACTIVITIES

Henry Walthert, CAE

Executive Director, Wood Preservation Canada

One of the major activities of Wood Preservation Canada in 2013 is the completion of the new edition Technical Recommendations for the Design and Operation of Wood Preservation Facilities (TRD). Working with Environment Canada, the TRD, last published in 2004, has undergone modifications on two aspects; structure of the document and Technical Recommendations. The goal of the TRD modification is to align it with the PMRA reevaluation requirements, to ensure recommendations are up to date and to include a generic chapter for new preservatives. The document will be available electronically (no print copies).

The enforcement of the TRD's has been the role of the Canadian Wood Preservation Certification Authority since 2007 and this activity continues today. The CWPCA program will be completing its second three year audit cycle this year. Fifty three of the fifty four treating plants operating in Canada are currently enrolled in the program. Compliance for most plants is greater than 95 %. The program requires plants using CEPA toxics to score greater than 95% and plants using non-CEPA products to score in excess of 90%. Each plant must submit an annual internal audit and is subject to an external audit conducted once in every three year cycle.

The benefits of TRD compliance under the CWPCA program includes:

Greater employee satisfaction

Cleaner process = less hazardous waste

Insurance savings

Easier financing

Market acceptance

Due diligence

WPC has also been involved in the follow through of the Pest Management Regulatory Agency, Health Canada reevaluation of heavy duty wood preservatives. The heavy duty wood preservative labels for products containing CEPA toxic substances now include a pesticide label requirement for compliance with TRDs. This includes CCA, ACZA, creosote and pentachlorophenol.

Another component of the reevaluation was the development of a Risk Management Plan for these products developed by PMRA. The main component of this plan is the formation of working group consisting of Environment Canada and PMRA with appropriate consultation with industry. The purpose of the working group is to follow up on issues that have been identified as possible measures to reduce risk and o stay engaged with evolving practices/technologies to ensure they are represented in future editions of the TRDs.

In March 2012 PMRA published a PRVD (proposed reevaluation decision) on the Re-evaluation of Boric Acid and its Salts (Boron). WPC submitted comments in support of the registration of borates. All of the comments received are now being reviewed by PMRA.

More recently, the United Nations Persistent Organic Pollutants (POP's) Review Committee under the Stockholm Convention agreed to develop a risk management profile on the use of pentachlorophenol. This is the first step in a long process, which might lead to use restrictions for penta. Because the United States is not a signatory to the Stockholm Agreement it will not directly affect the use of pentachlorophenol in the US, but could trigger further examination during the next EPA re-registration process. Canada is a signatory and any restriction could have an effect on Canadian registration. WPC is actively involved with the Penta Task Force.

Two new initiatives undertaken by WPC is the promotion of timber bridges and permanent wood foundations. The recognition that wood is a preferred building material has resulted in the resurgence in interest worldwide in the construction of timber bridges. The development of a new Canadian standard for wood foundations will increase opportunities for the use of pressure treated wood in foundations.

The Canadian Standards Association is nearing the completion of the new edition of CSA S406 Specification of Permanent Wood Foundations for Housing and Small Buildings. Public review closes November 22, 2013. Publication of the new standard is expected in early 2014.

The third edition will include the following:

(a) 3-storey construction of homes is now permitted, with revised design tables;

(b) the clear span has been increased from 8m to 12m;

c) revisions have been made to sealant and damp proofing requirements, and optional drainage layers have been added;

d) variable granular bed depths are now specified;

(e) nail diameters and spacing have been included;

(f) standard stud sizes have been increased from 2”x4” to 2”x8”

(g) details for wall openings and walkouts have been revised.

Finally the CSA A366 Technical Committee will be entering another five year cycle and the following items are in the work plan.

- Complete review of the CSA O80 Wood Preservation standard scheduled for 2014
- Publication of new edition expected in 2015
- Review and publication of new edition of the CSA O322 *Procedure for Certification of Pressure-Treated Wood Materials for Use in Preserved Wood Foundations*

WOOD COATING

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Summary

This paper summarizes the result of two studies conducted at the University of Toronto on effect of wood treatment on coating performance. Number of commercially formulated coatings was applied on preservative and heat-treated wood samples and their performance characteristics were evaluated over 3 years of natural weathering exposure for preservative treated wood and 18 months for thermally-modified samples.

In the preservative study, Cu-based preservatives (ACQ and CA) were compared with CCA pressure treated wood samples. The results showed that wood treatments both with preservative and thermal modification enhanced coating performance. Preservative treatments reduced colour change and thermal treatment reduced water-uptake and checking of the wood. Application of coatings on treated-wood reduced preservative component leaching on average by 60%, and surface checking by 30-40%.

1. Intoduction

Coatings are applied on exterior wood structures to protect the wood from weathering degradation agents such as UV and moisture (Williams et al., 1996). Non-durable wood species are usually treated with preservative treating solution to provide protection against decay fungi (Forest Products Laboratory, 1999). For almost half a century, chromated copper arsenate (CCA) was the dominant wood preservative in the North American market; thus, most exterior wood coatings were formulated for application on CCA-treated wood.

In 2004, along with voluntarily shift of wood preservative industries from CCA to non-chromium and non-arsenic based preservatives, Health Canada (Health Canada, 2005) recommended application of semi-transparent stains once a year on existing CCA-treated residential structures. However, there is not enough evidence on how effective these coatings are in reducing As and Cr leachate during long-term natural weathering. There was an immediate need for research to learn how coating performance will be affected by change in preservative formulations. Also, the new Cu-based preservative were reported to leach copper in a much greater amount than CCA (Temiz et al., 2006; Waldron et al., 2005) and although copper is less toxic to human, it is highly toxic in aquatic environment (Flemming and Trevors, 1989). The main objective of the preservative study was to evaluate ability of coating in reducing preservative components leaching from treated wood while comparing coating performance on different preservative treated wood.

Thermal treatment as a green technique is gaining interest especially in Europe as a way to protect the wood without addition of any preservative chemicals. Although, heat-treated wood is not recommended for ground contact application, it does provide some degree of biological protection for above ground exterior use (Esteves and Pereira, 2009; Rapp and Sailer; Wang and Cooper, 2003). The main advantage of thermal treatment over preservative treatment is the exceptional dimensional stability of thermally-modified wood. In thermal modification usually wood is heated to high temperature around 200°C (either in steam or oil) for a few hours. Vegetable oils may be used as an oxygen free media to uniformly transfer heat to the wood. The only problem would be loss of coating adhesion if there remains excess oil on the surface after heat-treatment. The second study was focused on evaluating performance of a range of coating formulations on oil-heat treated wood and compare their performance on preservative-treated wood.

2. Methodology

A set of flat-grained southern pine (SP) wood samples were treated with three different types of preservatives: CCA-C (47.5% Cr_2O_3, 18.5% CuO, and 34% As_2O_5), ACQ-C (66.7% copper oxide, 33.3% quat), and CA-B (96.1% copper, 3.9% tebuconazole). All preservative treated-wood samples were pressure treated to above ground retention according to AWPA standard and the samples were allowed to fix for 1 week at 50°C and 95% relative humidity.

Another set of radial-grained southern pine, and flat-grained spruce wood samples were heated to 200°C in a hot soybean oil bath with 10% wax for three hours and left in an oven at 100°C over night to gradually cool down. An extra set of samples was used as untreated (control) samples.

Nine different penetrating stains (one transparent and eight semi-transparent) were applied on the top surface of heat-treated wood samples (SP: 34mm x 112mm x 135mm, and spruce: 15mm x 80mm x 100mm) and their end grains were sealed by white acrylic sealer. All stains were applied twice based on manufacturer recommendations, except coating number one which was recommended as only one coat application; however, the total wet film thicknesses of all coatings were kept equally at 0.127 mm (5 mils).

Additionally, five commercially formulated semi-transparent stains were applied by brush on the top surface and end grain of preservative treated wood samples (20mm x 140mm x 280mm) more details of the preservative treatment and fixation schedule can be found in Nejad and Cooper (2010a). After one week of air drying, samples were exposed to natural weathering.

Performance characteristics of penetrating deck stains were evaluated during 18 months of natural weathering for heat-treated wood samples and over three years for samples treated with preservative chemical.

3. Results and Discussion

All preservative-treated wood had lower colour change than untreated wood samples either coated or uncoated (Figure 1). The reduced colour change of preservative-treated wood, compared to untreated-wood samples, could be due to potential lignin modification by metal oxides available in formulation of preservatives (Evans et al., 1992).

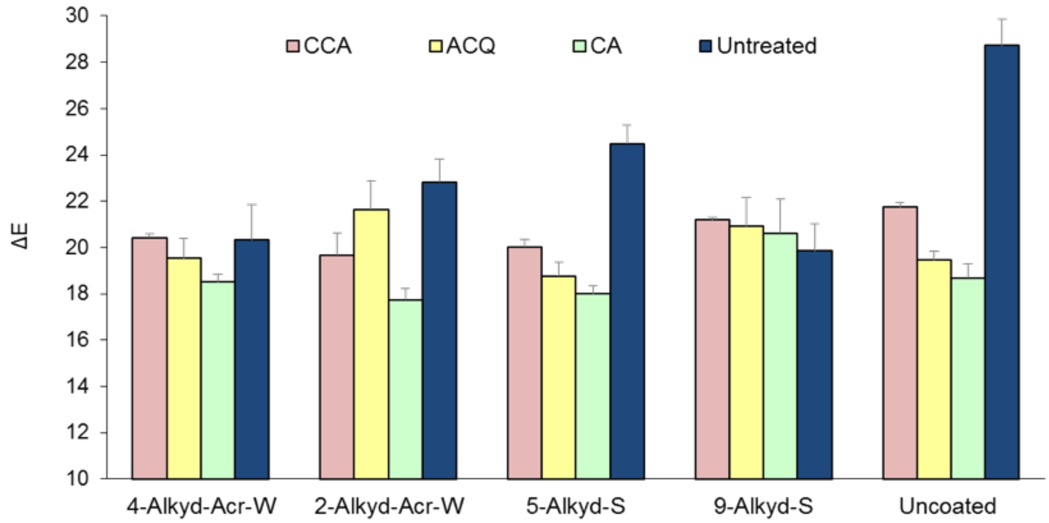

Figure 1: Average ΔE colour change of wood samples in preservative–treatment study after 3 years of natural weathering.

Among preservative treated woods, coatings had the best appearance ratings on CCA-treated wood with least coating surface erosion and fungal growth. Cu-amine treated wood had on average 50% higher water uptake than CCA-treated wood and had similar moisture content to untreated wood samples (Figure 2). This indicates that coating producer should change their formulation to have higher water repellency if it is to be applied on Cu-based preservatives.

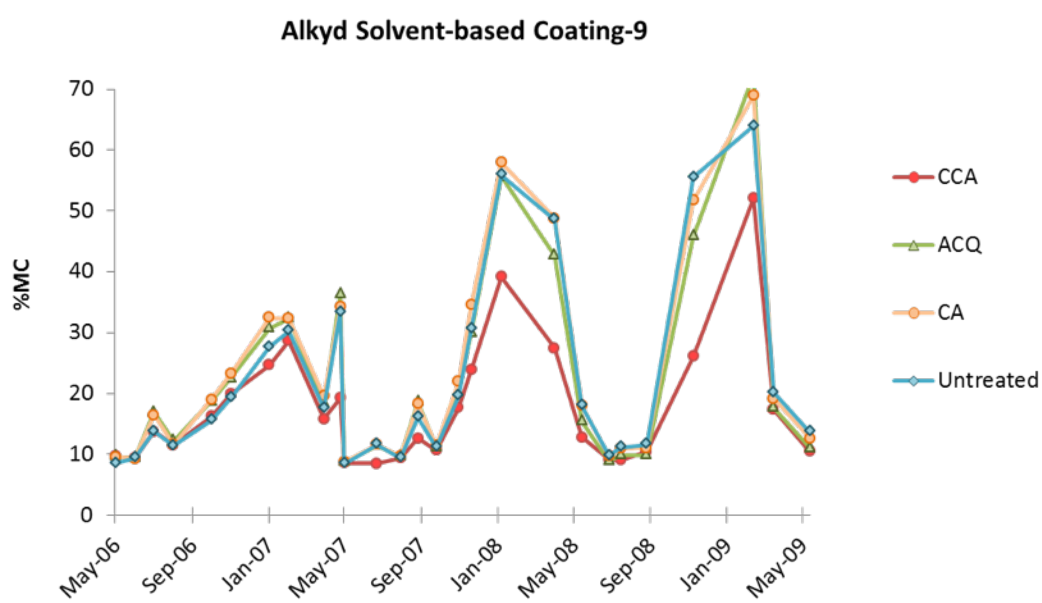

Figure 2: Average moisture content of preservative –treated and untreated wood samples coated with a solvent-based coating during 3 years of natural weathering.

Thermally modified wood on average had about 40% lower water uptake than untreated wood either coated or uncoated (Figure 3). This significant reduction in water permeability of wood after heat-treatment makes the heat-treated wood a great candidate for exterior structures such as fences and decks.

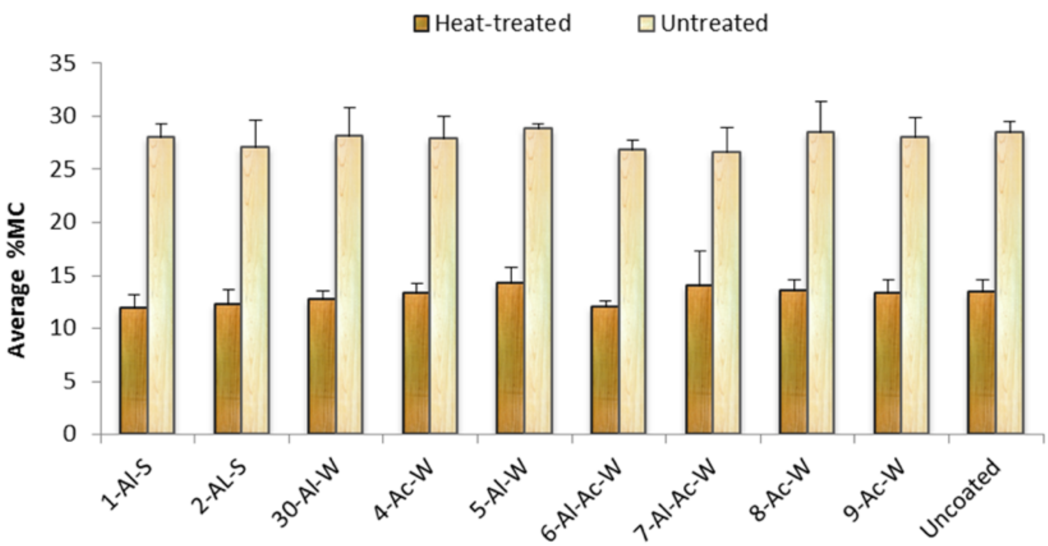

Figure 3: Average moisture content of coated and uncoated wood samples after one year of natural weathering in heat-treatment study (Al=Alkyd, Ac=Acrylic, W=Water-based, S=Solvent-based).

Similar to preservative-treated wood, the effect of heat-treatment was much greater than coatings in reducing water uptake during natural weathering exposure. Thermally modified wood turned to grey colour almost at the same rate as of untreated-wood samples as shown in the last column in Figure 4. Also, the transparent coatings shown at the column fifth from left to right was drastically degraded and turned grey like uncoated wood samples. Overall, heat-treated coated wood had higher performance ranking after 18 months of natural weathering than untreated coated wood samples with less surface checking and erosion.

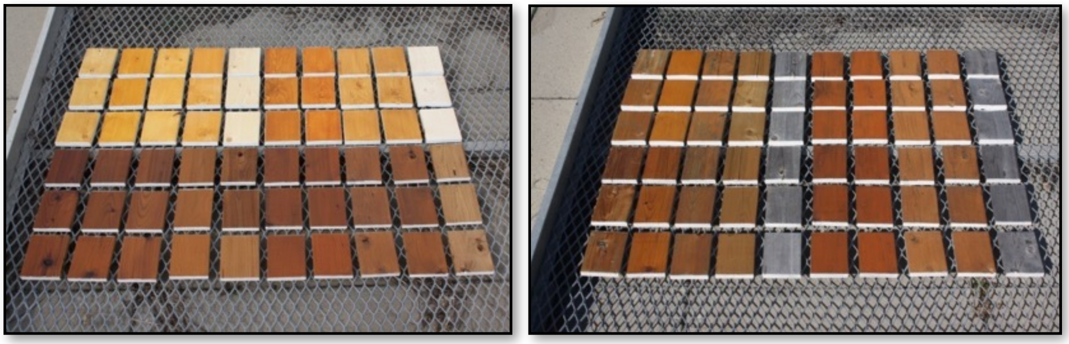

Figure 4: Coated heat-treated and coated-untreated spruce wood samples exposed to natural weathering before (left) and after one year (right)

Coatings significantly reduced surface checking of wood as measured by image analysis of samples (Nejad and Cooper, 2010b), and also reduced preservative component leaching from preservative treated wood during three years of natural exposure in Toronto (Nejad and Cooper, 2010a).

4. Conclusions

These studies showed that wood modification, either chemical or thermal, has significant effect on performance of coated wood samples. Therefore, there should be different coating formulation for each specific treated-wood products. For instance, while CCA-treated wood provided good water repellency, formulated coating for Cu-based preservative should have much higher water repellency than the ones that were formulated for CCA-treated wood. On the same line, coatings that are formulated for application on heat-treated wood do not need high water-repellency, but need much higher UV-resistance than the common coating formulated for preservative-treated wood.

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MMA-HARDENED HYBRID POPLAR WOOD — AN ALTERNATIVE TO HIGH-QUALITY LUMBER

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Summary

The dimensional stability, surface and mechanical properties of fast-growing poplar clones and their methyl methacrylate (MMA)-hardened wood related to potential end uses were investigated. The wood samples, obtained from 24 trees of 6 hybrid poplar clones in Quebec, were hardened with MMA. The effects of MMA hardening on the density, volume swelling coefficient (S), surface properties (hardness and abrasion resistance) and mechanical properties (flexural and compressive strength) were studied. Scanning electron microscopy and Fourier transform infrared analysis showed that filling the voids in the wood structure was the main hardening mechanism. The incorporation of the polymer increased the density of all of the poplar clones by 120–160% and decreased the water migration rate into the wood during the soaking. S values of hardened woods were significantly lower than those of controls, depending on the clone type. Incorporating MMA effectively improved the dimensional stability of poplar wood at the early soaking stage, but was less effective in the long term. The Janka hardness was found to be 2.5–4 times higher in the treated poplar wood than in the untreated poplar wood. The treated wood also exhibited superior abrasion resistance. Significant differences were observed among clones in bending and compression strength parallel to grain. Hardening treatment has considerably improved all strength properties except for strain at rupture in static bending. The improved properties of MMA-hardened hybrid poplar were comparable to some commercial hardwood species.

1. Introduction

Wood has been used for centuries as a raw material for making tools, furniture, flooring, and construction components, because of its unique properties including high specific strength, porous structure, and aesthetic characteristic. However, facing with the dwelling supply of commercial high-grade wood and stricter environmental legislation, the wood industry has turned to poplar and its hybrids as alternative wood sources due to their fast growth and ease hybridization. Poplar and its hybrids have been widely planted across the world. It is estimated that poplars account for over 50% of all hardwoods and approximately 11% of the entire Canadian timber resource (Avramidis and Mansfield, 2005). It is reported that the production of poplar wood was almost 45% of that of the total hardwood in Quebec province in 2009 (Blaise Parent, 2010). Nevertheless, it has been categorized as a low quality wood with low density, high moisture content, and low strength and decay-resistance properties (Balatinecz et al., 2001; Mátyás and Peszlen, 1997). In current, poplar wood is a primary source for pulp and paper industry and as raw material for engineering wood products such as oriented strand board (OSB), laminated veneer lumber (LVL) and structural composite lumber (Balatinecz et al., 2001).

To generate high values from poplar wood and preserve the wood from the decay, modification of its porous structure is regarded as an effective method. Of the available technologies, wood hardening through chemical impregnation into wood voids and subsequently curing the chemicals in situ has shown great potentials. After wood hardening, not only the strength, but also the density, surface and thermal properties, dimensional stability, and durability of the poplar wood are enhanced (Ding et al., 2013; Ding et al., 2008; Ding et al., 2012; Gao et al., 2009; Gao et al., 2009; Koubaa et al., 2012; Li et al., 2011a; Li et al., 2012a; Li et al., 2012b; Li et al., 2012c; Li et al., 2011b; Yildiz et al., 2005). Different polymeric monomers and resins have been employed, including methyl methacrylate (Ding et al., 2013; Ding et al., 2008; Ding et al., 2012; Koubaa et al., 2012; Li et al., 2011a; Li et al., 2012a; Li et al., 2012b; Li et al., 2012c; Yildiz et al., 2005), styrene (Li et al., 2012a; Li et al., 2012b; Yildiz et al., 2005), polyurethane resin (Gao et al., 2009; Gao et al., 2009), and maleic anhydride (Li et al., 2012c; Li et al., 2011b). Among those chemicals, methyl methacrylate is the most commonly used due to its cheap price, accessibility and low viscosity (Zhang et al., 2006a; Zhang et al., 2006b).

So far, very few studies on physical and mechanical properties of MMA hardened poplar wood have been carried out and the properties were not studied systematically (Li et al., 2011a; Li et al., 2011b; Yildiz et al., 2005). Information on these properties is lacking for not only hardened wood but for wood in general. This property determines the suitability of the wood for various high value applications, such as flooring, furniture table tops, and other uses, where the wood is subject to various environmental conditions, load, and traffic and mechanical friction and abrasion. Thus, the objectives of this study were (1) to understand the interaction between the hybrid poplar wood structure and the MMA monomer, (2) to evaluate the effect of MMA hardening on the density, dimensional stability, surface properties, and mechanical properties of hybrid poplar wood, (3) to study the interclonal variations in the density, dimensional stability, surface properties, and mechanical properties of hardened and nonhardened wood, and (4) to investigate the potential of impregnated hybrid polar wood for high-value products.

2. Methodology

Materials

Twenty-four hybrid poplar trees were chosen randomly from a six-year-old experimental plantation near Montreal, Quebec, Canada (Table 1). From each tree, a log was taken at between 0.5 m and breast height, and samples were extracted to measure the physical and mechanical properties. From each log, four standard specimens were prepared for each investigated property, according to standard test methods, to evaluate wood density, dimensional stability, hardness, abrasion resistance, three-point static bending, and compressive strength (both parallel and perpendicular to grain). The four specimens from each tree for each test were divided into two equally sized groups: a control group and a treated group. The controls were kept in an air-conditioned room at 21°C and 45% relative humidity for 60 days to reach a moisture content of 9% before testing. The treated group was designated for the hardening treatment.

An impregnating solution was formulated from a hydroquinone-inhibited monomer (methyl methacrylate MMA, $H_2C{=}C(CH_3)COOCH_3$), provided by Univar Canada Ltd. (Richmond, British Columbia, Canada), mixed with 0.5 wt% of Vazo 52 (2,2'-azobis-2,4-dimethylvaleronitrile), a low temperature polymerization initiator obtained from DuPont Canada Inc. (Mississauga, Ontario, Canada). The 0.5 wt% of Vazo 52 was based on the weight of the polymeric monomer mixture. The monomer solution was prepared immediately before the impregnation process to prevent self-assembling into polymethyl methacrylate (PMMA) polymer.

Table 1 General information on hybrid poplar clones

Clone	Clone code	Species cross	No. of trees
1	915313	*P.maximowiczii × balsamifera*	4
2	915508	*P.maximowiczii × balsamifera*	4
3	3729	*P.nigra × maximowiczii*	4
4	915303	*P.maximowiczii × balsamifera*	4
5	915311	*P.maximowiczii × balsamifera*	4
6	3531	*P.deltoides × nigra*	4

Hardening Process

Wood specimens of hybrid poplar clones to be treated were conditioned at room temperature (21ºC) and 45% relative humidity (RH) for five weeks to reach an equilibrium moisture content of 9%. After conditioning and before impregnation, specimens were then weighted and placed in an impregnation autoclave, then pressure vacuumed at approximate 10 kPa for 20 minutes. Next, the impregnation solution was introduced into the autoclave to immerse the wood samples. A pressure of 1.38 MPa was applied and maintained at room temperature for 20 minutes to ensure maximum impregnation. After pressure release, the impregnated samples were removed from the autoclave and excess monomer was wiped from the surface. The specimens were weighed and placed in the reactor for polymerization at 690 kPa nitrogen pressure and cured for 4 hours at 70°C. After curing, the reactor was depressurized and samples were removed and placed in a ventilated area to evaporate the non-polymerized monomer. Excess polymer was removed from the surface of some samples. Composite weights were measured again to the nearest 0.01 g.

Characterization

Polymer retention (*PR*) in the composites was calculated according to equation 1:

$$PR\ (\%) = (w_{hw}\text{-}w_s)/w_s \times 100 \qquad (1)$$

Where w_{hw} is the weight of the hardened wood sample and w_s is the initial weight of the corresponding untreated sample.

Samples with nominal dimensions 100×20×20 mm^3 (longitudinal × radial × tangential, L×R×T) were used to determine oven-dried density (ρ_o). The samples were oven-dried for more than 24 hours at 103 ± 2°C to achieve a constant weight. The dimensions of the samples were then determined in the three principal directions to the nearest 0.01 mm and the weights were recorded to the nearest 0.01 g. ρ_o was calculated according to equation 2:

$$\rho_o = M_o/V_o \qquad (2)$$

where M_o and V_o are the mass and volume of the oven-dried sample, respectively.

Density profiles of the hardened and nonhardened wood samples were measured with an X-ray densitometer on samples 2.5 cm in width. In order to observe the microstructure, the samples were fractured in a brittle manner after immersing them into liquid nitrogen. The fractured surface was coated with a thin layer of platinum using a sputter coater (SC7620, Quorum Technologies, West Sussex, UK), and the microstructure was examined using a scanning electron microscope (SEM) (JSM-6060, JEOL, Tokyo, Japan).

The infrared spectra of the untreated hybrid poplar wood, MMA-hardened poplar wood, and PMMA samples were recorded on a Tensor 27 Fourier transform infrared (FTIR) system (Bruker Optics, Ettlingen, Germany) equipped with a deuterated triglycine sulfate detector. For each sample, spectra were recorded by the collection of 164 scans in the range 4000–400 cm^{-1} at 4-cm^{-1} resolution. Pure powdered potassium bromide (KBr) was used as a reference substance. Samples for FTIR were carefully prepared in microcups as follows: 1 mg of each wood flour (100 mesh) or PMMA was mixed with KBr in the proportion of 1/100 wt% in an agate mortar and then transferred to a cup 4 mm in diameter, where it was lightly compressed and leveled with a spatula. Tilted baselines of the original spectra were not altered.

All samples were kept in an air-conditioned room at 21°C and 45% relative humidity for at least 4 weeks before the volumetric swelling, hardness, abrasion resistance, and mechanical properties tests.

Samples with dimensions 100×20×20 mm^3 (L×R×T) were used to determine the volumetric swelling properties according to ASTM D 1037-99. Swelling after submersion in water for periods of 2, 24, 48, 168, 336, and 720 hours were measured. After each saturation period, dimensions were determined to the nearest 0.01 mm in the three principal directions. Samples were then oven-dried for more than 24 hours at 103 ± 2°C until constant weight was reached. The same measurements were then repeated on the oven-dried samples. Volumetric swelling coefficient (S) was calculated according to the equation 3:

$$S\ (\%) = (V_w - V_o)/V_o \times 100 \qquad (3)$$

where V_o is the volume of the oven-dried sample, and V_w is the volume after water submersion.

Hardness tests were performed on a wide surface (tangential surface) measuring 75×150 mm^2 (T×L) according to ASTM D 143–94 and with a Zwick/Roell Z020 universal testing machine

(Ulm, Germany). Five penetrations were made into each specimen, with penetration points set 30 mm apart to prevent interference between the penetrations points. The specimen hardness was recorded as the average of the five hardness values measured.

The abrasion resistance was determined with a CS-17 Taber Abrader (North Tonawanda, New York, USA) according to ASTM D 4060 and was expressed as wear index, which is the weight loss in milligrams per specified number of cycles under a specified load (1000 g). The sample dimensions were 100×100×10 mm^3 (L×R×T), and the weight losses after 500, 1000, 1500, 2000, and 2500 cycles were recorded. The weight was measured with a digital scale to 0.0001 g of precision. Both the control and MMA-treated composites were tested without further finishing processes.

