CANADIAN WOOD PRESERVATION ASSOCIATION

PROCEEDINGS

35TH ANNUAL MEETING
OCTOBER 2014

TABLE OF CONTENTS

PROTECTION OF WOOD: A GLOBAL PERSPECTIVE ON THE FUTURE

Jeffrey J. Morrell

Department of Wood Science & Engineering, Oregon State University, Corvallis, OR 97331

Summary

The current state of wood protection is briefly reviewed, and then the issues that are currently affecting preservative treatments are summarized. The strategies for addressing these issues are discussed in relation to the role of wood as a renewable building material. The potential for addressing biological attack, ultraviolet light degradation and dimensional stability in a single product are discussed in relation to the need to produce a longer lasting material that retains the environmental attributes of wood.

Key Words: wood deterioration, wood protection, preservatives, barriers, wood modification

1. Introduction

Wood and wood-based materials have many desirable properties, but susceptibility to damage by combinations of sunlight exposure (primarily ultra-violet light), repeated wetting/drying and biological degradation remain as major negative attributes. These various agents combine to markedly shorten the useful lives of many wood based products and shorter service lives diminish the value of wood as a renewable resource while placing additional pressure on our forests.

While estimates of total global losses to degradation are scarce, Boyce (1961) long ago suggested that 10 % of the timber harvested in the United States was used to replace wood that had failed prematurely in service due to biodeterioration. Extended globally, the UN Food and Agricultural Organization (FAO, 2006) estimated global timber harvests to be 3 billion m^3 per year, with 60 % of this production being used for products and the remainder for fuel. The 10 % of harvest figure would translate into 180 million m^3 of wood that could be conserved by controlling degradation losses. This does not account for other squandered resources associated with energy consumption during harvesting and processing as well as installation, environmental impacts, and economic effects of the added harvesting. While it would be virtually impossible to completely eliminate this loss, it is readily apparent that wood must be used more efficiently and protected more fully if it is to reassume a leading role as a critical structural material. Preservative treatments already contribute to improve wood conservation through extended service life, but there is always room for improvement. An important aspect of this effort must be the continued development of effective strategies for protecting wood against UV light, wetting and biological attack.

Protecting wood from all of these agents is certainly not new, but the methods used for protection have come under increasing scrutiny from a skeptical public that questions the use of chemicals for all purposes. For over a century, we have depended on heavy duty preservatives such as creosote, pentachlorophenol or heavy metal combinations for wood protection, but public pressures have encouraged substitutions in many applications. These changes have not been uniform globally and examining the various strategies and patterns of change may help us to take a more holistic approach to wood protection. In this paper, we will review the general trends in wood protection in North America with references to activities taking place elsewhere. For the purposes of this review, we will concentrate on long term protection of exterior exposed solid wood products, thereby avoiding the limited market for whole-structure treatments and treated composites. While we recognize that naturally durable wood species have a role to play, they will not be discussed here and we will restrict ourselves to initial wood treatments excluding those used strictly to limit fungal mould and stain attack.

2. Current State of Affairs

Although wood protection is a global need, the vast majority of treated wood is used in temperate climates and the bulk is used in North America (Vlosky and Shupe, 2006). This market constitutes approximately 60 % of the total global market for treated wood. There remains a critical need for low cost wood protection for developing countries in tropical regions where deterioration rates are more severe.

The North American markets have long been dominated by the so-called heavy duty wood preservatives. Industrially, creosote, pentachlorophenol and heavy metal-based systems remain the dominant preservatives. While there have been challenges to the continued use of these chemicals, the producers have generated the required data to demonstrate that these systems can be safely used with minimal environmental impacts. The U. S. Environmental Protection Agency and Canada's Pesticide Management Regulatory Agency have both reviewed chemicals under their jurisdictions and continue to allow industrial uses (note: there are some differences in chemicals allowed between the two countries). In general, industrial uses of chemicals have been judged on their technical merits and very few chemicals are banned outright, although they may be restricted to specific uses. At the same time, some alternatives for industrial wood protection have emerged, including copper naphthenate and alkaline copper compounds. However, users, who are, by nature, conservative in adopting new systems without long term data, have been slow to adopt these systems.

On the residential side, the market was long dominated by chromated copper arsenate (CCA), but the 2004 decision by the manufacturers to withdraw the use of CCA for residential applications created opportunities for new systems. Much has happened in the intervening decade. The first CCA alternative was alkaline copper quaternary, closely followed by alkaline copper azole. These systems both depend upon copper as the primary biocide with smaller amounts of a carbon-based biocide to protect against copper tolerant organisms. Alkaline copper systems have been touted as more environmentally friendly because they lack arsenic or hexavalent chromium. However, they also contain much higher levels of copper than CCA and this can pose issues with regard to migration from the treated product. The high pH of these systems also creates the potential for corrosion of unprotected steel connections, necessitating the requirement for either hot-dip galvanized or stainless steel hardware. Despite their different handling characteristics, the use of these systems rapidly grew and they dominated the residential markets until the recent introduction of micronized copper systems. Micronized systems use finely ground copper suspensions in place of solubilized copper, along with either a triazole or quaternary ammonium co-biocide (MyIntyre and Freeman, 2008). Micronized systems are widely used to treat southern pine, which is highly permeable and easily treated, however, these systems are not suitable for more difficult to impregnate species, making them less suitable for treatment of most Canadian wood species. The shift to micronized systems has not been without debate because of concerns about the lack of long-term performance data and the lack of standardization by the American Wood Protection Association (AWPA); however, they appear to be performing well when properly applied.

The primary suppliers of wood preservative systems have also been working to develop metal-free alternatives (Morris, 2002). These systems can incorporate mixtures of triazoles, carbamates, quaternary ammonium compounds and various insecticides. While they appear to be working well for non-soil contact applications, they are not yet suitable for direct ground contact. As we will discuss later, the potential for replacing metal based preservative with these organics has largely been muted by their inability to perform well in soil contact. Interestingly, some producers of these colourless products have had to add colourants including small amounts of copper because the public expects treated wood to be coloured.

At the same time, the North American market has seen the emergence of alternative systems including various wood extracts, silanes, and a host of other systems that claim to provide non-biocidal protection. Unfortunately, there is very little publically available data to support these claims. There have also been attempts to introduce acetylated wood and heat treated wood into the market, but these products have not achieved substantial market acceptance, primarily because of higher cost.

Europe has seen the emergence of a host of alternative protection methods including acetylation, thermal modification, and furfurylation. Ironically, both acetylation and thermal modification have roots in North American research dating back to the 1950's.The situation in Europe is a bit different owing to a very different regulatory structure and a public willingness to pay more for wood products coupled with a lower risk of decay in many parts of the continent. This has fostered a willingness to look more closely at alternatives and a seeming willingness to accept some level of reduced performance. Europe has been the center of developments in dimensional stabilization, heat treatment, silanes, and barriers or coatings (Hill, 2006). All of these processes invariably produce materials that are more costly, but these costs do not appear to be a barrier to market entry, perhaps because alternative (non-wood) materials also have higher costs.

3. Future Concerns

In order to more fully understand where the use of treated wood is headed, we need to understand why changes are necessary.

There is no doubt that society has a strong desire for the use of less toxic chemicals for all purposes and wood protection is no exception. At the same time, there is increasing public concern about the potential for migration of preservatives into the surrounding environment. Virtually all of the currently used wood preservatives have some degree of water solubility. In addition, these molecules tend to have a much greater effect in aquatic environments because non-target organisms are literally bathed in the chemical. Concerns about preservative migration have led some regulatory bodies to severely restrict the use of treated wood (Brooks, 2011a, b; WWPI, 2012).

Another factor affecting the use of treated wood is disposal. The rules regarding disposal vary widely across the globe. In the U.S., the first recommendation for treated wood that has reached the end of its useful life is to reuse it in a similar application. For example, a utility pole might become a parking barrier or a railway sleeper might become a landscape timber. Ultimately, the wood will no longer be useful in any application. In most of North America, treated wood can be disposed of in lined municipal solid waste facilities (landfills) provided it meets certain criteria. Virtually all wood treated with oilborne preservatives meets these requirements and there is an exemption for water-based systems such as CCA. There is no shortage of landfill capacity in many parts of North America and this has made it difficult to develop alternative disposal options. Most industrial treated wood is given away or reused, while most residential treated wood appears to be placed into landfills.

Despite the lack of a major incentive to avoid land-filling, some options are emerging. Wood treated with oil-based materials contains almost 20 % by weight of oil and represents a valuable energy source. At present, creosoted railway sleepers are burned for energy production, but poles and other products are more difficult to process because of the presence of penta, which has more restrictive combustion permitting requirements. As a result, little penta treated wood is currently burned, but could be a useful bioenergy resource. The other issue related to disposal is the presence of heavy metal treated wood in waste streams that are destined for combustion. The final hurdle to developing alternative methods for resulting or recycling treated wood is the cost of collecting a widely dispersed material with differing degrees of treatment (Smith et al., 2002). Disposal represents a key lingering issue among wood users.

4. New Approaches

As with any industry, technologies related to preservative treated wood must continue to advance or alternative materials will be substituted. There are a number of opportunities involving new chemistries, treatment methods, non-biocidal treatments and coatings.

New Chemistries: The process of developing a new wood preservative can vary from as little as 5 to 10 or more years. This includes developing toxicological as well as performance data. In general, it is not economical to develop a chemical solely for wood protection. Many agricultural pesticides have been adapted for wood use as evidenced by the use of triazoles for wood protection. While chemicals are often developed without close public scrutiny until they are released, the time periods required for establishing efficacy of wood protectants generally results in gradual emergence of chemicals for increasingly more aggressive environments (Cabrera and Morrell, 2002; Pernak et al., 2004; Schultz and Nicholas, 2006; Schultz et al., 2004; Zabielska-Metjuk et all., 2004). One disconcerting observation for the development of new wood preservatives is the relative paucity of new chemicals entering major markets over the past few years. The exception has been micronized copper, which has only been commercially available for a few years but now dominates the residential market in the eastern U.S. (Preston et al., 2008; Cookson et al., 2008; McIntyre and Freeman, 2008; Larkin et al., 2008). This system, however, is still dependent on heavy metals and could be viewed as a modification more than a completely new development. The lack of a pool of readily available alternative treatments suggests the need for further development of new chemicals and could be an opportunity for the company that can create the ideal system.

The other area that continues to receive research interest is the potential for using natural products extracts for wood protection (Kawamura et al., 2011; Kondo and Imamura, 1986; Li et al., 2008; Schultz and Nicholas, 2000). Researchers have long sought to use heartwood extractives as potential wood preservatives; however, the approach has two problems. Extractives removed from highly durable woods are rarely as effective when introduced into less durable species. This may reflect that inability to achieve the same micro-distribution that was present in the original wood, as well as the tendency for these chemicals to be water soluble and therefore susceptible to leaching. A more important problem is that many naturally durable species are already in short supply, making it difficult to justify cutting more wood for production of natural preservatives. Extraction of by-products such as sawdust may be possible, but this material contains a mixture of non-durable sapwood and heartwood and may therefore produce lower yields. It may be more useful to employ these by-products for the production of durable composites, provided the materials are compatible with resins.

An alternative to the use of heartwood extracts might be the use of foliar extracts or materials from other organisms (Li et al., 2008). Many plants have evolved to produce foliage that contains an array of compounds designed to discourage attack by bacteria, fungi, and insects. Foliage may be an especially attractive source of biologically active compounds because it can be repeatedly harvested without cutting the tree, or alternatively, it could be collected at the same time the tree is harvested for wood. A number of recent studies suggest that foliage extracts exhibited activity against a variety of fungi and insects, although none of the extracts appears to have the broad spectrum toxicity necessary to function in a natural environment. It may be possible to combine extracts to produce a more effective cocktail of natural products. At the same time, it is important to remember that natural products extracts are, potentially, just as toxic to non-target organisms as synthetic pesticides. As these compounds are explored, it will be essential that they be tested accordingly to ensure that we do not inadvertently introduce more toxic molecules into the system.

Another interesting natural products approach has been the use of chitosans for wood protection (Maoz and Morrell, 2004; Eikenes et al., 2005). These compounds are derived from shrimp-farming operations and are available in large quantities. Modified chitosans have been shown to be effective against a variety of fungi, although their effectiveness against insects remains untested. Nevertheless, they offer the potential for producing anti-microbial compounds from what is largely a waste-product.

The search for lower toxicity systems for protecting wood against the diverse array of wood degrading agents will be essential for retaining the viability of wood as renewable construction material in adverse environments.

Non-biocidal Treatments: The protection of wood without biocides has long been a goal of many wood users. The use of glycol to bulk wood and the development of dimensional stabilizers such as acetic anhydride show that wood can made less susceptible to the water uptake that creates conditions conducive to biological attack (Hill, 2006). However, these approaches have drawbacks that include the need to impregnate with large volumes of expensive reactants, lingering odors, and textural changes. Alternatively, heat treatments can be used to modify the hemicelluloses in the wood to render the wood less susceptible to fungal attack (Esteves et al., 2007, 2011; Jamsa and Viitaniemi, 1998; Kamdem et al., 2002; Tjeerdsma et al., 1998; Vidrine et al., 2007). However, this process is not completely protective and can reduce wood properties.

Despite their limitations, dimensional stabilization strategies do have some applications, Wood modification clearly limits water uptake and this reduces the risk of fungal decay; however, the process does not appear to alter susceptibility to surface molds or UV degradation (DeVetter et al., 2010a, b; Donath et al., 2004; Dubey et al., 2012, Lande et al, 2004; Mai and Militz, 2004; Metsa-Kartelainen and Viitanen, 2012; Pfeffer et al., 2012; Weigel et al., 2012). Thus, there remains a need for non-biocidal treatments that are more broadly effective against abiotic and biotic agents of deterioration.

New-Treatment Practices: The wood treatment processes employed to impregnate the majority of treated wood used globally date to the middle part of the 19th century. The seeming lack of progress in this aspect of wood protection stems, in part, from the limited ability to overcome the inherent impermeability of heartwood and the overall effectiveness of existing treatment processes. Despite the overall acceptance of existing processes, there is considerable opportunity for both improving the quality of treatment and placing the chemical in the wood in such a way that it is less likely to migrate outward once in service.

Reducing the risk of preservative migration has become a major concern in some regions, notably where treated wood is used in close proximity to riparian zones. While there is no doubt that some chemical will migrate from treated wood, the goal is to ensure that the levels remain below those capable of inducing a negative environmental effect. Models have been developed that use migration rates for a given volume of treated wood coupled with information about specific waterway conditions such as pH or water current speed to predict total releases over time (Brooks, 2011b). These predictions can then be compared to known minimum effects levels for various organisms. At the same time, treatment practices have been modified to reduce the risk of over-treatment, remove surface deposits of chemical, reduce the risk of bleeding in service and, where ever possible, ensure that preservatives have been immobilized or reacted with the wood. These Best Management Practices are required in many localities across North America (WWPI, 2012).

At the same time, there is still a need for new treatment processes that result in more effective preservative penetration. While much of the coniferous wood treated globally has thick bands of easily treated sapwood, there are many species that resist impregnation. Developing methods for effectively treating these woods would help improve performance, thereby reducing the need to harvest additional trees. Modifications to existing liquid treatments, with the possible exception of dual treatments involving an initial boron treatment with a diffusion period, following by subsequent over-treatment with a heavy duty wood preservative are limited by the inherent impermeability of the resource. The further development of supercritical fluid treatment processes offers the potential for overcoming the inherent refractory nature of many major wood species (Kjellow and Hendriksen, 2009; Morrell et al., 1997). This process is currently commercially used in Denmark and has been explored elsewhere, but the high costs of entry in terms of equipment have largely limited development. Ultimately, SCF impregnation will emerge as a viable technology as we move to carbon-based systems and employ more wood-based composites.

There is a need for continued development of other novel systems for impregnating wood and for limiting the ability of the treatment to migrate outward once installed.

Coatings: While we have developed preservative systems capable of protecting wood against biological degradation for 50 years or more, most treated wood ultimately fails because its appearance declines to the point where the user will no longer accept it. This remains a major problem for wood in exterior applications.

Coatings can reduce damage caused by ultra-violet light as it strikes the wood and also reduce the ability of the wood to sorb water, thereby reducing the wetting and drying that leads to warping, twisting and checking.

UV degradation of lignin on the wood surface, coupled with subsequent removal of other wood components markedly reduces wood appearance (Feist, 1990; Hon and Chang, 1984; Schauwecker et al., 2009). While opaque coatings can reduce this damage, most wood users want to see the natural grain and colour of the wood. Transparent or semi-transparent coatings can provide some protection, but this protection generally declines within 1 to 2 years of exposure. Developing effective treatments that can be impregnated into wood to provide long term UV protection remains a major challenge. Iron oxide pigments, titanium dioxide, or hindered amine light stabilizers are just a few of the many possible surface protectants that have shown some promise, but most are rapidly inactivated by sunlight (Schauwecker et al., 2009; Schmalzl and Evans, 2003; Rowell and Banks, 1985). Water repellency is often produced through the inclusion of various waxes or silicates in the treating solution (Levi et al., 1970; Lesar and Humar, 2011; Sun et al., 2010). These treatments can reduce the rate of water uptake, but add cost to the system and only slow water uptake.

Ultimately, however, wood protection must be considered in a more holistic fashion. Biological performance is important, but so are resistance to water and UV light. The material must not only remain structurally sound, it must look sound as well. If it does not, the wood is replaced prematurely.

Material specifiers are increasingly comparing the environmental attributes of materials to make specifying decisions. One of the most important emerging tools for these comparisons is life cycle analysis (LCA). The LCA examines all of the inputs required to produce a product including energy and water along with the environmental impacts. There is no correct answer regarding a given material. LCA's allow users to compare the impacts of different materials that can be used for the same application. Wood, by virtue of its renewability, low manufacturing impacts, and ability to sequester carbon, should have a major advantage in these comparisons. However, service life plays a important role in these comparisons. Premature removal of wood sharply increases the overall life cycle impact. Thus, factors such as weathering and wood instability must be considered in performance because they often lead to premature wood replacement.

As a result, biological protectants, water repellents and coatings must all be considered as an integral part of a wood protection system that ensures long term performance. Another performance component is the original wood. Some species are inherently prone to warping and checking. While it is unlikely that species will be replaced, it may be possible to selectively sort lumber for treatment. For example, dimensional changes tend to be greatest in the tangential direction in most wood species (flat sawn wood). Selecting materials that are vertically sawn would result in a lower tendency to shrink and swell.

Careful material selection would reduce the tendency of treated wood to check and deform in service.

None of these approaches is without some cost; however, it is also important to avoid the view of wood as the cheapest material. In North America, treated wood is typically the least expensive decking material, followed by naturally durable heartwoods and finally by wood/plastic composites (WPC's). Surveys show that consumers perceive these products in terms of increasing quality in the same order. Purchasers have clearly shown a willingness to pay a premium for products that they perceive to be more durable and less maintenance intensive. At the same time, extensive advertising has convinced them that WPC's are greener. Wood based materials, however, should have more favorable LCA's provided they are properly treated and, consumers have demonstrated their willingness to pay for materials they perceive to combine greenness, durability and low maintenance. There appears to be niche for the development of a durable, more dimensionally stable wood product.

Barriers: Preservative treatment is ultimately a barrier that precludes entry by wood degrading organisms, but there have been recent efforts to develop physical barriers to protect wood. The first successful products originated in South Africa in response to early failures of creosoted utility poles and these products have spread across the globe (Baecker and Behr, 1995; Behr and Baecker, 1994; Behr et al., 1997). In some cases, they encapsulate untreated wood, but generally, they involve coating of preservative treated wood. Barriers reduce contact between soil and wood, thereby diminishing the risk of fungal decay and insect attack. They also reduce the potential for preservative migration from wood into the surrounding environment. Barriers clearly reduce the risk of environmental contamination, but they may also have a side benefit. Since less chemical will migrate from the wood and soil is not in direct contact, the barrier may allow the use lower preservative loadings to produce equivalent protection. Barriers can be simple polyethylene barriers or heavy plastic sleeves applied by shrink-wrapping. Other systems spray polyurea on the wood surface to provide a flexible coating whose thickness is based upon the environment to which the wood is exposed. Several barriers systems are currently standardized by the American Wood Protection Association (AWPA, 2012). These systems add cost and users must clearly determine if the added expense is worthwhile, but they help address the issues related to biocide mobility.

5. New Opportunities

Wood has a long history of use in a variety of applications and preservative treatments have played a major role in the extension of useful life, but there are still other opportunities for growth in the use of treated wood. Among these applications are wood used as solid packing material in global trade, wood used in mass timber structures and a higher end decking product.

Wood pallets seem to be everywhere and most people assume that they have always been used, but palletized shipping only dates back to the Second World War. Pallets make shipping easier and fast, but the lower quality wood used in these pallets and other solid wood packing materials can harbor insects and fungi. These organisms can be inadvertently introduced into new environments during shipping. Nearly all countries require that solid wood packing materials used in global trade be subjected to some type of mitigation treatment. The two most commonly applied treatments are heating to 56 C for 30 minutes or fumigation with methyl bromide. These treatments are not verifiable, nor do they prevent reinvasion. Preservative treatment may provide a more verifiable method for limiting the risk of pest introduction that also provides long term protection against reinvasion. Preliminary tests of solid wood packing material infested with the new house borer (*Arhopalus productus*) suggested that beetles were not killed by treatment with ACQ, borates or an organic preservative mixture, but also never completed their life cycle (Schauwecker and Morrell, 2008). Clearly, much additional work needs to be completed before preservative treatment is approved as a mitigation tool, but the volumes of wood used in this area are well worth the effort.

Mass timber structures are seeing increasing use in more temperate climates as a part of efforts to compete with concrete and steel in the high rise building market. Cross laminated timber is one of the primary products used in this area. While this material has a number of advantages over alternative materials, it will ultimately need some type of protection against biological degradation. This protection need not entail heavy duty wood preservation, but the fact that all buildings eventually leak means that these structures will experience water intrusion that creates conditions suitable for fungal attack. Some type of treatment will be needed to ensure performance. These appears to be a hesitancy to use traditional wood preservatives in this application, but alternatives such as thermal modification may find some use creating new markets for durable wood.

The most promising potential new market for treated wood is decking. Treated wood long dominated this market; however, wood/plastic composites (WPC) have continued to erode market share. Declining market share has been less noticeable because the overall decking market has also grown, masking the change. Wood decks have generally been perceived as lower quality than either WPC or naturally durable decks; however, there is also a general desire to use wood in decks. There is an opportunity to create wood decking products that are both durable and able to remain visually attractive for a longer period of time. Consumers have already shown their willingness to pay more than two times the cost of a treated wood deck for a WPC deck. There is clearly an opportunity to create a better decking product that is cost competitive with WPC products but incorporates features that make it more durable. These features might include a carbon based wood preservative, selection of materials that are more stable (i.e. vertical grain), and application of UV stabilizers to the wood. The resulting product would not compete with traditional lower cost wood decking, but rather with the higher end products.

6. Conclusions

Wood remains one of our most important renewable building materials. Continued use of this material under adverse conditions will require renewed interest in developing technologies that resist biological and physical damage. Some of these technologies are already available, but remain too costly. Other approaches are under exploration. Effectively protecting wood against biological and physical damage without depending on broad spectrum pesticides must remain a goal if wood is to retain its rightful place in a green society.

7. Literature

American Wood Protection Association. 2012. Annual Book of Standards, AWPA, Birmingham, Alabama.

Baecker, A.A.W. and M. Behr. 1995. Biostatic film as a primary treatment against pole failure in soil. International Research Group on Wood Preservation Document No IRG/WP/95-40053, Stockholm, Sweden.

Behr, M. and A.A.W.Baecker. 1994. Quantification of creosote migration down wooden poles and the prevention of its depletion during flood irrigation. . International Research Group on Wood Preservation Document No IRG/WP/94-50032, Stockholm, Sweden.

Behr, M.R., G.D. Shelver, and A.A.W. Baecker. 1997. Transmission poles with sub-standard retentions protected by Field Liners outperform standard poles in service. International Research Group on Wood Preservation Document No IRG/WP/97-40095, Stockholm, Sweden.

Brooks, K.M. 2011a. Fate and effects associated with contaminants released from pressure-treated wood into sensitive environments. In: Managing Treated wood in Aquatic Environments (J.J. Morrell, K.M. Brooks, and C.M. Davis, Eds.). Forest Products Society, Madison, WI. Pages 141-152

Brooks, K.M. 2011b. Modeling the environmental risks associated with press-treated wood used in sensitive environments. In: Managing Treated wood in Aquatic Environments (J.J. Morrell, K.M. Brooks, and C.M. Davis, Eds.). Forest Products Society, Madison, WI. Pages 241-308.

Boyce, J.S.1961. Forest Pathology (Third Edition). McGraw-Hill, New York, NY.

Cabrera, Y. and J.J. Morrell. 2012. Use of totally carbon-based preservatives to improve the performance of naturally durable woods. International Biodeterioration and Biodegradation 70:27-30.

Cookson, L.J., J.W. Creffield, K.J. McCarthy, and D.K. Scown. 2008. Australian field trials on the efficacy of micronized copper. Document No. IRG/WP/08-30480. International Research Group on Wood Protection Stockholm, Sweden.

DeVetter, L., J. Van den Bulcke, and J. Van Acker. 2010. Envelope treatment of wood based materials with concentrated organosilicons. European J. Wood Products 69:397-406.

DeVetter, L., J. Van den Bulcke, and J. Van Acker. 2010. Impact of organosilicon treatments on the wood-water relationship of solid wood. Holzforschung 64:463-468.

Donath, S., H. Militz, and C. Mai. 2004. Wood modification with alkoxysilanes. Wood Science & Technology 38:555-566.

Dubey, M., S. Pang., and J. Walker. 2012. Oil uptake by wood during heat-treatment and post-treatment cooling, and effects on wood dimensional stability. European J. Wood Products 70:183-190.

Eikenes, M., G. Alfredsen, E. Larnoy, H. Militz, B. Kreber, and C. Chittenden. 2005. Chitosan for wood protection- state of the art. Document No. IRG/WP/05-30378. International Research Group on Wood Protection Stockholm, Sweden.

Esteves, B., A. Marques, I. Domingos and H. Pereira. 2007. Improvement of technological quality of eucalypt wood by heat treatment in air at 170-200 C. Forest Products Journal 57(1/2):47-52.

Esteves, B., L. Nunes, and H. Pereira. 2011. Properties of furfurylated wood (*Pinus pinaster*). European J. Wood Products 69:521-525.

Food and Agriculture Organization of the United Nations (FAO). 2002. International standards for phytosanitary measures: guidelines for regulating wood packaging material in international trade. Rome, Italy.

FAO, 2006. Global Forest Resources Assessment 2005. Progress towards sustainable forest management. FAO Forestry Paper 147, 320 pp.

Feist, W.C.1990. Outdoor weathering and wood protection. Adv. Chemistry Series 225: 263-298.

Hill, C. 2006. Wood modification: Chemical, thermal and other processes. J. Wiley and Sons, Sussex, UK.

Hon,D.N.S. and S-T. Chang. 1984. Surface degradation of wood by ultraviolet light. J. Polymer Science, Polymer Chem Ed. 22:2227-2241.

Jamsa, S. and H. Viitaniemi. 1998. Heat treatment of wood. Better durability without chemicals Nod. Trbeskyttelsesdager Pages 47-51.

Kamdem, D.P., A. Pizzi, and A. Jermannaud. 2002. Durability of heat-treated wood. Holz-als Roh und Werkst. 60:1-6.

Kawamura, F., S.F.M. Ramle, O. Sulaiman R. Hashim, and S. Ohara. 2011. Anti-oxidant and antifungal activities of extracts from 15 selected hardwood species of Malaysian timber. European J. of Wood Products 69:207-212.

Kjellow, A.W. and O. Henriksen. 2009. Supercritical wood impregnation. J of Supercritical Fluids 50:297-304.

Kondo, R. and H. Imamura. 1986. Antifungal compounds in heartwood extractives of hinoki (*Chamaecyparis obtuse* Endl). Mokuzai Gakkaishi 32:213-217.

Lande, S., M. Westin, and M. Schneider. 2004. Properties of furfurylated wood. Scandinavian J. Forest Research 19 (Suppl 5):22-30.

Larkin, G.M., J. Zhang, D.L. Richter, R.J. Ziobro, and P.E. Laks. 2008. Biological performance of micronized copper wood preservative formulations in field and laboratory tests. Document No. IRG/WP/08-30488. International Research Group on Wood Protection Stockholm, Sweden.

Lesar, B. and M. Humar. 2011. Use of wax emulsions for improvement of wood durability and sorption properties. European J of Wood Products 69:231-238.

Levi, M.P., C. Coupe, and J. Nicholson. 1970. Distribution and effectiveness in *Pinus* sp. of a water-repellant additive for water-borne wood preservatives. Forest Products Journal 20 (11):32-37.

Li, S., C. Freitag, and J.J. Morrell. 2008. Preventing fungal attack of freshly sawn lumber using cinnamon extracts. Forest Products Journal 58(7/8):77-81.

McIntyre, C.R., and M.H. Freeman. 2008. Biological efficacy of micronized copper systems. Document No. IRG/WP/08-30485. International Research Group on Wood Protection Stockholm, Sweden.

Mai, K. and H. Militz. 2004. Modification of wood with silicon compounds. Treatment systems based on organic silicon compounds. Wood Science & Technology 37:453-461.

Maoz, M. and J.J. Morrell. 2004. Ability of chitosans to limit wood decay under laboratory conditions. Document No. IRG/WP/04-30339. International Research Group on Wood Preservation Stockholm, Sweden.

Metsa-Kortelainen and H. Viitanen. 2012. Wettability of sapwood and heartwood of thermally modified Norway spruce and Scots pine. European J. Wood Products 70:135-179.

Morrell, J.J. 1995. Importation of unprocessed logs into North America: review of pest mitigation procedures and their efficacy. Forest Products Journal. 45(9):41-50.

Morrell, J.J., K.L. Levien, E. Sahle Demessie and M.N. Acda. 1997. Impregnating wood with biocides using supercritical carbon dioxide: Process parameters performance and effects on wood properties. Proceedings American Wood Preservers' Association 93:367-384.

Morris, P.I. 2002. A vision for the future. In: Proceedings, Enhancing the Durability of Lumber and Engineered Wood Products. February 11-13, 2002. Radisson Resort Parkway, Kissimmee, Florida. Publication No. 7249, Forest Products Society, Madison, WI. Pages 231-238.

Pernak, J., J. Zabielska, A. Kropacz, and J. Foksowicz-Flaczyk. 2004. Ionic liquids in wood preservation. Holzforschung 58-286-291.

Pfeffer, A., C. Mai, and H. Militz. 2012. Weather characteristics of wood treated with water glass, siloxane or DMDHEU. European J. of Wood Products 70:165-176,

Preston, A., L. Jin, D. Nicholas, A. Zahora, P. Walcheski, K. Archer, and T. Schultz. 2008. Field stake tests with copper-based preservatives. Document No. IRG/WP/08-30459. International Research Group on Wood Protection Stockholm, Sweden.

Rowell, R.M. and W.B. Banks. 1985. Water repellency and dimensional stability of wood. FPL 50-RP. US Forest Products Laboratory, Madison Wisconsin. 24 p.

Schauwecker, C.F. and J.J. Morrell. 2008. Ability of pressure treatment with wood preservatives to kill or limit emergence of invasive insects using *Arhopalus productus* as a model species. Forest Products Journal 58(10):56-60.

Schauwecker, C., A. Preston, and J.J. Morrell. 2009. A new look at the weathering performance of solid-wood decking materials. JCT Coatings Tec 6(9):32-38.

Schmalzl, K.J. and P.D. Evans. 2003. Wood surface protection with some titanium, zirconium and manganese compounds. Polymer Degrad. Stab. 82:409-419.

Schultz, T. and D.D. Nicholas. 2006. Totally organic wood preservative systems for exterior residential applications. In: Proceedings Wood Protection 2006. (H.M. Barnes, Ed.) March 21-23, 2006, Omni Royal Orleans Hotel, New Orleans, Louisiana. Publication 7229, Forest Products Society, Madison, WI. Pages 289-294.

Schultz, T. and D.D. Nicholas. 2000. Naturally durable heartwood: evidence for a proposed dual defensive function of the extractives. Phytochemistry 54:47-52.

Schultz, T., D.D. Nicholas, and M.L. Prewitt. 2004. Environmentally-benign wood preservatives based on an organic biocide: anti-oxidant combinations: Ground-contact efficacy ratings and BHT depletion after four years of exposure. Holzforschung 58:300-304.

Smith, R., D. Alderman Jr., and P. Araman. 2002. What's stopping the recycling of recovered CCA-treated lumber. In: Proceedings, Enhancing the Durability of Lumber and Engineered Wood Products. February 11-13, 2002. Radisson Resort Parkway, Kissimme, Florida. Publication No. 7249, Forest Products Society, Madison, WI. Pages 47-50.

Sun, Q., H. Yu, Y. Liu, J. Li, Y. Lu, and J.F. Hunt. 2010. Improvement of water resistance and dimensional stability of wood through titanium dioxide coating. Holzforschung 64:757-761.

Tjeerdsma, B.F., M. Boonstra, and H. Militz. 1998. Thermal modification of non-durable wood species. 2. Improved wood properties of thermally treated wood. Document No IRG/WP/98-40124. International Research Group on Wood Preservation, Stockholm, Sweden. 10 p.

Vidrine, C., C. Freitag, J. Nicholson, and J. J. Morrell. 2007. Effects of heat treatments on decay resistance and material properties of ponderosa pine and yellow poplar. International Research Group on Wood Protection Document No IRG/WP/07-40374. Stockholm, Sweden.

Vlosky, R.P. and T.F. Shupe. 2006. An overview of the U.S. preservative wood treating industry. In: Proceedings Wood Protection 2006. (H.M. Barnes, Ed.) March 21-23, 2006, Omni Royal Orleans Hotel, New Orleans, Louisiana. Publication 7229, Forest Products Society, Madison, WI. Pages 271-276.

Weigel, M. U. Muller, R. Wimmer, and C. Hansmann. 2012. Ammonia vs. thermally modified timber- comparison of physical and mechanical properties. European J. Wood Products 70:233-239.

Western Wood Preservers Institute. 2012. Treated wood in aquatic environments. WWPI, Vancouver, WA. 34 pages.

Zabielska-Metjuk, E. Urbanik, and J. Pernak. 2004. New bis-quaternary ammonium and bis-imidazolium chloride wood preservatives. Holzforschung 58-292-299.

TEST AND TREAT PROGRAM TO IMPROVE THE SERVICE LIFE OF WOOD POLES

Dan Mastrocola[1], Robert Adam[2], Louis Gastonguay[2]

[1]Analyse et Amélioration de performance Réseau, Hydro-Québec Distribution, Montréal, Québec, Canada

[2]Sciences des matériaux, Institut de Recherche d'Hydro-Québec, Varennes, Québec, Canada

E-mail of corresponding author: gastonguay.louis@ireq.ca

Keywords: inspection, wood pole, remediation, solid rods, service life

Summary

In order to ensure the long-term stability and safety of their networks, Utilities and their stakeholders have a vested interest in looking at different ways to enhance the service life of their critical assets. Wood poles are the most common type of support used on Distribution networks and to a lesser extent Transmission networks. Hence they are viewed as a critical infrastructure asset that must be maintained. At Hydro-Québec, more than 2.5 million wood poles are used to support the Distribution and Transmission network that carries electricity to our customers throughout the province of Québec.

The ability to accurately estimate the condition of the pole along with a maintenance program to increase its service life is very important since it will have a cumulative impact on a utility's performance, as it will allow for a reduction in the number of poles requiring replacement, enhance the structural integrity of the network by removing weak poles and enhancing the resistance of the existing poles to natural degradation through the process of retreatment. As well it will help in preserving the environment by using fewer trees. Within the last few years, Hydro-Québec has put in place a test and treat program to enhance service life of our wood poles. To date, more than 750,000 poles have been inspected and remediated with solid rods (boric acid). Results after 11 years of field test, at our research facility, have shown that we can improve the useful service life of our poles by 7 to 10 years.

A software tool has been developed for the inventory and inspection of poles and associated equipment. This tool analyzes the collected information and recommends the maintenance action to be taken.. This test and treat program is helping us to reduce the number of poles requiring replacement by slowing the rate of degradation. In addition, the program helps us in eliminating those poles that are declared unfit for further service. This will improve the resistance of our network against weather events.

1. Introduction

The distribution network at Hydro-Québec is composed of about 2.5 million poles of which 1.85 million are utility owned. In any given year between 25k to 30k new poles are installed. About half of these new poles are for new installation and the remaining are replacements for poles taken out of service for various reasons. The mean age of our poles is approximately 27 years. The average replacement cost of a pole is about $ 4,000. Most of the poles on our network are composed of jack and red pine with a full length application of PCP (pentachlorophenol) as an initial treatment. In the fall of 2002, HQD (Hydro-Québec Distribution) began using CCA[1] with the inclusion of a polymer additive to help the climbability of these poles. For our PCP poles, we expected a service life of about 40 years. However, with time, early decay (between 15 to 20%) has been observed by the Distribution group. Early decay can be observed for different reasons like exposed heartwood, bleeding and bad initial treatment or a combination of the above.

2. Results and Discussion

Field test

The hypothesis was that the bleeding out of the oil containing the PCP was responsible for the early decay that was observed. In order to assess the hypothesis, measurements of the residual PCP concentration were done on poles from different group age and climatic regions throughout the province of Québec. The percentage of poles under the toxicity threshold for PCP is presented in figure 1 segmented by different age groups.

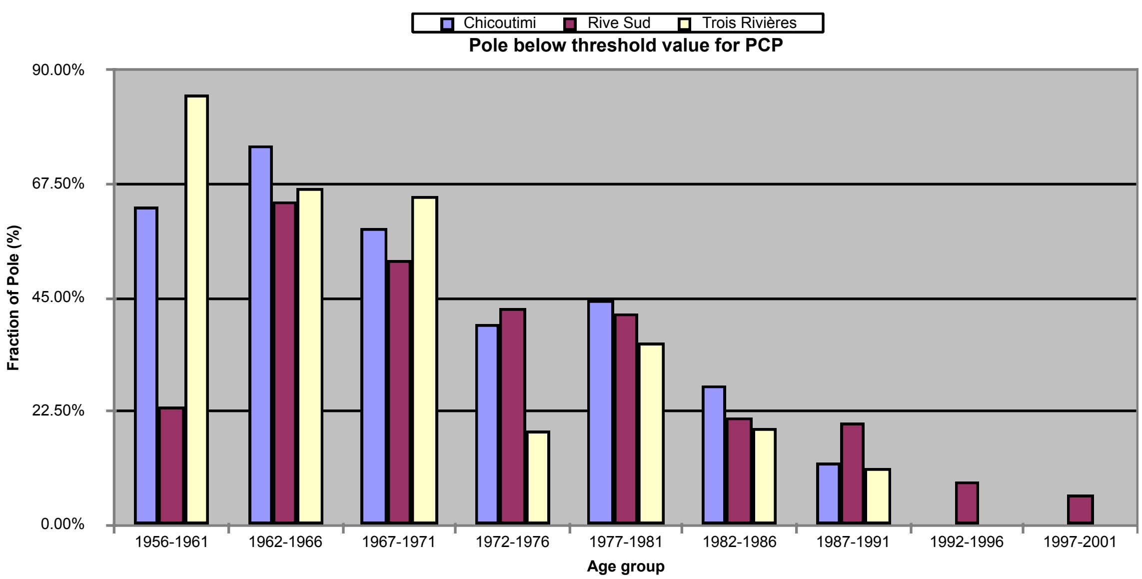


Figure 1: Percentage of poles below toxicity threshold as a function of age group

[1] Pole is classified as a CCA-PA

From this figure, we can observe that even for young poles (those less than 10 years of age), between 5 to 10% were below the toxicity threshold value for PCP. If we move to the next age group (1982-1986), we can observe that after 20 years in service already about 20% of our poles were found containing a concentration of PCP below the toxicity limit. This number increases to about 40% for the next age group (1977-1981). These results showed us that we needed to remediate our poles in order to enhance their resistance to natural decay. In order to validate the effectiveness of different ground line remediation products on the market, a test program was set up at our research facility (IREQ). While there were numerous types of products available on the market it was decided to focus the test using only external bandages (wraps) and solid rods. Table 1 describes the different products used for our test. Untreated pole sections were used in order to decrease the time for the total field trial.

Table 1: Products used for field trials

External bandages (Wraps)	Solid Rods
Cobrawrap	Cobra Rod
Pole Wrap	Impel Rod
	Flurod

Our test facility is shown in figure 2.

Figure 2: Test facility at IREQ

These poles section were left in the ground for 11 years. Untreated reference pole sections, after 11 years in the ground, are shown in figures 3 and 4.

Figure 3: Ground line section for a red pine reference after 11 years in the ground

Figure 4: Ground line section for a jack pine reference after 11 years in the ground

A total of 6 poles sections were used as reference and all of them were extensively degraded. If theses poles had been in actual service all of them would have been tagged for replacement.

An example of the results obtained for pole sections remediated with internal rods is presented in figure 5.

Figure 5: Pole section remediated with cobrarods after 11 years in ground.

The example in figure 5 is for a pole section treated with Cobrarods. As we can see, no degradation was observed at the ground line and this section is still well protected. A total of 18 poles section were treated with rods and only one of them showed degradation of any significance at the ground line. It was observed in this latter case that the rods were inserted too high up from the ground line to provide effective protection.

An example of the results observed for pole sections remediated with external bandages is presented in figure 6.

Figure 6: Pole section remediated with Pole Wrap after 11 years in the ground

Again, the ground line does not show any degradation. A total of 12 sections were remediated with bandages and only one pole section was degraded. The degradation was coming from the top of the pole section. We can conclude that we have demonstrated the efficacy of rods and wraps for remediation and protection to increase the service life of wood poles.

Implementation of the inspection program at HQD

The research work performed by IREQ and the follow on pilot project confirmed the benefits provided by a wood pole inspection program. In 2009, the business unit received regulatory approval to implement the test and treat program using only solid rods and to develop a software application to collect inventory and health information of this asset class and associated equipment, as well as providng recommendations as to treat or replace the pole. The software is tied into the GIS and SAP systems. The number of poles that have been inspected since 2009 are presented in figure 7.

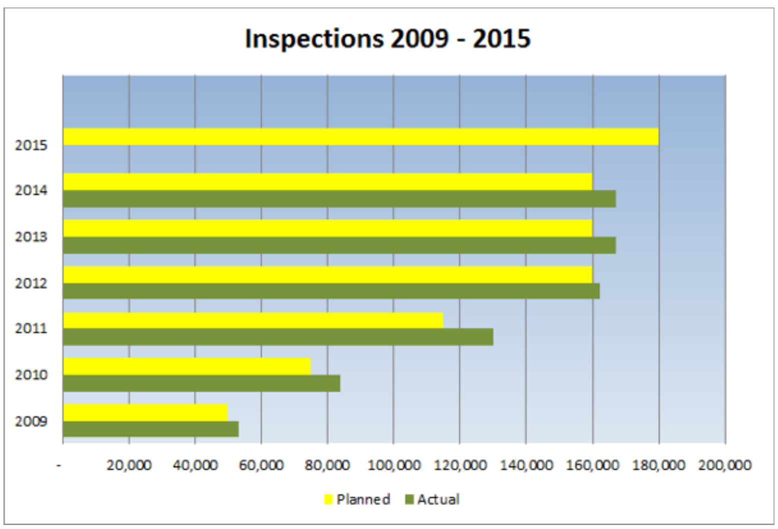


Figure 7: Poles inspected since 2009.

Since receiving regulatory approval in 2009, more than 750 000 out of the 1, 85 million poles have been inspected. To date, approximately 68% of these inspected poles received a full inspection and retreatment[2]. Because of the relatively young age of our pole population, over 28% received a "light" inspection with no retreatment. The previous research work as well as the inspection results to date has helped the HQD program to evolve in 3 ways;

- Refine and improve the inspection process

2

- Determine the causes of pole degradation and the remedial actions yo be taken
- Develop a mecano-probabilistic model to enhance the decision making process.

Refine and improve the inspection process

The current inspection program is built upon the standard hammer/bore concept but with many significant improvements based on past results. One effect has been how to identify and evaluate (score) different types of degradation that can be quantitative or qualitative in nature. Table 2 shows an example of the different rating elements.

Table 2: Rating element use for pole inspection

Rating Element	Measurement Category	Pole Section	Applicable to (Inspection Status)			
			IN	EX	RP	RU
Initial degrdation rating	Qualitative	A	x	x	x	x
Horizontal damage	Quantitative	B	-	x	x	x
Insects	Qualitative	B	-	x	x	x
Pole top condition	Qualitative	P	-	x	x	x
Checking (Longitudinal cracks)	Qualitative	A	-	x	x	x
Woodpecker damage	Qualitative	T,P	x	x	x	x
Inclination (from vertical)	Quantitative	B	x	x	x	x
G/L circumference	Quantitative	B	x	x	x	x
Reduction of circum below G/L	Quantitative	B	-	x	x	x
Shell thickness	Quantitative	B	-	x	x	x
Presence of a humid core	Qualitative	B	-	x	x	x
Sounding	Qualitative	B	x	x	x	x

All the inspection data are entered into the in-house developed software for analysis with a resulting condition assessment. The inspector evaluates all data to either confirm the assessment or alter it.

Determine the causes of pole degradation and the remedial action

Prior to the implementation of the program, information as to the primary causes of degradation was often just anecdotal in nature. The results collected to date and summarized below, shows that natural degradation found in the area in and around the ground line was the primary cause for the decision to replace the pole.

- Base; 70%
- Main trunk; < 10%
- Pole top; 20+%

Table 3 shows the main cause requiring replacement of the pole by section.

Table 3: Main cause of damage by region[3]

Base	
1	Internal decay and/or reduction in effective G/L circumference
2	Mechanical damage
3	Carpenter ants
Main trunk	
1	Woodpeckers
2	Severe checking
3	Shell delamination
Pole top	
1	Natural decay
2	Woodpeckers
3	Lightning strikes

The presence of natural decay in and around the ground line supports the need to intervene to stop this degradation via the application of retreatment products. Overall the results show that an earlier intervention (before degradation is too far advanced) would assist in retaining more poles in service as well as reducing the number of seriously degraded poles being found during this 1st inspection cycle. The data also illustrates the need to look at solutions to reduce the rate of natural decay at the pole top.

Develop a mecano-probabilistic model

[3] Base : First 2 meters of the pole from the G/L, Pole top: From top of pole descending 1 meter, Main trunk: Remainder excluding base and top.

The inhomogeneous nature of wood as well as the nature of the degradation such as when it commenced, its location on the pole and the ability to quantify the extent of the damage means that some factors (say shell reduction) can be "calculated" but only to an extent.

Other factors (presence/damage caused by wood peckers, insects, signs of delamination, etc.) are more difficult to model. As well the point at which the event occurred means that it is difficult to determine how long it has been present.

Figure 8 shows the degradation curve caused by ageing only and based on inspection data collected from 2011 to 2013.

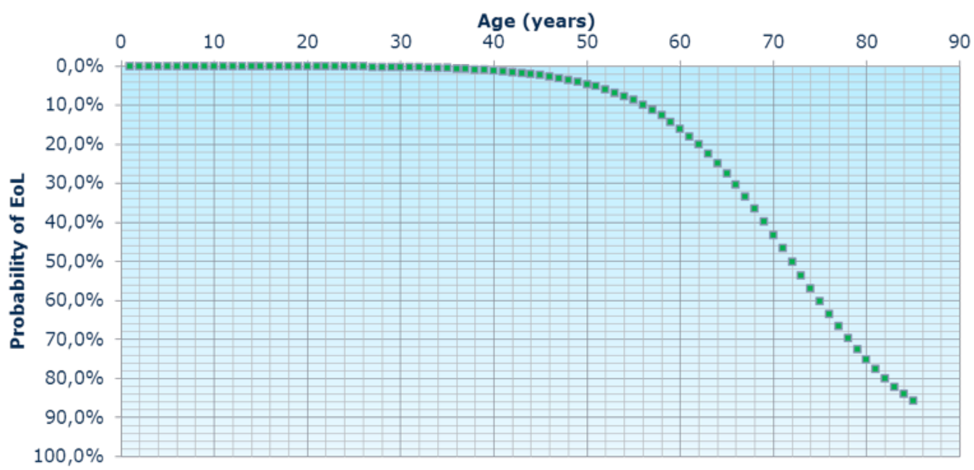


Figure 8: Degradation curve; natural ageing only.

Taking into account all factors, the actual mean life is in the area of 60+ years.

A mecano-probabilistic approach would allow the model the ability to evaluate both categories (quantitative and qualitative damage) where the mechanical aspect would allow us to calculate the reduction (as a percentage) in pole capacity and the qualitative elements could be modelled using a probabilistic approach giving each qualitative factor a "weighting".

This would be inputted into a Logistic Regression model. A Logistic regression analysis is different from an ordinary regression in that an ordinary regression uses least squares analysis to find a best fitting line and comes up with coefficients that predict the change in the dependent variable for one unit change in the independent variable. *In other words it is trying to determine a specific value.*

Logistic regression estimates the probability of an event occurring. This model fits better since what we are seeking to determine is the probability of an event occurring.

Figure 9 shows the concept of the degradation model.

This model could also permit us to evaluate the potential gain in additional useful life that could be expected from retreating the pole.

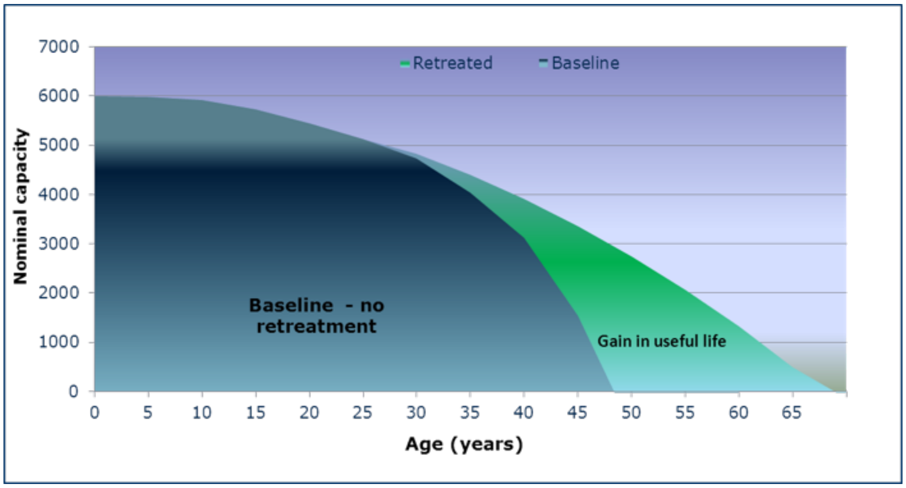


Figure 9: Simplified example of the model to be developed

Baseline: This is a simplified view of the degradation process for a utility pole that does not receive an inspection/retreatment during the course of its service life. While in this view we are only discussing « natural degradation », the trigger which starts the natural degradation could be an external factor such as insects, woodpecker damage, vehicle impact etc.