Three-point static bending tests were carried out using a universal testing machine (Zwick/Roell Z020) with a maximum load of 20 kN. The nominal poplar wood sample size for the test is 410×20×20 mm^3 (L×R×T), with actual height and width at the center measured before the test. Span length was 300 mm. The remaining procedures were conducted according to ASTM D 143-94. Modulus of elasticity (MOE, MPa), modulus of rupture (MOR, MPa), proportional limit (PL, MPa), and strain at MOR (S, %) were recorded for both untreated and hardened samples.

Compression tests, parallel and perpendicular, were performed on an MTS machine with a maximum load of 50 kN. Specimens were machined to 100×20×20 mm^3 (L×R×T) and 50×20×50 mm^3 (L×R×T) for parallel and perpendicular to grain tests, respectively. Actual cross-section area was measured before testing. Both operations were conducted in accordance with ASTM D 143-99. MOE (MPa), maximum crushing strength (MCS, MPa), and proportional limit (PL, MPa) were recorded by a computer linked to the machine for the parallel and perpendicular tests, respectively, for untreated and hardened samples.

Statistical analyses of the data were performed using Statistical Analysis System (SAS) software package (SAS Institute Inc., 2004). Analysis of variance (ANOVA) was performed using the Proc Mixed model and Least Squares Means (LSMEANS)/*p*-values for differences (PDIFF) option on the combined data (control and treated) to determine differences between mean values of control and treated samples in hybrid crosses. The residual normal distribution for each trait was verified by both the Shapiro–Wilk's W test and a normal probability plot using SAS Plot and univariate procedures. The homogeneity of variance for each trait was verified graphically by scatterplots of studentized residuals versus predicted values.

3. Results and Discussion

Density

The hardening treatment increased the density of hybrid poplar wood by 2.2−2.6 times, to 687−805 kg/m^3, depending on the clone (Table 2). The highest value was observed for clone 3531 and the lowest for clone 915303. The density of hardened wood was similar to or higher than that of many commercial hardwood species, e.g. silver maple (667 kg/m^3), red oak (665 kg/m^3), and white ash (719 kg/m^3). Fig. 1 illustrates an example of the density profile of a hybrid poplar sample before and after hardening. This profile shows that the wood sample was impregnated through its thickness. The density of the hardened sample was much higher than that of the nonhardened wood sample. The final density of the treated wood varied with polymer retention (PR), which varied among clones. PR decreased with increasing initial wood density in the hybrid poplar clones (Fig. 2). PR variation was attributed to the individual porosity of each wood (Ding et al., 2008).

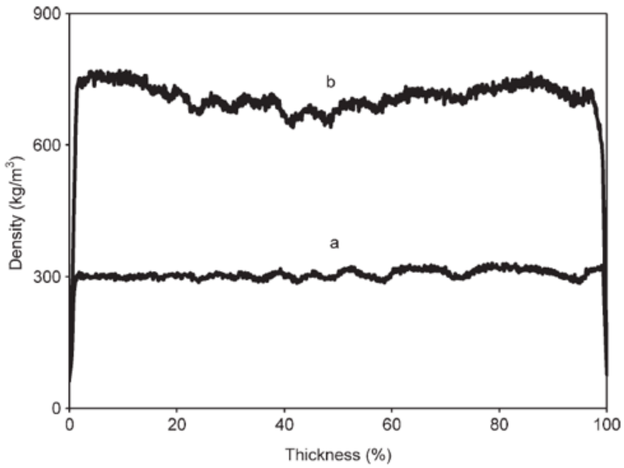

Figure 1. Density profile of hybrid poplar wood (a) and hardened hybrid poplar wood (b).

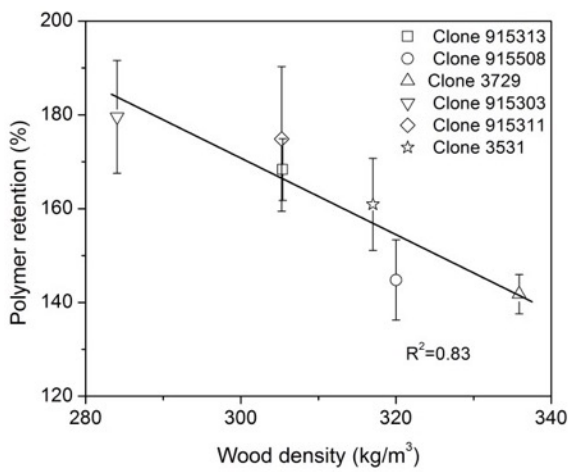

Figure 2. Relationship between the polymer retention and density for hybrid poplar clones.

Microstructure and FTIR analysis

SEM micrographs of the treated hybrid poplar wood (Fig. 3) clearly show that PMMA polymer filled most of the vessels, lumen, and other void spaces in the wood structure. Interaction between wood and MMA was confirmed by FTIR spectrum analysis of the untreated hybrid poplar wood, hardened wood, and PMMA, as shown in Fig. 4. The FTIR spectra for untreated samples show intensity bands in the regions 3400 cm^{-1}, 1735 cm^{-1}, 2905 cm^{-1}, 1510 and 1605 cm^{-1}, and 1158 cm^{-1} due to O–H stretching vibration, C═O stretching vibration, C–H stretching vibration, C═C stretching vibration, and C–O–C stretching vibration, respectively (Li et al., 2011b). These absorbance bands are due to hydroxyl groups in the cellulose, a carbonyl group of acetyl ester in the hemicellulose, and carbonyl aldehyde and aromatic compounds in the lignin. The absorbance bands of PMMA at 3440 cm^{-1}, 2978 and 2878 cm^{-1}, 1731 cm^{-1}, and 1000–1260 cm^{-1} can be associated with –OH stretching of the lattice water, asymmetrical and symmetrical C–H stretching of CH_3, C=O stretching, and C–O stretching, respectively (Yang and Dan, 2003). The FTIR spectra of treated hybrid poplar show almost the same functional peaks as the untreated wood, but with much lower absorbance. This is probably attributable to the lower concentration of wood fibers in the reference matrix (KBr). However, the presence of an absorbance peak at around 1730 cm^{-1} may result from the formation of C=O bonds between the wood fibers and the MMA monomer (Hu et al., 2007; Xu et al., 2010). However, wood lignin also contains C=O bonds. The shift of the –OH peak from 3425 cm^{-1} in solid wood to 3445 cm^{-1} in hardened wood was possibly due to the reaction between the –OH of the fiber cell wall and MMA (Hu et al., 2007; Li et al., 2011). Change in intensity of the C–H stretching of CH_3 was also reported due to the reaction between the –OH of the wood fiber at the surface and MMA (Hu et al., 2007).

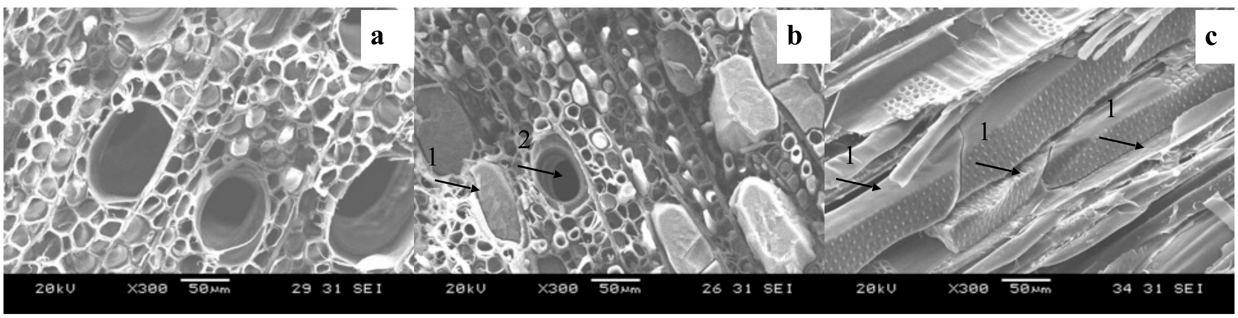

Figure 3. SEM micrographs of a) Untreated and b) cross section & c) tangential section of PMMA hardened hybrid poplar wood. Arrows indicate 1) absence of attachment of PMMA to wood tissue, and 2) unfilled cells.

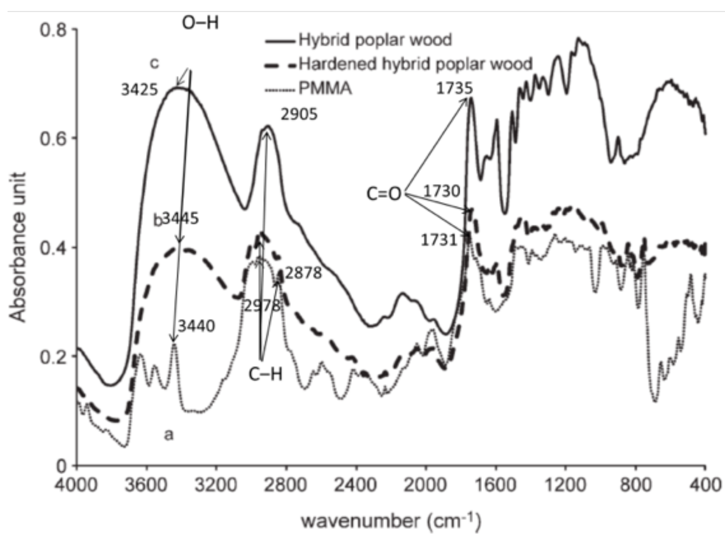

Figure 4. FTIR spectra of a) PMMA; b) treated hybrid poplar wood; and c) untreated hybrid poplar wood.

Dimensional stability

The volumetric swelling coefficient varied among clones for both control and treated wood, depending on soaking time (Table 2 & Fig. 5). Wood hardening treatment significantly improved the dimensional stability of hybrid poplar wood, especially at the start of soaking. The average volumetric swelling coefficient of the controls increased dramatically in the first 48 hours, with the coefficient remaining nearly constant thereafter. In contrast, the treated samples took much longer (more than 1 week) to reach a relatively steady swelling coefficient, at around 6.8%, nearly 60% that of the controls. The average coefficient (11.8% after 720 hours) obtained for untreated wood was slightly lower than the average volumetric shrinkage of 12.8% in ten *P. × euramerricana* clones reported by Koubaa et al. (Koubaa et al., 1998). The swelling coefficients of the hardened hybrid poplar samples were comparable to or lower than those of silver maple, red oak, and white ash, for which volumetric shrinkage was around 12.0%, 16.1%, and 13.3% (green to oven-dried), respectively (Alden, 1995). Control Clone 915303 showed the lowest coefficient after 720 hours at around 10.8%, more than twice that of treated Clone 915311. Cross-section SEM images of the treated hybrid poplar wood (Fig. 3) clearly show microcracks between the wood cell walls and PMMA. Our previous studies verified that the volume of voids in hybrid poplar wood with diameter ≤ 0.1 μm was increased by over 10 times after MMA hardening treatment although the overall void fraction was reduced by 71% (Ding et al., 2008). Water that passes through these microcracks into the wood cell therefore caused swelling. Thus, impregnation with MMA does not significantly change the hygroscopic properties of wood as previously reported (Zhang et al., 2006b; Ellis, 1994).

Another explanation is that water may pass through and fill small pores that the MMA monomer cannot enter. The volume changes during the soaking period were likely due to the absorbed bound water, which contribute to wood swelling. From the combined results of the SEM micrographs, the FTIR spectra, and the dimensional stability analysis, it can be concluded that there should be little or no interaction between the MMA monomer and the hydroxyl groups of the cellulose fibers.

Table 2 Density (kg/m^3) and volume swelling coefficient (%) for hybrid poplar clones

Clone	Density (kg/m^3)	Volume swelling coefficient (%)	
		After 24 hours	After 720 hours
		Control	
1	305 (5.8)	9.16 (4.3)	11.51 (8.9)
2	320 (5.5)	9.42 (2.8)	12.03 (6.3)
3	336 (3.4)	10.52 (4.6)	13.17 (5.0)
4	284 (5.4)	8.36 (3.3)	10.81 (4.9)
5	305 (4.3)	8.94 (6.3)	12.23 (7.9)

6	317 (6.2)	8.74 (2.3)	11.43 (2.6)
	Treated		
1	735 (3.1)	3.02 (9.3)	7.20 (13.1)
2	743 (1.6)	3.90 (15.7)	8.41 (16.9)
3	749 (1.6)	4.35 (9.0)	9.04 (8.7)
4	687 (2.0)	3.54 (15.2)	7.34 (9.0)
5	798 (4.7)	1.42 (14.3)	4.98 (7.1)
6	805 (3.6)	3.15 (4.2)	7.50 (13.7)

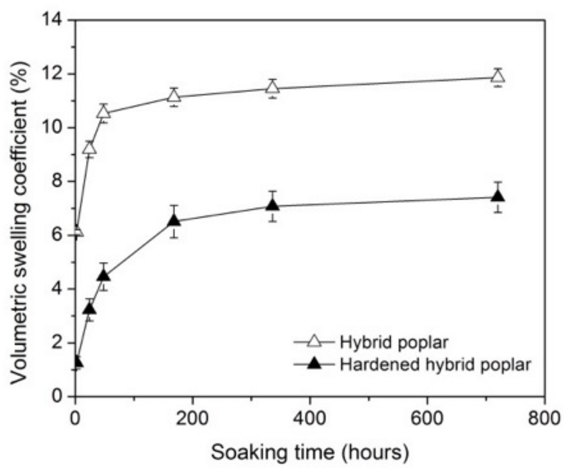

Figure 5. Average volumetric swelling coefficient (%) for control and treated hybrid poplar clones.

Surface properties

Janka Hardness

PMMA wood impregnation resulted in substantial increases in Janka hardness for all tested samples. Hardening increased the hardness of virgin wood by 1.5 to 2.9 times (Table 3). Two of the investigated clones fell into the range of 6.0–6.4 kN, which is comparable to or even better than that of many commercial species used for flooring, such as silver maple and red oak, and even their oil-finished wood (Koubaa et al., 2012; Koubaa, 2007). The Janka hardness test is most commonly used to determine whether a species is suitable for applications such as flooring, and it is the industry standard for determining the ability to tolerate denting. Therefore, MMA hardened poplar wood could potentially be used in the wood flooring industry, which would substantially increase the commercial potential of hybrid poplar.

Hardness varied among the studied clones. The highest value was observed for clone 915311. Clone 3531 was in second place. Treatment, clone and their interaction significantly affected the hardness of the studied clones. Relationships between density and hardness were also investigated for several species: northern white cedar, aspen, red oak, white ash, silver maple (Fig. 6). Average hardness showed close relationship with density for the investigated species (R^2 = 0.89). The variation in hardness among species could therefore be explained by variations in wood density.

Moreover, high impregnation rate increases not only the sample density but also the risk of brittle failure and a decrease in the hardness value. Indeed, the hardening process increased the risks of splitting the sample during the hardness test, although no splits were observed in the control group. The splitting is expected in hardened samples because PMMA hardening renders the samples more brittle (Schaudy and Proksch, 1982).

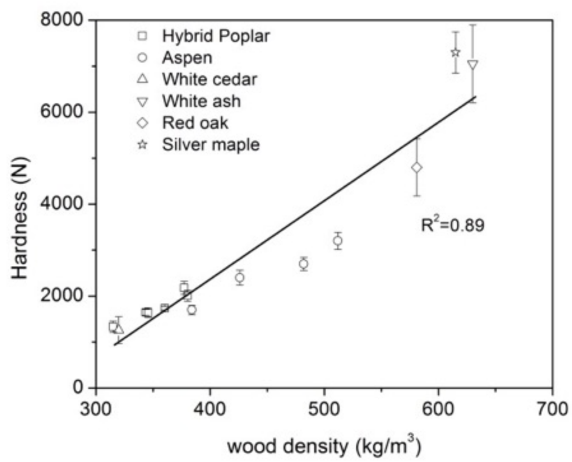

Figure 6. Relationship between wood density and hardness for different wood species.

Abrasion resistance

Abrasion resistance is the ability of a material to maintain its surface appearance and structure when subjected to a mechanical action such as rubbing or scratching. Lower wear index values are associated to the better the abrasive resistance. Wear index increased with abrasion cycles, and hardening had a positive effect on wear index (Table 3 & Fig. 7). Wood hardening substantially reduced the wear index of the samples by nearly 50 % after 500 cycles. However, the effect became slightly weaker with increasing abrasion cycles. At 2500 cycles, the effect nearly decreased. This result could be explained by the higher impregnation rate at the wood surface. Moving toward the core, the impregnation rate slightly decreased (Fig. 1), explaining the decrease in abrasion resistance with increasing abrasion cycles.

Table 3 Janka hardness (N) and wear index (%) for hybrid poplar clones

Clone	Hardness (N)	Wear index (%)	
		After 500 cycles	After 2000 cycles
Control			
1	1647 (8.2)	0.279 (13.9)	0.719 (12.1)

2	1738 (4.8)	0.242 (23.3)	0.617 (16.7)
3	2007 (12.0)	0.243 (27.6)	0.609 (12.2)
4	1334 (18.1)	0.301 (9.0)	0.661 (10.1)
5	1637 (12.6)	0.318 (11.5)	0.696 (11.2)
6	2178 (13.0)	0.187 (39.4)	0.468 (31.8)
		Treated	
1	5118 (10.9)	0.143 (14.1)	0.571 (7.2)
2	5290 (9.6)	0.136 (9.6)	0.558 (4.1)
3	5072 (16.1)	0.162 (14.2)	0.576 (3.2)
4	3776 (10.3)	0.223 (−)	0.746 (−)
5	6400 (14.8)	0.124 (−)	0.496 (−)
6	6033 (12.1)	0.103 (−)	0.406 (−)

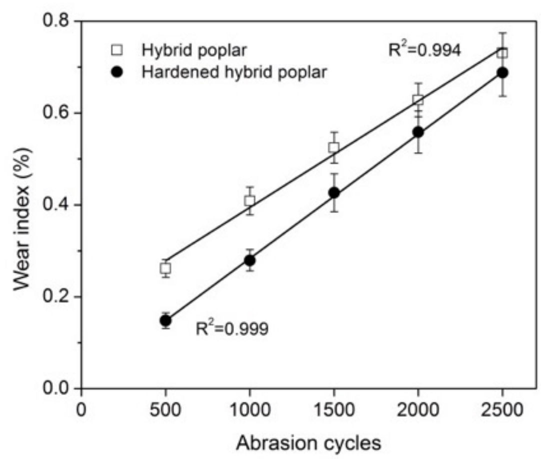

Figure 7. Variation in abrasion wear index for hardened unhardened wood of hybrid poplar.

Wear index varied among clones after 2000 cycles. This implies that hybrid poplars should be appropriately selected for desired surface properties. The hardened wood produced from clones 915311 and 3531 showed the lowest wear indexes at 0.50 and 0.41 after 2000 cycles, respectively. These wear indexed are nonetheless high compared to some commercial flooring species, such as silver maple (0.35) and red oak (0.16) (Koubaa, 2007), despite the high densities of the above two poplar composites. These relatively high wear indexes may result from surface morphology and roughness, which did not change significantly after MMA treatment. The density of control samples and the hardness of treated wood have played important roles in wear index determination. Koubaa (Koubaa, 2007) also reported that abrasion resistance was correlated to both surface hardness and material density. Rodriguez et al. (Rodriguez et al., 2006) found that surface property was related to not only polymer type, but also the additives that chemically bond to the wood substrate. Thus, crosslinking surface structure is liable to improve abrasive resistance, for example, by adding silica nanoparticles. Furthermore, surface coating, which is usually applied over the material, offers an alternative method to reduce friction and obtain better surface properties, allowing more high-value applications.

Mechanical properties

Static bending strength

Modulus of elasticity (MOE), proportional limit (PL) and modulus of rupture (MOR) were the most consistently improved properties after hardening treatment (Table 4). This is attributed to the voids in the wood filled by PMMA polymer, which acts as a bridge effectively transferring the stress from one end of wood cell to the other end. The analysis of variance showed that clone, treatment and their interaction had significant effects on MOE, PL and MOR, except for the interaction on MOE. Treatment significantly and negatively affected strain at MOR for poplar wood. Strains at proportional limit were observed to be increased for the 6 clones, which also indicate good interaction between the PMMA and wood, resulting in improved material elasticity. However, decreases in strain at MOR (S) were found for all studied clones (Table 4). Therefore, wood hardening with MMA weakened the plastic properties of wood and increased the brittleness of the composites. After treatment, clones 3729 showed the best performance in the bending test, followed by clone 915508. Coincidentally, these two clones showed the best properties for corresponding control samples. In contrast, clone 915303 was the worst for both control and treated wood.

Table 4 Comparison on static bending tests for hybrid poplar clones

Clone	MOE (GPa)	MOR (MPa)	S (%)
		Control	
1	4.36 (16)[a]	41.2 (12)	1.86 (18)
2	4.98 (11)	43.6 (8.3)	1.58 (36)
3	4.96 (13)	46.5 (8.2)	1.88 (22)
4	3.77 (8.8)	36.5 (7.4)	1.80 (13)
5	3.97 (8.2)	34.9 (7.8)	1.71 (33)
6	3.73 (17)	47.6 (11)	2.47 (16)
		Treated	
1	4.59 (6.5)	44.7 (3.3)	1.56 (20)
2	5.37 (11)	52.1 (6.8)	1.58 (33)
3	5.25 (11)	55.2 (2.4)	1.75 (22)

4	4.28 (9.1)	42.5 (10)	1.42 (19)
5	4.68 (3.4)	48.4 (9.9)	1.60 (20)
6	4.06 (16)	49.6 (5.9)	2.00 (22)

Note: MOE = Modulus of elasticity, MOR = Modulus of Rupture, S = Strain at MOR; [a]Coefficient of variation (%).

Compression strength

After wood hardening with MMA, all properties investigated improved to varying degrees (Table 5). MOE for C∥ was one of the least enhanced properties, with increases ranging from 2% to 27%. The highest increasing rate was observed in clone 915311 at 27%, followed by clone 915303 at 20%. On the other hand, the highest MOE values in the composites were found for two clones, 915508 and 3729. In contrast, 915508 and 3729 had the highest MOE values of the solid woods. High MOE increasing rates are not consistent with high MOE values after treatment. Highest maximum crushing strength (MCS) parallel to the grain was 42.4 MPa for clone 915508, an increase of 50% over control, followed by clones 3531 and 3729. These three clones also showed the best performance in the control group. The proportional limit showed a similar trend to ultimate compressive strength. Overall, as for compression parallel to grain, clones 915508, 3531 and 3729 showed the best properties for both control and hardened wood. Most of the gross wood samples for the compression parallel to grain test failed due to collapse caused by the bucking of the relatively thin wood cell walls because of instability of long-column type wood samples. The addition of polymer places a coating on the cell walls, which thickens them and greatly increases their lateral stability.

A wide range of improvements were also observed (10–56% for MOE and 166–290% for proportional limit) in compression perpendicular to grain for all studied clones after treatment. These especially high increasing rates are attributable to the polymer filling the wood. Composites from clones 3531, 915303, 915508 and 3729 showed similar properties, with no significant differences among them. For untreated wood, clones 3729 and 3531 showed the best performance of the 6 clones. In sum, clones 915508 and 3531 obtained the best properties for hardened wood in compression, both parallel and perpendicular to grain. In the solid wood samples, clone 3729 exhibited the best performance.

Table 5 Comparison on compression tests for hybrid poplar clones

Clone	MOE (GPa)*	MCS (MPa)*	MOE (GPa)‡
		Control	
1	2.91 (2.9)[a]	24.1 (8.8)	1.30 (9)
2	3.57 (16)	28.0 (12)	1.42 (23)
3	3.66 (12)	28.1 (8.5)	1.79 (18)
4	2.80 (21)	23.0 (11)	1.36(26)

5	2.71 (11)	25.1 (3.4)	1.39 (32)
6	3.22 (15)	26.9 (1.8)	1.78 (16)
		Treated	
1	3.26 (22)	30.1 (9.2)	1.78 (23)
2	4.05 (17)	42.4 (8.2)	2.15 (32)
3	3.72 (11)	32.2 (6.9)	1.96 (15)
4	3.35 (9.1)	32.6 (7.8)	2.07 (23)
5	3.43 (14)	34.6 (9.3)	1.93 (32)
6	3.27 (3.8)	35.0 (10)	2.13 (11)

Note: MOE = Modulus of elasticity, MCS = Maximum crushing strength, *Compression parallel to grain; ‡Compression perpendicular to grain; [a]Coefficient of variation (%).

Practical implications

Hybrid poplar wood through MMA hardening treatment greatly improved its density, dimensional stability, surface properties and mechanical properties. These improvements indicate the suitability of hardened poplar wood for end-uses where the untreated counterparts are not suitable. The potential applications range from interior to exterior uses such as kitchen and bathroom floorings and cabinets, deck flooring, etc. It was reported from a fungal decay resistance test that the mass loss of MMA-hardened poplar wood was decreased by 2.9 times (20.1% vs. 79.3 wt%) compared to the untreated wood (Li et al., 2010). Similar results were reported in a few other studies (Yildiz et al., 2005; He et al., 2011). Although the biodegradation resistance was enhanced, hardened hybrid poplar wood is still biodegradable in the compost environment since microorganisms can consume the natural cellulose component (Bhat and Kumar, 2006; Thakore et al., 2001) and the newly generated chemicals from hydrolysis and microbial attack will contribute to the scission of polymer chain into low-molecular-weight chains (Bhat and Kumar, 2006; Seidenstücker and Fritz, 1998).

So far, there has been little published information on recycling and environmental impacts of hardened wood. Future research should address these issues to document any hazard or risk for humans and for the environment. However, it is believed that the polymerized methyl methacrylate (PMMA) is a safe product and its use in wood composites should not present any risk. It has been used in several other applications including dentistry (Frazer et al., 2005; Guedes et al., 2006) and Orthopaedics (Jaeblon, 2010; McCaskie et al., 1998).

4. Conclusions

1) Hardening of hybrid poplar wood through MMA impregnation greatly improved its density, dimensional stability, surface properties and mechanical properties.
2) The improvements were clone-dependent in both untreated wood and MMA-hardened wood.
3) The hardening treatment had a negative effect on the wood plastic properties.
4) The hardening mechanism is due to PMMA filling of void spaces in wood structure as demonstrated from SEM images and FTIR analysis.
5) Improved dimensional stability, surface properties, and mechanical properties, make hardened hybrid poplar wood a good alternative to other commercial high-grade species, especially in flooring applications.

Acknowledgements

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MICRONIZED PIGMENT TECHNOLOGY FOR PRESSURE TREATMENT

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Untreated wood, when exposed in an outdoor environment, is subject to bio-deterioration due to the attack from decay fungi and insects. As a result, wood products for outdoor use are generally pressure treated with wood preservatives. One of the main components in wood, lignin, is rich in carbonyl double bonds, phenolic and biphenyl bonds, which readily absorb UV light and produce free radicals. These free radicals start to photodegrade wood. As a result, pressure treated wood is also subject to photo-degradation which will cause yellowing, fading and eventual graying of the surface of the wood. Pressure treated wood for residential use is often treated with a copper based preservative, such as alkaline copper quaternary ammonium compounds (ACQ), soluble copper azole (CA) or micronized copper azole or quat (MCA or MCQ). The copper-based preservative treatment can provide wood with long-term durability from decay and termite resistance. In addition, wood treated with a copper based preservative has an intrinsic green/blue colour, which, when exposed to sunlight, will change from green/blue, to suntan and finally a dark-gray colour (Figure 1). Often time, this initial green/blue colour or the colour change under sunlight is undesirable from the standpoint of consumers or homeowners. Homeowners would prefer to have colour choices other than green/blue, and have rather many colours with enhanced durability so that the pressure treated wood will demonstrate minimal colour change under UV weathering. As a result, there is a need for adding colour to pressure treated wood to enrich the surface appearance and enhance the UV weathering durability.

Wood preservation industry is also interested in non-traditional preservative systems, such as non-metal containing preservatives. Non-metal containing preservatives generally have very poor weathering under sunlight, and the wood will quickly change to a dark gray colour similar to the untreated wood. Again, a colourant additive for the metal-free preservative system is needed to enhance the resistance to UV photo-degradation and improve the weathering properties.