Retreated: Our hypothesis is that retreating the pole will slow the degradation process at the ground line and add to its useful service life. We also assume that the potential gain in useful life becomes smaller as the age at which the first retreatment is applied increases. As an example a pole retreated at 35 years of age will perhaps gain 10 additional years, whereas a pole retreated at 50 years of age may only gain 5 years. The study aims to try and identify the potential gain in order to optimize when and how to retreat.

3. Conclusion

The research efforts undertaken at IREQ as well as the pilot phase permitted Hydro-Québec Distribution to validate the benefits of implementing a test and treat program for its wood poles. Since obtaining regulatory approval in March of 2009, more than 750,000 poles have been inspected.

Detailed analysis of the results collected has permitted the utility to refine and enhance its inspection process. Most critically it has permitted the utility to develop a concept by which it can more accurately evaluate not just the current condition of the pole, but as well estimate with a high degree of confidence the expected condition of the pole over the span of the next inspection cycle. This allows the utility to assess in a more consistent manner if the pole can be kept in service and retreated or whether it should be removed from service in the short or medium term.

PRESERVED WOOD FOR MARINE USES

Dallin Brooks and Grady Brafford
Western Wood Preservers Institute, 12503 Mill Plain Blvd., Vancouver, WA. 98684 Timber Piling Council, P.O. Box 1784 Starkville, MS 39760

1. Introduction

One of the first known use of wood pilings was 4,000 BC by Neolithic tribes in Switzerland. They placed logs vertically into soft soil for structural support. These homes were built on piles to protect against wildlife, or extend over lakes and some evidence of these structures still remains today. The Tiber River Bridge built by the Romans in 642 BC used wood pilings and lasted more than 700 years. Some Roman roads and aqueducts supported on timber piling are still in good condition today.

Yet with this great history preserved wood for marine structures has slowly lost market share to alternative materials over the last several decades. A large part of this was due to the perception that alternative materials would last longer and take less maintenance. That has turned out to not be the truth, all materials whether it is concrete, steel, wood or plastic require maintenance and have specific issues related to their performance.

2. Methodology

Concrete piling has issues with spalling, soil displacement, changing pH, and disposal and are expensive. A number of recent issues have come to light with ports using concrete piling or floating piers and having expensive repair bills much sooner and more costly than expected.

Steel piling has issues with Corrosion, installation alignment, bending, failure and are expensive. In Alaska a recent sheet piling project worth $100 Million dollars was called into question when it did not meet seismic requirements. They have also had issues with steel in the north due to ice breakers crushing the steel piling when forcing the ice into them. Galvanized treated steel has been documented to affect Herring egg mortality and corrosion still becomes a problem when the surface galvanizing is damaged.

Plastic piling has issues with UV light causing degradation, brittleness and large amounts of steel cable to reinforce the plastic and are expensive. Plastic piling is still largely untested and these composites are a long way from mainstream use. Still they are begging to show up on projects.

Wood piling has issues with marine organisms, decay fungi, herring egg mortality, preservative movement and failure. However the processing, choice of preservative and meeting the appropriate standards such as the BMP and AWPA can mitigate some of these problems. Preserved wood in aquatic environments also has many advantages that make it ideal for use in marine structures.

3. Results and Discussion

Preserved wood advantages come from a long and proven lifespan. Many ports and marinas along the Pacific Ocean have old creosote treated piling dating back 60-90 years. Preserved wood is the most economical, low cost material for marine construction. It is also readily available with short lead-times, for emergencies due to it being locally produced. The renewability of wood has a lower energy production and carbon impact than recycled materials. When installed it has more flexibility, can handle rugged use, results in minimal on-site waste and is strong, durable and resilient. Wood is less noisy than other driven piling, has the lowest cost per ton of load carrying capacity and is well suited to withstand pressure of being driven into the soil.

Still perceptions are that wood is less hurricane resistant. Again that is simply not the case. In Pearlington, Mississippi Hurricane Katrina flooding reportedly only left one home standing. Is was on CCA piles and the water came within inches of the girders. Similar constructed beach houses meeting wind load standards have survived hurricanes from New Jersey to Texas. Figure 1 below shows a home in Galveston, Texas that survived Hurricane Ike.

House Surviving Hurricane Ike September 2008, courtesy of TPC

The concrete slabs can be seen empty I the background. The house was built on CCA piling. The stories of wood houses on preserved wood piling surviving hurricanes can go on and on. Timber pilings for foundations also resist attach from alkaline and acidic soil, does not require corrosion protection and is unaffected by electrolysis from stray electrical current.

Today's wood fibre has not changed significantly over time. There is little difference in "old wood" vs. "new wood" when assessing round timbers. This has been confirmed by testing done on southern yellow pine and Douglas fir wood poles by the Timber Piling Council. Horizontal force applied by cable at tip of the timber pile resulted in a bending stress that could be 36%-53% higher than currently allowed.

Property	Southern Pine	Douglas fir
Compression Parallel to Grain, F_c	1,200	1,250
Extreme Fiber in Bending, F_b	2,400	2,450
Horizontal Shear, F_v	110	115
Compression Perpendicular to Grain, F_c	250	230
Modulus of Elasticity, E	1,500,000	1,500,000

Table 1: Values are from ANSI/AF&PA NDS-2005, National Design Specification for Wood Construction, Supplement for Timber Poles and Piles. In lbs. /inch^2

4. Conclusions

Recent failures of concrete, steel, plastic and wood pilings show that there is no, one best material. Given that, there is little incentive to spend more, increase the overall environmental impact and have an increased unknown lifespan when selecting a piling product. Preserved wood piling and structures should still remain the first and most reliable choice. Such wood structures are able to handle hurricanes, floods, wind, seismic activity and more. The primitiveness of wood does not make it obsolete, it makes is a known performer that is renewable and preferred.

5. Literature

Timber Pile Design and Construction Manual, Author: James G. Collin, PH.D., P.E. The Collin Group, Ltd.

BC MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE TREATED WOOD BRIDGES

Ian Sturrock
BC Ministry of Transportation and Infrastructure
4B – 940 Blanshard St., Victoria, B.C. V8W 9T5

The BC Ministry of Transportation and Infrastructure (MOTI) has approximately 2800 bridges in its inventory; 516 of these bridges have at least one span made of timber. The most recent of these timber bridges was built four years ago and the oldest dates from the 1930s. The average age of the MOTI timber bridge inventory is about 40 years. The Ministry has several types of timber bridges that demonstrate where treated wood construction has performed very well and that highlight the importance of good preservative treatment.

Most of the MOTI's larger timber bridges are timber trusses or arches (see Figure 1). Because these types of structures have little redundancy, failure in one of the main load carrying members could result in collapse of the span. This lack of redundancy makes replacement of certain members extremely difficult and sometimes prohibitively expensive, thus underscoring the importance of high quality preservative treatment. Quality Management requirements for the fabrication and construction of timber highway bridges is described in the MOTI Standard Specification for Highway Construction (available at: http://www.th.gov.bc.ca/publications/const_maint/contract_serv/standardspecs.htm). Section 908 covers treated wood and makes reference to CSA O80 for the preservative treatment requirements. The Standard Specification sets out the responsibilities of the parties involved in bridge construction for various aspects of Quality Management. In industries where third-party plant certification is available the Ministry specifies that components for bridge construction must come from a certified plant. Plant certifications are available in the precast concrete and structural steel industries. The certification process in these industries are run at arm's length by industry trade associations such as the Canadian Institute of Steel Construction and the Canadian Precast/Prestressed Concrete Institute. Third party plant certification provides assurance to component purchasers that a fabricator has the facilities, expertise, personnel and the quality control processes necessary to produce products that meet the requirements of a purchaser's project. Unfortunately, third party certification for wood preservation plants is currently not available in Western Canada.

Most of the Ministry's older, timber bridges have utilized Douglas fir treated with creosote. While this preservative has generally worked well, there are certain uses where even the heavy creosote treatments of the past have been unable to achieve the 75 year design life called for in today's bridge design codes. For example, creosote treated timber piles have a lifespan of only 40 to 50 years. Several of the glulam girders built by MOTI, BC Ferries and the forest industry in the 1960 and 1970s have developed checks on surfaces exposed to sunlight which expose the untreated core of the girders to moisture and fungal spores. The MOTI has had to replace several of these girders after only 30 to 40 years of service life. Most of the Ministry's current inventory of timber bridges have timber decks and timber wearing surfaces, Wearing surfaces typically have to be replaced every four to ten years due to wear. Timber cross ties supporting the wearing surface last two to three wearing surface replacements, or 12 to 20 years. Treated timber pile caps last approximately 35 to 40 years and tend to rot from the ends where they are exposed to the environment.

The Ministry continues to use treated wood predominately in the maintenance of its existing timber bridge inventory rather than in new construction. Current spending for timber deck replacements is about $2 million annually. Any new timber bridges the MOTI does build will avoid the use of timber in areas such as foundations and wearing surfaces, where long term durability of treated wood is difficult to achieve. Two bridges recently built on Vancouver Island utilizing glulam girders with concrete wearing surfaces and concrete foundations (see figure 2) exemplify this trend.

Figure 1 – The St. Mary's Wycliffe Bridge, built in 1931, illustrates the durability of some timber structures, the lack of redundancy in long span trusses, the difficulty of replacing deteriorated truss members and thus the importance of good preservative treatment.

Figure 2. The Large Creek Bridge, built in 2010, has glulam girders with a concrete deck and foundations.

PRESERVED WOOD IN AGRICULTURE, HORTICULTURE AND VITICULTURE: A BRIEF OVERVIEW

Kevin Archer
Viance, LLC, 8001 IBM Drive, Building 403, Charlotte, NC 28262

1. Introduction

Wood has always been a highly useful material to the farmer. In the early days forests were cleared for crops and grazing. The felled wood from the cleared forests provided shelter, fuel and tools that were essential to the farmers' survival. Then, as the environment became tamed and under human control it became more and more important to enhance the longevity of structures constructed with wooden components. Today wood continues to provide an important role in agriculture because of its favourable cost, strength, beauty, working characteristics and availability. But, for all its positive attributes, it needs to be used intelligently and protected from decay, termites and the harmful effects of weathering.

In keeping with other applications for preserved wood, agriculture, horticulture and viticulture uses depend on the use of wood preservatives to prolong the useful life of the material in service. In the USA and Canada wood preservatives have to be registered as pesticides with either the US Environmental Protection Agency (US EPA) or the Canadian Pest Management Regulatory Agency (PMRA). Typical preservatives registered for agricultural, horticultural and viticulture uses include CCA, ACZA, Creosote, Pentachlorophenol, Copper azole and ACQ. The American Wood Protection Association (AWPA) and the Canadian Standards Association (CSA) set minimum standards for retention and penetration for these preservative systems. The majority of wood used for agriculture, horticultural and viticulture applications is treated to a heavy-duty ground contact retention generally AWPA UC4B or CSA UC4.1. However, some material intended for above ground use only (AWPA UC3B or CSA UC3.2) finds its way into agriculture, horticulture and viticulture as well.

Typically small round wood material in different diameters and lengths finds it way into agriculture, horticulture and viticulture. The round wood may be debarked, peeled or doweled, pointed or blunt ended and it may be full, half or quarter round stock. Some sawn material e.g. square posts and stakes and split rail fencing finds application in some sectors as well as plywood and glulam for farm building construction. Some typical end uses of treated wood and their size classes are illustrated in Table 1 below:

Size	Constant 2”, 3”, 4”	2-3”	3-4”	4-5”	5-6”	6-7”	7-8”	8-12”
6’		Fowl gate stays	Cattle fencing Line fencing					
		Woodlands	Forestry fencing					
			Sheep fencing					
7’		Cane berries	Cattle fencing	Line fencing	Corner posts	Corner posts		
		Blue berries	Line fencing	Hwy fencing				
		Fowl		Berry anchors				
8’	Ornamental tree stakes	Tree stakes	Grape stakes	Llama fencing	Corner posts	Corner posts	Corner posts	
			Horse fencing	Grape anchors	Corrals	Feed lots	Feed lots	
				Horse fencing	Buffalo fencing	Gate posts	Gate posts	
10’	Ornamental tree stakes	Tree stakes	Cross braces	Ginseng anchors	Gate posts	Pole Buildings		
	Tree stakes	Top rail	Ginseng line	Trellis anchors	Horse sheds	Gateposts		
	Top rail	Orchard props	Deer Fencing	Ostrich fencing				
		Cross braces	Trellis poles					
12’	Top rail	Irrigation pole	Fence rail	Trellis anchors	Horse sheds	Open sheds		
		Equestrian rail	Orchard trellis	Deer fencing	Elk fencing	Hwy game fencing		
		Fence rail	Deer fencing	Ostrich fencing				
20-30’				Hop poles	Pole buildings	Hay sheds		Yard lights
					Signage	Pole buildings		Utility poles
					Open sheds			

Table 1: Typical uses of agricultural, horticultural and viticulture commodities by size class

The life expectancy of treated material used for agriculture, horticulture and viticulture is, in common with residential and industrial uses of treated wood, contingent on the preservative type, the concentration of active ingredient and the extent of penetration. Round timbers with considerable amounts of sapwood are more easily penetrated than those with little sapwood. Preservative treatment can extend the average life of the wood in service considerably as summarized in Table 2 below.

To a major extent the wood species utilized for agriculture, horticulture and viticulture commodities in any given locale reflect the tree species commonly available in the area. In contrast to high value products such as utility poles agricultural materials are generally considered to be commodities at the lower end of the pricing spectrum and, as such they are not shipped large distances across country. Thus posts and poles used for agriculture in the US South East would more than likely comprise southern pine material whereas in the Pacific North West, Lodge pole, Douglas fir and Ponderosa pine is more prevalent. While regional availability of species is a dominant factor in the wood selection process for certain end uses there is a definite preference for round wood based on form i.e. taper and diameter as well as its strength characteristics. Treatability can also be a significant factor in selecting one species over another. Of all the available species Lodge pole pine is highly favoured because of its high strength, tight grain, minimal propensity to crack and check, low taper relatively high sapwood content and by the fact that it is relatively easily treated.

Species	Life Span (years)	
	Untreated	Treated
Aspen	1.4-14	30+
Ponderosa pine	3.5-14	35+
Lodge Pole pine	4-12	35+
Douglas fir	7-12	20+

Table 2: Preserving wood prolongs its useful life – Source USDA Forest Service (FPL data).

A literature search to locate specifications for agricultural, horticultural or viticulture wood commodities failed to yield anything useful. It appears that there are no consistent grading rules in place and specifications tend to be purchasing contract specific and somewhat simplistic in nature – no cracks or beetle kill material with minimal taper.

Similarly, for the most part, there do not appear to be any stringent government regulations in place, either Federal, State/Provincial or local to ensure performance or quality of preserved wood used on farms. Interestingly, the building codes in the USA seem to exempt agricultural buildings. The International Building Code is the primary non-residential model building code in the United States. Although the IBC: (1) covers agricultural buildings, and (2) has been adopted to varying degrees in all 50 states, most agricultural buildings are not designed in accordance with its provisions. This is because most state and local governments that adopt the IBC exempt "buildings used exclusively for farming purposes" from all building code provisions.

2. Structure of the Industry

Many agricultural/horticultural/ viticulture post and pole manufacturers operate their own treating vacuum pressure treating plants but treating service (TSO) production is also commonplace. Some treating plants supply agricultural posts, poles and stakes exclusively. Other plants produce agricultural commodities alongside residential and industrial materials. A frequent comment made by many of the plants surveyed was that excellent relationships with forest owners both private and state run is essential to remain viable as a business and to ensure a steady supply of wood to treat. In years gone by the small wood utilized for agriculture applications was considered by the larger logging companies almost as a "waste" or "by product" of saw log and pole production. This led to plentiful supplies of cheap raw material and it provided opportunities for small entrepreneurial forestry operations. In more recent times the trend has either been towards increasing competition for the better fiber resource by other industries leading to increased pricing or in other cases the small wood producer can often find that he/she is locked out for the forest because it is not worth the effort for the bigger companies to allow them to take the small wood. As a consequence the number of small wood operators has dwindled in recent years.

In addition to vacuum pressure treatment processing most agriculture, horticulture and viticulture treating operations include a variety of round machining activities such as pointing, debarking, peeling or doweling systems much of which is automated to produced high quality consistent form in the finished product.

The uses of preservative treated lumber in agriculture, horticulture and viticulture are varied. Some of the larger structural uses include silos and buildings for storage of grain and hay. Other common structures include barns for protection and shelter of livestock, cattle, dairy, pigs, sheep, poultry and other animals. Barns associated with Equestrian applications make expensive use of preserved wood for horse barns, stalls, stables, tack rooms and wash bays.

Farm fencing represents a significant market preserved wood as well. Fencing satisfies a legal need to keep animals under control and prevents them from wandering away. By the same token fences can keep unwanted animals out. (Figure1)

Figure 1: Fences can keep animals in as well as out (Source: Elizabeth Marion Princeton wood Preservers)

Fences can significantly improve livestock grazing efficiency by producing an affordable way to provide forage for livestock all year round. An often overlooked benefit of fencing is that when properly constructed it can provide significant protection for animals from wind which can have a more serious effect on livestock than extreme cold. Finally, the aesthetically pleasing aspect of farm fences in a pastoral setting particularly as it relates to horses should not be overlooked. Horse fence designs have been developed to address specific horse habits. Owners spend significant sums of money to protect their thoroughbreds from physical damages to their legs and hooves from poorly constructed fencing. Visibility of fences to horses is very important which explains why it is common to paint rails and posts on horse farms.

Preserved wood is used extensively to support a wide range of crops. Support structures include vineyard trellis posts and stakes, hop pole, tomato stakes, apple tree stakes and trellising, tree props, berry stakes, kiwi fruit trellising and supports for bird netting among others. Apple growers have been moving away form individual tree supporting stakes to trellis systems for a number of years. High-density planting systems allow apple tree framers to produce huge crops that cannot significantly exceed the ability of the trees to support the weight of fruit. It has been found that tree supported by trellising from the time of planting can produces 30% or more yield in the first five years after planting. The economic benefits of durable preserved wood support structures to apple tree farmers are obvious. Proper construction and installation of a vineyard trellis support system contributes significantly to the establishment and long term success of a vineyard. The trellis is the main support structure of the vines supporting the canopy and wind loads.

Figure 2: Acres of land devoted to viticulture showing extensive use of preserved wood

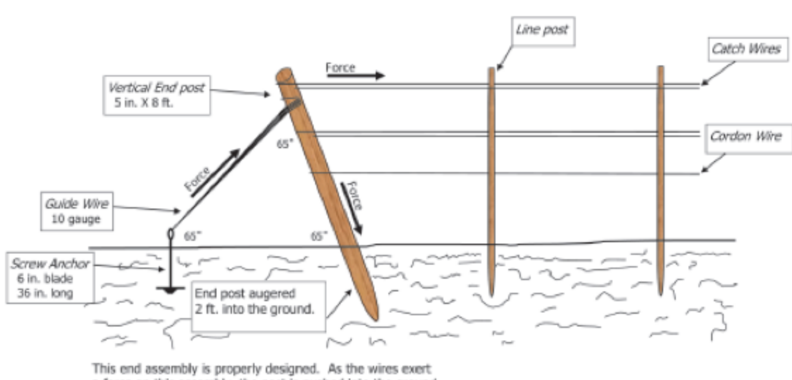


Figure 3: A well designed vineyard trellis system supports the vines as they grow and develop heavy fruit loads.

Figure 4: Hop poles

Figure 5: Poles supporting overhead nets protect crops from birds

3. Use Statistics

Surprisingly, no single agency in the USA or Canada appears to monitor treated wood usage in agricultural or horticultural applications. As a result useful statistics for the sector are virtually impossible to come by. Limited information was published in the now dated Mickelwright report (AWPA 1997) but perhaps Vlosky in his Statistical Overview of the US Wood Preserving industry collated the most informative data in a 2007 survey of the US industry as a whole. An excerpt from the Vlosky report published in 2009 is provided as Table 3 below:

Commodity	Units	Production Year	
		2007	2004
Waterborne			
Agricultural stakes	Cubic feet	558,404	2,118,220
Round fence posts	Cubic feet	16,070,958	No data
Oil borne			
Round fence posts	Cubic feet	2,320,992	No data

Table 3: Use statistics extracted from Statistical Overview of the US Wood Preserving industry, 2007. (Vlosky, 2009)

Fundamentally it is apparent that there is a serious lack of current statistical data on preserved wood usage in the agriculture, horticulture and viticulture sector. It might be helpful to the industry if organizations such as Wood Preservation Canada, the Western Wood Preservers' Association and Southern Pine Treaters' Association could find the funding to conduct market segment surveys.

Anecdotally, based many conversations with industry sources, there seems to be a consensus that the agricultural post and pole industry has seen a gradual decline in market share, production and employment levels since the early 1990's. The decline can be attributed to a number of reasons and perhaps the main one being the fact that the small round wood resource available in the forest is severely challenged. For many forest owners it is more economical to chip and bulldoze small wood thinnings, posts and tops into piles because the added value of firewood pallet stock and other low value products is barely worth the cost to harvest and transport. Other factors may also be contributing to the decline. As with all treated wood products lingering perceptions that the chemicals used to preserve the wood are toxic and the chemicals leach into the environment persist. The fact that preservative chemicals have been rigorously evaluated by regulatory agencies and found fit for purpose is frequently overlooked. Poor quality and lack of consistent performance continue to be issues as the quality of the available small wood resource declines. Competition from alternative products is also a growing problem. Vinyl and plastic fencing continues to make inroads into equestrian fencing in part because of the improved aesthetics. Steel and concrete posts are making inroads into vineyards. Resistance of such products to decay, termite attack combined with their perceived superior dimensional stability and consistent strength characteristics represent major reasons for buyers to switch from preserved wood. Treated wood also creates disposal issues in certain markets.

4. Summary

The main purpose of this presentation was to report on the use of wood in agriculture, horticulture and viticulture. In many respects the It proved to be a somewhat frustrating exercise due to the lack of statistics on use patterns and volumes of wood produced by the industry such that many aspects of the market. At the same time it proved to be a fascinating and rewarding exercise due to the multitude of interesting and innovative uses of preserved wood by the larger farming community. The industry would be well served with an in depth study of the current market and future market potential of preservative treated agricultural products.

5. Literature

Mickelwright J.T., 1997. Wood Preserving Statistics. American Wood Protection Association, 24p.

Vlosky R. 2009. Statistical Overview of the US Wood Preserving Industry 2007. Louisiana State University Forest Products Development Center, 81p.

WOOD FIRST

Steven Kuan
Forestry Innovation Investment, #1200 – 1130 W. Pender Street, Vancouver, B.C. V6E 4A4

1. Introduction

The forest sector is very important to British Columbia. Ninety-five percent of the forests in the province is owned by the crown. About 70 million cubic metres of wood is harvested every year (BC Stats 2014). The B.C. forest sector directly employs about 58,000 people, with the number of people in the wood products manufacturing sector making up about one-quarter of all the manufacturing jobs in the province (BC Stats 2014). Forty percent of the regional economies in B.C. is dependent on forestry.

The value of forest products exports from B.C. has reached $11.7 billion. B.C. is the number-one supplier of forest products to China, U.S., Japan and Taiwan and is a world leader in the export of softwood lumber. Over the past ten years, the markets for B.C. forest products have diversified. For example, the export to China now accounts for about 30% of the total (BC Stats 2014), compared to 5% in 2003.

In 2009, the government of British Columbia initiated a strategy (Ministry of Forests and Range 2009) to move the forest industry to a more diverse industry producing higher value wood products. The strategy embraces innovation and diversification to create a globally competitive, market-based operating climate. One action of the strategy was to champion Wood First. The goal of this action is to establish B.C. as a world-class centre of excellence in developing and using innovative wood products and building systems.

2. Wood First Program

Wood First is part of the Government of British Columbia's commitment to job creation and environmental sustainability. It is aimed at encouraging a cultural shift towards viewing wood as the first choice for construction, interior design and daily living. Wood First promotes and supports the increased use of wood products and systems in building design and construction. Greater use of wood supports the provincial forest sector through increased employment and revenues. A growing demand for wood-based products and building systems further fosters innovation and the growth of value-added businesses.

In support of Wood First, the government of British Columbia also in 2009 passed the Wood First Act to encourage greater use of wood in publicly-funded construction and amended the BC Building Code to allow wood-frame residential construction to go up to 6 storeys.

Education, research and outreach elements of Wood First are led by Forestry Innovation Investment (FII), the Province's market development agency for forest products. In addition to creating, diversifying and maintaining markets, FII fosters innovation in the forest sector and provides information on B.C.'s forests, wood products and wood building technologies. FII operates out of offices in Vancouver, Shanghai and Beijing in China, and Mumbai in India.

FII's Wood First Program focuses on:

- advancing innovation through research and product development;
- reducing barriers to wood use;
- educating professionals on opportunities to utilize and innovate with wood;
- promoting B.C.'s wood species, wood products and the benefits of building with wood; and
- raising the competitiveness of B.C.'s value-added wood sector.

Annual investment in the FII Wood First Program is $2,800,000.

In delivering the Program, FII works with trade associations, research institutions, design and construction communities, and manufacturers. They include:

- BC Wood Specialties Group
- Canadian Wood Council Wood *WORKS!* BC
- FPInnovations
- NEWBuildS
- University of British Columbia Centre for Advanced Wood Processing (UBC CAWP)

In particular, Wood First has supported two studies in the subject of wood stains. One study was a set of field tests conducted by FPInnovations to evaluate the performance of commercial penetrating stains (Stirling 2013); the other was an experimental study by UBC CAWP to examine the performance of exterior semi-transparent penetrating stains on Douglas Fir and western red cedar (Evans and Lotter 2014).