A commonly used conventional process for colouring and staining pressure treated wood is to apply an oil or water based pigment coatings on the surface of the wood. Depending on the type of preservative used, some of the coatings will not adhere to the wood, resulting in blistering or flaking in a short period of time. In addition, the surface application process provides only a surface colouration which will scratch or wear away and require additional treatment or servicing for exposure to long term weathering.

In order to maintain wood with a consistent colour with minimal colour change during weathering and yet preserve wood against deterioration, a colourant system is required to be added to the preservative system. In view of the many shortcomings applicable to the current methods of colouring and preserving wood, it is desirable to have a colouring and preserving system that provides aesthetic appearance, long-term weathering performance, and bio-efficacy. It is also desirable to have a process which is not only capable of colouring wood and preserving the wood by a single operation, but also results in the penetration of the colour into the wood to provide for long term application and stability.

Water soluble organic dyes were used in the past as in-solution colour additives for CCA or ACQ. The dye colourant generally penetrates well into wood along with the preservative components. However, the drawback for the dyes is that they generally fade fast under sunlight exposure. In recent years, a new micronized pigment technology was developed. The micronized pigment system is primarily based on using iron oxide pigment dispersion as colourants. The iron oxide pigment dispersions are present in various colour shades, so the variety of different colours can be achieved through mixing and colour matching. Through proper formulation technology, the micronized iron oxide based pigment dispersions are compatible with different preservative systems, such as amine soluble copper azoles (CA-C), micronized copper azole (MCA), or copper-free preservative systems (Figure 2-5). In comparison to organic dyes, iron oxide colourants have greater lightfastness and also function as a UV blocker. In addition, micronized iron oxide pigments can be mixed into the preservative treating solution as single step treatment or be used alone as a second step treatment. Micronized pigments are also compatible with other additives, such as water repellent and mold inhibitors. Many different colour shades, such as, light brown, dark brown, red brown, cedar tone, nature brown, earth tone, etc., can be achieved through the formulation technology. Micronized pigment plus preservative treated wood can be found in a variety applications, such as decking, fencing, siding, cladding, landscaping, agricultural fencing, etc (Figure 6).

Figure 1. The appearance of pressure treated wood after weathering in Griffin, GA for 2 years

Figure 2. Wood Treated with micronized pigments plus MCA

Figure 3. Wood treated with micronized pigments plus MCA

Figure 4. Hem fir treated with micronized pigments plus CA-C

Figure 5. Southern yellow pine treated with micronized pigments plus a non-metallic preservative

Figure 6. Different applications of micronized pigment/preservative treated wood

DURABLE WOOD IN DISASTER RELIEF HOUSING

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Summary

Humanity is being continuously shattered by disaster of all sorts. Earthquakes, hurricanes, tornadoes, flooding etc. represent typical natural expressions of force in our planet that lead to destruction and loss of homes. In addition, wars and famines produce displaced communities and lead to homelessness.

Canada as a developed and industrialised country is often called to support humanitarian efforts by providing food, medicine, logical support and housing. Typical help is provided through monetary support to a large group of organisations across the world. Canada also has significant industrial capacity that can be utilized to provide more than just monetary solutions when such tragedies arrive. For example, shelters for different situations can be developed and manufactured in Canada and then transported to zones in distress.

Important issues to be considered when it comes to Disaster Relief Housing/Shelters include good design and appropriate treatment options based on the climate and insect hazards prevailing in affected regions.

1. Introduction

Over the last four decades global population has increased almost linearly passing from 4 billion in the 1970's to over than 6 billion between 2000 and 2009. The number of disaster-affected people around the globe has also followed the same trend, reaching more than 2 billion over the last decade (2000-2009) (Figure 1). The main causes affecting those people are either the result of natural disasters (earthquake, flooding, tornados, etc.) or human activities (wars, conflicts, famine, etc.).

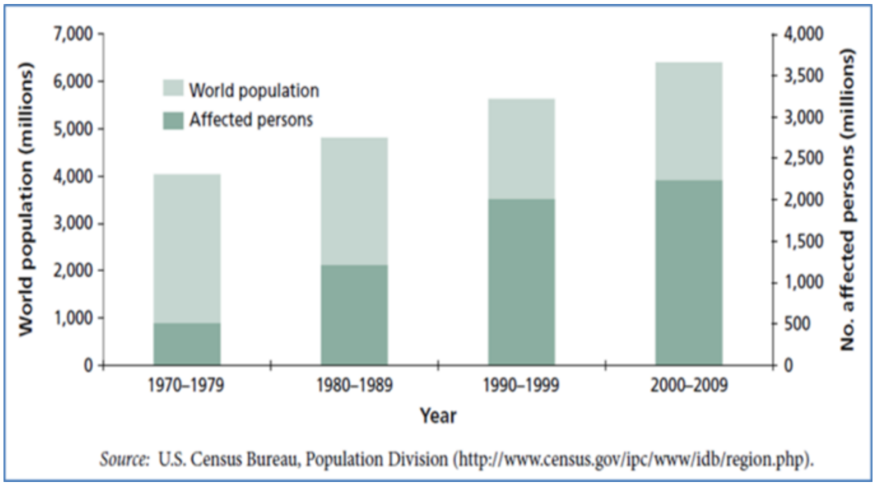


Figure 1 World population vs number of affected people

The proportion of people affected varies depending on the disaster type amplitude and frequencies. The population growth in some high-risk zones amplifies the exposure to hazards.

Unfortunately, the world's poorer nations are disproportionately affected and are the most vulnerable and marginalised people. Such vulnerability depends of course on several factors that influence the amount of damage and the loss of human life. Among these factors it is possible to find exposure, socio-economic instability and lack of resilience (IDEA, 2005). Resilience in this context is related to what is already in place to face a crisis (e.g. resources and adaptive capacities).

Help and reconstruction are required whenever a disaster occurs and should be a straightforward process due to the emerging needs of persons affected. The reconstruction process is divided into two sub-systems including organizational matters that are looking at financing sources, management and implementation and technical issues that include security, personal safety and protection from climate. Personal safety and protection from climate are among the most important things to implement after a disaster.

Depending on the scale and type of disaster, different types of disaster relief housing can be used as shelter. Emergency shelters, such as tents, can be easily built and be used for short period of time (1 - few days). They usually come without any features. At the next level, temporary shelters are designed to last for longer period of time (sometimes few weeks) and usually include food, water and medical supplies.

Figure 2 Temporary shelters around the world

Temporary shelters can provide a sense of dignity for people who are in need but because of their more robust conception tend to become permanent which is far from being their initial vocation. Actually, those types of shelters are not suited to be used as permanent housing. The third level would be disaster-relief housing which is designed to last 5 to 10 years and may, with further modification or addition become permanent housing.

2. Disaster Relief Housing and Durability Issues

NGO's (Non-governmental organization) have access to a limited budget and they usually want to build as many shelters as possible so they tend to go cheap on design and material which is not a good thing when considering durability issues. Furthermore, construction quality can be difficult to control and occupier improvements may also increase moisture and termite problems. We can think about use of untreated wood, addition of concrete embeds wood or even addition of materials containing insects. Depending on region and climate, issues can be different considering the fact that warm temperature favour termites while cold climate can have condensation problems due to bad envelope design.

During the conception phase, decay and termite hazard should be understood well enough to protect shelters from premature degradation. The use of the Scheffer Index (Scheffer 1971) value can be reasonably useful to indicate the potential for wood to decay above ground in a given climate. The Scheffer index is actually derived from equation using rainfall and temperature data as shown in equation 1.

[1]

Where T is the mean monthly temperature in Celcius, D is the mean number of days in the month with 0.25 mm or more precipitation and Σ is the sum (from December to January) for the year of the products for each month. In terms of termite hazard, Japan, USA and Europe have well defined termite zones. China has recently defined theirs (Ma *et al.* 2011).

There are three (3) main divisions in termite hazard zones; Division 1 - no termites (note that wood boring beetles may be a problem), Division 2 - *Reticulitermes* and other termite species but no *Coptotermes* and finally Division 3 - where *Coptotermes* species are present (drywood termites are also likely).

Many regions don't have well defined termite zones which necessitates the support of expert advice in the conception phase. The Caribbean and Indonesia are examples of areas that have recently suffered major natural disasters and also have significant termite hazards.

The 4Ds concept of moisture management developed for platform frame construction (Morris and Hazleden, 1999) can also be applied to disaster relief housing. The 4Ds are defined as follow;

Deflection – keeping water away from potential entry points.
Drainage – providing means of removing water that does enter.
Drying – allowing any remaining moisture to be removed by ventilation or diffusion.
Durability – providing materials with appropriate resistance to decay or termites.

Moisture management should also prevent water vapour from moving outward in temperate climates and inward in tropical climates. The use of a vapour/air barrier located on the correct side of the assembly (based on climate) will prevent water vapour from condensing at critical locations. Some design solutions could use pitched roofs with overhangs on all sides of housing, minimization of penetrations (roof and slab), minimization of rainfall traps, and minimization of wood-soil contact (even if treated, this can attract termites). To prevent wicking of water and to facilitate inspection for termites, support posts should be supported on concrete. If the design purpose is to reduce flood damage, improve ventilation and again facilitate inspection and termite control, raised floor is a good choice. The overall design should be congruent with local custom.

3. Integrated Termites Management

Integrated Pest Management (IPM) is a concept developed in agriculture that has been transferred to termite control. However, it is defined in different ways by different parties (Su and Sheffrahn 1998). In some cases it has been taken to mean simply reduction in use of pesticide, but in the strict sense it must comprise a combination of complementary tactics (Morris 2000). The approach presented in this paper is intended to show how wood preservation fits into IPM. Termite management control can be done through different lines of defense called the 6Ss.

Suppression – Reduce termite colonies in the area;
Site management – Remove termite food and potential habitation in soil;
Soil barrier – Chemical or physical barrier to termites;

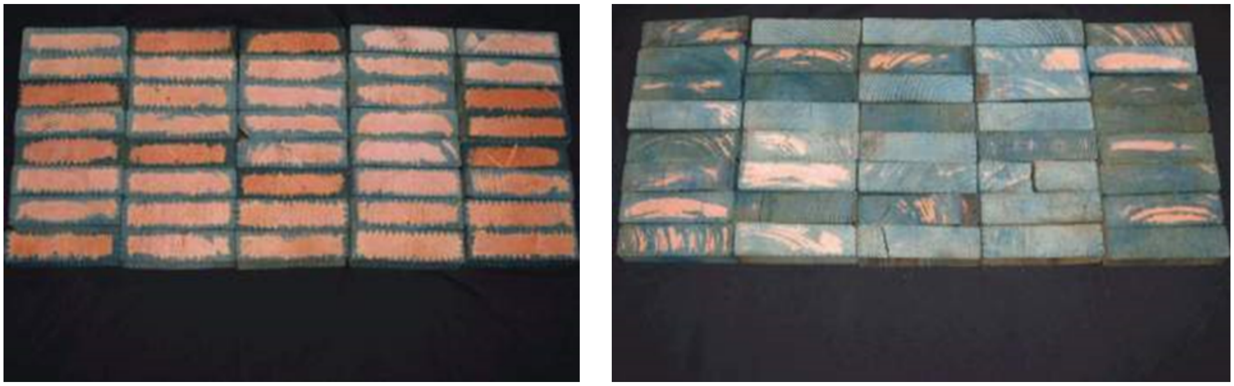
Slab/foundation – Detailing to minimize cracks, exposed slab edge for protection;
Structural durability – Treated wood (or steel);
Surveillance – Monitoring for termite activity which should lead to remedial treatment and fixing problems in the other 6 Ss that allowed termites in.

Unfortunately, when it comes to disaster relief housing, pest management control is sometimes more difficult to accomplish. Site management is feasible, slab/foundation detailing and structural durability can both be provided through a good design but suppression, soil barrier and surveillance can be expensive and impossible to integrate. But even with those lines of defense in place, tree dwelling termites, drywood termites and, if there is a water leak in the building, Formosan termites can all fly directly into the building and start colonies. Consequently, soil barriers and slab/foundation detailing are not enough which means that good structural durability is required which implies preservative treatment for wood. In Canada, most of our species are not resistant to termites with the exceptions of western red-cedar (non-preferred but still gets eaten), eastern white-cedar (non-preferred but still gets eaten), and yellow cedar which is the most termite resistant. For other species, preservative treatment is the only option. Thermal modification is not effective against termites (Shi *et al.* 2007).

When it comes to preservative treatment options, one must consider regulations from the exporting and/or importing countries, potential for human contact, building design, wood species and local decay and termite hazards. Most countries do not have robust standards of their own, and instead tend to follow European or American (AWPA) standards. Preference is often derived from historical or current political relationships with Britain, France or the United States. Regardless, all should be using ISO 21887 Use Classes; UC1 Interior, dry; UC2 Interior, damp; UC3 Outdoors above ground and UC4 Outdoors ground contact. It is important to note that the penetration requirements in Canadian standards are much reduced compared to AWPA standards because the decay and termite hazard in Canada are lower. Intensive research done by FPI and UBC had the standards for outdoor residential lumber reduced (i.e. no penetration requirement for 2x4 and smaller), which is fine for northern climates, but not for tropical/subtropical regions. Moreover, a shallow treatment penetration will not be adequately resistant to termites in many overseas markets.

4. Preservative Treatment Options

There are few available treatment options on the market and each has its own pros and con's. Alkaline Copper Quaternary (ACQ) and Copper Azole (CA) are pressure applied and both require wood incising (perforation) prior to treatment which can lead to a mechanical strength loss of about 25%. They both react with wood and stop moving when treatment pressure stops. The choice of species is critical when using these treatments. For example (Figure 3) incised Pacific Silver fir can be almost completely penetrated by ACQ treatment while incised white spruce takes just a shallow penetration when submitted to the same treatment methods.



(a) (b)

Figure 3 ACQ pressure treatment on white spruce (a) and pacific silver fir (b)

Recently micronized copper preservatives have been replacing ACQ and CA for many residential uses in North America. These systems could also be used in disaster relief housing; however, they are not presently listed in the AWPA book of standards, and therefore may be more difficult to specify.

The treatment results obtained for white spruce are not sufficient to prevent termites from infesting the material. Termites will eat through a thin shell of treatment but will most likely give up if the treated shell is thick enough. Based on that, borate treatment, which penetrates our wood almost completely, is favored for termite management.

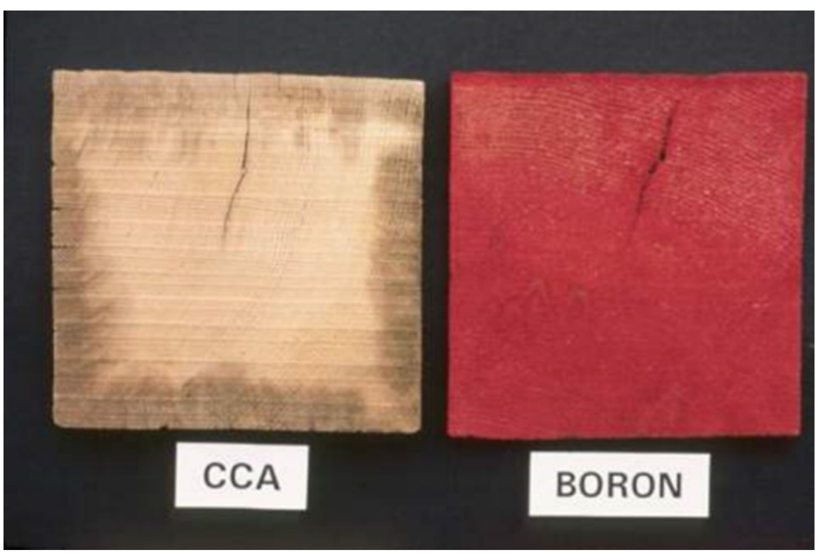


Figure 4 Borate penetration level (red colour reagent shows borate penetration)

Another treatment option is a new surface-applied technique developed for the New-Zealand market. This penetrating formulation, which is dipped or sprayed followed by a kiln conditioning, can be customized by fungicides and insecticides additions. Unfortunately, this system is not currently registered in Canada. Zinc-borate treatment can also be used during the manufacturing process of OSB panels. It is added as a powder in the blender and can effectively treat full cross section of processed panels. Zinc-borate product is resistant to leaching. Boards can be factory coated/sealed for exterior use.

In terms of new treatment available, or one that does not have a track record, one should always ask about active ingredients, loading achieved, penetration achieved, standards that can be met, if long term field test data are available and if there any existing warranty.

5. Preservative Treatment Specifications

The Aceh province in Indonesia was one of the hardest hit areas when the tsunami struck the island of Sumatra on Boxing Day 2004. In collaboration with Save the Children USA based in Westport, CT, Britco designed and engineered a cost-effective, long-term solution that will help rebuild families, rebuild communities and rebuild a future for thousands of children in Indonesia (http://www.britco.com/custom-buildings/specialty-buildings/disaster-relief-housing).

The homes were approximately 450 sq ft (42 sq meters) with 4 rooms and a covered deck and were designed to incorporate a traditional Indonesian look (figure 6). The homes have been designed to meet the seismic code for earthquakes and to be termite resistant. FPI was involved in the treatment options and recommended to FII to use ACQ treated plywood sheathing (no cladding supplied), incised hem-fir ACQ treated to AWPA standards for outside application and SPF borate treated to AWPA standards for inside applications which were protected from rain. Britco housing systems were inspected after 4 years and no evidence of termite attack was observed while extremely minor instances of decay were detected.

Figure 6 Britco_disaster relief housings – Aceh, Indonesia

In 2010, following the Haiti's 7.0 magnitude earthquake that devastated many houses, SNC-Lavalin designed and Maison Laprise provided over 4000 shelters (figure 7). FPI was consulted on the treatment specifications process and the recommendation was to use ACQ or CA treatment to AWPA standards for all components because they all could potentially be exposed to soil or rain (considering long-term behavior). Unfortunately, the material was "treated to refusal" instead. In that particular case, no inspection has been performed since the houses were constructed.

Figure 7 SNC-Lavalin/Maison Laprise_disaster relief housing – Haiti

6. Conclusions

Important issues are to be considered for Disaster Relief Housing/Shelters include:

- Fit design and treatment to local hazards (climate, insect, etc.)
- Look for simple design solutions that can improve durability
- Preservative treatment is mandatory vs. termites (deep penetration is essential for termite protection)
- Most Canadian species resist pressure-treatment
- Diffusible/penetrating treatments are best
- Specify precisely
- Quality assurance is critical

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FIELD TESTING OF WOOD PRESERVATIVES IN CANADA XXII: SHINGLES AND SHAKES

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Summary

FPInnovations has several long-term field tests of wood roofing material set up at different times. Experimental roof panels of western redcedar shakes, untreated and treated with chromated copper arsenate type B, have been in test for 40 years in the Lower Mainland of BC. No decay, and only moderate erosion and splitting, were present in the treated samples at the recent inspection, while the untreated shakes would have required replacement after twenty years.

Pine, spruce, and western redcedar shakes were inspected for decay and dimensional stability after 15 years of exposure at Vancouver, BC. The CCA type C-treated samples were mostly free of fungal attack, while decay of the untreated pine and spruce was well advanced. In terms of splitting, untreated western redcedar was superior to the other species. Splitting was not affected by CCA treatment. In terms of erosion, there was little difference between the untreated species but CCA treatment reduced erosion of the shake surface.

After ten years of exposure in a field test in southwestern BC, second growth western redcedar shingles treated with copper-based waterborne preservatives were in excellent condition, with virtually no visible decay. However, ACQ and CA-treated shingles did show substantially darker colour than typical for CCA-treated and untreated shingles. Untreated shingles were also still in good condition.

1. **Introduction**

Due to its natural durability and dimensional stability, western redcedar (*Thuja plicata* Donn) has for many years been the preferred species for the manufacture of wood roofing materials. In high decay hazard areas, pressure treatment with wood preservatives is recommended (Canadian Standards Association 1997). Chromated copper arsenate (CCA) has been the preservative of choice and it is still registered for this use by Canada's Pest Management Regulatory Agency (PMRA). Producers and users of treated shakes are understandably reluctant to change preservatives because of the cost effectiveness of CCA in enhancing resistance to decay and photodegradation (Morris and Ingram 2006), and its resistance to leaching in roofing applications (Morris, Byrne and Ingram 1995). CCA is currently the only preservative standardized for these products in Canada (Canadian Standards Association 2008).

In 1973, FPInnovations (then operating as the Western Forest Products Laboratory of the Canadian Forest Service) initiated an above-ground test of western redcedar shakes at a small clearing within the UBC Malcolm Knapp Research Forest. These were moved in 2002 to our new test site within the forest. Many of the preservatives tested are not of current interest, or were treated to the high retentions (9.6 kg/m^3) standardized at the time, but one experimental panel treated with CCA type B (CCA-B) to close to the current standard retention of 4.0 kg/m^3, was inspected after 40 years of exposure. Largely based on the results from this test (Morris and Ingram 1994), the retention specified for treatment of shakes in CSA standards was reduced from 9.6 kg/m^3 to 6.4 kg/m^3 and finally to 4.0 kg/m^3 in 1999.

Another FPInnovations roofing shakes study was designed to develop long-term performance data on untreated and CCA-treated pine, spruce and aspen shakes, with western redcedar included as reference material. The modern CCA type C (CCA-C) was used in this test. Based on historical information and inspections of pine shake roofs in the Prairie provinces and the arid western states of the USA, the Canadian Standards Association had developed a standard for northern pine shakes (CSA 1993) which required pine shakes to be pressure-treated with CCA only in areas where rainfall is higher than 500 mm per year. In Canada, this requirement for treatment based on rainfall would not apply in the North, parts of the interior of BC, and the Prairie provinces but would apply in Vancouver (Hare and Thomas 1974). Thousands of untreated pine shake roofs were installed on new homes in Alberta between 1989 and 1997. By 1996 homeowners in Edmonton had discovered that their untreated pine shake roofs were starting to rot after as little as four to seven years. Investigation of this problem revealed that brown-rot fungi, mainly *Gleophyllum sepiarium* (Wulf.:Fr.) Karst were infecting shakes on the roofs via airborne spores (Morris 2000). This fungus is particularly resistant to the high temperatures and cyclic wetting and drying typical of a roof environment. In 1998 Alberta put a requirement for preservative treatment of all pine shakes into its building code. In 1999 the Canadian Standards Association published a standard covering pressure treatment of shakes with CCA (CSA 1999). However these measures were too late to save the pine shake industry which completely collapsed. This paper covers the performance data after 15 years of exposure.

In January 2004, the preservative suppliers and PMRA agreed to a voluntary withdrawal of CCA for most residential applications. The preservatives introduced to replace CCA in these applications were alkaline copper quaternary (ACQ) and copper azole (CA). While CCA remained registered for shingles and shakes, it was considered prudent to evaluate the performance of these alternative waterborne preservatives for shingles and shakes. Since this was a long-term experiment it was considered likely that old growth western red cedar may be largely replaced by second growth by the time this field test would yield useful results, therefore second growth western red cedar was used throughout.

Another impetus for this test was that limited early work on second growth western redcedar (WRC) suggested that it would be considerably less durable than old growth (Nault 1988). Some wood preservative manufacturers responded by producing new carbon-preservatives specifically designed for second growth WRC. It therefore seemed doubly important to develop performance data on treatment of second growth WRC shingles and shakes with alternative preservatives. More recent work suggests that second growth material from long-rotation managed forests is just as durable as old growth (Freitag and Morrell 2001, Laks *et al*. 2009) and those early studies may apply only to juvenile or perhaps plantation-grown WRC. This paper describes results of an evaluation of the shingles after ten years in test.

2. **Materials and Methods**

2.1. **Installation of CCA-B-Treated WRC Shakes**

Commercially CCA-B-treated and untreated old growth western redcedar barn shakes, 450 mm in length, were nailed to 1.2 x 1.2 m CCA-treated plywood panels using a building paper interlayment and installed in 1973 on frames approximately one metre above ground level. The installation method was based on the procedures recommended by the Council of Forest Industries of British Columbia (COFI 1972). The panels were sloped 20^{o} to the horizontal, facing south and without obstruction to sunlight. CCA-B retention was determined by uptake (treating plant records) and by analysis using x-ray fluorescence spectrometry (XRF) performed by FPInnovations of the full cross-sections (AWPA 1994c), one 0-25 mm from the butt and one from the middle of the face of the shake (Table 1).

Table 1 Gauge and assay retentions of CCA-B-treated shakes installed in 1973

Gauge Retention (kg/m³)	Assay retention (kg/m³)	
	Butt	Face
4.7	16.5	3.8

2.2. **Treatment and Installation of the Pine, Spruce, and Aspen Shakes**

Pine, spruce and aspen shakes in green condition were obtained from Majestic Forest Products in Edmonton, AB. Western redcedar shakes, to be used as reference material, were obtained from Western Wood Preservers in Aldergrove, BC. The shakes were 600 mm in length, between 100 to 150 mm wide, and approximately 20 mm thick at the butt. The species of the individual shakes was confirmed and the bundles randomized. Each species was separated into three equal sets. One of the sets was left untreated as a control. In order to meet a target retention of 4.0 kg/m³, a test set of material was treated first, then the solution strength was adjusted for the experimental set.

The retention of 4.0 kg/m³ was selected because it is the retention specified in the AWPA standard for southern pine shakes (AWPA 1994a), and it is the retention specified by the Canadian Standards Association for most wood products for above-ground exposure (CSA 1989). Since this test was set up in 1995, the Canadian Standards Association has specified this lower CCA retention for pressure treatment of shakes (CSA 1999).

The shakes were cut to specific sizes before treatment to fit onto the test panel. The shakes of each species were pressure treated with different solution strengths of CCA-C (Table 2), based on uptake in test treatments targeting 4.0 kg/m^3. The following schedule was used: 30 minute vacuum at 740 mm Hg, followed by a 1 hour press at 1035 kPa, then a final 15 minute vacuum.

Twenty shakes from each species were weighed before and after treatment to determine solution uptake, stored outside covered with a tarpaulin for one week to allow CCA fixation to occur, and air-dried. A sample was taken from each of the 20 shakes according to AWPA M3-84 Method 1 (AWPA 1994b). A cut was made across the width at a point where the thickness was approximately 15 mm, and the sawdust was collected. This was combined from the 20 replicates and ground into one composite sample. The CCA content was then determined by XRF (AWPA 1994c). The retention for aspen shakes ended up higher than intended but this was considered reasonable due to the need for higher loadings of CCA in hardwoods compared to softwoods to provide equivalent protection (Morris and Ingram 1991).

Table 2 Analysis results of pine, spruce, and aspen samples used for exposure

Species	Solution Concentration	Exposure samples analysis retention kg/m^3
Pine	2.2	4.2
Spruce	3.3	4.1
Aspen	3.0	6.1

The treated and untreated pine, spruce and aspen, and the untreated cedar shakes, were used to construct roof panels on 1.2 x 1.2 m CCA treated plywood, 16 mm thick, supported by frames approximately one metre above ground level (Figure 1). Application of the shakes to the panels was according to recommended procedures (Majestic Forest Products, undated). The shakes were placed with maximum weather exposure of 10 inches, spaced 6 to 12 mm apart, with under-laid and inter-laid 15 lb. roofing felt. There were approximately 30 to 40 shakes per panel. Fifty mm double-dipped galvanized nails were used in construction. The panels were sloped 20^o to the horizontal, facing south and without obstruction to sunlight. Two panels were prepared per variable to provide one for long-term exposure and one for sacrificial analysis (if required) and these panels were randomly allocated to locations within the test site. The panels were installed in May 1995 at the rear of the Forintek Canada Corp. (now FPInnovations) laboratory in Vancouver, BC.

Figure 1 Pine, spruce and aspen shake test immediately after installation at Vancouver

2.3. Treatment and Installation of Sign Shelter WRC Shingles

Approximately 10 bundles of second-growth #1 grade 18 in "Perfection" western redcedar shingles were obtained from Riverside Shingle Products in Port Coquitlam, BC. The shingles were pressure-treated at FPInnovations' laboratory in Vancouver. The treatment schedule used was a 30 minute initial vacuum at 711 mm Hg, followed by 60 minutes press at 676 kPa, then a final 15 minute vacuum. Retentions were based on gauge uptake. To confirm uptake retentions, analysis samples were taken using a saw cut from the tip to butt of the shingles treated with copper-containing formulations, and analyzed for preservative retention using XRF (Table 3).