3. Impact and Trends

Since its launch in 2009, Wood First has stimulated many exciting projects that showcase B.C.'s innovative wood products. Early projects include the new venues built for the 2010 Vancouver Olympic and Paralympic Winter Games, such as the Richmond Olympic Oval and the Vancouver Trade and Convention Centre. Aesthetically pleasing and functional schools and facilities constructed out of wood have been planned, designed and constructed all over the province. Wood is now used in many new and different ways in both architectural and structural applications and both on the exterior and in the interior of buildings.

The code amendment in 2009 has created a boom in mid-rise wood-frame residential construction. Today in the province, there are 153 mid-rise residential projects in various stages of development, from project planning through to design, permitting and completed construction. The mid-rise market is expected to expand even more as provisions for mid-rise commercial buildings as well as mid-rise residential buildings are being reviewed for inclusion in the 2015 edition of the National Building Code of Canada.

Interest for taller and larger wood buildings is growing in B.C. and around the world. In 2012, the study "The Case for Tall Wood Buildings" (mgb ARCHITECUTRE+DESIGN et al. 2012), conducted by a team of experts in British Columbia, presented the technical feasibility of a 30-storey tall wood building. Many tall wood buildings have been built outside of Canada in the past few years, and B.C. has made use of opportunities to learn from many of these projects (Forestry Innovation Investment and Bi-national Softwood Lumber Council 2014). B.C. is demonstrating its leadership in this field with the recent completion of the 29.5-metre high Wood Innovation and Design Centre in Prince George, B.C.

FII is a key resource for information on the B.C. forest economy and B.C. wood products. New and up-to-date information is continually provided through publications, presentations, videos, project profiles and bulletins on the websites managed by FII – naturally:wood.com and woodfirstbc.ca.

4. Conclusions

Wood First helps to develop, strengthen and promote the expertise in wood building design and construction and wood products manufacturing in B.C. Recent advances in these areas, combined with innovative ideas, are allowing wood to be used in a variety of new ways in building construction. The increase in the use of wood and the change in the type and range of use, application and products are presenting the wood preservation sector with new opportunities, along with new challenges as the expectation and demand continue to change.

5. Literature

BC Stats. 2014.

Evans, P., Lotter, B. 2014. Improving the Performance of Semi-Transparent Stains on Douglas Fir and Western Red Cedar Using a Plasma Pre-Treatment. Report to Forestry Innovation Investment. The University of British Columbia Centre for Advanced Wood Processing.

Forestry Innovation Investment, Bi-national Softwood Lumber Council. 2014. Survey of International Tall Wood Buildings.

mgb ARCHITECTURE + DESIGN et al. 2012. The Case for Tall Wood Buildings: How Mass Timber Offers a Safe, Economical, and Environmental Friendly Alternative for Tall Building Structures.

Ministry of Forests and Range. 2009. Generating More Value from Our Forests. A Vision and Action Plan for Further Manufacturing.

Stirling, R. 2013. Initiation of Field Tests to Evaluate the Performance of Commercial Penetrating Stains. FPInnovations.

CHEMISTRY OF MICRONIZED COPPER TREATED WOOD

Wei Xue[1], Pierre Kennepohl[1], and John N.R. Ruddick*[2]
[1]Wei Xue, and [1]Pierre Kennepohl, Department of Chemistry, University of British Columbia, 2036 Main Mall, Vancouver, B.C., Canada V6T 1Z1
[2]John N.R. Ruddick, Department of Wood Science, University of British Columbia, 2424 Main Mall, Vancouver, B.C., Canada V6T 1Z4

Summary

The reaction of micronized copper with the heartwood and sapwood of lodgepole pine is discussed. The heartwood reaction often exceeded the maximum amount predicted from the cation exchange capacity for the expected hemicellulose reaction, and which has been observed previously for sapwood reactions. It is proposed that the increased reacted copper arises from a reaction of the resin acids following fungal degradation present in the heartwood. The reaction of micronized copper in blue stained red pine sapwood was found to be lower than unstained sapwood. It was suggested that this may be due to the degradation of the pectin rich areas in the pit structure of the stained sapwood.

1. Introduction

The reactions of micronized metals with wood are diametrically different from those of conventional wood preservative treatments. In these reactions the micronized copper carbonate is insoluble and is solubilized by acidic groups in wood which mobilizes the copper and also creates reactive sites for complex formation. The unreacted basic copper carbonate remains undissolved and is insoluble. Previous studies have shown that micronized copper reacts with the carboxylic acid groups present in wood, in particular those in hemicellulose, (Xue et al., 2012, 2013 and 2014). The amount of reacted copper that is observed – up to 0.3% Cu - is consistent with the cation exchange capacity (CEC) for wood when only the carboxylic acid protons react (Lee and Cooper, 2010).

As described in the earlier research, the reactions of the micronized copper can be studied by a combination of x-ray fluorescence spectroscopy (XRF) and electron paramagnetic spectroscopy (EPR). The total copper can be quantified using the XRF while the EPR is used to quantify the reacted copper. EPR has been used before to examine the structure of copper complexes. Ruddick (1992) showed that copper sulphate and ammoniacal copper solutions generated quite different EPR spectra at 77 °K. The hyperfine interaction $A_{//}$ was much greater in the ammoniacal copper solution. This relationship of the number of Cu-N bonds present in the structure on $g_{//}$ and $A_{//}$ had been discussed earlier by Peisach and Blumberg (1974). In addition, comparison of the hydrated copper ion EPR spectrum with that of copper complexed in wood also differed and this suggests that subtle changes in the bond geometry may be used to identify different copper complexes present in wood.

2. Methodology

Lodgepole pine "2 x 6" boards were treated in a pilot plant with micronized copper quat (MCQ), micronized copper azole (MCA) or micronized copper carbonate alone (MC). The boards were allowed to air dry for several months before being sampled. Samples were removed of both the sapwood and heartwood in selected boards. They were oven dried ground to 40 mesh sawdust and the copper content measured by XRF. They were then analyzed by EPR as described previously (Xue, et al., 2013). During the sampling of some of the boards it was noted that the heartwood of some boards contained extensive fungal colonization which had occurred in the tree. This was readily observed by the very permeable heartwood, indicated by the deep penetration of the micronized copper almost to the centre of the board. Additional samples were therefore collected of this intense green coloured heartwood, as well as a number of knots which also had a green preservative colour associated with them.

Red pine pole tops obtained from Ontario were sectioned to provide sapwood and heartwood samples, which were ground up to 40 mesh sawdust. Samples were removed from both stained and unstained sapwood, to determine the effect of blue stain on the reaction during treatment with micronized copper quat solutions.

3. Results and Discussion

In reviewing the total copper (Figure 1) and reacted copper (Figure 2) concentrations in treated lodgepole pine boards, the amount of reacted copper in some samples was higher than previously observed. Several were also much higher than predicted from the cation exchange capacity for wood (Figure 2). These values occurred in the treated heartwood, raising the possibility of the acidic extractive components interacting with the micronized copper. Curiously, while the total (Figure 1) and reacted copper (Figure 2) contents at a depth of 3 mm from the surface were usually much lower than those found in earlier sapwood studies, one value at 3 mm depth in heartwood was 0.45 % Cu. This suggests that some characteristic of these boards is enhancing the reaction in the usually less permeable heartwood. The samples recovered from knots were similar to those from adjacent surfaces. The reacted copper in the sapwood sample was much lower than that recorded in other sapwood treatments. These observations suggest that the resinous lodgepole pine was enhancing the reactions in heartwood but at the same time limiting the reaction in the usually permeable sapwood.

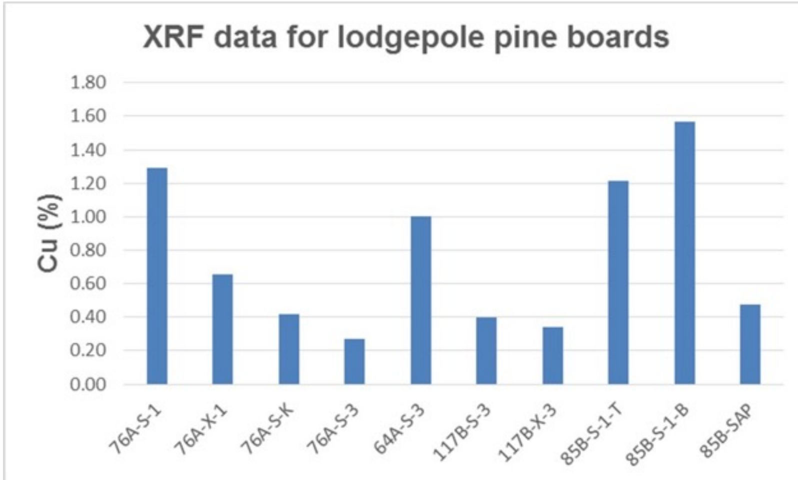


Figure 1. Total micronized copper in treated lodgepole pine boards

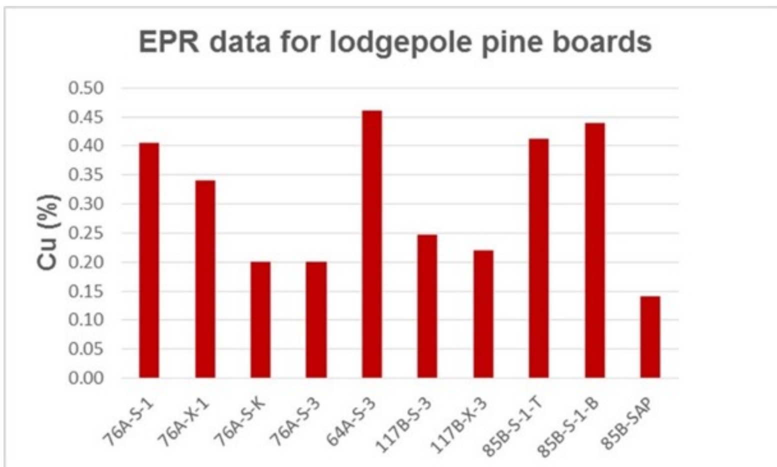


Figure 2. Percent reacted copper in MCQ treated lodgepole pine boards.

To further examine this effect the EPR parameters were examined to see if differences could be detected in the various spectra. Previous spectra of MCQ treated sapwood have shown that the typical spectral parameters are a $g_{//}$ value which ranges from 2.32 to 2.38 gauss relative to 2,2-diphenyl-1-picrylhydrazyl (DPPH). This corresponds to the product from the reaction of the basic copper carbonate with the acidic groups in hemicellulose and in pectin. Initial studies of the EPR spectra of southern pine and lodgepole pine sapwood and heartwood recovered from MCQ treated boards, revealed that while the sapwood values exhibited $A_{//}$ values of 132 to 135 gauss, the heartwood values in the southern pine and lodgepole pine samples were often much higher ranging from 142 to 146 gauss (Figure 3). This suggested that a second copper wood species is present in the heartwood samples.

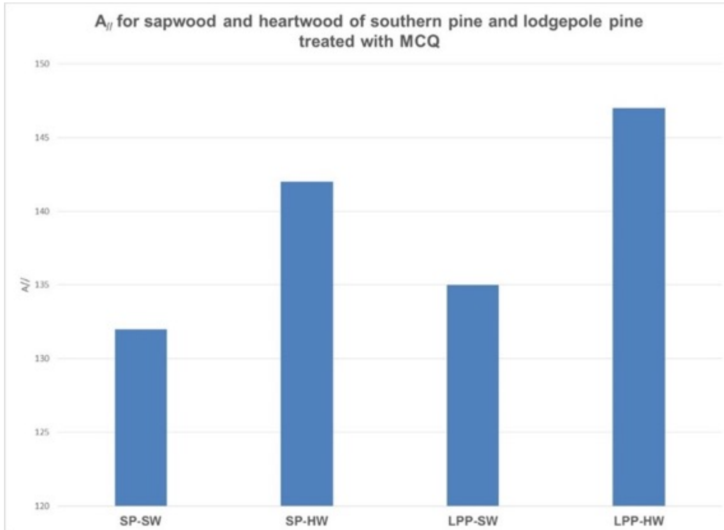


Figure 3. EPR $A_{//}$ values for sapwood and heartwood of southern pine and lodgepole pine boards.

In order to expand this knowledge of the reaction of resin acids with micronized copper in wood, the spectral parameters of the reacted knot material were determined. These should exhibit the effects of the resinous material known to be located in knots. The results are shown in Figure 4. The data is for samples at a depth of 2-3 mm from the original surface of the board. They confirm that while the green coloured heartwood had hyperfine interactions of 139 and 136 gauss, the adjacent knots had much higher values of 148 gauss. Interestingly the reacted copper concentrations in the knots were about 0.15% Cu while those in the green coloured heartwood (0.40 %Cu) easily exceeded the cation exchange capacity for hemicellulose of 0.3% Cu. This suggests that the green heartwood material contains mixed reactions of copper with hemicellulose glucuronic acid and also resin acids. Laboratory studies of copper with resin acids suggested that while saponification processes could lead to the formation of copper – resin products, the reaction was not easily achieved using resin acids directly. Further research is needed to fully understand the interactions of micronized copper with heartwood extractives in lodgepole pine. The observation of higher reacted copper concentrations than those predicted by the cation exchange capacity of wood, lends support for the need for additional basic copper carbonate as described by Freeman and McIntyre (2013) as a “reservoir” effect.

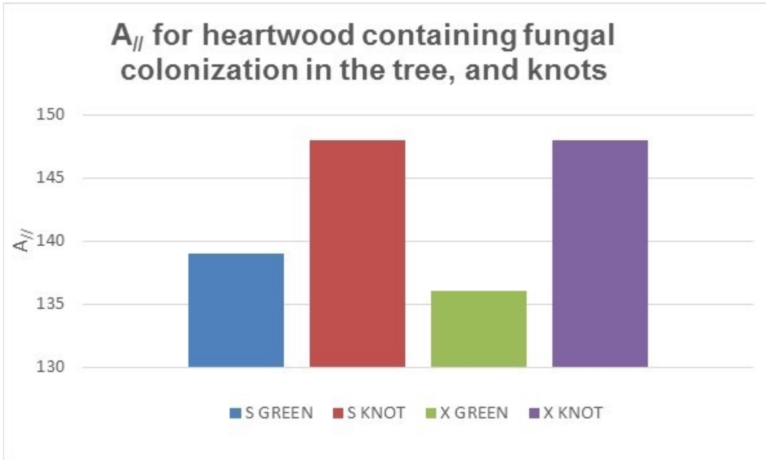


Figure 4. $A_{//}$ for knots and adjacent green coloured heartwood of a lodgepole pine board.

The second study involved the samples recovered from red pine sapwood and heartwood sawdust from an untreated red pine pole section. The sawdust was treated with MCQ. While the total copper content was similar in the blue stained and unstained control sapwood samples, at approximately 0.45% Cu the reacted copper concentrations were quite different, with that in the blue stained sapwood being much less. (Figure 5). This was attributed to the blue stain fungus degrading the pectin rich material in the pit structures thereby reducing the reaction of the micronized copper in the stained sapwood. Further research is needed to confirm this observation in other samples.

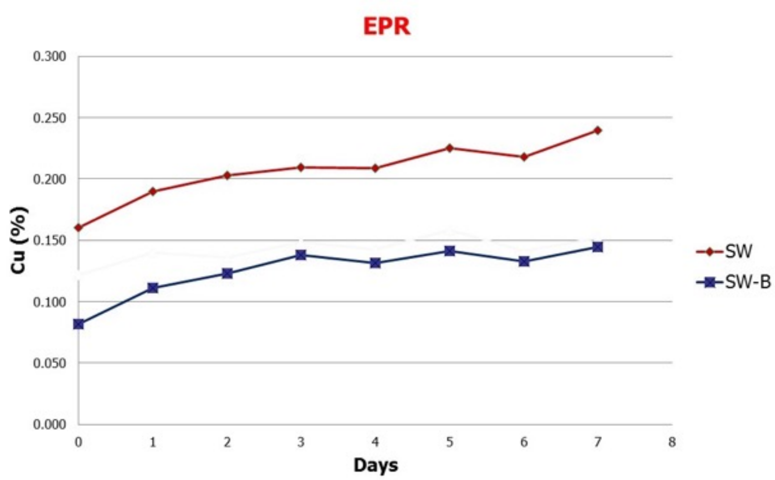


Figure 5. Reacted copper in blue stained red pine and unstained control

4. Conclusions

In lodgepole pine boards, heartwood often exhibited reacted concentrations in excess of the amount predicted from the cation exchange capacity of hemicellulose at a pH of 3 to 4.5. The EPR parameters were consistent with the presence of mixed copper reaction products involving resin acids. Reaction products of micronized copper with knots consistently had EPR spectra with high values of $A_{//}$ of the order of 146 gauss or more.

The reaction of micronized copper with blue stained red pine sapwood produced lower reacted copper contents than unstained red pine. It is thought that the blue stain fungi are degrading the pectin rich material in the pit structure, resulting in a lower reaction.

5. Literature

Freeman, M. H. and C. R. McIntyre. 2013. Micronized Copper Wood Preservatives: Strong Indications of the Reservoir Effect. Internat. Res. Group on Wood Preserv. Document No. IRG/WP 13-30609

Lee, M. J. and P. Cooper. 2010. Copper monoethanolamine adsorption in wood and its relation to cation exchange capacity (CEC). Holzforschung 64:653-658

Peisach, J., and W. E. Blumberg. 1974. Structural implications derived from the analysis of electron paramagnetic resonance spectra of natural and artificial copper proteins. Arch. Biochem. Biophys. 165:691 – 708.

Ruddick, J. N. R. 1992. The fixation chemistry of copper based wood preservatives. Proc. Canadian Wood Preserv. Assoc. 13:116 – 137.

Xue, W, P. Kennepohl and J.N.R. Ruddick. 2014. Reacted copper(II) concentrations in earlywood and latewood of micronized copper treated Canadian softwood species. Holzforschung, (In press).

Xue, W, P. Kennepohl and J. N. R. Ruddick. 2013. Quantification of mobilized copper (II) in micronized copper treated wood by electron paramagnetic resonance (EPR) spectroscopy. Holzforschung. 67:815-823.

Xue, W, P. Kennepohl and J.N.R. Ruddick. 2012. Investigation of copper solubilisation and reaction in micronized copper treated wood by electron paramagnetic resonance (EPR) spectroscopy. Holzforschung. 66:889-895.

DURABILITY RELATED RESEACRH IN NEWBuildS NETWORK

Ying-Hei Chui
University of New Brunswick, Fredericton, New Brunswick

Summary

A five-year multi-disciplinary research network was established under the Natural Sciences and Engineering Research Council's (NSERC) Forest Sector R&D Initiative in 2010 to support the development of innovative construction technologies and advanced design methodologies, and to review some of the building code barriers, with the ultimate goal of increasing the use of wood products in mid-rise and non-residential construction. The network, referred to as NEWBuildS, consists of researchers from 13 Canadian universities, FPInnovations, National Research Council and the Canadian Wood Council. Because a building is required to be designed to meet the requirements of a number of performance attributes, including structural, fire, serviceability, acoustic, energy efficiency and durability, a multi-disciplinary team of researchers with these backgrounds was assembled to conduct collaborative research projects in this Network. This will ensure that any proposed solutions will meet the key objectives of the National Building Code of Canada. This paper provides an overview of the structure of NEWBuildS, its research program, and some details on durability related projects.

1. Introduction

The use of wood in building construction historically has been limited to low-rise residential buildings because of restrictions imposed by the building codes. The introduction of the National Building Code of Canada imposed a height limit of 4 storeys in Canada in 1940's. Interestingly, wood buildings taller than 4 storeys were constructed prior to the 1940's, and a lot of them are still functional today. A survey conducted by FPInnovations (Koo, 2013) has found over forty 5 to 8 storey high wood buildings that were built between 1872 and 1930 in Toronto and Vancouver. Increased emphasis on sustainable building designs and the emergence of engineered wood products and systems have led to a strong interest in bringing back these mid-rise buildings. The storey limit in Canada in some provincial building codes (British Columbia, Quebec and Toronto) has been raised from four to six since 2009. The trend is to construct even taller wood buildings. The tallest modern wood building in the world currently stands at 10 storeys. This is a cross laminated timber (CLT) building located in Melbourne, Australia. Construction companies and building designers are exploring various design concepts of buildings taller than 10 storeys with wood alone or in hybridized systems consisting of timber in conjunction with other materials. If these concepts are to be realized in practice, continued research to develop new technologies, including innovative products, systems, design tools and construction techniques, and to remove unjustified building code barriers, is required. Under the Natural Sciences and Engineering Research Council's (NSERC) Forest Sector R&D Initiative, a five-year multi-disciplinary strategic research network, known as NEWBuildS, was established in 2010 to support the development of such technologies and advanced design methodologies, and the review of some of the key building code barriers to use of wood products beyond low-rise construction. The vision of the NEWBuildS network is to increase the use of wood products in multi-storey buildings for residential and non-residential purposes in Canada and other markets.

2. Overview of NEWBuildS network

The research program of NEWBuildS was established in collaboration with FPInnovations, wood industry and design community. The research network consists of about 40 researchers from 13 Canadian universities, FPInnovations, National Research Council of Canada (NRC) and the Canadian Wood Council (CWC). Figure 1 shows the membership of NEWBuildS. The research activities are organized into four linked research themes:

- Theme 1: Cross laminated timber (CLT) – material characterization and structural performance
- Theme 2: Hybrid building systems – structural performance
- Theme 3: Building systems – fire performance, acoustic and vibration serviceability
- Theme 4: Building systems – durability, sustainability and enhanced products

In total, 37 research projects are funded covering a range of disciplines, including structural engineering, structural serviceability, fire engineering, acoustics, building envelope and sustainability. An estimated 70 highly qualified personnel (HQP) will be trained during the conduct of these 37 projects.

Figure 1 - Members of NEWBuildS.

3. Research program of NEWBuildS

NEWBuildS is investigating the use of traditional light wood frame in mid-rise residential construction, as well as heavy systems built with wood products or with an innovative approach to combine wood with different materials (hybrid system). Because a building is required to be designed to meet the requirements of a number of performance attributes, including structural, fire, serviceability, acoustic and durability, a multi-disciplinary team of researchers with these backgrounds have been assembled to conduct collaborative research projects in this network. This will ensure that any proposed solutions will meet the key objectives of the National Building Code of Canada (NRC 2010).

Theme 1 – Cross laminated timber

This theme focuses on material characterization of CLT and structural performance of CLT building assemblies. It will generate technical information, such as design properties, product evaluation procedures and system-based uses, in support of the development of a national manufacturing industry for CLT and building applications in Canada. This research will also develop CLT product designs that utilize Canadian forest resources in a sustainable manner.

CLT was developed and used in Europe for over a decade. In North America, the first CLT product standard, ANSI/APA PRG 320-2011 (APA 2011), was published in December 2011. ANSI/APA PRG 320 provides requirements and test methods for qualification and quality assurance of CLT. This standard lists seven stress classes covering major wood species in North America.

Under NEWBuildS, complementary work is being undertaken for further expanding the use of CLT in multi-storey and non-residential construction, where the structural, fire and moisture loads can have different characteristics compared with the traditional low-rise wood frame construction. There have been substantial interactions between Canadian and European researchers who have conducted research on CLT for the past few years. Based on these interactions and earlier research findings from FPInnovations, and Canadian universities, research topics related to material property characteristics and structural performance of CLT building systems or sub-systems in the Canadian context were identified as priorities. Canadian design community is familiar with traditional post-and-beam and stick-frame construction. CLT presents a different type of structural form based on connecting plate-like sub-systems to form a complete building. There is a need to implement engineering design specifications and procedures in the Canadian material design standard (CSA O86) and in the National Building Code of Canada (NRC 2010), and investigate connection behaviours, in-plane stiffness and strength of floor and roof diaphragms, stability of wall systems and dynamic response of buildings under wind and seismic excitation. These topics are subject of research projects under theme 1.

Theme 2- Hybrid building systems – structural performance

This theme focuses on structural performance of mid-rise wood frame buildings and buildings using hybrid construction systems such as heavy timber and innovative approaches that combine wood with concrete or wood with steel.

In April 2009, the province of British Columbia modified its building code to permit the construction of 5- and 6-storey light wood-frame, multi-unit residential buildings. Figure 2 shows the first 6-storey building constructed in B.C. Since then, the provinces of Quebec and Ontario have announced similar, but broader, changes in their building regulations. At that time, which roughly coincided with the establishment of NEWBuildS, the wood industry and engineering professionals identified research topics that would provide valuable information to improve the design and construction of mid-rise, light wood-frame buildings in Canada. These topics included design guidance on floor diaphragms to transfer design loads on buildings to walls, cumulative shrinkage due to changes in moisture content of wood, reliable design models for predicting inter-storey drift and fundamental natural frequency of multi-storey wood frame buildings under lateral load and the role played by non-structural components and interaction between wood and other substructures.

Figure 2 - First 6-storey light wood frame building in BC.

Design for mid-rise heavy frame timber systems in Canada is possible but will require special structural engineering design skills on the engineers as there are no guidelines in current design standards. The challenge can be the design of lateral bracing systems and the interface with reinforced concrete shear walls and connections between members and between framework and diaphragm. It is widely recognized that the innovative approach is to combine the use of wood with other structural materials such as steel and reinforced concrete to form an efficient hybrid structural system that utilizes the strengths of one material to address the weaknesses of other materials employed. Buildings can be designed with lower weight of wood and lateral resistance of a steel and concrete frame. An example of such a hybrid structure is shown in Figure 2.