The four water-based preservatives used were ACQ Type D (carbonate formula) supplied by Timber Specialties Co, copper azole (Wolman® NB) supplied by Arch Wood Protection Inc., oxine copper, a proprietary formulation of copper-8-hydroxyquinoline supplied by Mattersmiths Holdings Ltd. in New Zealand (US Patent 6720313), and a carbon-based preservative containing propiconazole (Arch 100SL) supplied by Arch Wood Protection Inc. One set was left untreated.

Table 3 Shingle preservative retentions by gauge uptake and assay

Preservative	Retention (kg/m³)		
	Target	Gauge	Full-length assay
ACQ-D	4.0	3.9 (1.0)	4.7 (1.6)
CA*	1.7	1.7 (0.4)	2.0 (0.7)
Oxine copper	0.32	0.41 (0.15)	0.38 (0.06)
Propiconazole	0.24	0.27 (0.05)	-

* *Copper azole expressed in terms of copper metal; standard deviations are given in parentheses*

The shingles were used to cover the roof of an interpretive sign shelter located at FPInnovations' field test site at UBC Malcolm Knapp Research Forest at Maple Ridge, BC. The shingles were installed in September 2003 on CCA-treated plywood overlaid with building paper, according to Cedar Shake and Shingle Bureau procedures (Cedar Shake and Shingle Bureau 2009). Each of the four experimental treatments was installed in a separate section, separated by several untreated shingles (Figure 2). In addition one section was prepared of untreated samples. Each treatment was exposed in both north and south directions.

Figure 2 Sign shelter from the north immediately after installation at Maple Ridge.

2.4. **Test Sites**

The UBC Malcolm Knapp Research Forest site in Maple Ridge, BC has rainfall of over 2000 mm per year and has mean daily maximum and minimum temperatures of 6°C and 1°C in January, and 23°C and 12°C in July. Using Scheffer's climate index (Scheffer 1971) with recent climate data (Morris and Wang 2008) it has a climate index of 63 which falls within the moderate decay hazard zone for outdoor above-ground exposure.

Vancouver, BC is also in the zone of medium above-ground decay potential using Scheffer's (1971) climate index and the test site is relatively close to the airport. The updated Scheffer index value for Vancouver airport (Morris and Wang 2008) is 50. Temperatures annually average 10°C, with a December average of 3°C and a July average of 17°C. The site receives about 1900 hours of bright sunshine and approximately 1250 mm of precipitation per year, with an average 34 mm of rain in July and 140 mm of rain in December.

2.5. **Inspection**

The shakes and shingles were visually evaluated for physical condition on a 0 − 4 scale (Table 4), appearance, and the presence of decay using the new AWPA criteria. Filler shakes less than 50 mm wide were ignored. Splitting refers to an opening through the entire thickness of the piece, unlike checking which is just on the surface.

Table 4 Rating criteria for shakes and shingles

Decay		Physical condition		
AWPA Rating	Description	Rating	Erosion	Splitting
10	Sound	0	None	None
9.5	Trace-suspect	1	< 1 mm	0 – 10 mm
9	Slight attack	2	1 – 3 mm	10 – 50 mm
8	Moderate attack	3	3 – 5 mm	50 mm – full
7	Moderate/severe attack	4	> 5 mm	Full length
6	Severe attack			
4	Very severe attack			
0	Failure			

3. Results and Discussion

3.1. CCA-B-Treated WRC Shakes

The untreated roof would have required repair at 15 years and replacement at 20 years (Morris and Ingram 2006). At 40 years, the untreated shakes had either failed or were severely attacked, for a mean decay rating of 1.2 (Table 5, Figure 3). In contrast, all CCA-B-treated shakes were sound (Table 5, Figure 4), with moderate erosion and splitting.

Table 5 Condition of WRC shakes after 40 years

Preservative	Gauge retention kg/m³	Mean rating		
		Decay	Erosion	Splitting
none	0.0	1.2 (1.8)	NA	NA
CCA-B	4.7	10.0 (0.0)	2.0 (0.0)	2.2 (1.7)

Standard deviation given in parentheses

CCA-C, a more balanced formulation than CCA-B, would be expected to perform even better.

Figure 3 Untreated western redcedar shakes at Maple Ridge after 40 years

Figure 4 Inspection of CCA-B-treated western redcedar shakes at Maple Ridge after 40 years

3.2. **Pine, Spruce, and WRC Shakes**

In pine and spruce shakes, the CCA retentions determined by analysis came very close to the target of 4.0 kg/m³ (Table 2). The inspection immediately after installation showed no decay or erosion on any of the test material, as would be expected (Table 6).

Table 6 Inspection data on pine, spruce, and WRC shakes at the time of installation and after fifteen years of exposure in Vancouver, BC

Species	Treatment	Panel	Decay		Erosion		Splitting	
			Initial	15 years	Initial	15 years	Initial	15 years
Pine	None	1	10.0 (0.0)	3.0 (3.2)	0.0 (0.0)	2.0 (0.0)	0.1 (0.5)	3.0 (0.9)
		2	10.0 (0.0)	6.6 (3.3)	0.0 (0.0)	1.2 (0.5)	0.2 (0.9)	3.1 (0.6)
	CCA	1	10.0 (0.0)	9.7 (0.5)	0.0 (0.0)	1.0 (0.0)	0.2 (0.7)	2.6 (0.8)
		2	10.0 (0.0)	9.8 (0.6)	0.0 (0.0)	0.9 (0.4)	1.1 (1.4)	2.8 (0.8)
Spruce	None	1	10.0 (0.0)	1.9 (3.0)	0.0 (0.0)	2.0 (0.0)	0.0 (0.0)	3.0 (0.3)
		2	10.0 (0.0)	6.9 (2.2)	0.0 (0.0)	2.2 (0.6)	0.1 (0.5)	2.5 (0.9)
	CCA	1	10.0 (0.0)	9.3 (0.4)	0.0 (0.0)	1.0 (0.2)	0.3 (1.0)	3.1 (0.4)
		2	10.0 (0.0)	9.8 (0.4)	0.0 (0.0)	0.0 (2.0)	0.9 (1.4)	3.1 (0.6)
WRC	None	1	10.0 (0.0)	8.2 (1.5)	0.0 (0.0)	2.0 (0.4)	0.0 (0.0)	1.3 (1.3)
		2	10.0 (0.0)	8.7 (1.1)	0.0 (0.0)	2.1 (0.3)	0.0 (0.0)	1.1 (1.2)

Standard deviations are given in parentheses

A decision was made at the 15-year evaluation to not inspect the aspen panels, since the severe distortion of this material made it unsuitable as a roofing material. At the 15-year evaluation a majority of the CCA-treated spruce and pine shakes were still sound (Figure 5), but some were now rated 9 for very early signs of decay, for mean ratings of 9.3 to 9.8 (Table 6). In contrast all untreated panels would have required replacement at some point between ten and fifteen years if part of a residential roof (Figure 6). In both pine and spruce, one of the panels contained substantially more decay than the other (Table 6). This may be due in part to the natural variability of decay fungus germination via airborne spores and slight differences in the amount of shade, airflow and drying rates for the duplicate panels. However, there appeared to be spread of decay from shake to shake by direct contact so once established on one replicate on one panel the decay fungus was likely able to spread to other replicates on the same panel. Fruitbodies of *G. sepiarium* were common on untreated shakes of both species. Pine was noted at the 10-year inspection to be in slightly better condition than spruce, but that difference had disappeared by the 15-year evaluation. The untreated western red cedar control shakes were essentially free from decay at the ten-year inspection (data not presented), but by 15 years in service early decay had become well-established, with average ratings of 8.2 and 8.7 for the two panels.

Erosion was noticeable on untreated shakes of all species, with mean ratings of approximately 1.5 for pine and 2 for spruce and western red cedar. No erosion was found on CCA-treated samples after five years of exposure. CCA treatment is known to reduce erosion of shakes (Morris *et al.* 1995), probably due to the photo-protective effects of the chromium (Feist and

Ross 1989) and copper (Liu *et al.* 1994). At the 15-year evaluation, both pine and one spruce panel were rated an average of 1, while the other spruce panel had virtually no erosion.

Figure 5 CCA-C-treated pine shakes at Vancouver after 15 years.

Figure 6 Untreated pine shakes at Vancouver after 15 years.

Treated pine and spruce shakes had already split more than the untreated material within days of installation (Table 6). This was probably promoted by rapid wetting of the surface layers of the shake inherent in the pressure treatment process. At that stage, there were no discernable differences in splitting between pine and spruce, and there was no splitting in the untreated western red cedar shakes. At 15 years, splitting in the pine and spruce shakes had progressed to a mean rating of approximately 3, and was similar in untreated and CCA-treated samples. Some splitting was also now evident on some western red cedar samples, with a mean rating of about 1.

The results for untreated pine shakes at this location did not duplicate the experience of homeowners in Alberta where advanced decay, noticeable as black patches, was noted after as little as six years. One explanation for this may be the difference in climate (Hare and Thomas 1974). Although Vancouver, BC, receives more than twice the annual precipitation of Edmonton, AB, it is distributed quite differently throughout the year. As noted by Morris and Ingram (2006), the warmest months of the year is the period when the maximum rain falls in Edmonton. This is also when decay fungal activity would be expected to peak. In contrast, Vancouver has relatively dry summers, with about half the amount of rain as Edmonton in the summer months.

3.3. **Sign Shelter Shingles**

Mean decay, erosion, and splitting ratings for the shingles after ten years of exposure are given in Table 7. At the five-year inspection the untreated controls were rated as sound, however discoloration from algae and/or staining organisms had begun. By the ten-year evaluation, early decay had become established in some of the untreated shingles. Untreated shingles were given mean ratings of 9.5 on the north side and 9.6 on the south side. After 10 years, the mean rating for erosion was 2 on both north and south sides. At ten years, splitting was minor overall, but was worse on the more quickly drying southern exposure.

Table 7 Shingle ratings after ten years' exposure at Maple Ridge, BC

	Mean rating					
Preservative	**Decay**		**Erosion**		**Splitting**	
	North	**South**	**North**	**South**	**North**	**South**
Untreated	9.5 (0.8)	9.6 (0.5)	1.9 (0.4)	1.8 (0.4)	0.1 (0.6)	0.6 (1.2)
ACQ-D	10.0 (0.2)	10.0 (0.2)	1.0 (0.2)	1.0 (0.1)	0.2 (0.6)	0.4 (1.1)
Copper azole	10.0 (0.0)	9.9 (0.3)	1.0 (0.0)	1.0 (0.1)	0.1 (0.7)	0.7 (1.3)
Oxine copper	10.0 (0.2)	10.0 (0.1)	2.0 (0.0)	2.0 (0.1)	0.1 (0.5)	0.7 (1.3)
Propiconazole	10.0 (0.1)	10.0 (0.0)	2.0 (0.0)	2.0 (0.1)	0.0 (0.0)	0.6 (1.1)

Standard deviations are given in parentheses

Overall, the appearance of all treated panels remained good at the ten-year evaluation. The ACQ-D and CA treated shingles had weathered to a grey-brown although this was substantially darker than typical for CCA-treated shingles or untreated shingles (Figure 9). The propiconazole-treated shingles were mostly a silver-grey and the oxine-copper-treated shingles looked similar to the controls (Figure 7).

The shingles in this study treated with each of the four preservatives were virtually free from decay after ten years. One ACQ-D-treated sample on each face was given a rating of 8, which was also the case at five years. This was considered to be pre-treatment decay. Six south-facing copper azole-treated shakes and three oxine copper-treated shingles on the north face were rated 9.

Erosion on the ACQ-D- and CA-treated shingles was given mean ratings of 1 after ten years. These results confirm the protective effect of copper against erosion. In contrast, erosion comparable to that seen on the untreated controls was found on both the oxine copper- and propiconazole-treated shingles, with mean ratings of 2. Oxine copper contains only 0.09 kg/m^3 CuO, which is too low to provide substantial protection against erosion. Carbon-based preservatives do not provide protection against UV and visible light and therefore would not be expected to significantly reduce erosion.

Figure 7 Sign shelter from the south after 10 years in test (γ-joint test of field cut preservatives in foreground)

Splitting of the treated shingles was comparable to that found in the untreated controls. There were only one or two split samples per north facing panel of each treatment with the exception of propiconazole, where there was no splitting. On the south side of the roof, where the shingles would dry out faster after rain, although still relatively minor, splitting was more extensive, with several shingles of each treatment completely split, rated 4. Increased splitting is considered to be a concern with CCA-C-treated shakes and shingles. However, FPInnovations' previous data on shakes at this Maple Ridge test site (Morris and Ingram 1994) indicated that CCA-C treatment simply accelerates checking in the first year of exposure that would have occurred anyway on the same untreated sample. This appears to also be the case with these alternatives to CCA-C.

4. **Conclusions**

- Western redcedar shakes CCA-treated to meet CSA O80 will last well over 40 years.
- If the pine shake industry had used CCA treatment they would still be operating today.
- ACQ-D and CA have potential as treatment for western redcedar shingles and shakes but the much darker colour may be an issue for consumers.
- Carbon-based preservatives have potential as treatments for western redcedar shingles and shakes but they would need to be provided with UV protection.

Acknowledgements

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TRU-CORE® PROTECTION SYSTEM FOR WOOD: AN UPDATE

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Summary

Wood is the most versatile, practical and sustainable building material in the world. In modern countries, wood is a well-managed renewable resource that has a small carbon footprint. Wood does suffer from a lack of durability against invasive organisms such as insects and fungi. Steel, aluminum and composites have emerged as viable alternative building materials. These sectors market the deficiencies of wood to better position their products. As these materials continue to take market share away from wood, the need to cost-effectively increase the durability of wood remains an always present target within the forest products industry. The use of chemical treatments to impart fungal and insect resistance into wood has been utilized for over a century. Today, many of these preservatives are delivered into the wood using the same decades-old methods and chemicals. The TRU-CORE wood preservation system is a chemically based infusion process that is capable of delivering key wood protectants completely throughout the wood. This is achieved without the use of pressure or vacuum. This waterbased system imparts a minimal amount of added moisture into the wood during the process, so there is no need to dry after treatment. As short activation period is utilized to achieve full penetration. The TRU-CORE process is in commercial use in the United States, New Zealand and Australia where numerous programs have been developed for residential and industrial wood products.

Introduction

Today wood remains the most widely utilized building material in North America and the majority of the world. As a building material, wood has numerous positive environmental attributes that includes low embodied energy, low carbon impact and sustainability. These complement its physical attributes such as strength and practicality (Falk, 2010).[1,2]

After the U.S. housing market crash in the mid to late 2000's, the global demand for wood plummeted. Current data indicates that the recovery has been consistently trending positive. It is projected that G8 countries will account for more than $336 billion into the global forestry products industry by 2015, which is nearing its 2010 mark of $354 billion (FP, 2013).[3] The U.S. accounted for greater than 40% of the 2010 market, and that trend will continue into 2015. Of particular interest of these U.S. values is the continued demand for decks. It is projected that the U.S. decking market will exceed $6 billion and reach a demand volume of 3.5 billion lineal feet (Freedonia, 2011).[4] These projected values includes alternative decking materials such as wood-plastic, plastic and wood-plastic composite.

Even with their high initial cost, these alternative decking materials remain attractive to some consumers due to its perceived minimal maintenance and projected long lifetime. It can be assumed that the consumer also perceives these decks to be impervious to degradation caused fungal organisms and long-term exposure to moisture. Recent marketing efforts by the alternative building materials for decking sector have concentrated on issues that have historically hindered a more wide-spread acceptance. These include the matched appearance of these materials to that of natural wood, the eco-friendly background of the materials utilized in the manufacture process and the manufacture process itself. By fundamental practice, these processes are much more impactful than the harvesting and processing of timber. Based on life-cycle assessment and embodied energies, the net carbon emissions in producing a ton of various materials, including framing lumber, recycled steel, virgin steel and plastic were calculated by the EPA (EPA, 2006).[5] The values for plastic, recycled steel and virgin steel were approximately 76, 7 and 21 times, respectively, more net carbon emissions prohibitive than that of lumber. Incorporation of recycled wood and plastic into these alternative building materials for decking may reduce these factors to 13-21 times more net carbon emission prohibitive than that of wood.[6]

Even with the significant advancements in the production and appearance of alternative engineered building materials, wood continues to remain the preferred material of choice due to price, practicality and minimal environmental impact compared to other materials.

As continued development in the design and manufacturing of these alternative materials progresses, similar activities must occur for wood and engineered wood products. The need to produce new and improved wood products that meet ever increasing durability and environmental guidelines must continue at a constant rate. To assist in these areas, the utilization of technologically advanced chemical preservative systems can ensure that forest products companies maintain a competitive edge over the alternative building material sector. The utilization of wood preservation chemicals ensures efficiencies by the wood products companies and imparts added durability into the wood product through the use of organic, inorganic and organometallic biocides. The imparting of added durability with these chemicals into wood products negates the main competitive argument, that wood is not durable and susceptible to attack by fungal organisms and invasive insects.

The global wood preservation industry has long utilized these anti-fungal and anti-insecticidal chemicals to impart durability into wood products. Typical examples include: windows and doors, sill plates, decking and fencing. Engineered wood products that make up the framing, sheathing and flooring components of homes are rarely treated due to cost and difficulties in treating. In particular, the issues with treating have been the lack of penetration through simple dip, flood or spray applications; and the loss of structural properties with high mass uptake pressure/vacuum impregnation. Wood destined for external exposure such as decking is typically treated with robust biocides such as CCA, copper quat or copper azole. When properly treated, these biocides provide excellent protection against rot and other fungal organisms. However, the processes used to deliver these protectant materials into the wood typically impart massive amounts of excess water into the wood and require aggressive additions of pressure to drive the fluid as deep as the wood characteristics will allow.

The TRU-CORE Protection System was specifically developed to address the need for a modern, state-of-the-art wood preservation process that can rapidly penetrate solid wood profiles and engineered wood substrates that cannot be treated by historical methods. Utilization of this technology creates a durable wood product that can survive a robust lifetime.

TRU-CORE Protection System

The TRU-CORE Protection System is a unique, chemical-based infusion process that delivers wood protectants deep into the wood. For most species, full and complete penetration of the sapwood and heartwood is achieved without the use of: aggressive pressure/vacuum treating techniques; high uptakes of excess carrier solvent(s) or the use of organic based solvents (Ross, 2013; Ross, 2010; Ross, 2010; Ross, 2011; Ross, 2007; Ross, 2006; Clawson *et.al.* 2013).[7-13] This state-of-the-art wood preservation technology is the subject of numerous U.S. and foreign patents (Ward and Scott, 2011).[14-15] The waterborne system utilizes non-volatile, polar amine oxides as carrier molecules to penetrate the cellular structure of the wood and deposit the key protectant molecules deep within the wood. The penetration and binding are controlled using a suitable buffering system which buffers the natural acids present within the wood. In most cases, borates are used for the buffer system (Ross and Cutler, 2011).[18] The use of these chemicals in the buffering system may contribute to additional biocidal activity of the system. In addition, documented synergistic efficacy has been reported for borates and synthetic pyrtheroid insecticides, and other chemical pairings of the TRU-CORE system (Ward *et.al.* 2011; Ross *et.al.* 2006).[16-17] Conventional biocides are incorporated into the TRU-CORE chemical system and then applied to the wood utilizing standards techniques such as dip, flood, spray, in-line spray and pressure/vacuum assisted impregnation. In the case of pressure/vacuum impregnation, the cycles times and added pressures are drastically minimized when complimented with the TRU-CORE technology.

The traditional biocides that can be inserted into the TRU-CORE technology include, but are not limited to: iodocarbamate, azoles, synthetic pyrethroids, synthetic neonicotinoids, borates, solubilized copper quat and copper azole.

Unlike conventional treating methods that impart massive amounts of excess water during the treating procedure, the TRU-CORE process imparts minimal amounts of water into the wood. Mass uptakes for the TRU-CORE process are typically less than 3% (m/m) for dip, flood or in-line spray applications. These mass uptakes are typically achieved from seconds of exposure, with full penetration achieved after a 12-24 h activation period. Mass uptakes for the pressure/vacuum assisted treatment of external exposure wood articles treated with conventional durable biocides are usually 100-150% (m/m). With TRU-CORE technology, those same biocides are imparted into wood with mass uptakes that are less than 25% (m/m). Given the low mass pickups, and corresponding small amounts of water that are imparted into wood during the TRU-CORE treatment, there are no adverse effects on the on the appearance and the mechanical properties of the wood. More importantly to TRU-CORE technology users, there is no need for post-treatment drying. Users of the TRU-CORE technology have experienced massive efficiencies in their wood preservation process, yielding significant cost savings.

Applications

To date, there are nearly 50 commercial TRU-CORE programs that have been specifically designed to meet individual customer needs. Select programs, discussed below in detail include: the preservation of framing lumber, weatherboard, millwork, fencing, engineered wood, railroad ties and decking.

Structural Framing

The inception of the TRU-CORE technology came in response to the New Zealand Government legislation that required structural framing lumber in residential buildings to last a minimum of 50 years in service (NZ DBH, 2004).[19] This was in reaction to New Zealand's massive "leaky house" crisis that accounted for $11.3 billion dollars in damage caused by subpar building practices geared towards weather-tightness problems (NZ DBH, 2004).[20] The increased moisture contents in the homes and adjacent structures, along with minimal air circulation, caused optimal conditions for decay organisms to compromise the wooden structure. In response to this issue, the New Zealand government developed a standard requirement that all applicable wood be treated to impart fugal protection (NZ Std. 3640, 2013).[21] Interestingly, a similar event, referred to as the "leaky condo crisis" occurred in coastal British Columbia in dwellings built from approximately 1980-2000.

The TRU-CORE technology is used to meet the requirements of Hazard Class 1.2 and 3.1 (commonly known as H1.2 and H3.1, respectively), where borates are used as the main preservative. The discussion for the potential use of boron in wood preservation dates back to the 1930's in New Zealand and Australia (Freeman *et.al*, 2009).[22] Its use was formally recognized in 1958 for exterior, non-ground contact. Excellent work performed by Drysdale paved the way for boron to be used as a standalone fungicide and insecticide in New Zealand for specific end use patterns (Drysdale, 1994).[23] For two decades, extensive research was conducted to optimize the delivery and stability of borates in solution and within the wood. Today, the TRU-CORE system is widely utilized as the system of choice to deliver H1.2 and H3.1 compliant loadings of borates into the cross-sectional profile with full and complete penetration of the sapwood and heartwood of Radiata Pine and Douglas Fir. Currently, NZ3640 only requires full sapwood penetration for these hazard classes. The benefits of treated heartwood, though not commonly discussed in the wood preservation industry, were thoroughly reported for pine species by the Koppers Company (Ward *et.al*, 1983).[24] The data, which shows degradation of strength of the heartwood-only samples and quantifiable presence of decay fungi, illustrates the need for heartwood treatment.

For the New Zealand H3.1 products, the application of the TRU-CORE technology for borates is typically achieved using an in-line spray application. For H1.2, the preferred method of application in New Zealand utilizes modern pressure treating vessels coupled with the TRU-CORE technology. This is preferred as high volumes of wood can be sent through the cylinder due to the short cycle times. With the inclusion of the TRU-CORE technology, the treating cycle times are often minutes long compared to hours using conventional methods and chemicals. The wood exits the cylinder with no need to dry due to the low mass-uptake of the process. Recently, these same TRU-CORE technologies have been successfully adapted in Australia for borate treatment of wood for Hazard Classes 1 and 2 (commonly referred to as H1 and H2). In most cases, an organic based insecticide is also required to impart further termite resistance. High volumes of Baltics, mixed Pines and native Eucalyptus species are currently being treated using the TRU-CORE technology for H1 and H2 applications. The complete and full penetration of these products, including the heartwood, has been thoroughly documented by globally leading wood preservation scientists (Ahmed Shiday and French, 2011) and industry experts (Riddle, 2013).[25, 26, 30]

Weatherboard

In the U.S., New Zealand and Australia the TRU-CORE technology is being utilized to deliver azoles and insecticides into primed siding, fascia and trim board. These compounds include the azole fungicides and synthetic insecticides. The inclusion of borates as the system buffer and the amine oxide carrier allow for synergism between the actives (Ward *et.al,* 2002).[27] This TRU-CORE water based azole/insecticide system is typically applied by spray or flood *via* an in-line treating system. These treated articles are fully penetrated with the active ingredients after a brief activation period. This full penetration eliminates the need to retreat cut ends in the field.

Millwork

In addition to the TRU-CORE system for weatherboard, the TRU-CORE Millwork water-based azole (and optional insecticides) system has been developed for the U.S. millwork industry (Clawson and Ward, 2013).[28] Currently, manufacturers of these components for high value wood window and doors utilize organic solvent based systems to deliver the actives into the wood in a robust perimetrical envelope. The solvent-based wood preservative systems are applied to the wood using flood, dip, spray or double vacuum techniques. The solvent based process allows for good end-grain penetration and quick dry time for the parts. Flammability, costs and volatile emissions of the organic solvents are the understood and managed issues that accompany usage of solvent based millwork chemicals.

TRU-CORE treatment of millwork components allows for excellent end grain penetration and complete side grain penetration of actives into the core of the wood. Because of the low-mass pick-up of 2-3% (m/m) of the treating solution, this penetration is accomplished without grain raise, retention of dimensional tolerances and no need to dry the treated part. The advanced technology behind the TRU-CORE chemistry also allows for incorporation of a non-wax based water repellent and dimensional stabilizer into the treating solution. When equally compared to solvent based millwork formula analogs, the TRU-CORE Millwork system has demonstrated improved performance against white and brown-rot organisms based on the synergism between the amine oxides and fungicides (Amburgey *et.al.*, 2010).[29] Aggressive external exposure testing of primed L-joint samples in Hilo, HI show the same trend that the TRU-CORE Millwork azole system outperforms the solvent based azole formulas (MSU, 2013).[31] The water repellent and efficacy performance of the TRU-CORE Millwork system greatly exceeds the minimum requirements set forth by the Window and Door Manufacturers Association (WDMA, 2009),[32] and is recognized as an approved chemical formulation for treatment of wood window and door components by this globally leading standards organization.

Fencing

The TRU-CORE technology has answered an immediate need to robustly protect residential above-ground fencing against decay, mold and insect attack. This is achieved using an in-line spray application of a TRU-CORE azole/IPBC system. Historical SPF species used in these products have been difficult to treat using standard pressure assisted applications. Typical penetration patterns are a 2-3 mm perimetrical envelope, leaving the entire un-penetrated center susceptible to fungal attack. Most reports indicate that the articles were rotting within a few years.

Utilizing the TRU-CORE technology, SPF fence boards are fully penetrated. The performance of the TRU-CORE system for fencing over soluble ammonical copper azole was demonstrated for a leading pressure treating company in a comparative accelerated decay test (Kop-Coat Inc., 2010).[33] The test utilized Kop-Coat Inc.'s proprietary K300 28-day Rapid Laboratory Decay Test. The severity of this test has been systematically shown to exceed the typical three month standard soil and agar block test methods utilized by various laboratories. In this test, commercially treated-to-refusal with soluble copper azole, SPF fencing boards were submitted by a global leading fencing company. Matched untreated SPF boards were treated using the TRU-CORE system and after activation, the fully penetrated samples were cut from the center of the treated article. After 28 days, the TRU-CORE protected fencing was quantitatively scored at 99% protection (100% scale), while the copper azole was scored at 47%. In addition to removing the costs associated with pressure treating, the TRU-CORE technology provided a substantial improvement in the durability of SPF fencing.

Engineered Wood

An impressive addition to the family of commercial TRU-CORE programs is the treatment engineered woods. To date, the TRU-CORE technology has been utilized to fully penetrate I-joists, plywood, OSB, LVL, PSL and LSL. These articles are treated to a number of different global specifications, so there are numerous customized programs utilizing the TRU-CORE technology. The actives that have been incorporated into the TRU-CORE Engineered Wood system include borates, propiconazole, tebuconazole, IPBC, permethrin, imidacloprid and soluble copper quat. Most recently, a TRU-CORE system, known as the TRU-CORE Type I was designed to impart borates and permethrin into I-joists. This preservative and the application process has been accepted and endorsed by one of the world's largest engineered wood companies (Weyerhaeuser, 2012).[34] Extensive strength tests were conducted on the I-joists to demonstrate that there was no reduction in the mechanical strength properties (Ross, 2013).[13]

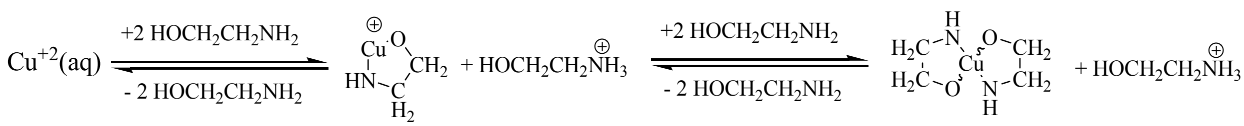
The TRU-CORE Type I system has been extensively tested against fungi and termites by numerous 3rd party laboratories. Termite testing of TRU-CORE SYP OSB panels was conducted by Louisiana State University according to AWPA E1-97 test protocol with excellent results (LSU, 2009).[35,10] The TRU-CORE treated OSB had a termite mortality of 43.62% compared to 16.52% for the untreated OSB and 10.99% for the untreated SYP control. The untreated solid SYP control lost 26.85% of its weight compared to 8.65% for the untreated OSB control and 0.89% for the TRU-CORE treated OSB. In terms of Visual Rating, using the 0 (worst) to 10 (best) scale, the untreated solid SYP had an average rating of 1.6; the untreated SYP OSB had an average rating of 5.1; and the TRU-CORE treated OSB had an average rating of 9.8. Decay testing of TRU-CORE treated OSB panels from the same group utilized in the LSU single choice termite test were tested against G. trabeum rot fungi at Mississippi State University using AWPA E10-01. In this test, the untreated solid SYP control lost 61% weight; the untreated SYP OSB lost 42% weight; and the TRU-CORE treated SYP OSB lost only 1.6% weight, which is statistically insignificant.
To complement the performance testing of the TRU-CORE Type I treated OSB, additional tests on solid wood samples were conducted at Mississippi State University (Ross, 2013).[13] Field termite testing on SYP blocks according to AWPA E21-11 is ongoing at the Dorman Lake and Saucier sites in Mississippi. At both sites, the TRU-CORE treated samples display perfect scores of 10.0 while the borate only treated samples are rated at 9.8 and 8.0 at the two sites, respectively. Laboratory termite resistance was conducted according to AWPA E1-09 using SYP blocks. After 4 weeks of exposure in the no choice test using Formosan termites, the borate treated controls exhibited an average weight loss of 2.88% with a visual block rating of 8.2 out of 10.0. The TRU-CORE treated blocks exhibited a loss of 0.03% with a visual block rating of 10.0 out of 10.0. Untreated controls exhibited an average weight loss of 18.65% with a visual block rating of 6.0 out of 10.0. AWPA E22-09 decay tests using aspen and SYP solid blocks against both brown and white rot fungi resulted in excellent resistance.

Rairoad Crossties

A highly-advanced TRU-CORE system has been exclusively developed for the world's largest railroad crosstie treater. This process allows for the cost-effective implementation of a dual treatment process with borates and creosote. The dual treatment methodology was pioneered by Amburgey *et. al.* using a timely boron diffusion treatment that was then over-treated with creosote (Amburgey and Saunders, 2009).[36] Utilizing the TRU-CORE technology, borates are quickly delivered into properly seasoned ties using a pressure assisted cycle. Immediately following removal of the waterbased TRU-CORE borate pre-treatment solution from the cylinder, creosote is added in the same cylinder and treating according to standard cycles. Retention and penetration values of borates within white oak, red oak and mixed gum ties treated with the TRU-CORE system matched those reported by Amburgey and Sanders diffusion-based dual treatment. The TRU-CORE chemical infusion technology allowed for a practical dual treatment process that was completed in hours rather than weeks with the diffusion method.

Decking

The use of TRU-CORE technology to deliver durable biocides into decking represents the culmination of modern, state-of-the-art chemical technology within the wood preservation industry. These durable biocides are typically copper based and are accompanied by a secondary biocide to ensure a long service life (Freeman and McIntyre, 2008).[37] Typical copper based preservatives include: Copper Chromate Aresenic (CCA); ammonical solubilized copper quat; ammonical solubilized copper azole and micronized versions of copper quat and copper azole. For the typical ammonical solubilized copper systems, copper carbonate is dissolved in water and monoethanolamine is added to ensure the soluble copper cations stay in solution and do not sludge out as insoluble oxides. Additional alkanolamines or ammonia can also be used to form the copper complex.



The copper monoethanolamine complex is sold as a concentrate or mixed with a secondary biocide. The secondary biocides are quaternary ammonium compounds (quats) and azoles. If the stand alone copper monoethanolamine complex is utilized, these same co-biocides are tank blended prior to treatment.

To date, the standard application of these wood preservatives has been through pressure assistance with the typical treat-to-refusal methodology. These applications are accompanied by prohibitively high volumetric loadings of water, long press times and high applied pressures. The wood exiting the cylinder has typically gained 150-200% (m/m) of its original weight. In countries that require wood to be sold at less than 25% moisture content, this requires expensive drying operations after treatment. In countries where there is no dry wood requirement, the wet wood is typically shipped as is after it is allowed to drip on a contained pad for up to 48 h. Shipping this heavy wood allows fewer products to be shipped *per* load, resulting in higher freight costs. For refractory species such as Douglas Fir, concentrated aqueous ammonia is sometimes blended into the ready to use treating solution in an attempt to increase penetration. This use of aqueous ammonia and deep incisions typically results in a meager envelope of penetration on the refractory species. The untreated center core of these profiles, often claimed to be acceptable in woods considered durable, is still prone to fungal attack over the service life of the wood component.

Utilizing the TRU-CORE technology to deliver solubilized copper quat/azole into wood has allowed for fully penetrated H3 and H3.2 decking to be quickly and efficiently manufactured in Australia and New Zealand. Because of the low mass pick-up of this process, the wood is fully fit-for purpose in meeting moisture contents with no need to dry. Typical volumetric uptakes for the TRU-CORE copper quat process range from 25-65 L/m^3 depending on the species and profile. The chemical infusion properties of the TRU-CORE system are complemented with specialized modified empty cell pressure treating process. This cycle was custom designed over years of laboratory and commercial trials to be paired with the TRU-CORE chemistry. Modern commercial full cell processes for copper quat typically imparts 300-450 L/m^3. The species being treated in New Zealand include Radiata Pine and Douglas Fir. Baltics, mixed Pines and native Eucalyptus species are currently being treated using the TRU-CORE technology for H3 applications in Australia. The TRU-CORE copper quat treated wood has been reviewed by numerous 3rd party auditing agencies and wood industry experts in New Zealand and Australia. To date, the programs have provided total analytical compliance with the requirements for copper and quat retentions and penetrations set forth in the standards of both countries.

In fact, the penetration of the co-biocide in the TRU-CORE treated wood has been shown to be more robust than the historical high volumetric uptake treatments (Clawson, 2013).[38] This is clearly evident in solubilized copper azole systems. This data was collected from a trial conducted using the U.S. pilot pressure treating plant at the Kop-Coat Inc. Global Center of R&D Excellence. The trial utilized matched and end-sealed Radiata Pine 45x90 mm samples. All seven of the parent boards contained approximately 30% heartwood that was uniformly distributed in the sub-samples. To demonstrate the steep gradient that is evidenced in the co-biocide, different volumetric uptakes were targeted using commercially relevant full cell processes. Targeted volumetric uptakes for the full cell treated samples were 450 L/m^3 and 360 L/m^3. Those targeted for the TRU-CORE copper azole system were 68L/m^3 and 30L/m^3. The concentrations of the copper and azole within the standard and TRU-CORE copper azole solution concentrates were adjusted to meet the minimum retention in the Australian H3 standard. Those requirements specified in AS1604.1 indicate that 2990 ppm of copper and azole is required in the penetration zone. The penetration zone is composed of all sapwood and an 8 mm envelope of the heartwood adjacent to the sapwood. Of this total retention requirement, the minimum allowable amounts of the components are 2571 ppm of copper and 102 ppm of the azole. Identical assay zones for the deepest heartwood and deepest sapwood were taken from the matched samples for each treatment system. For each system, assay zones were extracted from the seven individual samples, ground, combined and homogenized as a uniform single sample. Tebuconazole results (shown in ppm) were obtained using a GCMS under standard azole detection techniques and are shown below in Table 1.

Table 1: Tebucaonazole Values (ppm) in Assay Zones from Standard Copper Azole/Full Cell and TRU-CORE Copper Azole/ Modified Full-Cell

Full Cell	Modified Empty Cell

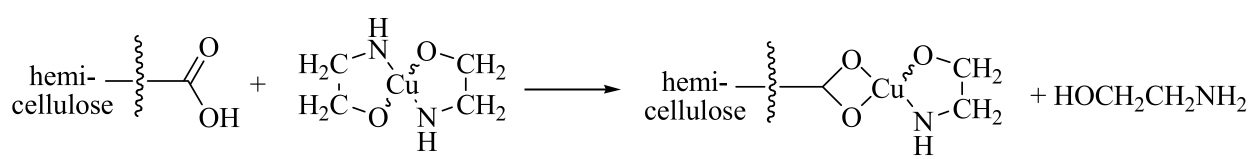
	450 L/m^3	360 L/m^3	68 L/m^3	30 L/m3
Deepest Sapwood	135	102	162	122
Deepest Heartwood	27	16	145	110

The above data illustrates the need for routine analytical verification of penetration of both the copper and the co-bioicde. There is evidence that suggests that the co-biocide is rarely quantified in copper treated wood. Colorimetric "spot tests" are unreliable methods to ensure that ample quantities of the necessary copper are present. Relying on the assumption that the co-biocide is present in analogous proportional quantities to the copper is never recommended. It should be realized that colorimetric tests are used as guides that must accompany sound analytical data.

In addition to "masking" poor penetration of co-biocides, colorimetric indicators for copper penetration are plagued by the chemical limits of the indicators. Namely, they are limited by their critical dependence on the moisture content within the wood. The indicators work by the key organic chemicals forming complexes with aqueous copper cations. These complexes that form are chromophoric in nature, so they produce a drastic color change when compared to that of the parent solution. Historical copper indicators that have been used include: PAN, Rubeanic Acid and Chrome Azurol S. All of these indicators are based in alcoholic solutions. Recently, these indicators have been have been re-characterized by Kop-Coat Inc. for various groups in the forestry industry (Clawson and Ward, 2013).[39] In particular, the detection limits of the various indicators for aqueous copper ions in model aqueous solutions and on wood were republished. When the moisture content of the wood is below 15% there is a significant reduction in the response of the colorimetric indicator to present copper. In some cases, the response is totally absent. Two globally recognized and independent scientists with extensive expertise in polymers, organometallic and transition metal chemistry published the observation of these same results (Dacko, 2013 and Wheldon, 2013).[40,41] These reports and the actual experiments were demonstrated by Kop-Coat Inc. technical personnel to numerous organizations within the U.S., New Zealand and Australia. This service to the industry was performed in an effort to reinforce the importance of routine analytical validation of penetration as part of a proper quality assurance program. This was also in response to recent suggestions made by historical parties in the field of copper pressure treating that the only means to prove penetration compliance against a standard is to utilize these colorimetric indicator tests.

Further reinforcing the importance of not relying on colorimetric tests alone is the fact that the response of the indicator is dependent on the exact species/state of the metal and the surrounding pH of the wood. Again, this was demonstrated by Kop-Coat Inc. and verified by the same independent scientists. Of particular importance was the clear and concise evidence that oxides of copper do not react with colorimetric indicators in the presence of water in model solution studies. This is based on the fact all oxides of copper are insoluble in water and will not dissociate into aqueous copper cations. As previously mentioned, the positive reaction between copper and the indicator can only occur when copper is in ionic, solubilized form or part of a water soluble copper compound. Water must be present to allow the reaction between the copper cation and the indicator. This was also demonstrated and reported in the independent reports by methodically drying down matched wafers of full cell treated standard copper quat Radiata Pine. The parent boards were treated to 300 L/m^3 with a solution whose copper and quat concentrations were tailored to meet the retention target of 3500 ppm of copper and quat for H3.2 in NZS 3640. Once removed from the cylinder, the moisture was higher than the capability of the moisture meter. The sample was then cut into 20 wafers. The saw blade was cleaned in between each cut to ensure no saw blade dragging or contamination. The first wafer was immediately tested for copper penetration patterns using PAN indicator. The sample resulted in a total and complete color change across the entire profile. Though it is recommended that samples be oven dried prior to application of the colorimetric indicator, the common practice that is encountered in the industry is to test in this same manner. The remaining wafers were then slowly dried in a convection oven. With each increment down in moisture, the penetration became less impressive. The wafers at the lower moisture content (21-25%, 16-20% and 11-15%) had a significant reduction in the response of the color indicator. Little to no purple color was evidenced as the trend followed the lower moisture levels, the reduction in robust response. The color formed when the indicator solution was applied on the 11-15% wafer was a burnt orange red that seemed to be nothing more than a composite color of the yellow PAN indicator solution and the green color of the wood. Extensive observation of the stained profile (11-15% moisture) did not reveal any appreciable purple color. This supports the notion that the copper cannot readily be accessed by the PAN indicator due the lack of moisture available to allow the reaction between the indicator and the copper.

The availability of the copper to participate in the aqueous reaction with the colorimetric indicator can also have a significant impact on the response/lack of response of the color change. Specifically, if the copper is bound or has formed into an insoluble complex with key functional groups on the chemical backbone of the wood, it is unlikely to be available as free copper cations that can react with colorimetric indicators. Model studies utilizing unrefined cellulosic pulp confirm that copper becomes fixated to the fibers once added (Norkus *et.al.*, 2002).[42] These studies concentrated on the effect of pH of the treating solutions impact on the resulting copper concentrations remaining in the cellulosic pulp after leaching experiments. These studies mentioned above, in addition to others, show that an insoluble copper precipitate is responsible for the retention of the copper in the wood. Excellent research by Kamden showed how the copper selectively binds to the cellulosic carboxylic acid functionalities by readily displacing a monoethanolamine group (Kamden and Zhang, 2000).[43]



The speed at which this binding occurs is directly related to pH. A higher pH, non-buffered solution will result in the alkaline copper solution more slowly binding to the key functional groups within the wood. Numerous researchers have confirmed this chemistry in earlier and more recent work. All reports clearly illustrate the deposition of water insoluble copper precipitates into wood (Hulme, 1979; Jensen, 1979; Hartford, 1972; Matsunga *et.al.*, 2004).[44-47] These insoluble precipitates are formed as the moisture is diminished and the soluble copper complexes are readily deposited into the wood. This can be facilitated through accelerated drying of alkaline copper treated wood or with processes that impart low levels of water into the wood and allowed to naturally equilibrate. The TRU-CORE system is a prime example of that system. Copper precipitation is the most important copper fixation mechanism of alkaline copper treat wood. Additional research investigated how pH effects the nature of the copper species within the wood from the alkaline copper treating solutions (Lee and Cooper, 2012).[48] The researchers were able to show how high concentrations of alkaline copper solutions require significant pH drops (from the wood acids) to favor precipitation within the wood. This is practically relevant for understanding that low copper fixation is evidenced during wet conditioning/equilibration from high pH treating solutions. The authors were also able to prove through X-ray diffraction analyses that the insoluble copper precipitates that formed within the wood were mixed oxides of copper. Additional researchers have also reported on the conversion and deposition of oxides of copper into wood from the copper ethanolamine complexes (Hoffman *et.al.*, 2003).[49]

Using the TRU-CORE process, complete penetration of the sapwood and heartwood with copper and the co-biocide is accomplished with minimal amounts of water imparted into the wood. The low moisture content in the deepest portion of the wood and the presence of a system buffer that is imparted into the wood create a perfect scenario where colorimetric indicators cannot be relied upon. To date, seven separate plant commissioning studies have been completed showing analytical compliance. In each case, there were reduced responses using colorimetric indicators.

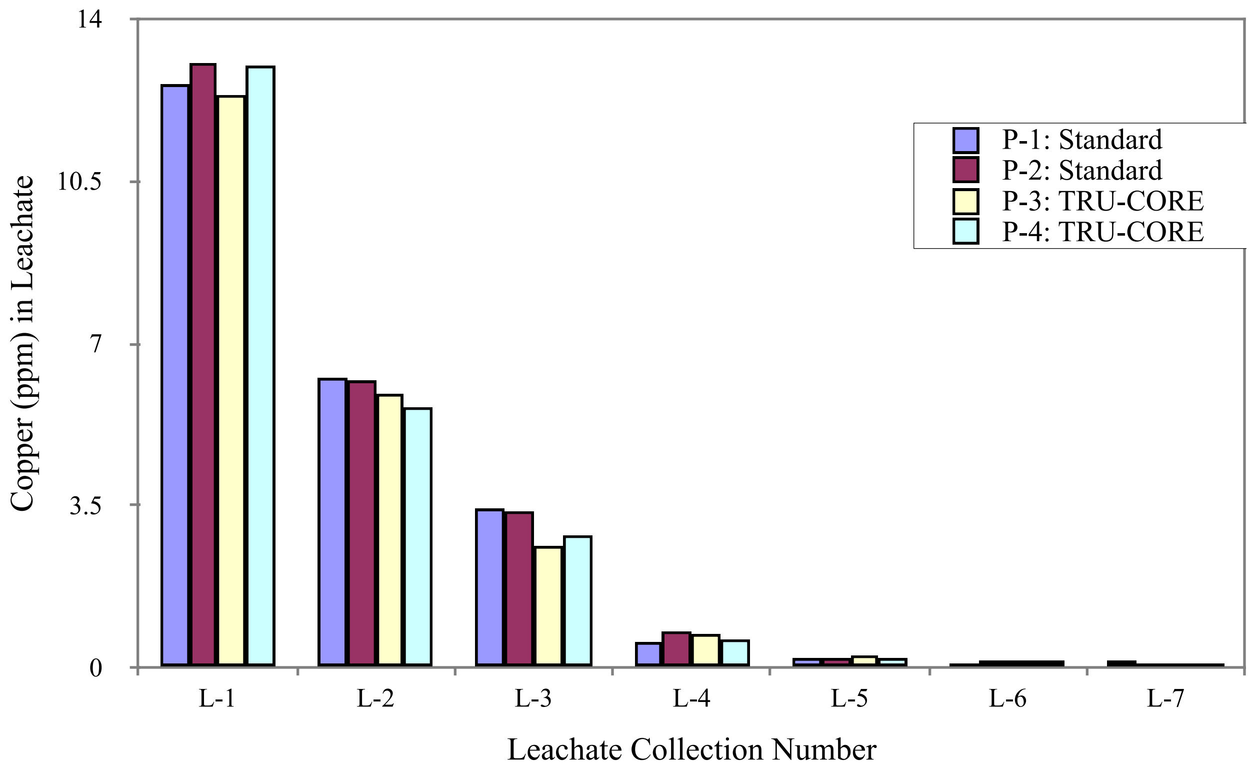
To provide TRU-CORE licensees with a simple and effective means to monitor penetration, Kop-Coat Inc. developed an impressive colorimetric method to quantify copper within any area of the penetration zone. This method utilizes an internally calibrated handheld colorimeter that is pre-programmed with the capability to quantify copper using a standardized packet of a copper reagent. This device and method is utilized by the U.S. Environmental Protection Agency (EPA) to quantify copper in various media. Kop-Coat Inc. utilized this base technology to pioneer the Quantitative Copper Penetration (QCP) test kit.

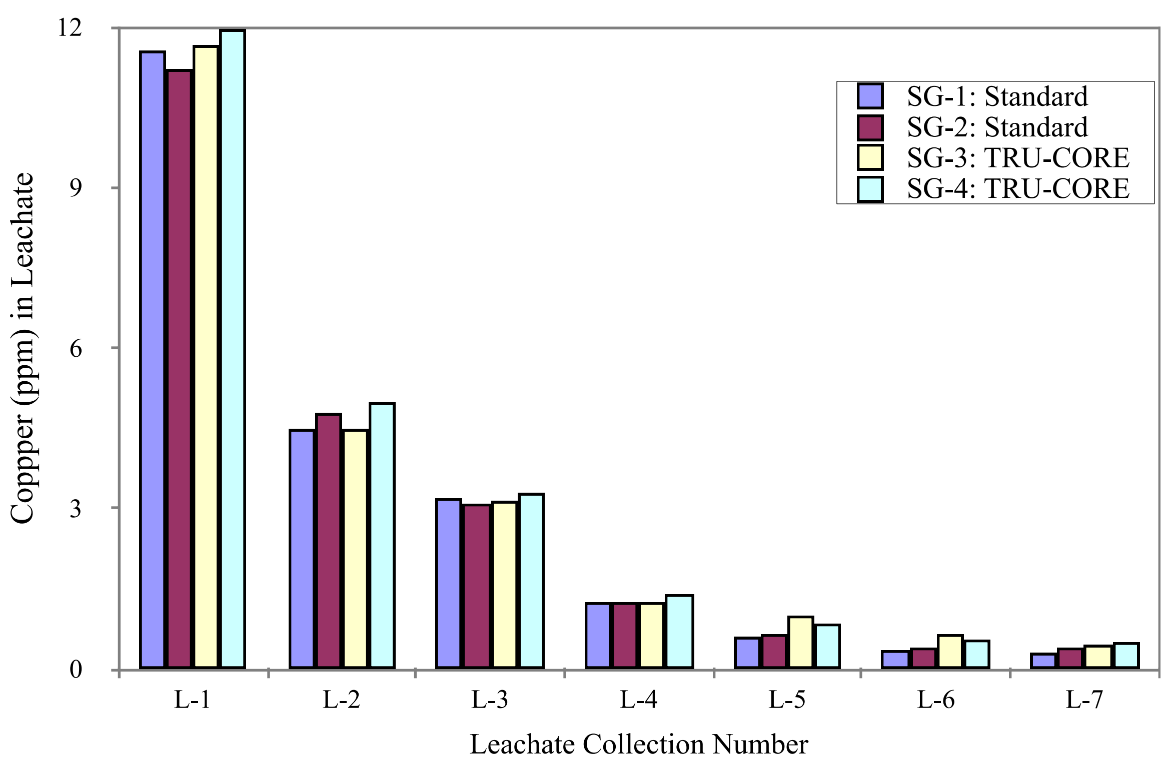
The QCP method involves excising a sample from anywhere in the penetration zone using a boring tool or cleaving from a wafer. The sample is then homogenized using a household chopper. A dilute solution of mineral acid is added to a weighed amount of the ground sample and then quickly digested on a hot plate. This process is essential to solubilize the bound/ insoluble copper species. A small aliquot of this liquid is filtered and then added to a sample cell. The solution is buffered using an acetate solution before adding a commercially standardized packet of copper reagent. The colorimeter then reads the concentration of copper in solution based on the extent of the color. This solution concentration of copper is simply converted back to the concentration within the wood by simple math based on the original and final weight of the sample and the dilution of the aliquot. To ensure that the wood itself does not influence the result from the colorimeter, a species specific untreated control is subjected to the same conditions. The process can be completed in a manner of minutes and has been received with excellent response in the field.

A validation study was completed with matched ground samples being tested using the QCP method and on Inductively Coupled Plasma (ICP) Spectroscopy. The experiment revealed that the QCP is slightly under-detecting copper in the wood by 15-25%. This is expected as the capabilities of the laboratory equipment are vastly superior to those for handheld field instruments. For a field based QA/QC tool, the QCP test kit provides quantitative proof that copper is present in any assay of interest within the penetration zone.

A leaching study of TRU-CORE copper quat treated wood was conducted according to APWA E11-12. The TRU-CORE copper quat was compared to standard commodity copper quat treated wood. In this experiment Ponderosa Pine and Sweet Gum samples were utilized. The pre-conditioned samples were vacuum impregnated with the treating solutions before reconditioning. The leaching solutions were tested utilizing an ICP. The validated method has a reported standard deviation of $\pm$ 4ppm, so the leaching data for the TRU-CORE copper quat and the standard copper quat is identical. The graphical results of the copper detected in each of the separate leachates are shown below in Figure 1. For clarity, P1 and P2 represent the replicate pine groups of sample sets (qty. 4 per set) for the standard copper quat. P3 and P4 represent the replicate pine groups of samples (qty. 4 per set) sets for the TRU-CORE copper quat system. SG1 and SG2 represent the replicate sweet gum groups of sample sets (qty. 4 per set) for the standard copper quat. SG3 and SG4 represent the replicate sweet gum groups of samples (qty. 4 per set) sets for the TRU-CORE copper quat system

Figure 1 and 2: E11-12 Leaching Summary of Standard Copper Quat and TRU-CORE Copper Quat on Ponderosa Pine and Sweet Gum Samples





As is typical with all preservative systems, TRU-CORE copper quat treated samples were placed out in external exposure in a number of countries in 2013. The studies will be reported on in the out years. Because the TRU-CORE copper quat system utilizes established biocide packages incorporated into a system with the synergistic amine oxide adjuvants and borate buffers, the performance of the system is equal to or better than historical systems. This fact was confirmed in laboratory fungal testing using Kop-Coat Inc.'s proprietary K300 28-day Rapid Laboratory Decay Test. As previously mentioned, the severity of this test has been systematically shown to exceed the typical three month standard soil and agar block test methods utilized by various. In this test, matched triple end-sealed, 45x90 mm Radiata Pine samples were pressure treated using standard copper quat treatment solution and the TRU-CORE copper quat solution. Respectively, the volumetric loadings were 325 L/m^3 and 39 L/m^3. The samples were treated to this uptake using a commercial full cell process and Kop-Coat Inc.'s modified empty cell. In each case, the copper and quat concentrations within the treating solutions were adjusted to target the combined copper quat retention of 3500 ppm. The TRU-CORE samples were allowed to dry for 48 h. The high volumetric uptake copper quat samples were carefully dried to 18% moisture in a convection oven to simulate commercial kiln drying. Five (5) mm thick samples were cut from the center of the samples and subjected to the fungal organisms utilized in the K300 test. After 28 days, the TRU-CORE copper quat decking was quantitatively scored at 116% protection (100% scale), while the standard copper quat was scored at 102%. Values greater than 100% indicate that a zone of inhibition has formed around the sample.

Conclusions

The TRU-CORE Wood Preservation System is a chemical-based infusion process to completely transport key wood protecting bioicdes into the wood. The key components of the TRU-CORE system are amine oxides and buffers, which often bring synergistic amplification of efficacy when paired with most modern established biocides. The system may be applied to the wood in a dip, spray or flood application. Because of the low mass pick-up associated with these applications, there is no need to dry the treated articles. Additionally, the TRU-CORE technology has been instrumental in improving penetration in refractory species such as White Oak and Douglas Fir. For larger wood products destined for external exposure/ground contact, the TRU-CORE technology has demonstrated commercial success when durable bioicdes are imparted into the wood through pressure assisted applications. Massive efficiency gains in the pressure assisted treatment of decking materials have been realized as the process is absent of high volumetric uptakes that requires costly drying after treatment. In addition, the use of analytical quality field equipment can provide quantitative proof of the superior treatment associated with the TRU-CORE system. The commercial success of the TRU-CORE system has been proven due to its versatility, ease of use, proven performance, excellent health, safety and environmental profile and cost-effectiveness. The TRU-CORE technology is systematically allowing for the creation of durable wood products that can compete with alternative building materials.

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[2]For clarity, embodied energy is defined as the quantity of energy required to harvest, mine, manufacture and transport to the point of use a material or product.

[3]*Forest Products-Global Group of Eight (G8) Industry Guide*. July 2013. 183 pp.

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PRESSURE TREATMENT OF LUMBER WITH COLOURANT ADDITIVES

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Summary

The market for pressure preservative treated wood containing colourant additives is very much in its infancy. In recent years several colourant products have been successfully introduced into niche markets but broad spectrum acceptance of coloured wood has not taken place. In principle the use of colourant additives with wood pressure treatment formulations provides the wood treating industry with an opportunity to add value to treated wood and, at the same time, the ability to enhance its performance of wood in service. This paper explores some of the challenges associated with the development of colourant technology for pressure treatment applications from a technical perspective.