Figure 3 - A hybrid structure consisting of steel frame and wood floor panels.

Based on the above, theme two research projects can be classified into two categories. The first group of projects addresses the technical gaps, as outlined above, for mid-rise (5- and 6-storey) light wood frame buildings. The second category investigates the structural performance of various hybrid building systems, including light-wood with a reinforced masonry core, light wood frame with different bracing systems, concrete slab-timber beam composite floor system, steel frame within wood infill panels, and concrete core with heavy timber frame.

Theme 3 – Building system – fire performance, acoustic and vibration serviceability

This theme focuses mainly on fire performance of mid-rise and non-residential buildings. It also covers projects addressing vibrational serviceability and sound insulation of building systems since construction details affect fire performance often have an impact on sound and vibration transmission between compartments.

One of the key projects in theme 3 is to evaluate the rationale behind the building dimension limits in the National Building Code of Canada. This project has generated valuable information for the relevant building code committee, which contributed to the upcoming change in the National Building Code of Canada to raise the storey limit from 4 to 6 for combustible construction. In addition it provided the basis for the research plans of other fire-related projects in NEWBuildS. These projects include the development of a comprehensive fire risk model that can be used to predict the fire spread anb smoke development in multi-storey buildings, performance of heavy timber connection in fire, and fire performance of CLT panels and assemblies.

The other projects in theme 3 address vibration performance of CLT floors and acoustic performance of mid-rise light wood frame and CLT buildings. Researchers working within this theme will interact regularly to ensure that recommended engineering practices and construction details will not be in conflict with each other.

<u>Theme 4 - Building systems – Durability, sustainability and enhanced products</u>

This theme studies durability and energy efficiency issues for wood construction in multi-storey and non-residential buildings. It also covers sustainability and enhanced wood products with coating and treatment to protect wood from decay and burning. This is the theme that is of most interest to the Canadian wood preservation industry and building envelope consultants.

Moisture has an impact on wood such as dimensional stability, decay and mould and is affected by design of building envelope and integrity for moisture ingress and accumulation. The extension of wood construction to 6 storeys and taller, whether using platform-frame, heavy timber, CLT or hybrids, requires attention to building envelope details for moisture management. Furthermore, the moisture load from wind-driven rain and stack effect pressures will be higher due to increase in building height. To this end, a systematic group of three projects were developed to generate technical information that will allow building envelope designers to design durable building envelope for mid-rise and taller buildings. The first project collects data on rain loading on building surfaces. This is achieved by instrumenting a number of mid-rise buildings across the country with different climate characteristics, Figure 4. The second project develops computational fluid dynamics (CFD) model to predict rain loading pattern on building surface with different rain droplet sizes, wind direction and speed, building geometries and overhang configurations, Figure 5. Together these two projects will generate technical information for building designers to design cladding system, drainage and envelope details to ensure dry building envelope in multi-storey wood buildings.

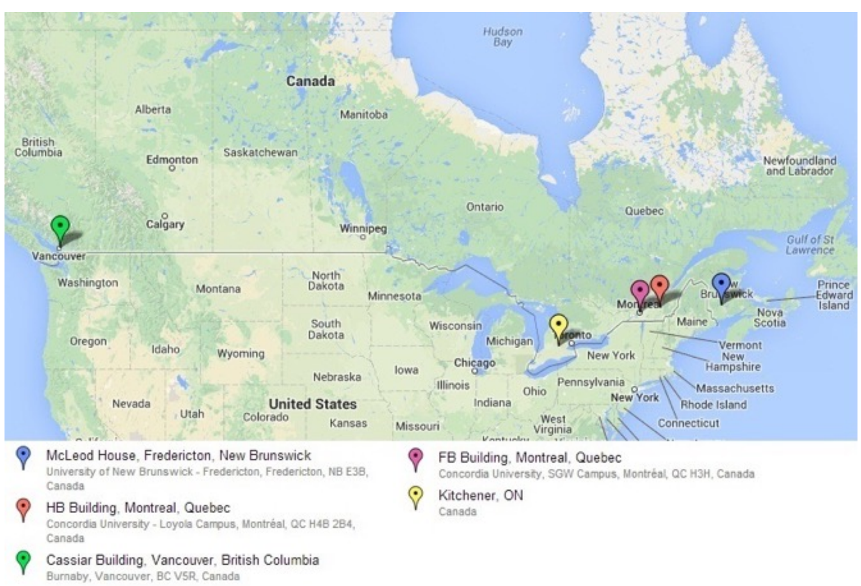


Figure 4 - Locations of buildings instrumented to collect rain load data (source: Dr. Hua Ge, Concordia University)

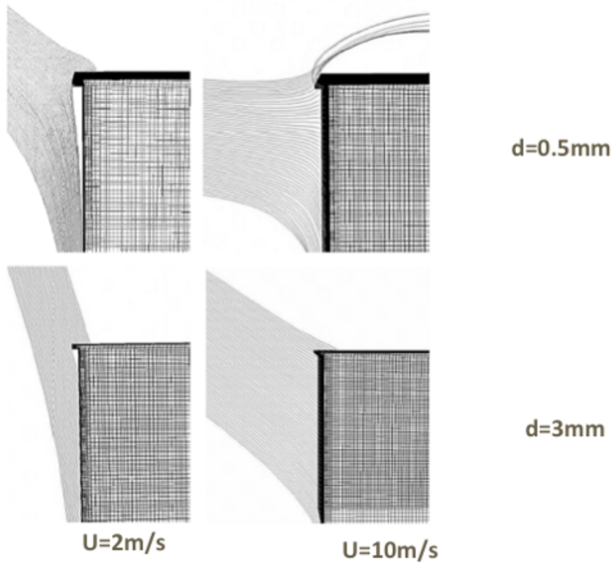


Figure 5 - Rain drop trajectory patterns on building surfaces influenced by wind speed (u), droplet size (d) and overhang. (Mohaddes 2013)

A third project investigates the influence of hygrothermal performance of CLT wall construction in various geographic locations in Canada. Of specific interest in the first instance was the drying performance of CLT wall. A key conclusion was that since CLT is a good moisture retarder, the use of high permeance wall assemblies for CLT construction is recommended to reduce the risk of moisture buit-up in CLT wall (McClung 2012). Work is continuing to derive specific CLT construction details for different climatic conditions. As a second line of defence, boron rods can be an effective means to prevent decay in CLT construction in case its building envelope is compromised. In this pre-treatment process, boron rods are inserted into wood and the preservative chemical will only be released when wood reaches a certain moisture content. A project was undertaken to identify the best locations and orientation with respect to the layer wood grain direction for boron rods in CLT (Saadat 2012). Figure 6 illustrates the diffusion patterns of borate in CLT in two orientations.

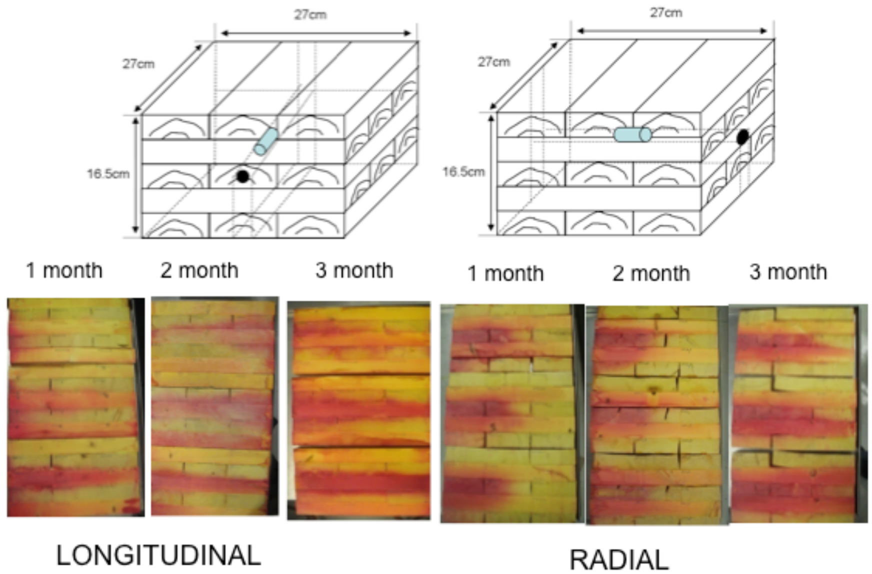


Figure 6 - Diffusion of borate in radial and longitudinal diections in CLT.

With the introduction of the energy efficiency requirements in the National Energy Code for Buildings (NECB) in 2011, two additional projects were initiated by NEWBuildS to address energy efficiency related issues. The first project investigated the risks associated with higher RSI value assemblies that are now mandated by the building codes (Fox 2014). Six high RSI wall assemblies were studied. Of specific interest in the project was the condensation and drying capacity of these assemblies that would lead to mould growth and decay. A second energy-related project was designed to identify suitable wall construction details that have adequate structural capacities for use in mid-rise construction while meeting the RSI requirement of the building codes. Among the wall assemblies studied included staggered studs and I-studs at close spacings. In both energy-related projects, a test hut approach was adopted, with one located at Waterloo, Ontario and the other at Edmonton, Alberta.

4. Conclusion

The Canadian research community in wood building systems organized itself under the NSERC Forest Sector R&D Initiative. The research undertaken by NEWBuildS network is well aligned with the research undertaken by FPInnovations, and ambitious but scientifically and technically feasible. It has brought together a world-class team of researchers, using a multi-disciplinary approach to address critical issues for the Canadian wood and building industries. There are challenges for the management of this complex network and the implementation of its outcomes such as addressing current building code limitations which prevent the use of wood in mid- and high-rise structures. NEWBuildS will reach out for collaborations with other international centres of expertise, create a virtual knowledge gateway and repository for the generated data, and maintain the momentum and synergy among the Network participants beyond the 5-year window of funding.

The anticipated outcomes and achievements of the NEWBuildS research program are:

- To strengthen the national innovation capacity in support of the wood industry and lay the foundation for future technical activities that lead to the expansion of wood use in non-traditional building construction.
- To develop tools for the technical evaluation of CLT, and for predicting responses of selected CLT and hybrid building systems to structural strength and serviceability, fire and moisture loads. (Figure 7).
- To develop technical information in support of the use of wood-based products in mid-rise and non-residential construction for building codes, material design standards and product standards. (Figure 7).

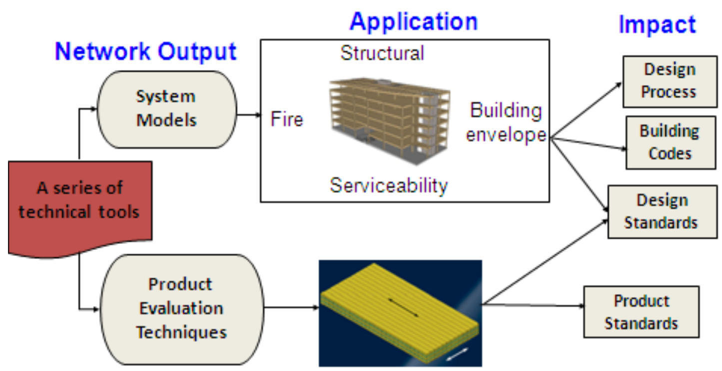


Figure 7 - Expected technical outcomes of NEWBuildS research program.

5. Literature

APA. 2011. Standard for performance-rated cross-laminated timber. ANSI/APA PRG320-2011. APA – The Engineered Wood Association, Tacoma, WA.

CSA. 2014. Engineering design in wood. Canadian Standard CSA O86-14. Canadian Standards Association, Mississauga, ON.

Fox, M. J. 2014. Hygrothermal performance of highly insulated wood frame walls with air leakage: Field measurements and simulations. MASc Thesis. Ryerson University, Toronto, ON.

Koo, K. 2013. A study on historical tall-wood buildings in Toronto and Vancouver. Report number 2013/12. FPInnovations, Vancouver, BC.

McClung, V. R. 2012. Field study of hygrothermal performance of cross laminated timber wall assemblies with built in moisture. MASc thesis, Ryerson Univeristy, Toronto, ON.

Mohaddes, S. 2013. A numerical study of the effects of overhangs on the wind-driven rain wetting of building facades. MASc thesis, Ryerson Univeristy, Toronto, ON.

NRC. 2010. National Building Code of Canada. National Research Council, Ottawa, ON.

Saadat, N. 2012. Factors affecting distribution of borate to protect building envelope components from biodegradation. MSc thesis. University of Toronto, Toronto, ON.

THERMAL MODIFICATION OF WOOD

Duygu Kocaefe, Yasar Kocaefe
Groupe de recherhe sur la thermostansformation du bois (GRTB)
University of Quebec at Chicoutimi, Dept. of Applied Sciences, 555, boul. de l'Université, Chicoutimi, Quebec, Canada G7H 2B1

Summary

Thermal modification of wood improves certain wood properties (biological resistance, dimensional stability, color, etc.) without the necessity to treat wood with chemicals. However, the application of this method to North American species requires the development of heat treatment recipes suitable for these species. In addition, industries need support for the application and the development of heat treatment technologies. Mathematical modelling is an excellent approach that can be used for this purpose.

The GRTB (Groupe de recherche sur la thermotransformation du bois – Research Group on Wood Thermotransformation) at the University of Quebec at Chicoutimi, Canada, works in the field of wood heat treatment developing recipes, technologies, and mathematical models as well as coatings. The group also works on the physical and chemical characterization of heat-treated wood. This paper gives an overview of the work carried out by this group during last ten years.

1. Introduction

Wood thermal modification (also called torrefaction, thermotransformation or high temperature heat treatment) is a wood protection method that involves no chemical treatment, and heat-treated wood is an environmentally friendly wood product (Dirol and Guyonnet, 1993; Al'ent al. 2002). During heat treatment, wood composition is modified. Hemicelluloses decompose. Also, lignin and cellulose are modified (Fengel, 1989; Tjeerdsma et al., 1998; Weiland and Guyonnet, 2001; Sinoven et al., 2002; Pavlo and Niemz, 2003; Nuopponen et al., 2004). Therefore, wood which is subjected to high temperatures (above 200°C) becomes more hydrophobic compared to wood dried using conventional methods (Kocaefe et al., 2008a). It is thus less prone to shrinking and swelling, and consequently its dimensional stability improves (Stamm, 1956; Basch and Lewin, 1973; Bhuiyan et al., 2000; Kamdem, 2002; Reppelin and Guyonnet, 2005; Sandor et al., 2006, 2008). It has an attractive dark color (Pavlo and Niemz, 2003). Its biological resistance also improves due to the absence of absorbed water (hydrophobic) and the decomposition of hemicelluloses, which are the principal nutrient for fungi (Hakku et al., 2006; Kocaefe et al., 2008b). However, the elasticity of wood decreases to different extents depending on the species (Santos, 2000; Yildiz et al., 2002; Kocaefe et al., 2007; Kocaefe et al., 2010). It is therefore important to optimize the treatment conditions which will allow wood to attain the above properties while minimizing the loss of mechanical properties.

The wood thermal modification processes such as Plato , oil treatment, Thermowood, Perdure (Viitaniemi, 1997; Rapp, 2001) were first developed in Europe. Therefore, the heat treatment recipes were developed for the European species, and they were not necessarily suitable for the North American species. This became a problem for Canadian companies who bought heat treatment furnaces. The GRTB (Groupe de recherche sur la thermotransformation du bois/Research group on wood thermotransformation) at the University of Quebec at Chicoutimi developed a method to adapt the treatment recipies or to develop new ones for the industry, which would prescribe the necessary conditions for a given wood species to attain the desired properties (Kocaefe, 2008c) . This also involves chemical, biological, and mechanical characterization of heat-treated wood in order to illustrate and quantify the amelioration obtained due to heat treatment (Lekounougou and Kocaefe, 2014a, 2104b, 2014c, 2013, 2012; Kocaefe et al., 2008a, 2007a; Shi et al., 2007).

The group developed fundamental mathematical models (Younsi et al., 2011, 2010a, 2008a, 2006a, 2006b; Kocaefe et al., 2007b) as well as the mathematical models of the industrial furnaces for both Perdure and Thermowood technologies (Younsi et al., 2010b; Kocaefe et al., 2008c; Osma et al., 2008) and worked with industries to improve their processes, to increase their production capacity, and to decrease the production cost (Kocaefe et al., 2009.; Poncsak et al., 2011). The group also developed a new technology for wood heat treatment and designed a furnace with adaptable dimensions (Kocaefe, 2013a). This is useful for small companies which cannot use large commercial furnaces. Also a project was carried out with Hydro-Quebec to test the possibility of thermally treating electrical poles (Younsi et al., 2010c; Poncsak et al., 2009; Gastonguay et al., 2009; Younsi et al., 2008b) .

Another domaine of research which is of interest to industry is the protection of heat-treated wood from the effect of UV. The heat-treated wood has a dark color which is appealing for decorative purposes. However, it loses this color when it is subjected to UV for extended times. The commercially available coatings contain toxic components and cover the surface of the wood. In order to develop natural and environmentally friendly coatings, the mechanisms of decomposition of the heat-treated surfaces under the influence of UV were studied (Kocefe et al., 2013b, 2013c; Huang et al., 2013b, 2012a, 2012b, 2012c, 2012d) and coatings that are transparent and nontoxic were developed using tree bark extracts and other additives (Saha et al., 2013a, 2013b, 2013c, 2011a, 2011b, 2011c; Kocaefe et al., 2012).

Presently, the work is continuing on the development of other coatings, the combined heat treatment and acetylation, and the improvement of bio-coke properties (Huang et al., 2013a).

2. Methodology

Recipe Development and Wood Characterization

GRTB has three (laboratory scale, prototype, and industrial scale) furnaces (Figure 1). The recipe treatment starts in the laboratory. The heat treatment experiments are carried out in a thermogravimetric analyser with small wood samples (0.035m x 0.035m x 0.2m) under different conditions. Then, the best conditions are chosen based on the wood properties. The second step is the trial of these recipes in a proptotype furnace. Finally, the treatment is tested in the industrial furnace.

Three-point bending (ASTM D-143-8), janka hardness (ASTM D-1324-83), screw withdrawal ASTM D-1761-88), resistance to fungi decay (ASTM D-2017), and dimensional stability (ASTM D 1037-105) tests are carried out to characterize untreated and heat-treated wood, and they are correlated with the conditions of the treatment.

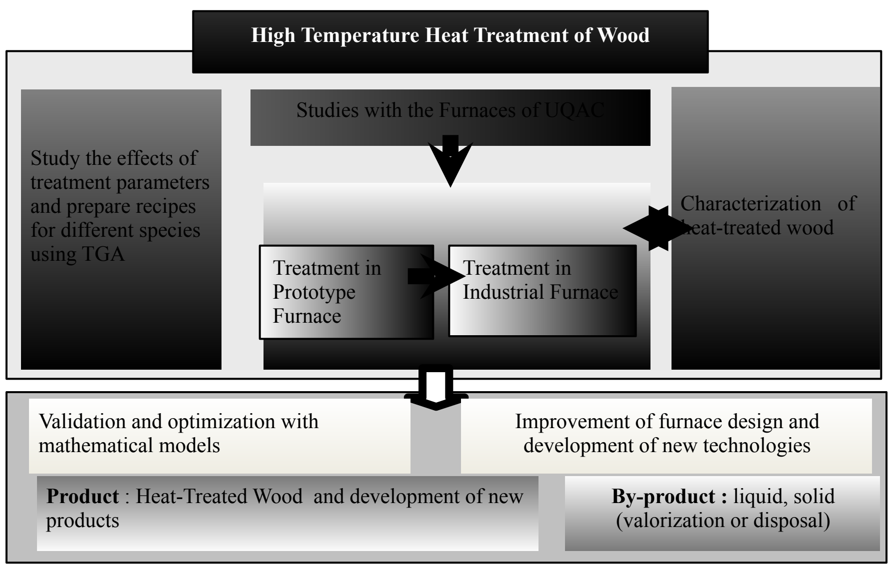


Figure 1: Research Infrastructure of GRTB at UQAC

Mechanism of Aging and Coating Development

Artificial aging or weathering tests (ASTM G155) are carried out on untreated and heat-treated wood surfaces with and without coating.

Surface of the samples are characterized using optical microscopy, SEM, FT-IR, XPS, fluorescence microscopy, inverse gas chromatography, color measurements, and sessile-drop wettability tests.

Mathematical Modelling

Different fundamental mathematical models and models of industrial wood heat treatment furnaces for different technologies (UQAC, Thermowood, and Perdure technologies) were developed. The fundamental models solve the coupled heat and mass (moisture) transfer equations in wood using FEMLAB which employs the finite element technique. The industrial furnace models are developed using the CFX commercial code. These models use the finite volume method and represent the detailed geometry of a given furnace. They solve the coupled flow, heat and mass transfer equations in gas as well as heat and mass transfer equations in wood. The velocity, temperature, and humidity distributions in gas and temperature and humidity distributions in wood are calculated as a function of time.

Bilogical Resistance

The accelerated biological resistance tests are carried out using the ASTM D-2017 (1994) standard.

Bio-Coke Characterization and Improvement

The bio-coke is heat-treated (calcined) in a thermogravimetric analyzer equipped with induction heating. Optical microscopy and SEM are used to evaluate the macro and microstructure of bio-coke, and FT-IR and XPS are used to study the surface chemical composition. The crystalline length was determined using XRD. Wettability of bio-coke by petroleum pitch is measured with the sessile-drop system.

3. Results and Discussion

This article gives an overview of the work carried out by GRTB. For the details of the specific topic, the reader is invited to consult the relevant publications.

Recipe Development and Wood Characterization

The wood samples are treated, and the effect of different parameters on the wood properties are studied. Figure 2 shows the effect of the heating rate, the wood intial moisture content and the gas humidity on the weight loss of jack pine. As it can be seen from this figure, the higher the heating rate is, the faster the weight loss is; but, fast treatment heating rates might result in crack formation (Figure 2a). As the gas humidity increases, the weight loss decreases since the moisture gradiant between wood and gas is smaller in this case (Figure

2b). If the initial wood moisture content is higher, the weight loss is lower, which is again due to thesmall moisture gradient (Figure 2c). The effect of the maximum treatment temperature and the soaking time (the holding time at the maximum treatment temperature) were also studied.

Wood treated at the lowest heating rate has much lower MOR (Modulus of Rupture) compared to the untreated wood, which can be attributed to long treatment times. However, MOR increases with increasing heating rate (Figure 3a). Treatment at low gas humidity slightly decreases MOR since the lack of humidity results in a brittle product. Increasing the gas humidity seems to improve MOR (Figure 3b). The dimensional stability increases with increasing heating rate in the radial direction. However, in the tangential direction, increasing heating rate decreases the dimensional stability. Further increase improves it again (Figure 3c). Similarly, increasing gas humidity first decreases and then increases the dimensional stability both in tangential and radial directions. These findings are related to the effect of each parameter has on the thermotransformation reactions. The effects of different treatment conditions on MOE (Modulus of Elasticity), hardness, and screw withdrawal are also studied (Kocaefe et al. 2010).