Introduction

Over the last decade extruded wood plastic composites and 100% plastic wood composites have changed the playing field with respect to consumer expectations of the colour, aesthetics and weathering characteristics of residential decking products. These new "high technology" products have provided consumers with colour options that were not historically available with pressure treated lumber which, even today, is typically green in colour due to the wide spread usage of water-borne copper based preservatives such as CCA, ACZA, ACQ and copper azole. In treated wood circles "green" has become synonymous with durability and quality. In fact, the colour green has become so pervasive and accepted by consumers that it is generally believed, especially in the south east U.S. pine markets, that if wood is not "green" it will not last and the darker the "green" is the longer it will last. Given that, one might have expected that the developers of composite decking would have considered bringing green coloured wood/plastic or 100% plastic composites to market but that does not seem to have been the case. At times it seems that every colour but green is an option. Undoubtedly the wide range of colours available in wood plastic composites has contributed to some loss of market share away from traditional treated lumber. Logically the availability of pressure treated wood in colours other than green might be a way to reclaim that market share.

While it is fair to say that the North American market for treated wood pressure impregnated with colourant additives is in its infancy, in some regions, for example Canada, the U.S. West Coast and in Colourado the market is relatively mature. Historically, in those markets, old growth western red cedar and redwood are generally considered more durable and aesthetically pleasing with better weathering characteristics than wood pressure treated with copper based preservative systems. Enterprising wood treaters have long been in the business of reproducing the natural colours of cedar and redwood with a variety of pre-stain technologies. More recently the idea of using colourant additive technology for the pressure treatment of lumber at the same time as the preservative treatment has surfaced. In many ways it represents a natural extension of industry efforts to counter the effects of weathering with water repellant/stabilizer technology and by so doing to enhance the aesthetics of treated wood in service.

This paper reviews the opportunities and challenges associated with the use of colourant additives for wood pressure treatment from a technical development perspective.

Options Available for Colouring Wood

A wide variety of film forming paints and penetrating stains applied by brush or spray are available to DIY practitioners and/or contractors for the colouration of wood. Typically such products are applied to the upper (visible) treated wood surfaces after the structure is fabricated. The exercise is somewhat labor intensive but in general requires minimal skill well within the average homeowners' level of expertise. Many colour choices are available to the homeowner but unfortunately the "beauty" is only surface deep and in a relatively short time frame wear patterns can develop from foot traffic. Film forming coatings often split and peel and, when they do, preparation for recoating can be problematic and time consuming.

A more durable colouring option that has been very successful on the U.S. West Coast is the use of "factory" pre-coat stains prior to the pressure treatment process. Redwood brown tone pre-stain (Photo 1) and Cedar tone pre stain for Douglas fir and hem-fir lumber (Photo 2) have been popular. Generally speaking pre-stain colourants are very uniform in appearance but that same uniformity leads to the loss of some wood aesthetic characteristics such as grain pattern etc. The application of pre-stain by machine spray is a simple if not messy process (Photo 3). In addition, since the pre-stain is essentially a surface coating, wear patterns from foot traffic can be an issue over time (Photo 4). Pre-stain options also create cost and handling issues for wood treaters as units of lumber need to be separated and restacked prior to treatment. There is also significant potential for negative impacts on preservative penetration into already refractory wood species

Photo 1: Incised Douglas fir pre-stained to intended to resemble redwood and then treated with copper azole

Photo 2: Cedar tone pre-stain with ACQ treated Hem-fir

Photo 3: Typical configuration of pre-stain spraying equipment.

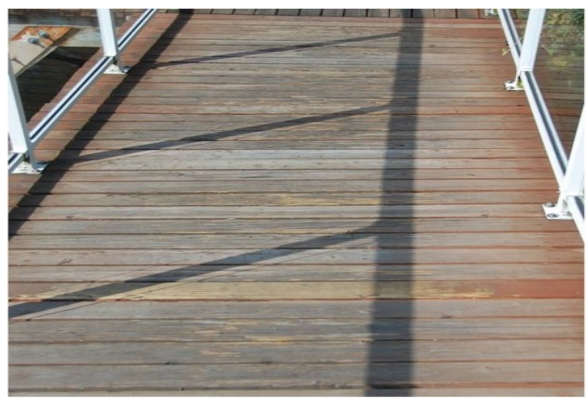

Photo 4: Pre-stain decking showing track wear patterns from foot traffic.

Pressure treatment with a colourant additive included as part of the treating solution potentially provides the treater more flexibility over pre-stain approaches to colour but there are some significant issues to consider. First and foremost there has to be consideration of whether or not to use a one step or two step treatment process. Chemical compatibility of the colourant system with the preservative formulation being used is critical to a one step process. For obvious reasons the colourant and the preservative formulation must be mixed. Components that are incompatible, for example an acid based dye system and an alkaline wood treatment solution, would likely lead to solution fall out. Compatibility is also important to two step processes as some mixing of the solutions is inevitable but the issue is less of an problem. However, a two step process involves extra treating time and that can lead to increased treating cost particularly in a high volume, short treatment cycle pine plant. In addition, deep impregnation of a colourant into wood "wastes" the colourant because it is needed primarily on the surface of the wood.

Somewhere in the decision making process a fundamental question that must be addressed is what colour to choose. There is no simple answer to that question and regional differences can play an important role in the decision. One might think that the range of colours available should be vast but in practice the number is quite small. Many of the available colours do not effectively cover up the green "hue" arising from the use of copper based preservatives. In addition, availability of "spare" work tanks at treating plants severely limits the number of colours that can be used.

Colourant Types

Three main types of colourants are available for the colouring of wood using pressure impregnation processes. Those colourants include water soluble dyes, organic pigments and inorganic pigments. Water soluble dyes impart a significant amount colour at relatively low concentration. They tend to be inexpensive, yield uniform coverage of natural blemishes and defects, bright and provide a significant "wow" factor at the point of sale. Water soluble dyes suffer one significant defect in that they fade rapidly after exposure to sunlight.

Organic pigments generally provide better light fastness than dyes but they are still susceptible to UV degradation. Costs can vary widely from low to very high and light fastness is generally directly proportional to cost. There can be formulation problems with quaternary ammonium compound containing preservative systems and uniform penetration of colour into packs of lumber can be an issue.

Inorganic pigments made from metal oxides of tin, lead, cadmium, titanium, chromium, cobalt, molybdenum and iron provide a wide range of colour possibilities but the iron oxide family is generally most applicable to wood. Iron oxides can be readily milled down to sub micron particle sizes desirable for treating wood. As a rule of thumb a particle size in the range 200-500 nm is desirable for wood pressure treatment applications. If iron oxide is milled too small the particles have a tendency to become "transparent" and relatively high concentrations of pigment are required to achieve significant colour saturation. Large particle sizes above 1 micron have a tendency to fall out of solution and are difficult to formulate into a stable dispersion. Instability and settling can be addressed through recirculation and agitation systems in treating plants but the optimal solution is a stable dispersion.

A combination of water soluble dye and inorganic pigments has the potential to provide the best solution. The dye component provides colour uniformity and the "wow" factor at the point of sale. As it fades in service there is a transition to the pigment colour and, if the combination is chosen well, the colour transition is seamless and thus acceptable to the consumer.

Wood is of course a naturally variable biological material and in fact much of the allure of wood and wood products is due to its variability in appearance due to heartwood sapwood colour differences, growth rings and defects. That inherent natural variability leads to colour variations from one piece of wood to another and within the same piece of wood. Colour variations can develop from the use of different treating cycles, different colourant concentrations, as a result of different base preservative systems being used, pre-existing discolourations from stain and mold, "sun burn", sticker marks and corner protectors, strapping and uneven penetration into tight bundles among other things (Photos 5-9). Such factors represent challenges to a wood treater attempting to produce a uniform consistent product but they are not insurmountable.

Photo 5: Colour variations with wood treated with a brown pigment dye system associated with heartwood/sapwood and species differences

Photo 6: Colour variation in southern pine pressure treated with a pigment system. Column1 from left Modified full cell cycle, Column 2 Short press time, Column 3 extended press time and Column 4 full cell cycle

Photo 7: Colour variation in untreated southern pine associated with "sun burn". The light coloured corner was protected from exposure to the sun by a plastic placard.

Photo 8: Colouration due to "sun burn" in lumber pressure treated with brown dye/ pigment formulation

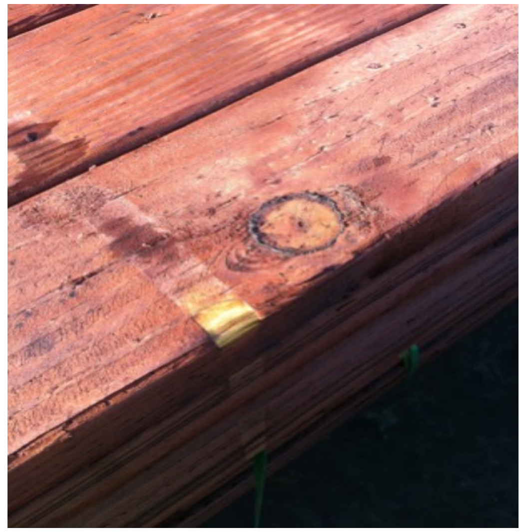

Photo 9: Colour variation associated with tight banding and corner protectors

Quality Control

Quality control can be important for controlling colour consistency and fortunately the concentration and the colour intensity provided by dyes and pigment can be determined using spectrophotometric methods of absorbance at a specific wavelength (Figure 1) and iron oxide concentration in solution can be readily determined using x-ray fluorescence techniques (Figure 2).

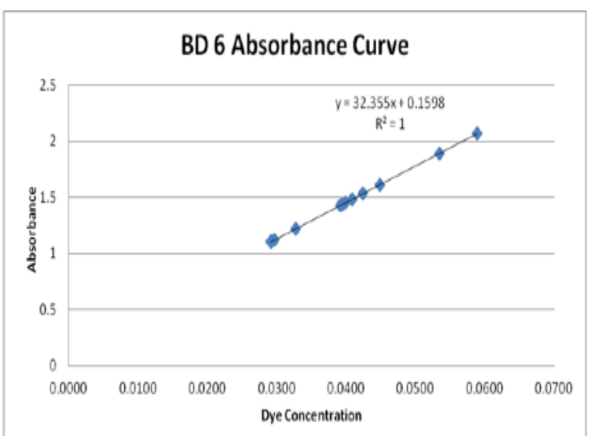

Figure 1: Absorbance concentration curve for a brown pigment dye system.

Figure 2:

Product performance

It is often stated that beauty is in the eye of the beholder and with respect to colourant treated wood that is certainly true. Perceived product performance is closely associated with light fastness and customer expectations of that attribute can vary widely. Common questions from customers are how long will the colour last and when will I have to recoat or rejuvenate the colour of my deck or fence? There is no simple answer to either question as it depends on many factors such as where the structure is installed and whether or not it is in a vertical or horizontal configuration. It does however beg the question of how colour fastness be tested and how changes in colour can be objectively measured on a consistent basis.

The simplest way to address the testing question is to conduct outdoor weathering trials examining colour changes over time, but where should one test and for how long? At least two global bench mark outdoor test sites are recognized in North America, Central Florida and Arizona. Private testing companies operate test facilities at both locations and it is possible to have those organizations evaluate sample materials using a variety of exposure configurations on a fee for service basis. It is however a simple exercise to evaluate the performance of colourants in treated wood where ever there is the space to set up an outdoor test. Viance has a adopted a number of vertical fence test configurations as well as horizontal decking arrangements at its Harrisburg NC plant manufacturing location as Photos 10- 12 illustrate.

Photo 10: Vertical fence panel test in Harrisburg, NC illustrating a range of different colourant systems at the time installation.

Photo 11: The same fence panel test after 43 weeks exposure. The small samples in the bottom left corner of each group are unexposed retains to illustrate the change from the original colour. It can be readily observed that some changes are quite pronounced.

Photo 12: An alternative design vertical fence test located at the Viance manufacturing facility in Harrisburg, NC. The upper photo represents the samples at the time of installation. The lower photo after four weeks exposure. Note the small unexposed retained sample in the bottom left corner of each series of pickets. Even after 4 weeks, changes in the different samples are self evident.

New

After 4 weeks

A criticism of outdoor weathering tests is that they take too long to produce meaningful data. Marketing people and customers alike seem to have a need for instantaneous gratification with regard to colour longevity. The development scientist/researcher resorts to accelerated testing to find the answers. Quite a wide variety of techniques are available most having been developed for materials testing in the automotive and paint industries (e.g. ASTM D6695 and ASTM G113). Several standard methods using QUV chambers or accelerated weather-o-meters have been adapted from other industries to test wood products. Such devices utilize different types of high intensity xenon-arc lamps with spectral characteristics of natural sunlight coupled with water sprays and heating and cooling to simulate and accelerate weathering processes (Photo 13 and 14). A common problem with these type of approaches is that the biological component (stain and mold fungi) associated with wood weathering in a natural environment is missing (Compare photos 15 and 16).

Photo 15: "Unnatural" bleached appearance of untreated southern pine weathered in a Xenon arc weather-o-meter for 2000 hours.

Photo 16: Typical "graying" of wood in-service associated with the growth of mold and stain fungi. These fungi are absent in the weather-o-meter environment hence the radical difference in appearance.

The primary components of weathering are light, moisture and heat. The more the accelerated test procedure alters any of those factors from the natural condition the more likely it is that the accelerated weather testing will produce results that differ from real world exposure. Relativity of performance under accelerated conditions to real world performance is an important consideration. In particular how long does 'X' hours in an accelerated testing machine represent in the real world. This brings in to play the concept of the acceleration factor defined as Time (outdoors)/Time (accelerated). There are few definitive studies comparing accelerated weathering studies of wood to natural outdoor exposure (Ratu, 2009). The few studies that have been conducted report acceleration factors in the range of 10-20 X but it depends on where the comparisons are made. In our own laboratory we have adopted 2000 hours as a useful duration for accelerated testing. Of course arithmetically 2000 hours equates to 83 days but the sun does not shine 24 hours a day. Estimates of the number of sunlight hours a day averaged over a year can be surprisingly low and of the order of 5-6 hours a day. Using a conservative 10 x acceleration factor 83 days = 830 days or 2.3 years. Using a 15x factor the accelerated exposure testing equates to 3.4 years in outdoor exposure. While the relativity of the accelerated tests to natural exposure conditions can be debated performance comparisons among different treatments over time can provide interesting results. For illustration purposes Photo 16 shows changes in appearance of southern pine pressure treated with a non metallic preservative system with and without a brown pigment colourant formulation exposed in an accelerated weather-o-meter for up to 2000 hours.

Photo 17: Accelerated Weather-o-meter exposure of southern pine pressure treated with a brown pigment colourant for different exposure times up to 2000 hours.

Photo 17 reveals changes in appearance of hem fir and Douglas fir pressure treated with ACQ containing a brown dye/pigment colourant formulation and exposed in an accelerated weather-o-meter for up to 2000 hours. Comparisons can be made with the performance of brown pre-stained Douglas fir for the same length of time.

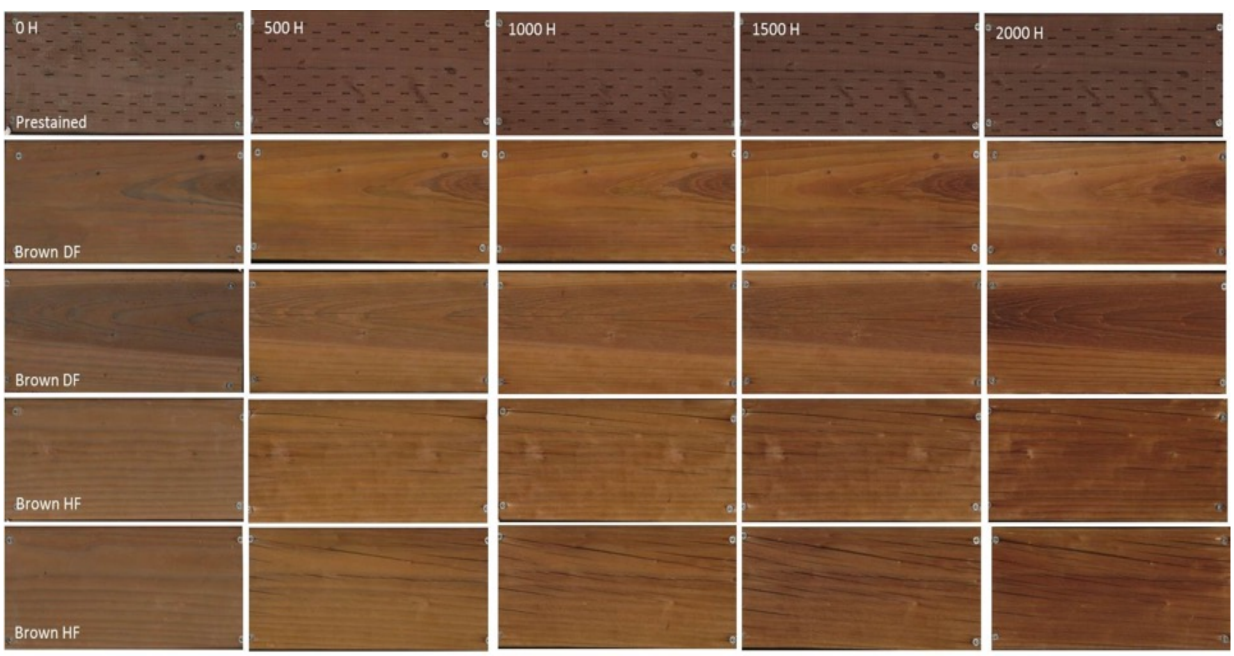

Photo 18: Accelerated Weather-o-meter exposure of Hem fir and Douglas fir pressure treated with a brown pigment/dye formulation at different exposure times up to 2000 hours.

Objective measurement of colour change

Clearly Photos 17 and 18 illustrate differences in colour among treatments and wood species over time but how does one objectively quantify the observed differences. Colour perception by humans varies widely but equally importantly colours look different in different lighting e.g. bright sunlight as compared to artificial light, dawn versus dusk, summer versus winter, vertical orientation versus horizontal configurations and so on. Colour relativity to the original colour at the time of purchase or to the colour at the time of installation is an important comparison. This is especially true if and when performance warranties are part of the picture.

It is possible to quantify colour and colour changes using the three component theory of colour vision. With the exception of some colour blind individuals the human eye possesses three receptors for three primary colours red, green and blue. All colours are seen but most importantly they can be expressed as combinations of the three primaries. By convention colours can expressed using the CIELAB system or L* a* b*. The three coordinates of CIELAB represent the lightness of the colour (***L**** = 0 yields black and ***L**** = 100 indicates diffuse white), its position between red/magenta and green (***a****, negative values indicate green while positive values indicate magenta) and its position between yellow and blue (***b****, negative values indicate blue and positive values indicate yellow). Since the *L*a*b** model is a three-dimensional model, it can only be represented properly in a three-dimensional space (Figure 3). Fortunately these measurements can be obtained using a simple, inexpensive and portable colourimeter (Photo.18). Most of us are familiar with this type of instrument but probably do realize it. Similar technology is used by paint stores to colour match paints and stains.

Photo 19: An example of a portable colourimeter unit

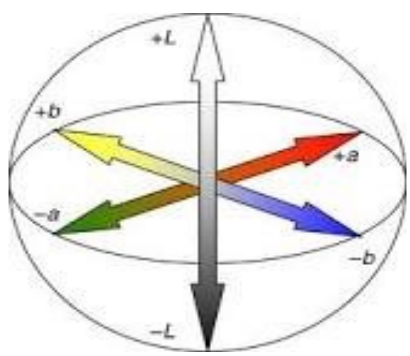

Figure 3: Three dimensional representation of the L*a*b* model. Changes in colour, intensity (saturation) and hue can be plotted in the three dimensional space effectively removing subjectivity from colour measurement.

In the Viance development laboratory we are just beginning to evaluate the value of the technique for measurement of colour change in naturally weathered wood and wood weathered under accelerated conditions. Some preliminary results comparing L*a*b* values for matched samples of colourant treated wood exposed in the weather-o-meter and in a natural outdoor environment are illustrated in Photo 20 below. In this instance the relative L* a* b* values obtained for the test samples before exposure and after exposure in two different environments were converted to actual colours using Adobe® Photoshop®. Photo 20 reveals that the colour of the test samples have changed from the initial colour at the start of the test in both exposure environments and that the change in colour differs from one exposure to the other. The significance of the results at this preliminary stage is not clear.

Photo 20: Preliminary results showing relative L* a* b* colour representation of matched samples of wood pressure treated with a colourant before exposure, after exposure outdoors and after exposure in an accelerated weather-o-meter.

Finally our testing program is considering options for wipe testing, abrasion/rub off testing, colour tracking from treated wood to other surfaces, wear patterns and the remediation of weathered coloured wood. It is hoped that the results of those assessments can be discussed at a later date.

Summary

In summary, the product development process for wood pressure treatment colour additives has been a learning experience and it is definitely a work in progress. It is clear, based on on-going testing, that colourant additives have the potential to improve the weathering characteristics of wood in service. It is also true that colourants have the potential to provide new opportunities for the treated wood industry to compete successfully in the marketplace. While it is unlikely that coloured pressure treated wood will dominate the market there are definite value added niche opportunities for coloured decking components.

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CHEMISTRY OF COPPER PRESERVATIVE TREATED WOOD

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Summary

The reaction chemistry of micronized copper wood preservatives is fundamentally different from any previous inorganic preservative system. In order to study the chemistry analytical procedures had to be developed which allowed the determination of the amounts of total copper as well as the copper which reacted with the wood forming copper-wood complexes. With the success of this approach it also became possible to examine conventional amine copper treated wood and measure the amount of precipitated copper carbonate formed during the "fixation" process. As part of the ongoing study of micronized copper treated wood, the impact of soil exposure on the changes in the total copper and reacted copper in stakes removed from slices from red pine 4 x 4's was studied. A water treatment was carried out on the sawdust from the recovered stakes following the initial measurements, in order to measure the pH changes in the wood during the soil exposure. The effect of this water treatment on the total copper and reacted copper remaining in the sawdust was also assessed.

Introduction

Waterborne preservatives have a long history. In 1770 Sir John Pringle published the first list of wood preservatives in the U.K. and further lists were published in 1810 in the Encyclopedia Britannica. Three of the most common preservatives were copper sulphate, mercuric chloride and zinc chloride. The main problems with these simple metal salt based preservatives were, high leachability, low resistance to tolerant fungi and in the case of the mercuric chloride high toxicity. However, the use of metal based preservatives continued to evolve and formulated compositions were introduced in the mid-1900's. Two of the most successful in North America were ammoniacal copper arsenate (ACA) and chromated copper arsenate (CCA). These formulated products when placed into wood underwent a chemical "fixation" process that made the treated wood resistant to chemical loss through leaching (Hartford, 1973). In 2003 the North American industry agreed to limit the use of arsenic based preservative for the preservation of wood treated for the residential market. In its place pressure treatments based on amine-copper were widely adopted (Ruddick, 2007). The two most successful were alkaline copper quaternary ammonium compound (known as alkaline copper quat and designated as ACQ) and alkaline copper triazole (known as copper azole and designated as CA). In the last decade a new preservative system has been commercialized which is based on a completely different concept. It uses micronized particles of a copper compound which are dispersed in water together with a co-biocide such as didecyldimethylammonium carbonate or tebuconazole. Such mixtures are similar to the amine copper formulations. However, their chemistry is markedly different (Xie, Kennepohl and Ruddick, 2012).

Fixation of ammoniacal copper preservatives

The fixation chemistry of ammoniacal copper preservatives has been widely studied. Initial discussion of ACA erroneously referred to ammoniacal copper arsenite, since arsenic trioxide was use in its manufacture. At the treating plant the ammonium hydroxide solution which contained basic copper carbonate and the arsenite, was stirred while passing air through the hollow stirrer. However the exothermic reaction which took place in the solution resulted in the oxidation of the arsenic, (Ruddick and Mathur, 1976). The fixation chemistry was controlled principally by the loss of ammonia from the treated wood, leading to the formation of diamminocopper-wood complexes which were resistant to leaching. However, because of the relative excess arsenic content, copper arsenate precipitate was also formed. The tetramminocopper cationic complex present in the treating solution was very reactive to phenolic protons present in wood, leading to side reactions with phenolic based extractives. One of these caused a black coloured product with taxifolin in Douglas-fir causing the treated wood to be almost black in appearance (Ruddick and Xie, 1994). This was a significant factor in why ACA was not commercialized for the treatment of residential products.

Fixation of amine copper preservatives

The fixation of amine copper preservatives in wood has also been widely studied. Unlike ammonium hydroxide, monoethanolamine has a high boiling point and so fixation is not initiated by loss of solvent. Instead the basic amine undergoes an acid-base reaction with the acidic protons present in wood. Lee and Cooper (2010) demonstrated clearly that amine solutions, have an ability to react with the carboxylic acid protons and phenolic protons. From their cation exchange capacity measurement it is possible to determine the exchange capacity of each of the acid functionalities.

Comparing the reaction chemistry of conventional amine copper and micronized copper solutions

In general all previous inorganic salt based aqueous preservatives contained similar overall chemical reactions. The wood was treated with solutions containing the solubilized copper. When this solution reacted with the wood three product streams resulted. The first was the targeted product of a copper wood complex, which resisted leaching during use of the treated wood and protected the wood from biodegradation. The second was unreacted copper solvent complex which remained mobile in the treated wood and could leach during service. The third product stream was a precipitate, usually of copper carbonate (unless alternative more insoluble copper products such as copper arsenate or copper dithiocarbamate were chemically favoured). This was insoluble and would reside in the treated wood. Here the acid base reactions occurring are important in fixing the copper preservative in the wood. It is possible for other chemicals in the formulation to compete with these reactions of copper. A good example of this is the cation exchange of quats in ACQ.

The chemistry of micronized copper preservatives is diametrically opposite to that of the typical copper preservatives. In micronized copper solutions, the copper remains insoluble. The acid base reactions which take place in wood are needed to solubilize the copper, free up reaction sites and complex the copper, rendering the copper treated wood leach resistant and protecting it from decay. The unreacted copper carbonate remains in the wood and because of its low solubility in water, is leach resistant in service.

So in all of these reactions the end result is a) the formation of stable copper wood complexes; b) some unreacted copper; and c) some precipitated copper. The key difference is that for amine copper systems the unreacted copper left in the wood is soluble while the unreacted copper in the micronized copper is insoluble copper carbonate.

For the micronized copper solutions, the carboxylic acid protons are important for solubilizing the copper and from the research of Lee and Cooper (2010) it may be calculated that about 0.3 % Cu should be produced under optimum conditions in softwoods.

In order to study the reaction products formed in micronized copper treated wood it was necessary to develop a protocol for distinguishing between the basic copper carbonate and the reacted copper. This was achieved through a combination of x-ray fluorescence spectroscopy (XRF) and electron paramagnetic resonance spectroscopy (EPR). The former measures the total copper present in a sample, while the latter measures only the copper present in a paramagnetic species. While this is most copper complexes, a notable copper species that can't be detected by EPR is basic copper carbonate because this compound is antiferromagnetic. Since the interaction of the paramagnetic copper with the applied magnetic field is influenced by the geometry and bonding of the copper species, information on the type of copper complexes formed can be gained.

An indirect benefit of the development of the ability to speciate the copper in micronized copper treated wood, was the ability to examine the reaction products in other copper systems. When this was done for amine copper treated wood, the higher XRF results compared to the EPR values, confirmed that basic copper carbonate which is EPR "silent" was being formed as a reaction product in significant amounts.

The question then arose, that since all of the simple metal based systems produce a precipitated product in the treated wood, what is its role. More recently Freeman and McIntyre have discussed this under a "reservoir effect" (Freeman and McIntyre 2013). However, if the precipitated copper is to act as a reservoir, it must be activated when needed. The question that arises, is how is this activation achieved?

To address this question a number of studies were undertaken for micronized copper treated wood. In the first micronized copper quat (MCQ) treated red pine "4 x 4" fence posts were sampled to produce surface slices. These were then further cut up to produce matching small stakes (with a thickness of about 3 mm). Care was taken to remove areas associated with knots or other defects. The stakes were then buried full length is soil in small basins. The soil characteristics for one study are shown in Table 1.

Table 1. The soil characteristics for the exposure of stakes in soil 1.

pH	Total OM (%)	Total N (%)	Avail. Cu (ppm)	Avail. Fe (ppm)	Sand	Silt	Clay
5.0	15.3	0.33	1.5	38	68 %	21 %	11 %

At time intervals of 2, 4 and 8 weeks samples were removed. The samples were cleaned to remove surface soil and then oven dried before being ground to 40 mesh sawdust. They were analyzed for total copper using XRF and for reacted copper using EPR (Xue, Kennepohl and Ruddick, 2013). The results are shown in Figures 1 and 2. In addition, the pH of the exposed wood was measured using the method of Vidrine et al., 2010. The sawdust was then dried and examined again by XRF and EPR, to determine total and reacted copper following the "leaching" behaviour when the sawdust was ultrasonicated for the pH measurement. These data are also shown in Figure 3. From the data the exposure of the MCQ treated stakes in the soil caused a gradual loss of total copper during the 8 weeks of exposure (Figure 1). The application of the leaching regime did not cause any further leaching of total copper. This is hardly surprising since the soil was in excess of 50% moisture content, so that any leachable copper would have been lost. The reacted copper is shown in Figure 2. It increased with increasing exposure time from 0.10 % Cu initially to almost 0.23% Cu after 8 weeks. It is possible to assign the increase in reacted copper to reaction of the humic acid in the soil (Cooper et. al., 2001). However, other experiments in which stakes were vacuum impregnated with water and kept submerged in a static leaching regime for 12 weeks also showed an increase in reacted copper. This suggests the potential for movement of the micronized copper carbonate in the wood when it is wet. This would enhance the reacted copper content due to optimization of the reaction with wood carboxylic acid functionalities present in wood. It is however, also possible that the reaction in soil was assisted by the mobile water soluble acids present in the soil.

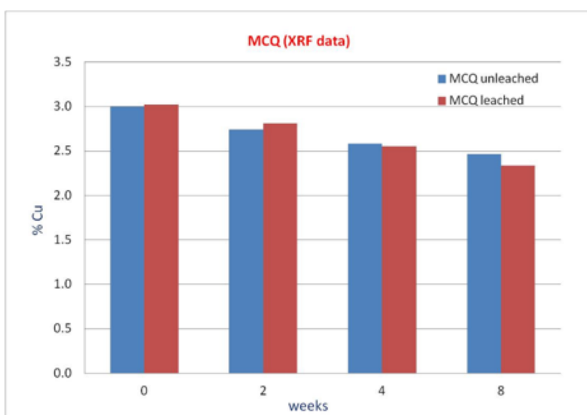

Figure 1. The change in total copper content (Cu % by mass) in MCQ treated stakes after 0, 2, 4 and 8 weeks exposure

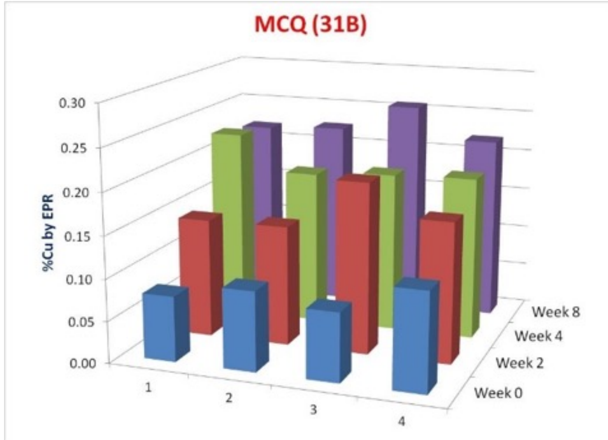

Figure 2. The change in reacted copper content (Cu % by mass) in MCQ treated stakes after 0, 2, 4 and 8 weeks exposure

The impact of leaching to measure the pH changes in the sawdust after soil exposure of the stakes was large. To check whether the ultrasonication was responsible, additional leaching studies without ultrasonication were carried out. They too showed an increase in the reacted copper content. It is suggested that this combination of drying and wetting of the sawdust after soil exposure allows micronized copper carbonate to continue movement in the wood cell structure, resulting in a maximizing of the reaction with the carboxylic acid functions in the wood. The role of humic acids in assisting the further reaction of the micronized copper carbonate cannot be discounted although the maximum reacted copper is similar to concentrations found in earlier sawdust experiments where no soil exposure had taken place.

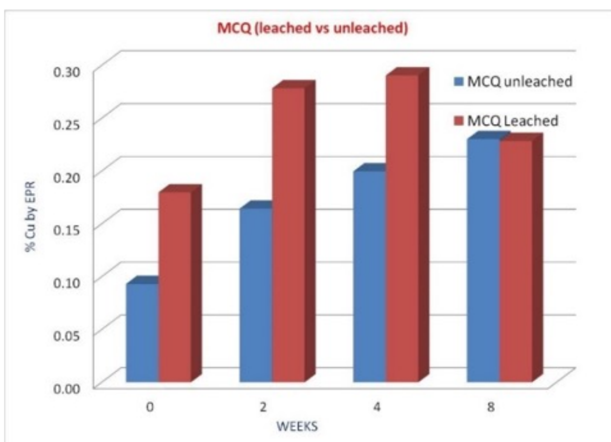

Figure 3. The change in reacted copper content (Cu % by mass) in MCQ treated stakes after 0, 2, 4 and 8 weeks exposure and leaching (Vidrine et al., 2010)

Impact of fungal colonization of wood prior to treatment

Recently, experiments were reported in which controlled exposure of spruce (*Picea* sp) wood to a white rot fungus *Dichomitus squalens* prior to treatment with amine copper and micronized copper solutions, (Morris, Dale and Symons, 2012). The study showed a significant improvement in preservative uptake and penetration. Sawdust samples of the bioincised and control material were treated with micronized copper solutions. The results for micronized copper azole (MCA) are shown in Figure 4. The amount of reacted copper significantly enhanced the reacted copper content to almost 0.25%. Nevertheless this is similar to the concentrations that can be achieved in sapwood under optimum conditions. So it is unclear whether the presence of the fungal byproducts of the decay process can increase the reacted copper concentrations.

Future research

Perhaps one of the most important factors impacting the reaction of the precipitated copper in treated wood is the colonization of the treated wood by fungi. A research project has been initiated to examine this aspect, incorporating, mould fungi, brown rot, white rot and soft rot fungi. It is known that copper tolerant brown rot fungi can release acids to mobilize and complex with the copper. An EPR study with copper chemicals has been reported by Humar et al., 2002 which showed the production of oxalic acid by some brown rot fungi with the formation of copper oxalate which is EPR silent.

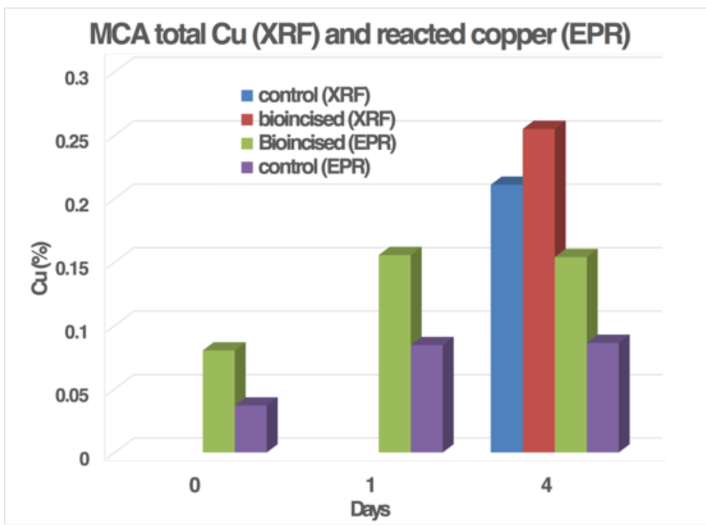

Figure 4. The change in total and reacted copper content (Cu % by mass) in MCA treated spruce blocks following bioincising compared to unincised controls

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ACZA: UPDATE ON A VERSATILE WOOD PRSERVATIVE SYSTEM

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Summary

ACZA and its predecessor, ACA, have been used for treatment since 1935. Most commercial treatment has been using Douglas fir for a wide variety of above ground, ground contact, fresh water and salt water applications. ACZA represented an improvement of the earlier formulation with respect to efficacy, leaching and appearance. Thirty years of commercial production, long term field tests and laboratory fungal and termite tests have demonstrated the efficacy and performance of ACZA treated wood. Recent approval by AWPA for use in railroad crossties has resulted in considerable new testing and initiation of new field studies to monitor long term performance. Solution corrosion, wood corrosion, conductivity, spike holding and strength properties are shown to be in line with wood treated with other preservatives. Fire retardant properties are improved by use of ACZA. Treatment is in all cases as good, or in the case of white oak, somewhat better than traditional creosote. Life cycle analysis showed that the environmental impact is less than that of competitive materials. The performance of ACZA treated wood can be enhanced by the addition of borates to provide protection beyond the depth of the ACZA penetration in refractory species and secondary treatments can be added to improve the surface properties and climbability of ACZA utility poles.

1. Introduction

ACZA is a reformulation of the original Ammoniacal Copper Arsenate (ACA) preservative. ACA was developed by University of California researchers in 1924 to 1926. Its ability to treat refractory species of wood, including easily decayed species such as white fir led to the first commercial plant being built in 1935. The Chemmonite® trade name associated with ACA and later ACZA treated wood was formerly owned by the J.H. Baxter Company and sold to Arch Wood Protection 2007.

ACZA is somewhat of an anomaly in wood preservatives. Although a waterborne, it is treated hot, has a distinctive ammonia odor and is commonly used for treatment of refractory species for industrial applications which is otherwise a market for oil-borne preservatives such as creosote and pentachlorophenol. However, like a traditional water-borne preservative ACZA reacts to become relatively immobile in the wood; as the ammonia gases off it leaves a relatively insoluble precipitate in the wood.

Between 1941 and 1942 over 180,000 Douglas fir and white fir crossties were treated with ACA at gauge retentions below the currently approved AWPA assay retention of 0.40 pcf. After 7 to 9 years of exposure, only 1.1% of these were removed due to biological attack as shown in Table

1. It was reported at the time, that many of these were older ties that had decay prior to treatment, contributing to their premature failure.

Table 1. Service Record of ACA Treated Crossties

Species	Avg. Gauge Retention	Quantity (State)	Year of Inspecti on	Years in Service	Removed for Decay or insects	% Removed Decay/ Insects
White & Douglas Fir	N/A	297 (CA)	1945	9	4	1.3
	0.15	180,000 (CA)	1945	Up to 9	2,000	1.1
White Fir	0.15	51 (CA)	1945	7	0	0
Douglas Fir	0.30	50 (WA)	1945	8	0	0
Douglas Fir	0.30	45 (WA)	1945	8	0	0
Totals		180,443			2004	1.1

Data from *Chemonite Its History and Development*, AWPA Proceedings, 1947

In the 1970's research led to an improvement of the formula ACA formula which resulted in 50% of the arsenate being replaced with zinc oxide. A complete data package for the current ACZA formulation with a 2:1:1 ratio of copper to zinc to arsenate was submitted to AWPA and approved in 1983. It has had listings for treatment of many industrial wood products in both AWPA and CSA since that time. It is registered with both EPA and PMRA.

ACZA represented an improvement in efficacy and corrosion characteristics while reducing the leaching and environmental impact of the preservative. Another recent improvement is the conversion from a "mix your own" preservative at treating facilities to a delivered, liquid concentrate. This resulted in reduced worker exposure, greater ease of use and better product consistency.

In recent years ACZA has been revived with new applications and methods for treatment of ties, utility poles and other products. New applications for Douglas fir, southern pine and hardwood crossties have been approved in AWPA standards. As the applications for ACZA have expanded, especially into railroad crossties, many new evaluations have been conducted or are underway. These include efficacy in hardwoods, corrosion, conductivity, spike holding, fire retardancy and strength properties. Test treatments have been conducted with and without the addition of borates and ET oil emulsions.

2. Laboratory Efficacy Tests

How well a preservative protects wood from decay or insect attack is important in determining its potential uses, particularly for the protection of wood in heavy duty industrial applications. ACZA has a proven ability to protect a variety of hardwood and softwood species.

1. Termite and Carpenter Ants

ACZA further protects wood from difficult-to-control insects, including Formosan termites and carpenter ants. ACZA is a slow acting, non-repellent termiticide, which allows termites to spread the preservative throughout the colony – affecting the entire colony. ACZA treated Douglas fir was exposed to Formosan Subterranean Termites in the ASTM D 3345-74 test [*Resistance of ACZA Treated Douglas-fir Heartwood to the Formosan Subterranean Termite*, AWPA Proceedings, 1988]. Test specimens are treated and weighed prior to and after exposure to termites to determine weight loss, which reflects the level of termite attack. Table 2 shows the effective protection that ACZA provides against termites compared to untreated controls.

Table 2. Weight Loss of ACZA treated Douglas fir Exposed to Formosan Subterranean Termites

Retention (pcf)	Weight Loss (%)
0.00	-40.8
0.11	0.0
0.20	0.0
0.31	-0.5
0.41	-0.5
0.62	-0.5

Carpenter ants are another challenge, because they do not actually ingest the wood but remove it when building their colonies and pathways. In tests conducted at Spokane Falls Community College, ACZA was found to be an excellent repellent and prevented carpenter ant attack at all retention levels. Since the ants do not ingest wood, it is surmised that the ants' habit of cleaning each other leads to the ingestion of ACZA.

6.2. Soil Block Fungal Tests

Soil block testing for efficacy of ACZA in hardwoods was done at Oregon State University and reported at the International Research Group on Wood Prservation [*Accelerated Laboratory*

Testing of Preservatives on Thirteen North American Wood Species, J.J. Morrell and C.M. Freitag, IRG WP 99-30201]

Table 3. Soil Block Test Species, Preservatives and Fungi

Species
Gum
Red Oak
White Oak
Red Maple
Red Pine

Preservatives
ACZA
CuN
Penta
Creosote

Fungi	
G. trabeum	Brown rot
P. placenta	
W. cocos	
P. subserialis	White rot
T. versicolor	
X. frustulatus & P. merismoides	

Table 4. Soil Block Test & AWPA Standard Retentions

Preservative	OSU Test Retention	Sawn Material U1 Spec A - UC 4A	Crossties U1 Spec C - UC4A-C
Creosote	8 pcf	6-10 pcf / Refusal*	7-8 pcf / Refusal*
Penta Type A	0.40 pcf	0.30-0.50 pcf / Refusal*	0.35-0.40 pcf / Refusal*
CuN	0.06 pcf	0.06 pcf	0.055-0.06 pcf / Refusal*
ACZA	0.40 pcf	0.40 pcf	0.40 pcf

*Treatment to refusal is specified for White Oak only

At the ground contact standardized retentions, ACZA demonstrated good control of all of the test fungi. Overall, the weight loss of ACZA blocks was better than copper napthenate and pentachlorophenol and was comparable to creosote treatment.

6.3. RTA-AWPRP Testing

ACZA treated crossties are being added to the Railway Ties Associations Alternate Wood Preservative Research Project (RTA-AWPRP) at both locations in Mississippi and will be evaluated by Mississippi State University. The test will include ACZA and ACZA with borates and various surface protectants. Updated reports on this project will be made as available.

Table 5. RTA-AWPRP Tie Preservative Matrix

RTA Tie Mix	ACZA	ACZA + DOT	ACZA + ETBr	ACZA + oil	ACZA + DOT + oil	ACZA + DOT + ETBr	P2 Creosote	Untreated Controls
Red Oak	x	x	x	x	x	x		
White Oak	x	x	x	x	x	x		
Douglas-fir	x	x				x	x	x

3. Ancillary Property Tests

3.1 ACZA Solution Corrosion

ACZA is an alkaline oxide formulation that has been stored in plain carbon steel tanks at treating facilities since its initial use. Since it contains ammonia, brass or bronze components should not be used in contact with the solution.

3.2 ACZA Treated Wood Corrosion

The addition of zinc to the original ACA formulation was accepted as reducing corrosion, however, the extent had not been documented until 1987-88 when ACA and ACZA were tested for corrosion in accordance with Mil-L-19140E. This is a similar procedure to AWPA E12 where metal test coupons are secured between two treated wood blocks. Hot-dipped galvanized SAE 1010 steel was tested in contact with ACA and ACZA treated Douglas fir sapwood treated to 0.60 pcf. Four assemblies of each treatment were exposed for 60 days at 120°F and 90% relative humidity.

Table 6. Mil-L-19140E Corrosion Test Results

Assembly	ACZA % Wt. Loss	Assembly	ACA % Wt. Loss
1	0.205	5	0.216
2	0.112	6	0.326
3	0.037	7	0.626
4	0.142	8	0.338
Average	0.124	Average	0.377

These results show that the formulation change from ACA to ACZA reduced the corrosion of galvanized steel in contact with the treated wood by more than 50%.

Timber Products Inspection conducted shear tests on hardware from ACA treated utility poles that were in service for 38 years [*Bolt Breaking Results After 38 Years*, Timber Products Lab Report 84-015, 1984]. The working load at the point of yield and at the ultimate (maximum) strength at breaking are reported in Table 7.

Table 7. Bolt Strength after 38 Years of Service

Sample Bolt #	Diameter Inches	Length Inches	Yield Pounds	Yield PSI	Ultimate Pounds*	Ultimate PSI
Pole C	.566	10	11,100	44,116	16,450	65,380
Pole 518	.564	10	11,800	47,200	15,650	62,600
Pole 521	.562	12	9900	39,909	13,850	55,833
Pole 517	.568	12	10,200	40,254	14,130	55,843
Pole B	.519	12	9200	43,396	12,800	60,377
Pole 519	.571	14	12,450	48,619	17,700	69,121
Pole B	.547	16	8550	36,382	12,850	54,681
Pole 524	.569	18	11,400	44,882	16,900	66,535
Guy Bolt Pole A	.551	10	8700	36,554	12,700	53,361
Eye Bolt 519	.542	11	8700	37,662	12,200	52,814

The minimum design strength for bolts of this size is 12,400 pounds per paragraph 6.1 of EEI Specification TD-1. All of the tested bolts exceeded this minimum except for Eye Bolt 519 which failed at 12,200 pounds.

The spikes from the Spike Withdrawal Test at Oregon state were measure and weighed and experienced negligible size or weigth loss in creosote or ACZA treated tie spikes. [*Effect of Initial Preservative Treatment on Spike Performance in Douglas-fir Ties: Two Year Results*, J.J. Morrell et. al., 2012].

4. Conductivity

While effect of ACZA treatment on utility poles was included in the 1983 AWPA data package, conductivity is also a concern in crosstie installations due to signaling equipment used by railroads. Several types of tests have been conducted using actual poles, boards and even pellets of the dried preservative. All tests have found the conductivity of ACZA treated wood to be equivalent to that of untreated wood. Moisture content rather than the preservative is the determining factor in conductivity. ACA and ACZA have been used in utility poles for over 50 years with no conductivity issues. The Albany Eastern Railroad, a short line in the damp climate of western Oregon, has been using ACZA Douglas fir ties for over three years in switch/signaling applications and has found no conductivity issues. They have stated that "We have 6 crossings with approximately 2,400 ties per crossing. All 6 crossings have AC-DC circuits, with no problems to the systems." Note the dampness on the ties in Figure 1 below.

Figure 1. Signal connection on ACZA Douglas fir tie

.

5. Spike Holding

The ability of treated ties to hold rail spikes is paramount to their function. A test has been set up at Oregon State University to provide ongoing testing over years comparing untreated, creosote and ACZA treated ties placed above grade and on grade. The before exposure withdrawal force was based on 30 replicates; the one and two-year exposure values were based on 15 replicates. Results were reported to Arch in [*Effect of Initial Preservative Treatment on Spike Performance in Douglas-fir Ties: Two Year Results*, J.J. Morrell et. al., 2012]. The ACZA ties, as shown in the Table 8, have performed well to date.

Table 8. Spike Withdrawal from Douglas fir Crossties

Treatment	Withdrawal Force in Pounds (Standard Deviation)				
	Before Exposure	After 1 Year of Exposure		After 2 Years of Exposure	
		Above Ground	On soil	Above Ground	On Soil
ACZA	3753 (788)*	5905 (1269)	5704 (1401)	6340 (1634)	6941 (1868)*
Creosote	3269 (641)	4359 (1562)	4686 (2039)	5189 (1754)	5408 (1574)
None	3576 (1023)	4964 (1621)	5260 (1619)	5146 (1367)	5755 (1617)

*Values differ significantly from creosote ties in the same exposure at α=0.05.

6. Fire Retardancy (ASTM 84 / UL 723)

The potential impact of fire on wood products has always been a concern; any effect a preservative system may have on reducing the potential for damage from fire increases the probability of continued or increased use. Flame spread testing was done by U.S. Testing Labs and Underwriters Laboratory on ACZA treated Douglas fir 2 x6 and was reported on in a J.H. Baxter Technical Bulletin in 1997, [*The Fire Retarding Properties of ACZA Treated Douglas fir and Redwood Lumber]*. These tests demonstrated that treatment reduced flame spread. ACZA treated wood was more difficult to ignite than untreated wood and at a retention of 0.35 pcf, had a flame spread rating of 41.7 and smoke development of 115.8 which meets the requirements for a Class B/Class II fire retardant. This is less than the AWPA minimum retention of 0.40 pcf for ACZA ties and 0.60 pcf for poles. At a higher retention of 1.86 pcf, ACZA treated Douglas fir achieved a Class A/Class I rating with a flame spread of 24.8 and a smoke development of 78.2. Results of these tests are summarized in Table 9.

Table 9. Douglas-fir 2x6 Flame Spread Test Results

Retention (pcf)	Flame Spread	Smoke Development
0.35	41.7	115.8
0.95	40.0	80.0
1.37	30.9	36.9
1.86	24.8	78.2
3.20	25.0	20.0

Recent in house studies by Arch support these earlier results and show that the addition of borates to the ACZA will further improve the fire retardancy. The results of a simple comparative test that compares the char area on a panel supported over a Bunsen burner flame are shown in Table 10.

Table 10. Char Index

	Retentions – pcf ACZA (% BAE)				
Species	**0 (0)**	**0.25 (0)**	**0.25 (0.25)**	**0.40 (0)**	**0.40 (0.25)**
SY Pine	96	65	48	52	40
D Fir	52	38	36	36	32
R Oak	60	42	39	47	32
Maple	56	55	45	45	31

Data from [*Internal Fire Screening,* W. Thomas, Arch Wood Protection: Internal Report, 2013]

7. Strength Testing

The effect of preservatives on the strength of wood is important in determining if a preservative treated product can meet the requirements for the intended application. Properties of particular interest for railroad crosstie applications are compression perpendicular to grain (direction of loading from rails), bending (flexure from two-point loading) and hardness (plate cutting)

7.1 ASTM D143 Compression Perpendicular to Grain

Mississippi State University tested the effects of steaming and treatment on the strength of hardwoods in compression perpendicular to grain. Results [*Evaluation of Arch Preservative Formulations: Arch D143-2013,* H.M. Barnes et. al., 2013] are shown in Tables 11 and 12.

Table 11 – Compression Perpendicular to Grain - Red Oak

Group		ACZA vs. Controls		Creosote vs. Controls	
Steamed	Treated	Mean	Statistical Group	Mean	Statistical Group
No	No	2,227	A	2227	CD
No	Yes	1,884	B	2342	C
Yes	No	2,118	A	2218	D
Yes	Yes	2,109	A	2217	CD

In red oak only the ACZA treated, unsteamed group was statistically lower than its untreated control. There was no statistical difference from treatment with either ACZA or creosote in the steamed groups

Table 12 – Compression Perpendicular to Grain - Sweetgum

Group		ACZA vs. Controls		Creosote vs. Controls	
Steamed	Treated	Mean	Statistical Group	Mean	Statistical Group
No	No	1392	AB	1392	D
No	Yes	1311	AB	1519	CD
Yes	No	1416	A	1416	D
Yes	Yes	1275	B	1598	C

In sweetgum only the treated and steamed groups were statistically lower than their untreated controls, but this was true for both ACZA and creosote.

The test report concluded that "There is no practical effect of steaming on compression perpendicular to grain when treating with ACZA or creosote."

7.2 ASTM D143 Static Bending

The results of static bending tests were also reported by Dr. Barnes in the same report with the compression testing, the mean property results are listed in Table 13. He concluded that:

"Compared to untreated, steamed stock, no steaming treatment caused a significant reduction in any bending property evaluated. While there were differences among treatments, no clear trend emerged. When compared to untreated, unsteamed red oak, a drop of 10% or less was noted across all properties evaluated. This is consistent with published data which indicates a 10%, or less, drop in properties after treatment. From a strength and stiffness standpoint, steaming and subsequent treatment of red oak causes no problems and should be fine for treatments requiring steaming before treatment."

Table 13 – Mean Property comparisons from Static Bending using Tukey's Test

Treatment	**Condition**	**MOE (mm x psi)**	**MOR (psi)**	**WML (in-lb./in³)**
ACZA	Steamed	1.764 **AB**	16,954 **B**	21.37 **AB**
ACZA	Unsteamed	1.702 **B**	16,309 **B**	20.44 **AB**
Creosote	Steamed	1.820 **AB**	18,456 **AB**	21.22 **AB**
Creosote	Unsteamed	1.837 **AB**	18,147 **AB**	19.56 **B**
Untreated	Steamed	1.705 **B**	17,144 **AB**	20.48 **AB**
Untreated	Unsteamed	1.861 **A**	18,296 **A**	23.37 **A**

Means not followed by a common letter are significantly different at p=0.05

7.3 ASTM D1037 Ball Hardness

The tendency for tie plates to cut into the surface of crossties makes surface hardness an important property. Timber Products Inspection conducted the ASTM D1037 Janka Ball Hardness Test to measure the effect of ACZA treatment on surface hardness of matched ACZA and untreated samples of maple.

Table 14. Ball Hardness Results

	Ultimate Load (lbs.)	
Specimen	**ACZA Treated**	**Untreated Controls**
1	1165	1145
2	1242	1402
3	1123	1159
4	1169	1219
5	1163	1271
6	1209	1246
7	1209	1316
Average	1183	1251

Data from [*ASTM D1037 Hardness Test*, Timber Products Inspection: Project No. A13-008, 2013].

The results showed there was no meaningful difference between the hardness of ACZA treated and untreated maple.

8. Treatment of ACZA Crossties

Although ACZA had been listed for treatment of hardwood species in the AWPA standards for many years, there was no historical record or knowledge regarding hardwood treatment. All commercial treatment in recent history has been with softwoods, primarily Douglas fir.

Just like softwoods, hardwoods differ considerably in structure and characteristics resulting in wide variability in treatment. Ties are typically separated into oaks and mixed hard woods. The oaks generally have little sapwood on a tie and the treatability of the heartwood is quite different for red and white oaks. White oak has tyloses which block the longitudinal vessels making it extremely difficult to penetrate. Red Oak generally lacks tyloses and can be penetrated with preservatives much more easily than white oak. Mixed hardwoods will also vary, but more of them such as gums and soft maple can have much more sapwood which is easily treated.

6.1. **Test Hardwood Crosstie Treatments**

Pilot plant testing confirmed the potential for treatment of hardwoods so the next step was to do commercial trials. Air dried red oak, white oak and gum ties were shipped from the east to an ACZA plant in Oregon for ACZA treatment. The moisture content of the air dried ties was measured by oven dry method in the outer three inches and recorded.

Table 15. Average Moisture Content by Species and Zone

Species	0-1”	1-2”	2-3”
Red Oak	16%	34%	40%
White Oak	22%	37%	45%
Gum	20%	31%	36%

Seven charges with packs of the various hardwoods were treated in the plants Douglas-fir charges. Some charges included a borate additive to the ACZA. ACZA initially imparts a dark color to ties, typically a dark bluish green/black which turns more to a dark brown after storage to lighter green over time. The results of treatment are represented by the two charges detailed in Tables 16 and 17 which show that hardwoods can be properly treated with ACZA as well as borates. Typical penetration is illustrated in figures 3 and 4.