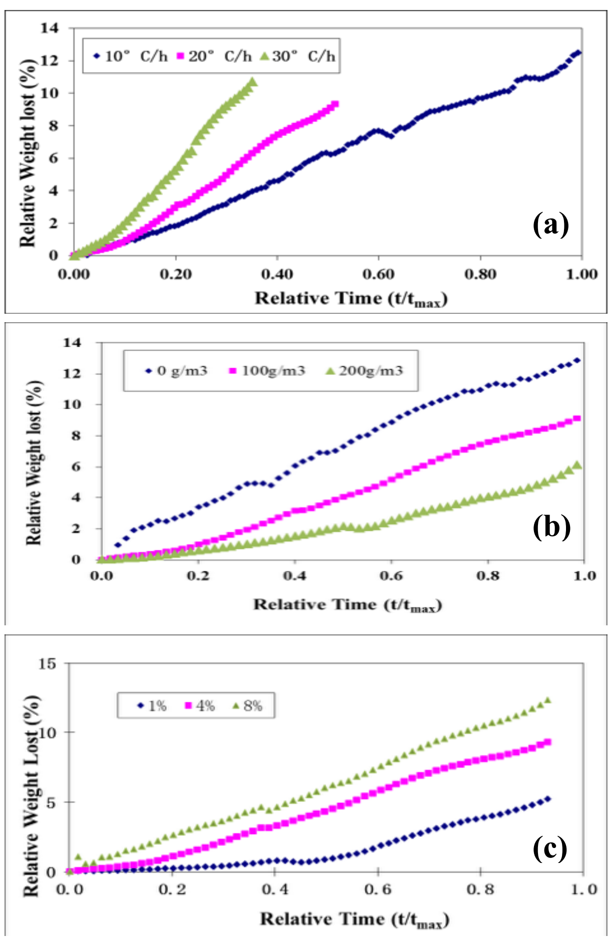
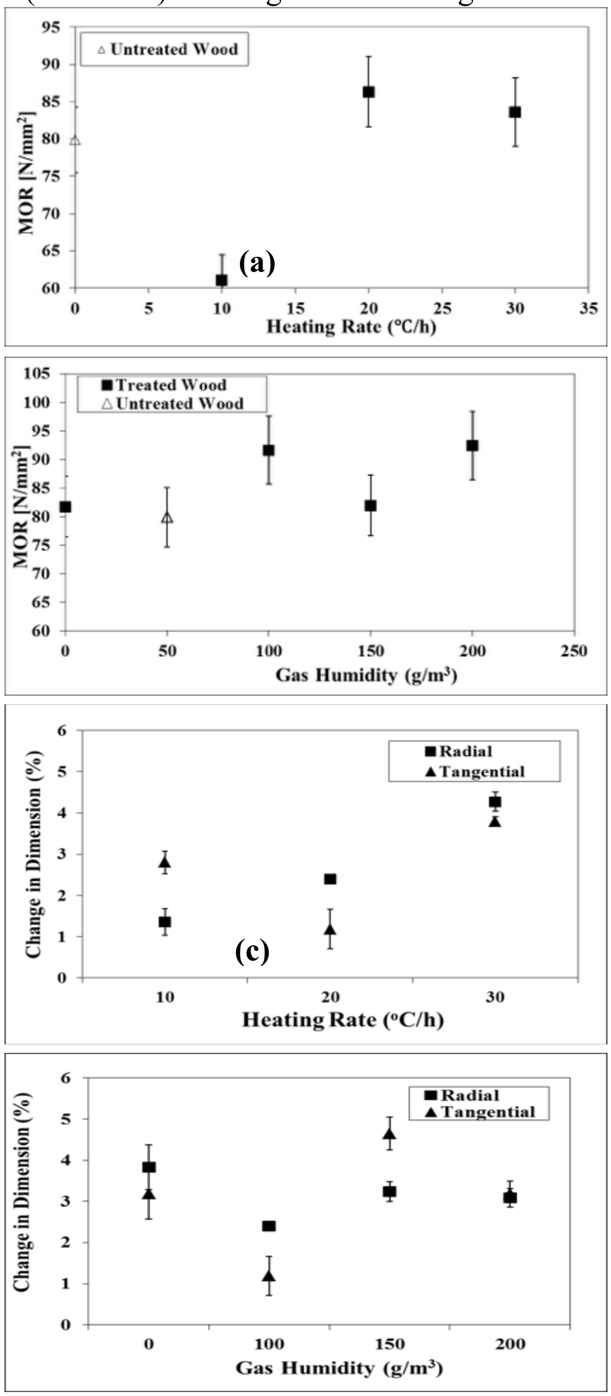


Figure 2: Effect of (a) Heating Rate, (b) Gas Humidity, and (c) Initial Moisture Content of Wood (Jack Pine) on Weight Loss During Heat treatment



(b)

(d)

Figure 3: Effect of (a) Heating Rate on MOR (b) Gas Humidity on MOR (c) Heating Rate on Dimensional Stability (d) Gas Humidity on Dimensional Stability

The recipes are developed for different industrial partners according to the specifications needed. Wood is treated under different conditions until the required properties are obtained. Figure 4 gives some examples. Treatment conditions are modified to improve the dimensional stability for three species. For one of the species, the dimensional stability improved with increasing treatment parameter (Figure 4a). For the second species, dimensional stability reached a maximum value and then decreased (Figure 4b). For the third species, dimensional stability reached a stable value after which no further improvement was observed (Figure 4c). The treatment parameter where the dimensional stability is maximum is chosen for the treatment recipe after the verification of other properties. Figure 4d shows a similar adjustment for screw withdrawal force for another species.

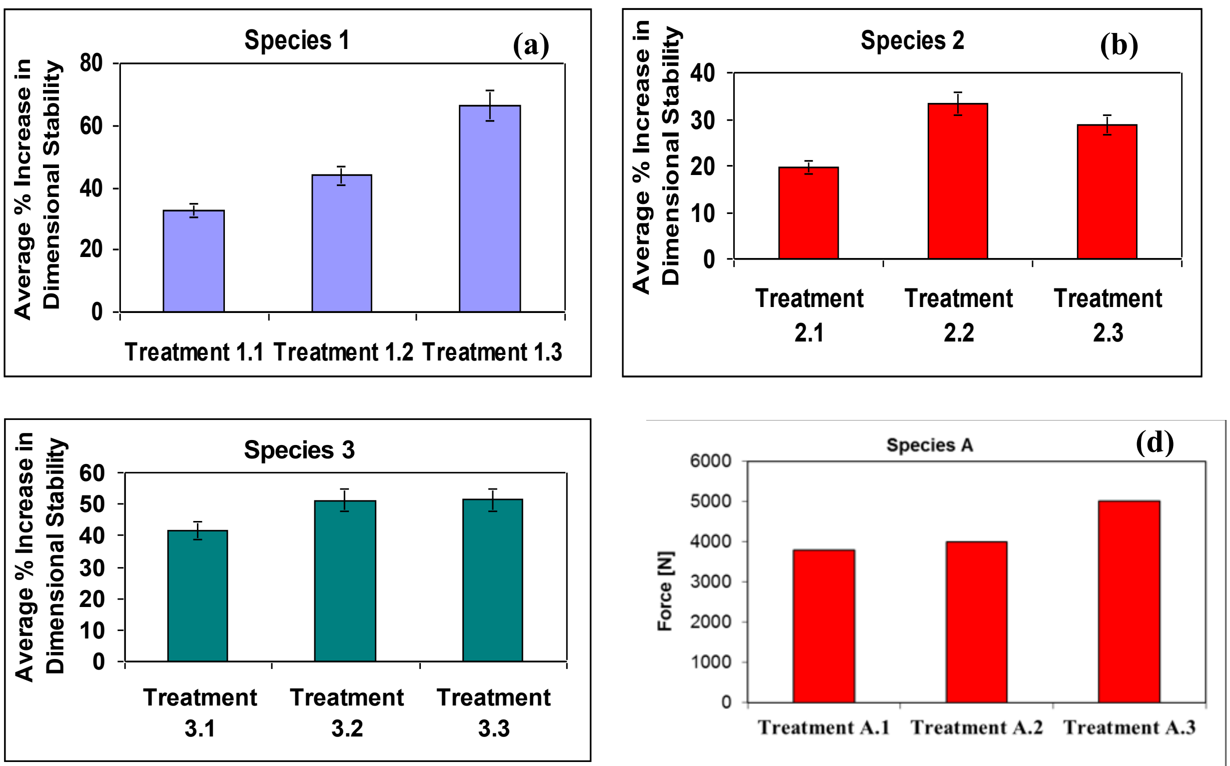


Figure 4: Effect of Different Treatment Conditions on (a, b, c) Dimensional Stability (d) Screw Withdrawal

Mechanism of Aging and Coating Development

The degradation mechanisms of the three untreated and heat-treated North American species (jack pine (*Pinus banksiana*), aspen (*Populus tremuloides*), and birch (*Betula papyrifera*)) due to UV exposure were studied in order to understand the chemical and physical changes taking place. The artificial aging tests were performed. Colour measurement, contact angle test for wettability analysis, Fourier transforms infrared spectroscopy (FTIR), and X-ray photoelectron spectroscopy (XPS) for chemical analysis, florescence microscopy (FM) and scanning electron spectroscopy (SEM) for microscopic structural analysis were carried out.

It was found that the colour change occurring during aging of heat-treated wood is the result of increasing lignin condensation and decreasing extractives content on wood surfaces caused by the heat treatment. Changes in the wettability during the weathering of heat-treated wood are caused by a combination of structural and chemical modifications on the wood surface. Lignin in heat-treated woods is more sensitive to aging than other components. As a result of the findings of this study, it was proposed that the aging mechanism of heat-treated woods involves the degradation of lignin matrix and extractives, and consequently wood colour becomes lighter.
The structure changes more and at a faster rate on untreated wood surfaces than on heat-treated wood surfaces for all three species. However, at the end of the1512 h of aging time, the difference is insignificant. An artificial aging period of 1512 h corresponds to 3 to 5 years of natural aging depending on the climatic conditions.

Figure 5 shows the SEM images of the three species before and after heat treatment as well as after the artificial aging of heat-treated wood. It can be seen that the degradation due to artificial weathering occurs preferentially in the middle lamella of the wood surface where the lignin concentration is higher than in the cell wall (Huang, 2012e).

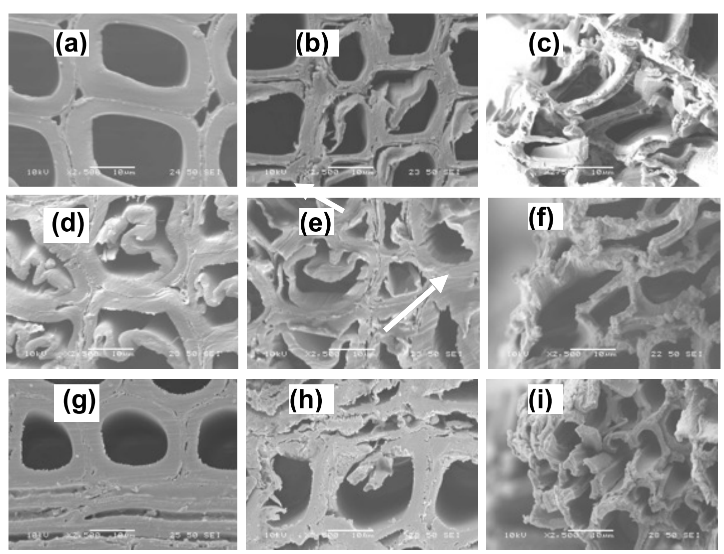


Figure 5: SEM images (×2500) on transverse wood surfaces before and after 1512 h of artificial aging: (a) untreated jack pine before aging; (b) heat-treated jack pine before aging; (c) heat-treated jack pine after aging; (d) untreated aspen before aging; (e) heat-treated

aspen before aging; (f) heat-treated aspen after aging; (g) untreated birch before aging; (h) heat-treated birch before aging; (i) heat-treated birch after aging (Huang, 2012e)

During the coating development study (Saha, 2011d), different organic and inorganic UV stabilizers and natural antioxidants (bark extracts, needle extracts, and even organosolv nano lignins) were evaluated first. Then, different inorganic micro and nano UV absorbers (micro and nano titania particles, ZnO nano particles, and CeO_2 nano particles) and their mixtures with natural antioxidants were tested. Also, the suitability of different polymers (sol-gel coating, soy based polymer coating, and acrylic polyurethane coatings) as a coating base were assessed. The developed coatings were compared with a common industrial coating.

The results (Figure 6) show that the acrylic polyurethane is a suitable base that can be used with bark extracts and lignin stabilizer, CeO_2 nano particles, and with or without lignin stabilizer. These coatings protected wood from UV better than the industrial coatings tested. Bark extracts seem to be a good additive for coating development.

Industrial Coating

Figure 6: Colour Variation of Different Acrylic Polyurethane Coatings and the Industrial Coating as a Function of Exposure Time (Saha, 2011d)

Mathematical Modelling

During heat treatment, wood is exposed to hot gases. Simultaneous heat and mass transfer takes place in wood as well as between wood and hot gases. The heat is transferred from the gas to the wood surface by convection and from wood surface to the interior of wood by conduction. Due to the low conductivity of wood, the rate of heat transfer is slow within the wood. As the wood is heated, the moisture in wood is heated, partially vaporized, and transferred to the surface; afterwards, it is transferred to the gas.

The fundamental models (Model based on Luikov's approach, Diffusion Model and Multiphase Model) predicting the temperature and moisture profile in wood have been developed for the thermal treatment process (Kocaefe et al., 2006; Younsi et al., 2006a, 2006b, 2006c, 2006d, 2010b). Also, models of industrial heat treatment furnaces for different technologies (Thermowood, Perdure, UQAC Technologies) were developed (Poncsak et al, 2001; Osma, 2008; Kocaefe, 2009; Kocaefe, 20013a) and used for the improvement of furnace design, increasing production capacity, and energy savings. These models predict the velocity, temperature, and humidity profile in gas as well as the temperature and moisture profile in wood. Figure 7 shows the temperature and moisture profiles predicted in a Perdure technology furnace (Osma, 2008).

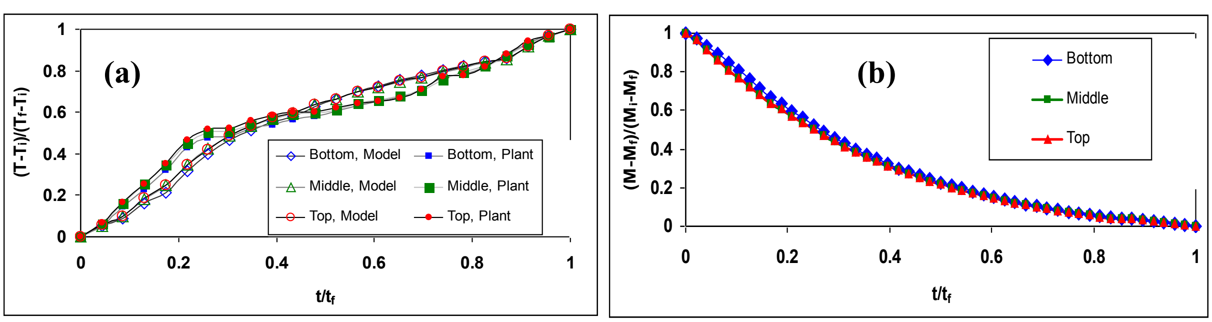


Figure 7: Temperature and Wood Moisture Profile in Perdure Furnace (Osma, 2008)

Biological Resistance

The effect of heat treatment on the biological resistance of jack pine (*Pinus banksiana)*, black spruce (*Picea mariana)*, white birch (*Betula papyrifera)*, and aspen (*Populus tremuloides)* against brown (*P. Placenta*, *G. Trabeum* and *C. Puteana*) and white fungi (*T. Versicolor)* were studied

Brown rot and white rot fungi are the most common genera that cause the destructive decay of wood in service (Green and Highley 1997; Monrroy et al. 2011). Brown rot fungi consume the hemicelluloses and cellulose of cell walls, leaving the lignin essentially undigested, modified by demethylation and oxidation. White rot fungi degrade cellulose and lignin simultaneously. The results showed that the heat treatment improved the biological resistance of the species in general. However, the degree of improvement changed depending on the species (Lekounougou, 2014a, 2014b, 2014c, 2013, 2012, 2011). Figure 8 shows the results of fungi resistance test for jack pine.

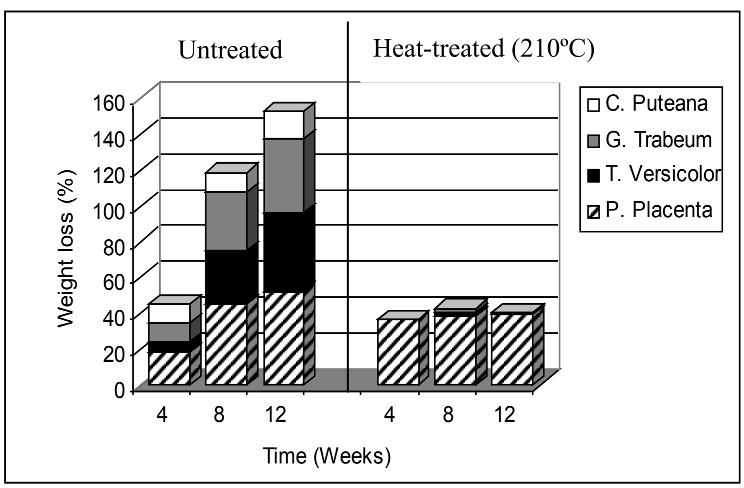


Figure 8: Weight Loss of Untreated and Heat-Treated Jack Pine due to Exposure to Four Fungi

Bio-Coke

Anodes used in aluminium industry are made of petroleum coke, rejected green and baked anodes, and butts as well as coal tar pitch. Replacing part of the petroleum coke with bio-coke can make the process more environmentally friendly. However, bio-coke is more porous and less dense compared to the petroleum coke. Also, its crystalline length is much lower than that of the petroleum coke. A study was carried out to evaluate the potential of bio-coke as anode raw material and to investigate how to improve its properties. It was found that bio-coke has an anisotropic lamellar structure similar to that of petroleum coke and thus seems to be suitable for anode production (Huang et al., 2013). However, its chemical composition is different than that of the petroleum coke composition and its crystal length is much lower than that of the petroleum coke. Bio-coke was further heat treated to improve its properties (Huang et al., 2014). Heat treatment seems to improve the crystalline length.

4. Conclusions

Thermal modification of wood is an ecological wood protection method. The heat treatment recipes required depend on the wood species and their geographical origins. GRTB successfully established a recipe development method that is tailored to the requirements of the industry and the application field.

The aging mechanism of heat treated wood was studied, and non-toxic and transparent coatings were successfully developed for protecting the heat-treated wood from UV.

The tests carried out with brown and white fungi showed that the wood treatment improves the biological resistance of wood in general.

The tests with bio-coke showed that it might be possible to use it as anode raw material and replace a small part of the petroleum coke with bio-coke after the improvement of its properties with heat treatment. Further study is required on this subject.

5. Literature

Al´en, R.; Kotilainen, R.; Zaman, A. Thermochemical behavior of Norway spruce (Picea abies) at 180–225◦C. Wood Sci. Technol. 2002, 36, 163–171.

Basch, A.; Lewin, M. The influence of fine structure on the Pyrolysis of cellulose. I. Pyrolysis in the vacuum. J. Polym. Sci. 1973, 11, 3071–3093.

Bhuiyan, M.T.R.; Hirai, N.; Sobue, N. Changes of crystallinity in wood cellulose by heat treatment under dried and moist conditions. J. Wood Sci. 2000, 46, 431–436.

Dirol, D.; Guyonnet, R. The Improvement of Wood Durability by Retification Process. Document No. IRG/WP 98–40015. Int. Res. Group on Wood Protection, Stockholm, Sweden, 1993.

Fengel, D.; Wegener, G. Wood: Chemistry, Ultrastructure, Reactions; Walter de Gruyter: Berlin, 1989.

Green, F., and Highley, T. L. 1997. Mechanism of brown-rot decay: paradigm or paradox. Int. Biodeter. Biodegrad. 30: 113-124.

Hakkou, M., Pétrissans, M., Gérardin, P., Zoulalian, A., Investigations of the reasons for fungal durability of heat-treated beech wood, Polym. Degrad. Stab. 91 (2006) 393-397.

Huang X., Kocaefe, D., Kocaefe, Bhattacharyay, D., "A structural and chemical study on the wettability of bio-coke by coal tar pitch for its use in carbon anodes in aluminum industry", submitted, 2014.

Huang, X., Kocaefe, D., Kocaefe, Y., Bhattacharyay, D., "Morphological and Microstructural Characterization of Bio-Coke as Potential Anode Raw Material for Aluminum Industry", COM 2013, Oct. 27-31 2013a, Montreal, Quebec. Published in "Green Composite Materials: Development, Manufacturing and Testing", pp.1057-1064.

Huang X., Kocaefe, D., Kocaefe, Y., Boluk, Y., Krause, C.., " Structural Analysis of Heat-Treated Birch (Betule papyrifera) Surface during Artificial Weathering", Appl. Surf. Sci. 264, 117– 127, 2013b.

Huang X., Kocaefe, D., Kocaefe, Y., Boluk, Y., Pichette, A., "Study of the Degradation Mechanisms of Heat-Treated Jack Pine (Pinus banksiana) under Artificial Sunlight Irradiation", Polymer Degradation and Stability, 97(7), 1197-1214, 2012a.

Huang, X., Kocaefe, D., Kocaefe, Y., Boluk, Y., Pichette, A., "Changes in Wettability of Heat-Treated Wood due to Artificial Weathering", Wood Science and Technology, 46(6), 1215-1237, 2012b.

Huang, X, Kocaefe, D., Boluk, Y., Kocaefe, Y., Pichette, A., "Effect of Surface Preparation on the Wettability of Heat Treated Jack Pine Wood Surface by Different Liquids", European Journal of Wood and Wood Products, 70(5), 711-717, 2012c.

Huang X., Kocaefe, D., Kocaefe, Y.,Boluk, Y., Pichette, A., "A spectrocolorimetric study on color modification of heat-treated wood during artificial weathering", Applied Surface Science, 258 (14), 5360-5369, 2012d.

Huang, X., "Study on the Degradation Mechanism of Heat-Treated Wood by UV Light", Ph.D. Thesis, University of Quebec at Chicoutimi, Chicoutimi, Quebec, Canada, 2012e.

Kamden, D.P.; Pizzi, A.; Jermannaud, A. Durability of heat-treated wood. Holz Roh. Werkst. 2002, 60, 1–6.

Kocaefe, D., Kocaefe, Y., Younsi, R., Oumarou, N., Lekounougou, S.T., " Mathematical Modelling of the High Temperature Treatment of Birch in a Prototype Furnace" , "Special Issue on Numerical Simulation of Fluid Flow and Heat Transfer Processes", Advances in

Mechanical Engineering (invited), vol. 2013, Article ID 194610, 8 pages, http://dx.doi.org/ 10.1155/2013 /194610, 2013a.

Kocaefe, D., Huang, X., Kocaefe, Y., Study of the Degradation of Heat-Treated jack Pine under Different Artificial Weathering Conditions, International Journal of Energy and Environment, 7(3), 97-106, 2013b.

Kocaefe, D., Huang, X., Kocaefe, Y., Boluk, Y., "Quantitative Characterization of Chemical Degradation of Heat-Treated Wood Surfaces During Artificial Weathering using XPS", Surf. Interface Anal. 45 (2), 639–649, 2013c.

Kocaefe, D., Saha, S., "Comparison of the Protection Effectiveness of Acrylic Polyurethane Coatings Containing Bark Extracts on Three Heat-treated North American Wood Species: Surface Degradation", Applied Surface Science ,258(13), 5283-5290, 2012.

Kocaefe, D., Poncsak, S.,Tang, J., "Effect of Heat Treatment on the Mechanical Properties of North American Jack Pine: Thermogravimetric Study", Journal of Materials Science, 45(3), 681-687, 2010.

Kocaefe, D. (invited), "Overview of Research Activities on High Temperature Heat Treatment of Wood at UQAC: Collaboration with PCI Industries (Perdure Technology)", AWPA (American Wood Protection Association) 105th Annual Meeting, Austin, Texas, USA, 19-21 April 2009.

Kocaefe, D., Poncsak, S., Boluk, Y., Effect of thermal treatment on the chemical composition and mechanical properties of birch and aspen, BioResources, 3, 2008a 517-537.

Kocaefe, D., Poncsak, S., Doré, G., Younsi, R., Effect of heat treatment on the wettability of white ash and soft maple by water, Eur. J. Wood and Wood Prod. 66, 2008b, 355-361.

Kocaefe, D., Poncsak, S., Younsi, R., "Novel Experimental Method of Recipe Development for Wood Thermotransformation, « Modelling of Wood Thermotransformation Furnace", 58th Chemical Engineering Conference, Ottawa, Ontario, 19-22 October 2008c.

Kocaefe, D., Chaudry, B., Poncsak, S., Bouazara, M., Pichette, A., Thermogravimetric study of high temperature treatment of aspen: Effect of treatment parameters on weight loss and mechanical properties. J. Mat. Sci. 2007a, 42(3), 854–866.

Kocaefe, D., Younsi, R., Poncsak, S., Kocaefe, Y., "Comparison of Different High Temperature Wood Heat Treatment Models", International Journal of Thermal Sciences, 46(7), 707-716, 2007b.

Kocaefe,D., Younsi,R., Chaudry,B. and Kocaefe, Y., "Modeling Study of Heat and Mass Transfer During High Temperature Treatment of Aspen", Wood Science and Technology, 40 (5), 371-391, 2006.

Lekounougou S., Kocaefe, D., "Impact of thermal modification on bioresistance of North American wood species, Pinus banksiana, Populus tremuloides and Betula papyrifera, against wood-rotting basidiomycete fungi", Wood Material Science and Engineering, published online, DOI:10.1080/17480272.2013.875062, 2014a

Lekounougou S., Kocaefe, D., "Effect of thermal modification temperature on the mechanical properties, dimensional stability, and biological durability of black spruce (Picea mariana)", Wood Material Science and Engineering, 9(2), 59–66, http:_//_dx.doi.org_/ 10.1080_/_17480272.2013.869256, 2014b.

Lekounougou S., Kocaefe, D. "Durability of thermally-modified Pinus banksiana (North American Pinus) wood against brown and white rot fungi", International Wood Products Journal, 5(2), 92-97, 2014c.

Lekounougou S, Kocaefe, D. "Bioresistance of Thermally-Modified Populus Tremuloides (North American Aspen) Wood against Four Decay Fungi", International Wood Products Journal, DOI 4(1), 46-51, 10.1179/2042645312Y.0000000018, 2013.

Lekounougou S, Kocaefe, D. "Comparative study on the durability of heat treated White Birch (Betula papyrifera) subjected to the attack of brown and white rot fungi", Wood Material Science and Engineering, 7(2), 101-106, 2012.

Lekounougou S, Kocaefe D*, Oumarou N, Kocaefe Y, Poncsak S., "Effect of Thermal Modification on Mechanical Properties of Canadian White Birch", International Wood products Journal, 2 (2): 101-107, 2011.

Monrroy, M., Ortega, I., Ramírez, M., Baeza, J., and Freer, J. 2011. Structural change in wood by brown rot fungi and effect on enzymatic hydrolysis. Enz. Microbiol Technol. 49: 472-477.

Nuopponen, M.; Vuorinen, T.; J¨ams¨a, S.; Viitaniemi, P. Thermal modifications in softwood studied by FT-IR and UV resonance Raman spectroscopies. J. Wood Chem. Technol. 2004, 24, 13–25.

Osma, A., Kocaefe, D., Kocaefe, Y., "Mathematical Modelling of an Industrial Furnace for High Temperature Heat Treatment of Wood", Can. J. Chem. Eng.,86, 693-699, 2008.

Pavlo, B.; Niemz, P. Effect of temperature on color and strength of spruce wood. Holzforschung. 2003, 57, 539–546.