Figure 2. Hardwoods Crossties Before and After Treatment

Table 16. Charge 2 Treatment Results

	ACZA Retention		ACZA Penetration
Species	0.0-0.6”	0.6-1.0”	
White Oak	0.54	0.24	Ranged from 1.75 inches to 2.75 inches
Red Oak	0.58	0.32	One core with less than 65% of annual rings penetrated it had 50% of the annual rings penetrated
Gum	0.86	0.49	100% of sapwood penetrated

Table 17. Charge 4 Treating Results

	ACZA Retention (pcf)		Borate Retention (pcf DOT)		ACZA Penetration
Species	0.0-0.6”	0.6-1.0”	0.0 -0.6”	0.6-1.0”	
White Oak	0.48	0.22	0.42	0.24	Up to 3 inches
Red Oak	0.51	0.35	0.46	0.33	1.1 inches to 3.0 inches (all cores exceeded 65% of annual rings)
Gum	0.64	0.35	0.71	0.61	100% of sapwood penetration
Douglas-fir	0.45	0.10	0.46	0.11	0.4 inch to 0.6 inches of penetration

Figure 3. Core Photos – ACZA Penetration with Copper Indicator

Gum **Red Oak** **White Oak**

Figure 4. Tie Cross Sections with Borate Indicator

Gum **Red Oak** **White Oak**

The observed penetration results, especially for white oak, exceeded expectations. To confirm and verify the penetration, CR Quality Services, Inc., an independent railroad tie inspection firm, re-inspected 140 ties from each species group. Their report issued October 30, 2012 summarized the ACZA penetration results with respect to their knowledge and experience of typical creosote treatment as follows:

- Gum – ACZA penetration was about the same as treatment with P-2 Creosote.
- Red Oak – ACZA penetration was about the same as treatment with P-2 Creosote.
- White Oak– ACZA penetration was better than crossties treatment with P-2 Creosote.

Commercial Canadian Hardwood Crosstie Treatment

In 2013 the Cambium Group installed ACZA treatment at their South River, Ontario Plant. After shakedown of the new equipment, test treatment of air dried hardwood test began in April to develop data on Canadian species for submission to CSA. This data has recently been submitted to CSA and proposals for inclusion of ACZA crossties will be acted on at their October meeting.

Figure 5. ACZA Treatment of Hardwood Ties in Canada

9. Treatment Standards

Based on the testing and treatment data, proposals for use of ACZA crossties have received approval for inclusion in the AWPA Book of Standards. Similar proposals have also been submitted for consideration by CSA. Table 17 lists the treating requirements for the approved species for ties currently listed in the AWPA Book of Standards. ACZA preservative is listed in Standard P-22 and treated wood products are listed Standard U1, Commodity Specification C and Standard T1 Section C.

Table 17. ACZA Treatment Requirements in 2013 AWPA Standards

Species	Assay Retention (pcf)	Penetration
Oak, Hickory	0.40	WO- 95% of sapwood RO – 65% of annual rings on twenty 3” cores
Mixed Hardwoods	0.40	1.5”or 75%
Southern & Ponderosa Pine	0.40	2.5”or 85% of sapwood
Coastal Doug-fir, Western Hemlock, Western Larch	0.40	0.5”and 90%
Intermountain Doug-fir	No data	0.5”and 90%
Jack, Red & Lodge Pole Pine	0.40	0.5”and 90%

Notes:

Whenever “or” is specified, it shall be interpreted to mean whichever is less.

Whenever “and” is specified, it shall be interpreted to mean whichever is greater.

White Oak must also have a minimum heartwood penetration of 33% in twenty 1.5” cores.

Incising is required for Coastal Douglas-fir, Western Hemlock, Western Larch, Intermountain Douglas-fir, Jack Pine, Lodge Pole Pine and Red Pine. Incising is optional for Oak and Hickory, Mixed Hardwoods, Southern Pine and Ponderosa Pine.

Another benefit for quality control is that ACZA solutions or treated wood can be analyzed easily at treating plants with X-ray fluorescence analyzers.

10. Field Test Sites

With commercial treatment of ACZA ties now a reality numerous field test sites have been establish to monitor performance of both hardwood and softwood ties treated with ACZA as well as borate additives and secondary treatments to enhance the surface protection.

6.1. **Oregon Installation - Douglas fir Crossties**

The first installation of Douglas fir cross ties was on the Albany and Eastern Railroad near Corvallis, OR in 2010. These ties were visually inspected after about three years of exposure. The appearance of the ties was good with no evidence of decay or excessive corrosion. The railroad is pleased with the results of the ACZA ties to date.

Figure 6. ACZA Douglas-fir 3 + Year Old Ties

Under Load

Switch Ties

Bridge Ties and Laminated Beams

6.2. **Southern Eastern Us - Hardwood Crossties**

The seven charges of treated hardwood ties from the commercial trials were returned to the east coast and installed in southwest Florida, southeast Georgia and eastern North Carolina. The North Carolina site is a Hazard Zone 4 exposure, the Georgia site is a Hazard Zone 5 exposure and the Florida site is a severe Hazard Zone exposure where the historical life of creosote treated hardwood ties has been 7 years. Beginning in 2013 Mississippi State University will conduct periodic evaluation of the test installations.

Figure 7. Hardwood Tie Test Installation Sites

SW Florida Site **Eastern NC Site** **SE Georgia Site**

Figure 8. Old and New Hardwood Ties in SW Florida

Seven Year Old Ties being removed

ACZA Hardwood Ties after 18 months

6.3. **Central Canada – Hardwood Crossties**

In addition, crossties treated at the Cambium Group – Jan Woodlands plant have recently been installed in Canada and their performance will be monitored periodically.

Figure 9. Canadian ACZA Hardwood Tie Installation

11. USE AND HANDLING

ACZA wood can be stored, handled and worked like untreated wood. As with any wood, wear gloves to avoid splinters, wear eye protection and a dust mask when sawing, drilling and sanding. Wash hands before eating or smoking. Refer to the ACZA Treated Wood MSDS for more information.

Minimize any cutting to obtain the maximum benefit of the treatment by not exposing untreated wood to decay hazards. If you do cut ACZA treated wood, however, the exposed areas can be protected by applying copper Ready-To-Use solution containing at least 1% copper—available over-the-counter at most home centers. Use a generous amount to completely cover any untreated areas of your project exposed by cutting or drilling. A second coat after drying is recommended.

12. ENVIRONMENTAL IMPACT

AZCA treated wood products share many of the environmental attributes of wood itself – most notably: renewable resource, low-energy production, and carbon sequestration. The preservative process adds to these benefits by extending service life, thereby reducing demands on forests and transportation of replacement material. Furthermore, ACZA forms insoluble precipitates in the wood, becoming very leach-resistant. The wood surface is non-oily at high temperatures or in fresh or salt water, making ACZA crossties and laminated beams good choices for use in sensitive environments as shown in Figure 10.

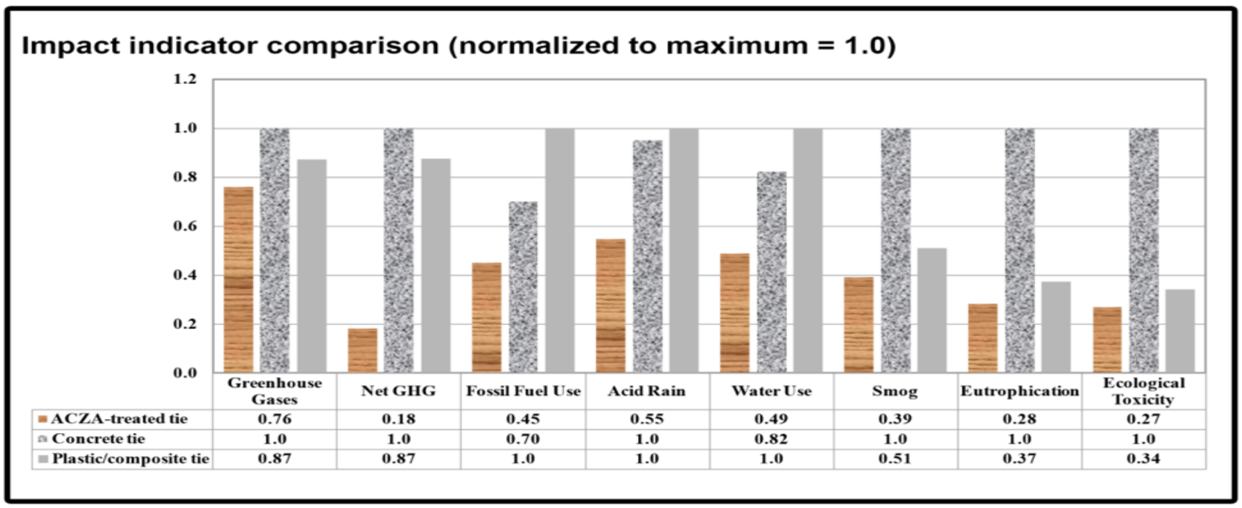
Figure 10. ACZA Douglas fir ties on a bridge trestle over a stream

6.1. **Life Cycle Analysis**

Today, it is common for construction materials to be evaluated to help users select products with the most favorable environmental impact. To this end, AquAeTer was contracted to perform a Life Cycle Analysis (LCA) comparing the use of ACZA treated wood to alternative products for its two main uses – crossties and utility poles. A Life Cycle Analysis determines the impact in specific categories over the expected life span of the products from raw materials to ultimate disposal.

ACZA treated crossties were compared to both concrete and wood-plastic composite ties. As indicated in Table 18, ACZA treated crosstie production and use has less environmental impact in all of the measured categories compared to the competitive products.

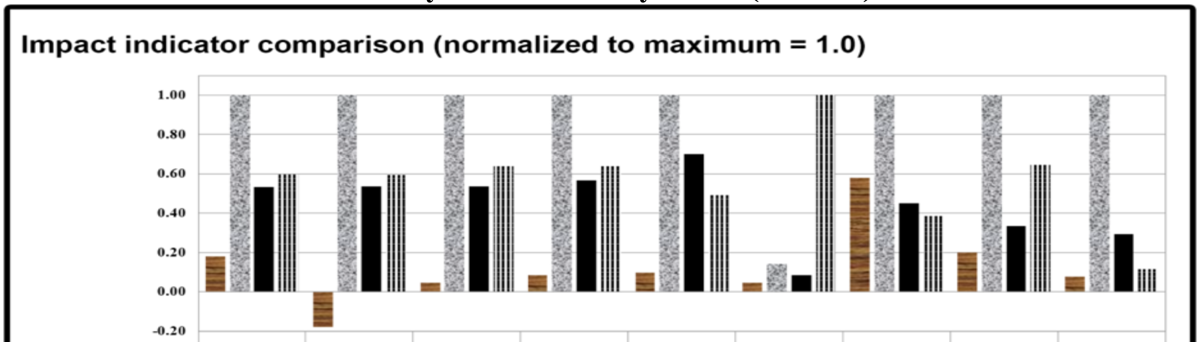
Table 18. Life Cycle Analysis (LCA) for ACZA Ties



	Greenhouse Gases	Net GHG	Fossil Fuel Use	Acid Rain	Water Use	Smog	Eutrophication	Ecological Toxicity
ACZA-treated tie	0.76	0.18	0.45	0.55	0.49	0.39	0.28	0.27
Concrete tie	1.0	1.0	0.70	1.0	0.82	1.0	1.0	1.0
Plastic/composite tie	0.87	0.87	1.0	1.0	1.0	0.51	0.37	0.34

ACZA treated utility poles were compared with concrete, steel and Fiber Reinforced Composite (FRC) poles. Again as shown in Table 19, ACZA treated utility pole production and use has less environmental impact in all of the measured categories compared to the competitive products.

Table 19. Life Cycle Analysis (LCA) for ACZA Poles



	Greenhouse Gas	Net GHG	Fossil Fuel Use	Total Energy Input	Acid Rain	Water Use	Smog	Eutrophication	Ecotoxicity
ACZA pole test	0.18	-0.18	0.047	0.08	0.10	0.048	0.58	0.20	0.079
Concrete pole	1.0	1.0	1.0	1.0	1.0	0.14	1.0	1.0	1.0
Steel pole	0.53	0.54	0.53	0.57	0.70	0.085	0.45	0.33	0.29
FRC pole complete life	0.60	0.59	0.64	0.64	0.49	1.0	0.38	0.64	0.11

6.2. **Disposal**

- In some cases ACZA treated wood products may be reused in less critical applications after they are taken out of service. When the useful life is over, ACZA treated wood should be disposed in appropriate landfill that accepts treated wood products. ACZA or other treated wood should not be burned in open fires or in stoves, fireplaces or residential boilers. However, treated wood from commercial or industrial use may be burned in commercial or industrial incinerators or boilers in accordance with local and federal regulations.

- **Notes on the thermal disposal of ACZA-treated wood**

- Can such residual material be "safely" treated by Enerkem's gasification technology?

- Safely means producing solid, liquid and atmospheric gaseous emissions that meet environmental regulations – **Yes**

- ACZA-treated wood can be effectively treated in our gasification process. We do not foresee any problem with Cu and Zn. The As will end up in mixed metal compounds whose stability needs to be assessed to provide the quantitative evidence that they are not toxic. - Enerkem

13. Secondary Treatment to Enhance ACZA Treated Products

A concern expressed with regard to waterborne preservative treatments is the lack of lubrication compared to the oil based creosote or pentachlorophenol treatments. This can result in hardness which can impact the gaff penetration for linemen who climb utility poles. The same technology that has a long history of use in CCA treated poles is also applicable to ACZA treated poles and crossties.

Poles were set in Conley, GA in 1988 to evaluate the climbability the ET® oil emulsification treatment on CCA treated poles; these poles were compared to CCA only (no oil) and penta treated poles. In 2012, ACZA treated Douglas fir poles were secondarily treated with a brown pigmented version of the ET® oil emulsion and, along with ACZA treated Douglas fir controls and CCA treated with ET® brown southern pine poles were installed in the Conley test site. In May 2013, the original poles were given their 25th anniversary climbing evaluation along with the ACZA poles installed the year before. Professional linemen for the evaluation were from utilities in Ohio, Texas and Georgia. The results are shown in Table 20 and have been published in the *Wolman ET Poles Retain Benefit Over Time*, Arch Wood Protection, 2013.

Figure 11. ACZA ET Brown DF Pole Evaluation

Table 20. 2013 Climbing Trial - After One-Year (Category Average)

Species	Treatment	Gaff Penetration	Gaff Insertion	Gaff Withdrawal	Confidence
Douglas-fir	ACZA	5.0	4.9	5.3	5.8
Douglas-fir	ACZA + ET Brown	5.6	5.9	6.0	6.5
SYP	CCA + ET Brown	6.0	6.2	6.9	6.7

The results are the mean scores for climbability awarded by linemen at the conclusion of climbing trials. Scores are based on a 1-10 scale, with 10 being highest rating. They showed that secondary treatment with ET Brown improved the climbability of ACZA treated Douglas fir poles.

14. Conclusions

AZCA has protected wood for over 30 years from wood destroying organisms and insects without undue effect on the strength, corrosion and conductivity properties of the wood. It can penetrate refractory species better than most waterborne systems and performs well in the harshest of environments. It is leach resistant, improves fire performance and has good spike holding properties in crossties. The ability to add borates to the ACZA treating solution improves the performance of ACZA treated wood against wood destroying organisms, fire and corrosion. Secondary treatments can be used to improve surface characteristics. The wide variety of recognized applications and superior protection and properties make ACZA treated wood a versatile and effective wood preservative system.

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100 YR OLD POST AND BEAM BUILDINGS

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Summary

Historical tall wood buildings were built in Canada and United States since 1900s. With increasing interest placed on modern tall wood buildings in the 21st Century, questions are raised related to the construction details of these historical buildings, the condition that they are in and how many of these buildings are still serving their owners in a satisfactory manner.

"Brick and Beam" building is used to describe adaptive re-use of the old industrial brick and heavy timber buildings constructed in late 1800's and early 1900's into unique work or living environments. They are low- to mid-rise buildings from three to nine stories with features of high ceilings, exposed structural wood beams and columns, sandblasted brick walls, hardwood floors and exposed forged metal connectors and mechanical systems.

Companies that strive for creativity and inspiration are often attracted to B & B offices for its ability to host stimulating space. These buildings are now fully updated with the latest modern technology and amenities with clients in telecommunication and information technology, business and professional services, media & entertainment industry.

This study confirmed that there are substantial number of historical tall wood buildings in Toronto and Vancouver where these buildings can be up to 9 storeys with building height of 100 feet (30 m). The sizes of these buildings are also worthy of mention as total floor space can be up to 312,000 ft^2 (29,000 m^2). Current rules and regulations on the retrofitting and renovation of the historical tall wood buildings are according to regional rules and regulations.

The historical B & B tall wood buildings are treasured by the current tenants as no such buildings were built after 1940s since the publication of the first National Building Code of Canada in 1941. Recently, a number of leading architects and engineers worldwide started to use modern heavy timber products such as Glued-laminated timber, Structural Composite Lumber (SCL) and Cross Laminated Timber (CLT) in modern tall wood buildings under "alternative solutions" path.

Interesting to note that the 21st century's first modern high-rise wood buildings are about the same height as those that were built at the beginning of 20th century!

1. Introduction

Tall wood buildings were built all across Canada during the period from 1850s and up to 1940. These buildings were built with un-reinforced brick with mortar in exterior walls and heavy timber beam and posts inside. They were originally built as factories, warehouses and manufacturing plants during the industrial era. The buildings were up to 9 storeys with ceilings height up to 22 feet (6.9 m). The building height can be as tall as 100 feet (30 m) and some buildings were large with total floor space up to 312,000 ft^2 (29,000 m^2).

This study provides background on the historical tall-wood buildings in the city of Toronto and Vancouver and their status as well as discussions on how the building codes address the historical buildings in Toronto and Vancouver. Figure 1 illustrated the typical tall brick and beam buildings in downtown Toronto.

312 Adelaide Street West, Toronto
Built 1895 - 8 storey - 71,000 ft^2

204-214 King Street East
Built 1901 - 7 storey – 134,430 ft^2

Figure 1 Typical tall brick and beam buildings in downtown Toronto

2. Methodology

In Canada, the term “Brick and Beam building” (B & B) is used to describe the adaptive re-use or re-purpose of the industrial old brick buildings constructed in the late 1800s and early 1900's into unique work or living environments. Urban renewal of Canadian cities has led to the renovations of these former industrial buildings into trendy office and loft condominiums.

The B & B buildings have the unique combinations of high open ceilings, exposed wood structural frames, open steel connections, exposed mechanical systems and sand blasted brick walls. These features served as a form of expression and identification for their original owner tenant. As a result, these attributes offers unique interior environments that appeals to people on many levels such as the offices as illustrated in Figure 2.

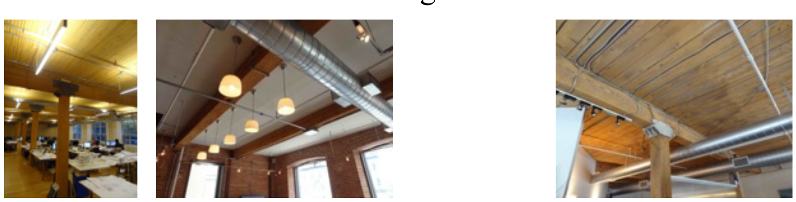

Figure 1 Brick and beam office with exposed wood beams and steel connections

Toronto has high concentration of B & B buildings that have been converted mainly to offices and some high-end/luxurious loft condominiums. They are located at the Toronto Entertainment District, Fashion District and St Lawrence Market area. Two other districts with high concentration of B & B buildings are the Distillatory District and Liberty Village area.

The B & B buildings in Vancouver are located mainly in Gastown and Yaletown. In Ottawa, the historical B & B buildings are mostly located in Byward Market. Kitchener also has the Warehouse / Innovation District and Tannery District which has recently listed Goggle Canada as its tenant. Similar buildings have also been identified in Montreal, where many historical tall wood buildings can be found near the "Vieux Port", mainly on St-Dizier and St-Paul streets.

In Toronto, there are a group of companies that specializes to acquire, renovate, retrofit and manage historical buildings to provide a dignified, sophisticated alternative to costly, conventional office space. They are Allied Properties REIT, York Heritage Properties, WTF Group, Capital Buildings, Greenwin Realty, YAD Investments Ltd, Dundee Realty Management Corp, Metro Ontario Group and others. Their web sites had provided full documentation and details. The significant heritage buildings are usually named such as Manufacturer's Building, The Reading Building and The Capital Building.

As a result, these companies acquired a reputation for the adaptive reuse of historical complexes and received many heritage and community awards. The designers created space that is youthful, exhilarating and attractive to a new corporate culture. These buildings are now fully updated with the latest modern technology and amenities. They are now fully recognized as a distinct and important office category. The top clients are telecommunication and information technology, business and professional services, media & entertainment industry.

The principal uses of these buildings are for office and retail occupancy. There are some buildings converted to trendy loft condominiums such as the Candy Factory Lofts and Massey Harris Lofts (former Massey Ferguson Head Office) such as in Figure 4.

Figure 4: Trendy loft condominium (photo: http://candyfactoryloft.com/?page_id=19)

129 B & B buildings	2 to 8 storeys
43 B & B buildings	5 storeys and higher
19 B & B Buildings	7 to 8 storeys
Maximum Height	100 ft. / 30 m
Maximum Building / Floor Space	220,000 ft^2 / 20,440 m^2
Years of construction	1859 and up to 1941

Table 1: Summary of B & B Buildings, Toronto

In Toronto, the Distillery District was designated as a national historic site as an outstanding example of “Victorian industrial design in terms of integrity, historical association and aesthetic qualities” The original historic site had 60 buildings. The 5 storey Stone Distillery is the oldest building built in 1859.

Figure 5: Distillery District today (photo courtesy: http://www.distilleryheritage.com)

The Toronto Carpet Factory buildings were built as a carpet manufacturing facility between 1889 and the 1920s and are now an office complex featuring several buildings clustered around internal courtyards and laneways. The original manufacturing facility had employed over 1,000 people then and the same number of people is working at various offices in the Toronto Carpet Factory today. It is a full city block in size with a complex of eight buildings and a combined office space of 312,000 ft^2 (29,000 m^2) on four-acre site. The main building is 6 storeys with a total office space of 190,000 ft^2 (18,000 m^2).

Figure 6: Toronto Carpet Factory, Toronto

In Vancouver, Gastown was originally the warehouse district in Vancouver. It was rebuilt in 1886 after "Great Vancouver Fire" losing all but two of its buildings. It is now a mix of hip contemporary boutiques, restaurants, nightclubs, professional offices and new upscale housing. Gastown has tall wood buildings as well as heritage buildings such as the Landing and Leckie Building. The buildings have retail occupancies in lower floors with residential occupancies in the upper floors. Some buildings were renovated with new additional upper floors.

Yaletown was an industrial area dominated by warehouses, factories and rail buildings. They are now converted into loft style apartments and offices with boutique stores, bars and restaurants at the ground level. Some buildings had also been renovated with new additional upper floors.

50 B & B buildings	2 to 9 storeys
18 B & B buildings	5 storeys and higher
6 B & B Buildings	7 to 9 storeys
Maximum Height	100 ft / 30 m
Maximum Building / Floor Space	175,000 ft2 / 16,250 m2
Years of construction	from 1905

Table 2: Summary of B & B Buildings, Vancouver

The Landing was constructed in 1905 as a warehouse building serving the gold rush miners during the Klondike Gold Rush. It is one of the largest B & B buildings with a total floor space of 175,000 $ft.^2$ (16,000 m^2). This heritage building was completely restored and renovated to meet modern building codes in 1987 with new concrete cores and reinforcements for seismic considerations. The Landing was seen as 7 storeys but one can count 9 storeys from waterfront side.

Figure 7: The Landing, Vancouver

Leckie Building is an Edwardian era warehouse/factory building with the first part of the structure built in 1908 and a large addition to the east was constructed in 1913. The building was renovated in 1991 and won a City of Vancouver Heritage Award for the structural upgrading as shown below. The diagonal steel rods are part of the seismic upgrading system and tied to anchors 90 feet below ground

Figure 8: Leckie Building and seismic reinforcement

3a. Results and Discussion

With the adaptive re-use of the historical industrial old B & B buildings to the trendy new offices and condominium, there is a need to renovate and retrofit with considerations for structural, fire and other performance issues to satisfy the requirements of the local jurisdiction. The B & B buildings can vary widely in terms of construction quality, material and current condition. This is crucial as some buildings may be in poor shape due to years of neglect or poor maintenance. As a result, there is a need for guidance in order to satisfy the safety requirements in accordance to local building codes or city By-laws.

The approach to address the issues for historical buildings varies across Canada. National Building Code of Canada (NBCC) addresses this issue in the User Guide – NBC 2010 Structural Commentaries; “Commentary L: Application of NBC Part 4 of Division B for the Structural Evaluation and Upgrading of Existing Buildings”. The purpose of Commentaries is to provide designer with detailed design information that will assist in the use of Part 4 of Division of National Building Code of Canada 2010 (NBC 2010). The Commentaries are provided as background information but not as mandatory requirements.

In Ontario, when a B & B building is renovated with a change in occupancy, such works falls under the Ontario Building Code 2006 (OBC) - Part 10: Change of Use and Part 11: Renovations

(OBC 2006). The Ontario Building Code requires evaluation of the building when a renovation occurs and requires the completed building to maintain its level of structural performance. All retrofit and renovation of historical buildings for new occupancy must conform to Part 10 and Part 11 of OBC.

Province of British Columbia has adopted the National Building Code with amendments which applies throughout the province with the exception of the City of Vancouver. The City of Vancouver adopts the National Building Code with its own amendments as the Vancouver Building Bylaw.

The approaches are different and one must use caution to ensure conformance to the appropriate building code and local By-laws.

3b. Discussion

The first tall wood building was built in 1859 in Canada on record and the last tall wood building was built around 1940s. In 1941 the Federal Government of Canada published the first National Building Code. The first building code set the maximum building heights for combustible construction to be 4 storeys and additional height limitations based on occupancy group and division. The maximum building height for "Heavy Timber: was is 75 feet for Group C Divison 4 (low hazard industrial) to be 75 feet while Group C division 1-3 (apartments & dwellings) had height limit of 55 feet. The limit for "Wood Frame" construction was 2 storeys with building height up 40 feet.

In April 2009, the BC for Residential Mid-Rise Wood-Frame Building Code Change were approved and become effective. The maximum height for wood-frame residential construction has been raised from four to six storeys with a height limit of 18 meters from grade to the floor level of the top storey. This code changes contained additional safeguards for issues related to fire safety and structural upgrades required.

There is a Joint Task Group between National Building of Canada, Canadian Wood Council, FPInnovations and several provinces to review the storey limit on the midrise combustible construction. The report of this Task Group should be available for public review in the coming months.

There is a heightened international interest on tall wood buildings with the availability of mass timber such as Cross Laminated Timber (CLT) , Structural Composite Lumber (SCL) and glulam. Modern tall wood buildings had been erected in various cities in Europe up to 9 stories. The Forte building, Melbourne, Australia is now the tallest timber building in the world at 10 storeys.

In Canada, Mr. Michael Green, architect, published his study on the "Case for Tall Wood Buildings" and how mass timber offers a Safe, Economical and Environmentally friendly alternatives for tall building structures in 2012. The Canadian Wood Council (CWC) & Natural Resource Canada (NRCan) have initiated the Canadian Tall Wood Demonstration Project and requested the industry for Expression of Interest in 2013. They will evaluate the submissions & announce the proponent and project in early 2014. To complement this project, FPInnovations published the "Technical Guide for the Design and Construction of Tall Wood Buildings in Canada 90% draft" in August 2013.

4. Conclusions

The historical brick and beam (B & B) buildings in Canada have been constructed in the late 19th and in the early 29th Centuries. The combination of solid timber beams and columns, sandblasted brick walls, high ceilings and central core locations have attracted the groups of dedicated and devoted clientele.

This study confirmed that there are a substantial number of historical tall wood buildings in Toronto and Vancouver where these treasured buildings can be up to 9 storeys with building height of 100 feet (30 m). The sizes of these buildings are also worthy of mention as total floor space can be up to 312,000 ft^2 (29,000 m^2).

While the B & B buildings can be retrofitted and renovated according to the regional rules and regulations, the current building codes only allow new heavy timber buildings up to 4 storeys because since the publication of the first National Building Code of Canada in 1941.

Having a limit on 4 storey limitation on combustible construction in the building codes puts many of the historical tall wood buildings outside the boundaries of "acceptable solutions". Recently, a number of leading architects and engineers worldwide started to use modern heavy timber products such as Glued-laminated timber, Structural Composite Lumber (SCL) and Cross Laminated Timber (CLT) in modern tall wood buildings under "alternative solutions" path in the Objective-Based approach such as provided in current National Building Code of Canada.

Interesting to note that the 21st century's first modern high-rise wood buildings are about the same height as those were built at the beginning of 20th century!

A renaissance in wood construction is underway. Stay connected.

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