Poncsak, S., Kocaefe, D., Younsi, R., "Improvement of Heat Treatment of Jack Pine (Pinus banksiana) using ThermoWood Technology", European Journal of Wood Products, 69(2), 281-86, 2011.

Poncsak S, Kocaefe, D., Younsi, R., Kocaefe, Y., Gastonguay, L., "Thermal Treatment of Electrical Poles", Wood Science and Technology, 43(5), 471-486, 2009.

Poncsak, S., Kocaefe, D, Bouazara, M., Pichette, A., Effect of high temperature treatment on the mechanical properties of birch (Betula papyrifera), Wood Sci.Technol. 40 (2006) 647-663.

Rapp, A. O. (2001). Review on heat treatments of wood. COST Action E22 - Environmental of wood protection, Antibes (France).

Repellin, V.; Guyonnet, R. Evaluation of heat-treated wood swelling by differential scanning calorimetry in relation to chemical composition. Holzforschung 2005, 59, 28–34.

Saha, S., Kocaefe, D., Boluk, Y., Pichette, A., "Surface Degradation of CeO_2 Stabilized Acrylic Polyurethane Coated Thermally treated Jack Pine during Accelerated Weathering",Applied Surface Science, 276(1),86- 94, http://dx.doi.org/10.1016/j.apsusc. 2013.03.031, 2013a.

Saha, S., Kocaefe, D., Krause, C., Boluk, Y., Pichette, A., "Enhancing Exterior Durability of Heat-Treated Jack Pine by Photo-Stabilization by Acrylic Polyurethane Coating using Bark Extract Part 2: Wetting Characteristics and Fluorescence Microscopy Analysis", Progress in Organic Coatings, 76 (2-3) 504– 512, 2013b.

Saha, S., Kocaefe, D., Boluk, Y., Mshvildadze, V., Legault, J., Pichette, A., " Boreal Forest Conifer Extracts : Potential Natural Additives for Acrylic Polyurethane Coatings for the Protection of Heat-Treated Jack Pine", Journal Coatings Technology and Research, 10(1), 109-122, 2013c.

Saha, S., Kocaefe, D., Krause, C., Larouche, T., "Effect of Titania and Zinc Oxide Particles on Acrylic Polyurethane Coating Performance", Progress in Organic Coatings, 70, 170-177, 2011a.

Saha, S., Kocaefe, D., Boluk, Y., Pichette, A., "Enhancing Exterior Durability of Jack Pine by Photo-Stabilization of Acrylic Polyurethane Coating using Bark Extract: Part 1- Effect of UV on Color Change and ATR-FTIR Analysis ", Progress in Organic Coatings, 70, (4), 376-82, 2011b.

Saha, S., Kocaefe, D., Sarkar, D., Boluk, Y., Pichette, A. "Effect of TiO_2 Containing Nano-Coatings on the Color protection of Heat-Treated Jack-Pine" JCT Research , 8(2), 183-190, 2011c.

Saha, s., "Study on the Color Change of Heat-Treated Wood Caused by UV Light: Coating development", University of Quebec at Chicoutimi, Quebec, Canada, 2011d.

Santos, J.A. Mechanical behaviour of Eucalyptus wood modified by heat. Wood Sci. Technol. 2000, 34, 39–43.

Shi, J.L., Kocaefe, D., Zhang, J. "Mechanical Behaviour of Québec Wood Species Heat-Treated Using ThermoWood Process", Holz als Roh- und Werkstoff, 65(4), 255-259, 2007

Sinoven, H.; Maunu, S.L.; Sundholm, F.; Jamsa, S.; Viitaniemi, P. Magnetic resonance studies of thermally modified wood. Holzforschung 2002, 56, 648–654.

Stamm, AJ., Thermal degradation of cellulose, Industrial and Engineering Chemistry, 1956, Vol. 48, No. 3, 413-417.

Tjeerdsma, B.F.; Boonstra, M.; Pizzi, A.; Tekely, H.; Millitz, H. Characterisation of thermally modified wood molecular reasons for wood performance improvement. Holz Roh. Werkst. 1998, 56, 149–153.

Viitaniemi, P., Thermowood-Modified wood for improved performance. Wood: The ecological material 4th Eurowood Symposium, Stockholm, Sweeden, September 22-23, Tratek, (Swedish Institute for Wood Technology Research), 1997, pp.67-70.

Weiland, J.J., Guyonnet, R., "Étude Physico-Chimique d'un traitement thermique du bois", Récents Progrès en Génie des Procédés, 15(88), 195-202 (2001)

Yildiz, S., Colakoglu, G., Yildiz, U .C., Gezer, E.D., Temiz A., Effects of Heat Treatment on Modulus of Elasticity of Beech Wood. Document No. IRG/WP 02– 40222. Int. Res. Group on Wood Protection, Stockholm, Sweden, 2002.

Younsi, R., Kocaefe, D., Poncsak, S., Huang, X., Saha, S., "High Thermal Treatment of Wood: A Basic Theory and Numerical Modeling", Energy, Environment and Economics, 19(3), 201-223, 2011.

Younsi, R., Poncsak, S., Kocaefe, D., "Experimental and Numerical Investigation of Heat and Mass Transfer During Thermal Treatment of Wood", Drying Technology, 28(10), 1148-56, 2010a.

Younsi, R., Kocaefe, D., Poncsak, S., Kocaefe, Y., "Computational and Experimental Analysis of High Temperature Thermal Treatment of Wood Based on Thermo Wood Technology", International Communications in Heat and Mass Transfer, 37(1), 21-28, 2010b.

Younsi, R., Kocaefe, D., Poncsak, S., Kocaefe, Y., Gastonguay, L., "A High-Temperature Thermal Treatment of Wood using a Multiscale Computational Model: Application to Wood Poles, Bioresource Technology, 101(12), 4630-4638, 2010c.

Younsi, R., Kocaefe, D., Poncsak, S., Tang, J., "Numerical and Experimental Validation of the Transient Heat and Mass Transfer During Heat Treatment of Pine Wood", International Journal of Modelling and Simulation, 28(2), 117-123, 2008a.

Younsi, R., Kocaefe, D., Poncsák, S., Kocaefe, Y., Gastonguay, L., "CFD Modeling and Experimental Validation of Heat and Mass Transfer in Wood Poles Subjected to High Temperatures: A Conjugate Approach", Heat and Mass Transfer, 44, 1497-1509, 2008b.

Younsi, R., Kocaefe, D., Kocaefe, Y., "Three-Dimensional Simulation of Heat and Moisture Transfer in Wood", Applied Thermal Engineering, Volume 26, Issues 11-12, 1274-1285, 2006a.

Younsi, R., Kocaefe, D., Poncsák, S. et Kocaefe, Y., " Thermal Modelling of High Temperature Treatment of Wood Based on Luikov's Approach ", International Journal of Energy and Research, Volume 30(9), 699-711, 2006b.

Younsi, R., Kocaefe, D., Poncsak, S., Kocaefe, Y., "Transient Multiphase Model for the High Temperature Thermal Treatment of Wood", AIChE, 52(7), 2340-49, 2006c.

Younsi, R., Kocaefe, D., Poncsak, S., Kocaefe, Y., "A Diffusion-Based Model for Transient High Temperature Treatment of Wood", Journal of Building Physics 30(2), 113-135, 2006d.

GENETIC MODIFICATION OF WOOD: SYRINGYL-RICH LIGNIN RENDERS POPLAR MORE RESISTANT TO DEGRADATION BY WOOD FUNGI

Oleksandr Skyba

Department of Wood Science, University of British Columbia, 4030-2424 Main Mall, Vancouver, BC, V6T 1Z4, Canada

The importance and utility of lignocellulosic substrates has become more significant to industry since woody biomass is now, not only considered a feedstock for the manufacture of traditional commodities (lumber and lumber-products, and paper) and cellulose-based chemicals, but also as the starting feedstock for bioenergy. Wood and other lignocellulosic materials are formed from three main polymeric constituents: cellulose, lignin and hemicelluloses. Lignin is a complex aromatic polymer which is assembled via free radical coupling of monolignol precursors derived from three *p*-hydroxycinnamyl alcohols with varying degree of methoxylation, resulting in guaiacyl (G), syringyl (S) and *p*-hydroxyphenyl (H) subunits. These monomers vary depending on wood species, tissue type and environmental stress.

Wood decay fungi are among the few microorganisms capable of degrading the complex lignocellulosic matrix. They are conventionally classified into one of three major groups: brown-, white- and soft-rot fungi. Studies have demonstrated that white-rot fungi possess lignocellulolytic enzymatic systems that, if used during pre-treatment, can lead to energy reductions during mechanical, are beneficial for biodegradation of recalcitrant biopolymers, and/or increase the efficiency of bioconversion. On the other hand, brown-rot fungi have been shown to possess specialized endoglucanases that can be used in industrial processes, and offer a unique opportunity for consolidated bioprocessing of lignocellulosic substrates. However, the inherent recalcitrance of lignin continues to pose challenges for industrial applications.

In secondary plant cell walls of wood, the lignin matrix that surrounds the cellulosic components acts as a barrier to wood decay, preventing the access of extracellular enzymes to the more readily degradable cellulose and hemicellulose moieties. Earlier studies provided evidence that differences in lignin content alone cannot explain the variation in wood decay rates, but that anatomical characteristics and cell wall ultrastructural differences are influential. Lignin remains a major factor and has been shown to affect cell wall degradation rates in both a concentration and composition-dependent manner. However, the most recent comprehensive research was done in 1994 studied the impact of the lignin composition on resistance to wood decay. These authors analyzed the degradation of wood from different tree species by *Trametes versicolor* and meticulously described variation in decay patterns in tissue types. This work used wood from different tree species to establish a model that effectively explained the impact of lignin monomer composition on wood decay rates. However, since variation in other wood characteristics, chemical, morphological and/or ultrastructural features were not considered the conclusions drawn remain ambiguous.

Advances in tree genetic engineering have facilitated the production of tree varieties with altered wood chemistry. Ferulate-5-hydroxylase (F5H) is a key rate-limiting enzyme required for the biosynthesis of syringyl (S) monolignols, and transgenic poplar lines over-expressing an Arabidopsis *F5H* gene under the control of the *cinnamate-4-hydroxylase* (*C4H*) promoter (*C4H::F5H*), exhibit substantially altered S lignin content (ranging from as high as 94 mol % syringyl units to 65 mol % in the wild-type trees).

These transgenic trees afford a unique opportunity to elucidate the impact of lignin monolignol composition on susceptibility to degradation by white- and brown-rot fungi, since all other wood phenotypes in these genotypes are similar to those in wild-type trees.

In order to elucidate the effects of lignin composition on the resistance of wood to degradation by decay fungi, wood specimens from two transgenic poplar lines expressing an Arabidopsis gene encoding ferulate 5-hydroxylase (F5H) driven by the cinnimate-4-hydroxylase promoter (*C4H::F5H* construct) that increased syringyl:guaiacyl (S/G) monolignol ratios relative to the untransformed control wood were incubated with brown-rot, selective white-rot and simultaneous white-rot decay fungi. Alterations in wood weight and chemical composition were monitored over the incubation time.

Transgenic poplar extremely rich in syringyl lignin exhibited improved resistance to degradation by an array of decay fungi, possessing a wide spectrum of lignocellulolytic activities and degradation mechanisms. Thus, lignin monomer composition and linearity of macromolecules are important parameters affecting wood durability. Low guaiacyl content did not render wood more susceptible to fungal decay, which is discordant with an existing theory about improved decay resistance accomplished by elevated guaiacyl content. The findings of this study reveal that transgenic poplar wood with extremely high syringyl content is recalcitrant to degradation, and therefore may afford improved performance where wood durability is a desired factor, especially in the long-term storage of feedstocks required for wood processing, such as pulping or bioenergy applications.

Literature

Skyba O, Douglas CJ & Mansfield SD. 2013. Syringyl-rich lignin renders poplars more resistant to degradation by wood decay fungi. Applied and Environmental Microbiology 79(8):2560-2571

TERMITE RESISTANCE OF SCOTS PINE MODIFIED WITH VINYL ACETATE, VINYL BENZOATE OR PHENOL FORMALDEHYDE RESIN

George Chan[1], Gilles Sèbe[2] and Philip D. Evans[1]
[1]Department of Wood Science, University of British Columbia, Vancouver, Canada
[2]Laboratory of Organic Polymer Chemistry, University of Bordeaux, France

Summary

Woods that are inherently resistant to termite attack often contain high levels of phenolic extractives that act as natural insecticides. The termite resistance of woods that lack such natural durability can be increased using biocides, or by chemically modifying the wood. In this study we hypothesized that chemical modification of wood with phenolic compounds would be more effective at increasing the termite resistance of wood than modification with vinyl acetate. Scots pine (*Pinus sylvestris* L.) veneers were dip-treated with low molecular weight phenol formaldehyde (PF) resin or esterified with vinyl benzoate or vinyl acetate, and weight gains of veneers resulting from chemical modification were calculated. Modified veneers and untreated controls were exposed to the subterranean termite species *Coptotermes acinaciformis* (Froggatt) for 9 months using a ground-proximity test, and weight losses of veneers were calculated. There was, as expected, an inverse relationship between weight gains due to chemical modification and weight losses of veneers caused by termites attack. However, at similar weight gains, modification using phenolic compounds (PF resin or vinyl benzoate) was more effective at restricting termite attack than modification with vinyl acetate. We conclude that chemical modification of wood using phenolic compounds shows promise as a way of increasing the resistance of wood to termite attack. Further research with a greater range of wood species and phenolic compounds is needed to confirm these preliminary findings.

A NEW MECHANISM TO EXPLAIN THE EROSION OF SOFTWOODS EXPOSED TO NATURAL WEATHERING

Siti Hazneza and Philip D. Evans
Department of Wood Science, University of British Columbia, Vancouver, Canada

Summary

The erosion of softwoods during natural weathering has been explained by loss of tracheids due to delignification and weakening of the interfacial layer (middle lamella) that bonds tracheids to each other. Thin walled earlywood tracheids are eroded more rapidly than denser latewood tracheids, which creates the rough corrugated surface that is one of the defining features of weathered softwoods. We propose an alternative mechanism for the erosion of softwoods exposed to the weather, based on scanning electron microscopy and confocal profilometry of Douglas fir samples exposed to natural weathering in Vancouver. Our observations confirm that weathered Douglas fir wood has a rough corrugated surface due to differential erosion of earlywood and latewood. Weathered Douglas fir wood surfaces develop longitudinal micro-checks and also transverse micro-checks that can cross several earlywood tracheids. Transverse micro-checks intersect with longitudinal checks and create loosely bonded slabs and fragments of earlywood cell walls that are easily eroded from the wood surface. Erosion of latewood also occurs due to loss of cell wall fragments. We conclude that the erosion of Douglas fir wood during weathering is due to loss of cell wall fragments rather than due to loss of tracheids. Differential erosion of wood surfaces in Douglas fir appears to be due, in part, to the loss of larger fragments of cell wall material from earlywood compared to latewood. Further research is underway to confirm if the same mechanism is responsible for the erosion of other softwoods exposed to natural and also artificial accelerated weathering.

THREE-DIMENSIONAL DIGITAL IMAGE CORRELATION OF STRAINS IN PROFILED WOOD DECKING EXPOSED TO WETTING & DRYING

Julian Mallet[1,2], Shankar Kalyanasundaram[1] and Philip D. Evans[2]
[1]College of Engineering & Computer Science, The Australian National University, Canberra, ACT 0200, Australia
[2] Department of Wood Science, University of British Columbia, Vancouver, Canada

Summary

We used three dimensional digital image correlation to measure the strains that developed at the surface of profiled radiata pine (*Pinus radiata* D.Don) deck boards subjected to an accelerated weathering cycle. We hypothesized that profiling would change strain distribution at the surface of decking boards, and also that profile geometry would influence strain patterns. Five groups of four deck board samples were produced from five different pieces of machine stress-graded radiata pine wood. Three profiles, based on those in common commercial use, were tested. Flat unprofiled boards acted a control. Each board was fixed to a rigid frame and subjected to a wetting and drying cycle. Full field surface strain data was collected using 3D digital image correlation. Strains varied across the surface of both flat and profiled boards. Profiling changed surface strain patterns; strain maxima and minima developed in the profile ridges and grooves during wetting, respectively, but this pattern of strains reversed during drying. Such a pronounced reversal of strains was not observed when flat boards were exposed to wetting and drying, although there was a shift towards negative strains when flat boards were dried. The difference in wetting and drying strains varied with profile type and was significantly higher in boards with hemispherical, rib profiles compared to those with wavy, ripple, profiles. We conclude that profiling changes surface strain distribution in deck boards exposed to wetting and drying, and causes high strains to develop in the grooves of profiled boards. These findings help explain why checks in profiled deck boards mainly develop in profile grooves where they are difficult to see.

EFFECTIVENESS OF HOT MELT WAXES AS EDGE SEALS FOR OSB

Wenchang He and Philip D. Evans
Department of Wood Science, University of British Columbia, Vancouver, Canada

Summary

This paper examines the use of hot-melt waxes as edge seals for oriented strand board (OSB). Waxes, each with a different melting point (m.p.) were sprayed in the molten state on to one of the edges of separate hot OSB samples. The remaining uncoated edges of each sample were sealed with elastomeric silicone sealant. The waxes that were tested were carnauba wax (m.p. 81°C), two petroleum waxes with melting points of 63°C, and 56°C, respectively, a petroleum jelly (m.p. 37 to 59°C) and a Fischer-Tropsch wax (m.p. 31°C). Treated samples were allowed to cool and they were then conditioned at 20 ± 1°C and 65 ± 5% r.h. for 3 days. Conditioned samples were floated on water for 72 h and reconditioned (as above) for 14 days. The thickness of the conditioned samples was measured at the edges adjacent to the edge-seal and 25 mm proximal to the edge using a digital calliper. The difference in these two measures of thickness was used calculate the differential edge swelling or edge flare of samples. The edge swelling of wax-treated samples was compared with those of untreated controls and samples sprayed with a conventional, commercial, edge seal. All but one of the waxes were significantly ($p<0.05$) better at reducing edge flare of OSB samples than the conventional edge seal, but the Fischer-Tropsch wax with the lowest melting point was ineffective. The petroleum jelly was the most effective edge seal because it filled surface voids and created a thin and continuous coating at the edges of OSB samples. Carnauba wax also created a coating at the edges of OSB, but the coating cracked when OSB samples were exposed to wetting and drying, which may explain why carnauba wax was less effective as an edge seal than petroleum jelly. Hot melt wax treatments show promise as edge seals for OSB, and further research is planned to test the effectiveness of a greater range of waxes as edge seals, and examine the relationship between wax properties and their ability to restrict edge flare of OSB.

OPTIMIZING PROFILING TO REDUCE THE CHECKING OF PACIFIC SILVER FIR DECKING

Kenneth J. Cheng, Philip D. Evans*
Centre for Advanced Wood Processing, 2424 Main Mall #2900, University of British Columbia, Vancouver, BC, V6T 1Z4

Summary

We characterize the geometry of the grooves and peaks of 'profiled' wooden decking. We classify profiled decking into three groups using the ratio of radii of surface grooves (R1) to those of peaks (R2) and propose a new name (*ribble*) for the profiles whose geometry falls between those of rib (R1/R2<30%) and ripple profiles (R1/R2> 60%). We design new profiles which systematically vary R1/R2 and height to width (H/W) ratios of profile peaks and grooves and examine the effect of profile geometry on the checking and planar distortion (cupping) of Pacific silver fir deck boards exposed to the weather. Profiling reduced the width of checks, but increased the cupping of deck boards. There was no entirely consistent trend of R1/R2 and H/W ratios on checking, but profiles with small R1/R2 ratios (rib profiles) and grooves deeper than 1.5 mm were more effective at restricting checking than a ribble profile, which was used commercially in Canada to profile Pacific silver fir. We conclude that it is possible to reduce surface checking of Pacific silver fir decking by altering the geometry of surface profiles. In principal the same approach could be used with other wood species to reduce the negative effects of surface checking on the appearance of wooden decking.

Keywords: Wood, decking, profiling, checking, cupping, confocal profilometry

1. Introduction

Wood is the main end-point for photosynthesis performed by trees (Ryan *et al.* 2010). Photosynthesis uses sunlight to split water into hydrogen and oxygen and the hydrogen generated by this process is combined with atmospheric carbon dioxide to make various organic molecules, including the 'building blocks' for wood (Barber 2009). The carbon dioxide used or 'sequestered' to make wood is not released until the wood decays or burns. This simple fact and our ability to harvest wood from sustainably managed plantations or forests has led to government policies designed to encourage the use of wood as part of mankind's efforts to combat global warming (Ministry for the Environment 2009, Government of British Columbia 2010). But the properties of wood sometimes fail to match the expectations of end-users, which is frustrating attempts to increase the use of

*Corresponding author. Tel: + 1 604 822 0517; fax: + 1 604 822 9159.
E-mail address: phil.evans@ubc.ca (Philip D. Evans).

wood. For example, you have probably noticed that outdoor wooden decks develop cracks and checks? Checks that develop in tropical woods with wavy or interlocked grain can create attractive serpentine or herring-bone patterns at wood surfaces. More often though checks ruin the appearance of wood so much so that many consumers are abandoning wooden decks in favour of decks made from plastic or a composite of plastic and wood particles, which don't crack as much as wood and require less maintenance (Green 2005, Markarian 2005). This trend is strengthening (The Freedonia Group 2012) , even in countries where wooden decking is derived from a renewable resource (plantations or managed forests) and where consumers show a preference for wood over wood-plastic composites when shown unweathered samples of the two materials (Jonsson *et al.* 2008, Lindberg *et al.* 2013). To help reverse this trend our research has focussed on designing and testing chemical treatments to reduce the weathering and checking of wood (Evans, Wingate-Hill and Cunningham 2009, Evans *et al.* 2013). The treatments we have tested have not completely solved the problem of the checking of wood, but a promising approach emerged recently from an entirely different domain, namely surface treatments designed to make wood less slippery.

Wood decking can be made less slippery by machining grooves into its surface and then inserting rough inorganic cement into the grooves (Hill and Moss 2000, Grip Deck 2013). Machining small ridges (peaks) and grooves into the surface of wood also makes wood decking less slippery (Shida *et al.* 1992, Hill and Moss 2000, Hislop 2006). Machining an irregular series of peaks and grooves into the surface of thin rectangular western red cedar (*Thuja plicata* Donn ex D.Don) boards (shakes) was employed in the past to mimic the rough appearance of hand-split shakes used to cover (clad) peoples' houses (Norlander and Knowles 1970). The same process was subsequently applied to plywood shakes and people noted that the machined or profiled plywood shakes checked less than flat plywood cladding (Johnson 1955). The positive effect of such irregular surface profiling was so significant that patents were granted for the process of profiling plywood to reduce surface checking (Deskey 1942, Bailey 1944a,b, Elmendorf 1950, Johnson 1955). Profiling also improved the performance of paint on plywood (Elmendorf 1960), and tests were also initiated to see if profiling improved paint performance on wood siding (Browne and Laughnan 1952). Profiling of wooden decking appears to have evolved later, but despite the antecedents with plywood and wooden siding there is no evidence that profiling of decking evolved for any other reason than to make decks less slippery. Nevertheless, recent research has shown that profiling reduces the width of checks in wooden decks exposed outdoors and makes the checks difficult to see (McFarling *et al.* 2009, Evans *et al.* 2010). Profiling does not alter cupping, an undesirable form of distortion that occurs when deck boards are exposed outdoors, according to McFarling et al. (McFarling *et al.* 2009, Morris and McFarling 2009).

Profiled decking is made in many different countries and in Canada there has been commercial interest in profiling Pacific silver fir (*Abies amabilis* Douglas ex J.Forbes) to improve its suitability for decking. However, to-date only two types of surface profiles have been tested to see if they reduce checking of Pacific silver fir (Evans *et al.* 2010, Morris and McFarling 2009). Hence, we think there may be scope to design surface profiles that are better at reducing checking of this species? We test this idea here and examine the effects of profiling on the cupping of deck boards. We also describe preliminary research, which characterized the geometry of surface profiles in profiled wooden decking manufactured in eight different countries.

2. Methodology

2.1 Commercially manufactured profiled decking samples

We cut samples, measuring 20 to 150 mm in length, 50 to 140 mm wide and 18 to 47 mm thick, from commercially manufactured profiled timber decking obtained from eight different countries (Table 1). Profiled samples were placed individually on the stage of a confocal profilometer (Altisurf 500) and the geometry of the profiles was measured along a 37 mm line running at right angles to the direction of grooves and peaks. Confocal profilometry employed a 3 mm probe at a gauge resolution of 0.333 nm and a spacing of 10 µm. The dimensions of the profiles were measured using image analysis software (Altimet Premium, v. 6.2.6142). The profile geometries of the different commercial decking samples are presented in Table 1. The profiled decking samples could be separated by plotting the height (H) to width (W) ratios of their profile peaks, and also the radii of their surface grooves (R1) divided by the radii of their peaks (R2). The latter parameter separated the different profiled decking samples into three different categories (Fig. 1): (1) rib profiles which have hemispherical peaks and small R1/R2 ratios, less than 30%; (2) ripple profiles which have undulating or wave-like dentate peaks, and R1/R2 ratios greater than 60%. Rib and ripple profiles have been mentioned previously although their geometries were not defined (McFarling *et al.* 2009, Morris and McFarling 2009, Evans *et al.* 2010). In addition to these profiles, a third profile was evident whose geometry fell between those of the rib and ripple profiles. We term profiles with these intermediate characteristics (profiles 17 to 19 in Fig. 1) *ribble* profiles to distinguish them from rib and ripple profiles. Ribble profiles had R1/R2 ratios from 30 to 60% (Fig. 1).

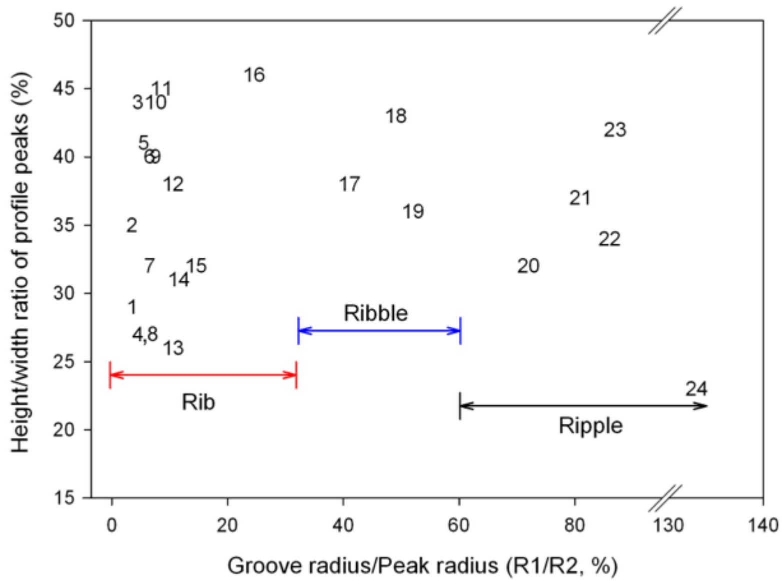


Figure 1. Geometry of surface profiles in wooden decking manufactured commercially in eight different countries. Numbers refer to the decking samples listed in Table 1.

Table 1. Dimensions of the profiles in profiled decking board samples manufactured commercially in: Aus = Australia; Can = Canada; Fin = Finland; Ger = Germany; Jpn = Japan; Neth = Netherlands; UK = United Kingdom; USA = United States of America

No.	Height (mm)	Width (mm)	Groove radius (mm)	Peak radius (mm)	No. Peaks /15 cm	Country	Species/density (g/cm^3)
1	1.16	4.00	0.09	2.54	37	Can	*P. menziesii* (0.47)
2	2.12	5.99	0.12	3.23	25	UK	*Picea* sp. (0.31)
3	2.19	5.03	0.12	2.37	29	Aus	*Intsia* sp. (0.75)
4	1.33	4.98	0.15	2.94	30	Aus	*P. radiata* (0.49)
5	2.00	4.92	0.14	2.28	30	Aus	*P. radiata* (0.37)
6	1.74	4.31	0.14	2.09	34	Jap	*Shorea* sp. (0.81)
7	1.54	4.83	0.17	2.49	31	Aus	*Pinus sp.* (0.54)
8	0.71	2.61	0.10	1.46	57	Jap	*A. mangium* (0.78)
9	1.98	4.97	0.16	2.01	30	Ger	*Larix* sp. (0.53)
10	2.12	4.79	0.18	2.17	31	Ger	*Handroanthus sp.* (0.92)
11	2.06	4.53	0.19	2.08	33	Fin	*P. sylvestris* (0.35)
12	1.80	4.76	0.24	2.18	31	Jap	*Handroanthus sp.* (0.94)
13	1.85	6.99	0.24	2.10	21	Fin	*Pinus sp.* (0.41)
14	1.53	5.01	0.29	2.37	29	Neth	*P. radiata* (0.54)
15	1.25	3.89	0.27	1.82	38	Can	*A. amabilis* (0.33)

16	2.29	4.96	0.45	1.83	30	Aus	*Intsia* sp. (0.67)
17	1.50	3.92	0.44	1.07	38	Can	*A. amabilis* (0.47)
18	2.08	4.84	0.73	1.49	30	USA	*Pinus sp.* (0.44)
19	1.82	4.99	0.50	0.97	30	Jap	*Callitris* sp. (0.60)
20	1.85	5.87	1.38	1.91	25	Ger	*Picea* sp. (0.47)
21	1.79	4.82	0.97	1.21	31	Can	*Pinus* sp. (0.50)
22	2.01	5.84	1.30	1.51	25	Ger	*Apuleia* sp. (0.82)
23	1.72	4.14	0.59	0.68	36	Can	*Pinus* sp. (0.41)
24	0.85	3.63	1.32	0.99	41	Can	*Tsuga* sp. (0.49)

The appearance and geometry of rib, ribble and ripple profiles can be seen in Fig. 2a-c. Our preliminary work to characterize the geometry of commercial profiles allowed us to design profiles with defined characteristics and examine the effects of profile geometry on the checking of Pacific silver fir decking boards exposed outdoors to 'natural' weathering.

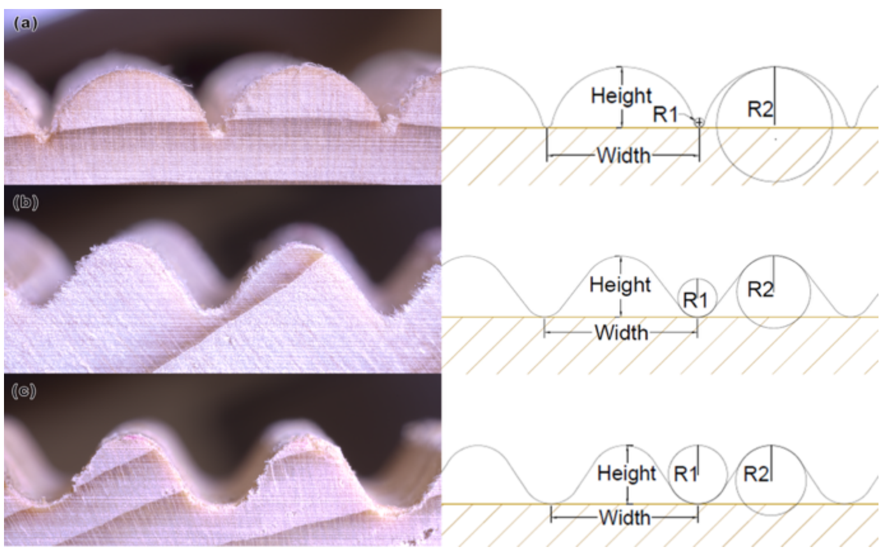


Figure 2. Appearance of profiles in Pacific silver fir: (a) Rib profile with R1/R2 ratio of 6.66% and H/W ratio of 40% (Rb); (b) Ribble profile with R1/R2 ratio of 50% and H/W ratio of 40% (Rbl); (c) Ripple profile with R1/R2 ratio of 83.3% and H/W ratio of 40% (Rp)

2.2 Design of new surface profiles and manufacture of customized tooling

Eleven different profiles were designed (Table 2). The geometries of the different designed profiles and those of the commercial profiles that most resemble the designed profiles are plotted in Fig. 3. There are three designed profiles within each of the rib (R1/R2 = 6.67%), ribble (R1/R2 = 50%) and ripple (R1/R2 = 83.3%) profile classifications, which vary the H/W ratios of profile peaks creating tall (+25%), standard (0%, baseline) and short (-25%) versions of each the different profile types (Fig. 3). The H/W ratios of profile peaks are comparable between each of the three profile categories. In addition, there are two more rib profiles in which the widths of the peaks are changed by ± 25% (Fig. 3). Accurate engineering drawings of each of the different profiles were produced using AutoCAD (Autodesk inc. 2013) and cutter knives capable of machining each profile were manufactured by a specialist tooling company. Two knives, 150 mm wide, with a body diameter (Ø) of 125 mm and hook angle of 15° were manufactured for each profile.

Table 2. Dimensions of the designed profiles used to manufacture profiled decking board from Pacific silver fir

Profile type	Peak height, mm	Peak width, mm	Groove radius, mm	Peak radius, mm	Peaks/ 15cm
Rib (Rb)	2.00	5.00	0.16	2.40	30
Rib+ (Rb+)	2.50	5.00	0.15	2.20	30
Rib- (Rb-)	1.50	5.00	0.16	2.40	30
Rib+w (Rb+w)	2.00	6.25	0.13	2.00	24
Rib-w (Rb-w)	2.00	3.75	0.11	1.70	40
Ribble (Rbl)	2.00	5.00	0.65	1.30	30
Ribble+ (Rbl+)	2.50	5.00	0.65	1.30	30
Ribble- (Rbl-)	1.50	5.00	0.65	1.30	30
Ripple (Rp)	2.00	5.00	1.00	1.20	30
Ripple+ (Rp+)	2.50	5.00	1.00	1.20	30
Ripple- (Rp-)	1.50	5.00	1.00	1.20	30

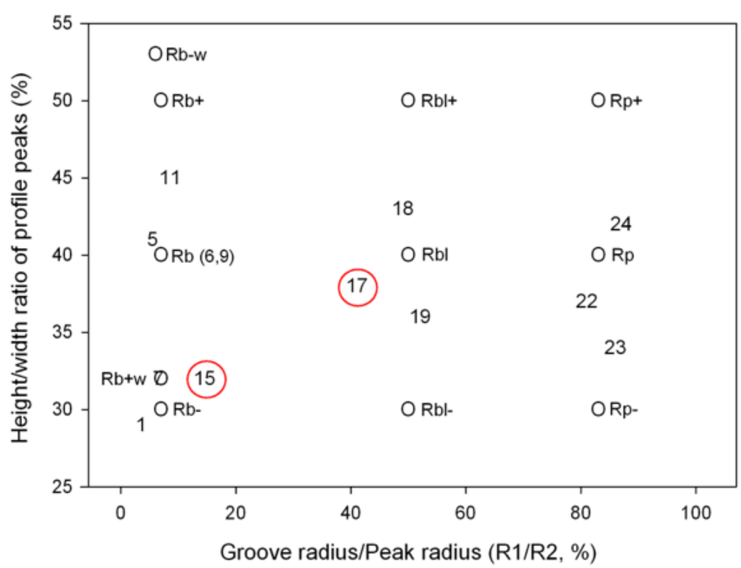


Figure 3. Geometry of designed profiles used to manufacture profiled decking from Pacific silver fir. The names of the different rib (Rb), ribble (Rbl) and ripple (Rp) profiles and precise R1/R2 and H/W ratios of the

profiles are listed in Table 2. The numbers on the figure refer to the commercially manufactured profiles (listed in Table 1) whose geometry is closest to those of the designed profiles. The numbers that are circled refer to profiles that have been used with Pacific silver fir

2.3 Manufacture of profiled Pacific silver fir decking

Six flat-sawn Pacific silver fir boards measuring 4877 x 140 x 40 mm were each cross-cut using a chop saw (Stromab PS 50/F), to produce 12 samples, each 400 mm in length. Each sample was planned to a thickness of 38 mm using a rotary planer (Martin T44). Samples from the first parent board were assigned at random to the different profile types, including the unprofiled control. The two relevant profile knives for the first selected profile were inserted into a 125 mm diameter, two-wing, cylindrical rotary cutter head with a hook angle of 15° (Great-Loc SG Positive Clamping Universal Tool System). The two knives were secured in place by applying even pressure to nine clamp screws. The cutter head was placed on the machine spindle of a moulding machine (Weinig Profimat 26 Super), aligned and then secured in place. The decking sample was then machined using a feed speed of 13 m/min, and a spindle speed of 6000 rpm to produce the selected profile. This process was then repeated for the second assigned profile and so on until all twelve samples from the first parent Pacific silver fir board were profiled. Then samples from the second parent board were profiled, as above, followed by samples from boards 3, 4, 5 and 6 until all 72 samples (6 boards x 12 samples) had been profiled. The final dimensions of the profiled boards were 400 (length) x 135 (width) x 31.75 mm (thickness). A bench drill was used to pre-drill 4 holes (Ø = 3.97 mm) in each of the deck board samples. Each hole was positioned 40 mm from end-grain, and 23 mm from the edge of the samples. The end-grain of the samples was sealed with epoxy resin (G2 Epoxy, System Three Resins) to reduce checks developing in end-grain and samples were air-dried in a conditioning room at 20 ± 1°C and 65 ± 5% relative humidity (r.h.) for two months.

2.4 Characterization of profiled decking boards and outdoor weathering

The growth rate and grain angle of each Pacific silver fir sample was measured using a ruler and protractor, as described previously (Evans *et al.* 2010). The density of separate matched wood samples and also samples cut from commercial profiled decking board samples were measured by water displacement and oven-drying overnight at 105 ± 5°C (Tables 1 and 3). Profiled samples and the matching flat controls cut from each of the six parent boards were screwed to separate wooden sub-frames made from pressure-treated ‘2 x 6’ lumber to create six mini-decks. Boards were fastened at each corner to the sub-frames using 25 mm long, square-head (8 mm) Robertson galvanized decking screws. A gap of 6.35 mm was left between each of the 12 boards in each rack to allow water to drain between boards. Unprofiled Pacific silver fir boards, measuring 400 x 50 x 31.75 mm, were screwed to each end of the row of 12 boards on each rack to prevent the sides of adjacent test samples from being exposed to the weather. The weathering racks were exposed outdoors in the FPInnovations test site on the Vancouver campus of the University of British Columbia, for 6 months from February 20th to August 20th 2012.

2.5 Characterization of checking and cupping

Table 3. Growth rate, density and grain angles of parent Pacific silver fir boards that were cut and machined to produce decking board samples

Board No.	Growth rings per cm	Basic density (g/cm^3)	Grain angle (◦)
1	9	0.38	1.2
2	24	0.38	1.5
3	30	0.41	1.1
4	27	0.40	2.0
5	8	0.33	0.3
6	23	0.37	1.0
Average	**20**	**0.38**	**1.2**

Visible checks on the weathered longitudinal surface of all samples (profiled and flat controls) except those that developed around fasteners were counted after six months of weathering. Samples were conditioned at 20 ± 1°C and 65 ± 5% r.h. for five days and the length and width of visible checks were measured using a transparent Perspex ruler and calibrated optical loupe (Evans *et al.* 2010). The positions of checks within grooves and peaks and whether they crossed peaks were also recorded. The cupping of deck board samples, defined as deviation from flatness transversely across the face of each conditioned sample, was measured before and after weathering. Each sample was placed on a flat surface against a steel fence and planer deviations were measured in three places using a dial gauge micrometer (Mitutoyo Digimatic Indicator ID-S1012EB) attached to a precision machined steel square (Hao and Avramidis 2004). Cupping is expressed in mm from the center of the board to the highest point of the distortion.

Samples measuring 25 x 135 x 31.75 mm were sawn from each weathered and conditioned decking board sample. Samples were conditioned at 20 ± 1°C and 65 ± 5% r.h. for 3 days. The cross-cut, transverse, face of each sample was sanded using an edge sander (Akhurst PMC-150) and a 150 grit abrasive belt. A brown gel stain (0.2 mL, Varathane 601 Golden Oak) was applied to the transverse face of each cross-cut specimen using a spatula and wiped off with cotton cloth after 300 seconds. The stain penetrated small checks occurring in the bottom of grooves, and made it easier to see them using a magnifying glass. The presence or absence of checks in the grooves of profiled specimens was noted. Photographs of the transverse faces of samples were taken at 4x magnification using a

Canon EOS 7D camera equipped with a Canon MP-E 65 mm 1 to 5 x macro lens. Samples were located 150 mm away from the camera and illuminated with a 4.5 Watt external light source (Litepanels Micro™). The camera was attached to a sliding plate (Manfrotto 454 Micrometric Positioning Sliding Plate) on a ball joint holder (Sirui K-20X) to obtain sharply focussed images of checks within the grooves of samples. In addition, confocal profilometry was used to obtain high quality images of an area measuring 185 mm^2 at the surface of profiled and weathered samples. The profilometer employed the same parameters used to measure the geometry of profiles in commercial decking samples.

2.6 Statistical analyses

Our experiment was a randomized block design. Each of the six weathering racks contained 12 board samples (profiled and the flat control) and represents a block. The factor of interest (profile type) was fully replicated in each block. Statistical analysis of the effect of profile type on checking used analysis of variance (ANOVA) for a randomized block design. The flat control sample was unprofiled therefore a sub-routine (*convstrt*) within the statistical program Genstat (Genstat 2009) was used to produce contrasts between the checking of this control and all 11 profiled samples, and also between all the profiled samples. The effects of profile type on the following numerical indicators of checking and cupping were analyzed: (1) Average width, length and area of the ten largest checks in each specimen; (2) Average area of the largest checks in each specimen (as for 1) that were located in the base of grooves, solely on profile peaks or crossing a groove and a peak; (3) Number of microscopic checks in the base of grooves divided by the total number of grooves in each specimen; (4) Cupping measured before (i) and after weathering (ii), and the difference in cupping (ii-i). All statistical computation including model checking to ensure data met the assumptions of ANOVA (normality, additivity and equality of variances) was performed using Genstat. Results are presented in graphs and error bars on each graph (± standard error of difference, $p<0.05$) can be used to estimate whether differences between individual means are statistically significant.

3. Results and Discussion

Checks in profiled boards when averaged across all profiles were significantly ($p = 0.004$) narrower than those in the unprofiled control (Con). However, the effectiveness of profiling at restricting check width varied significantly ($p = 0.022$) with profile geometry (Fig. 4). Boards with the rib (Rb) and wide rib (Rb+w) profiles had the narrowest checks, but the width of large checks in boards with the tall rib (Rb+), ribble (Rbl), ripple (Rp) and short ripple (Rp-) profiles were not significantly different ($p>0.05$) from that of checks in the unprofiled control (Fig. 4).

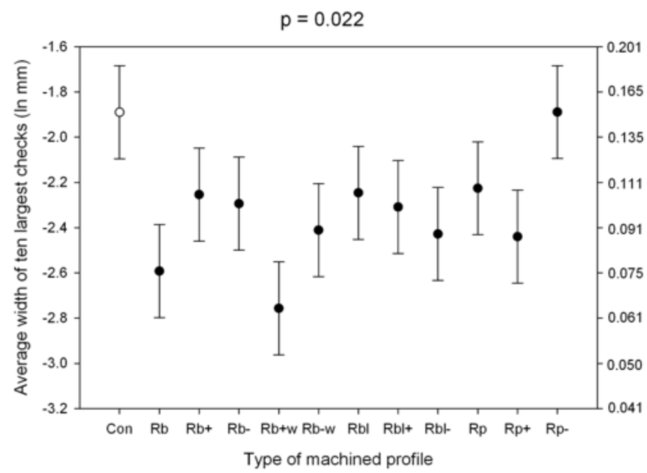


Figure 4. Average width of ten largest checks in profiled and flat (unprofiled) Pacific silver fir boards exposed outdoors to natural weathering for 6 months. The labels on the x-axis refer to the profiles listed in Table 2. Y1-axis refers to natural logarithms of check width. The Y2 axis contain values on a natural scale (e^x)

Boards with rib profiles, with the exception of those with a short rib profile (Rb-), had the shortest checks, but the lengths of checks in boards with these rib profiles were not significantly ($p>0.05$) different from that of checks in the unprofiled control (Fig. 5). Checks in boards with the short rib (Rb-), ribble (Rbl), short ribble (Rbl-), ripple (Rp) and short ripple (Rp-) profiles were all significantly longer ($p<0.05$) than those in the unprofiled control (Con) (Fig. 5).

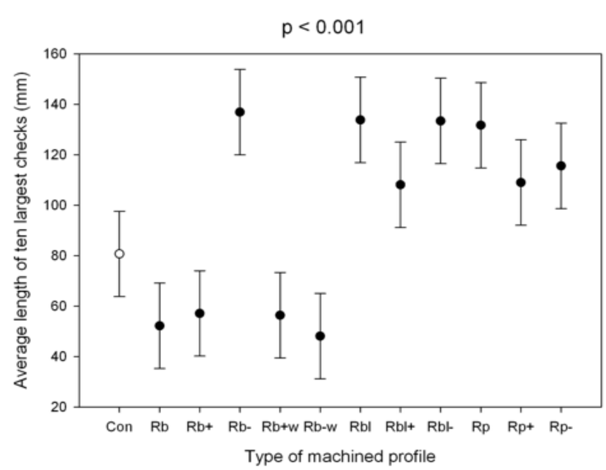


Figure 5. Average length of ten largest checks in profiled and flat Pacific silver fir boards exposed outdoors to natural weathering for 6 months

The area of large checks was significantly ($p<0.05$) smaller in boards with the rib (Rb), wide rib (Rb+w) and narrow rib (Rb-w) profiles compared to that of checks in the unprofiled control (Fig. 6), which reflects the effects of these profiles on check width and length (Figs. 4 and 5). We further sub-divide data for check area into 3 categories according to whether checks were located within grooves, on peaks or whether they crossed a peak. We chose to sub-divide check area data because checks on the peaks of profiles or ones that cross peaks are easier to see and hence mar the appearance of boards more than those that develop in grooves.

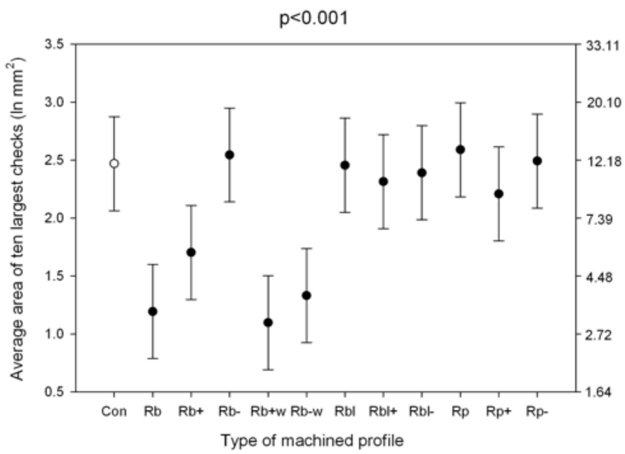


Figure 6. Average area of ten largest checks in profiled and flat Pacific silver fir boards exposed outdoors to natural weathering for 6 months

Checks with these different locations can be observed in Fig. 7, which shows topographical maps of the surface of profiled boards after they were exposed to the weather. Checks in grooves can be seen in each of the profiled samples, but they are particularly prominent in samples with the ripple (Rp) and short ribble (Rbl-) profiles (Fig. 7c,d). Checks that occur on the peaks of profiles can be seen on the left-hand sides of samples with the rib (Rb) and short ribble (Rbl-) profiles (Fig. 7a,d). The latter board type also contains a prominent check that crosses a profile peak (right-hand side of Fig. 7d). Profiles with different geometries (rib, ribble and ripple) developed all three types of checks, with the exception of boards with the tall ripple (Rp+) profile, which didn't develop checks on profile peaks (Fig. 8). Boards with the standard ripple (Rp), standard ribble (Rbl) and short ribble (Rbl-) profiles had the smallest area of checks on their peaks whereas boards with the rib profiles had the most, with the exception of boards with a short rib (Rb-) profile (Fig. 8). The area of checks on peaks in samples with the standard ripple (Rp), standard ribble (Rbl) and short ribble (Rbl-) profiles were significantly ($p<0.05$) smaller than those of checks in samples with the tall rib (Rb+), wide rib (Rb+w) and narrow rib (Rb-w) profiles. In contrast, the area of checks in grooves in samples with the ripple and ribble profiles were all significantly ($p<0.05$) greater than those of samples with the rib profiles, with the exception of samples with the short rib (Rb-) profile (Fig. 8). The area of large checks that crossed profile peaks was significantly ($p<0.05$) larger in samples with the short rib (Rb-) and short ripple (Rp-) profiles and lowest in samples with the tall ripple (Rp +) and narrow rib (Rb-w) profiles.

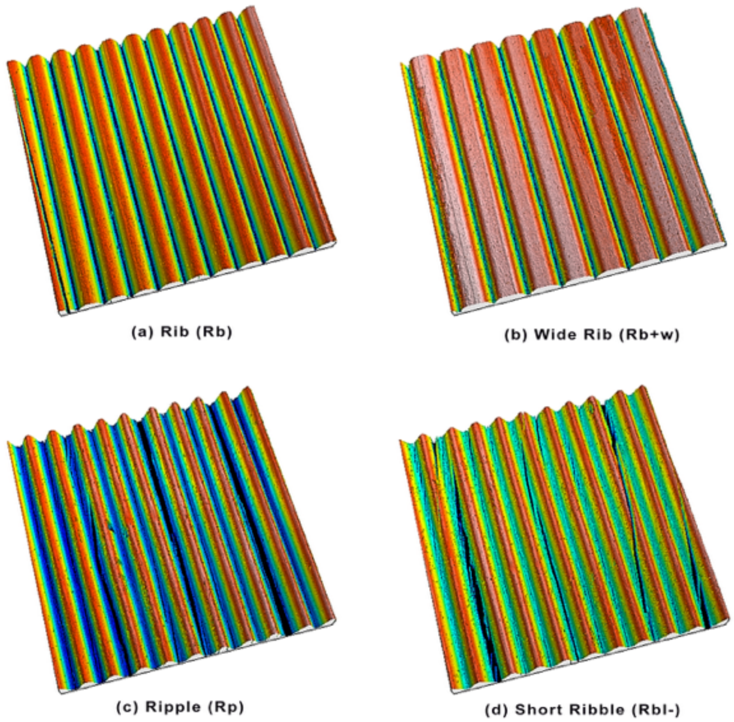


Figure 7. Confocal profilometry images of the surface topography of Pacific silver fir profiled decking surfaces exposed to natural weathering for 6 months: (a) Rib sample showing checks within grooves, and a large check on the top of a peak (far left); (b) Wide rib sample showing checks within grooves; (c) Short ribble sample showing large and small checks within grooves and two checks that cross profile peaks (far right); (d) Ripple profiles showing large and small checks within grooves

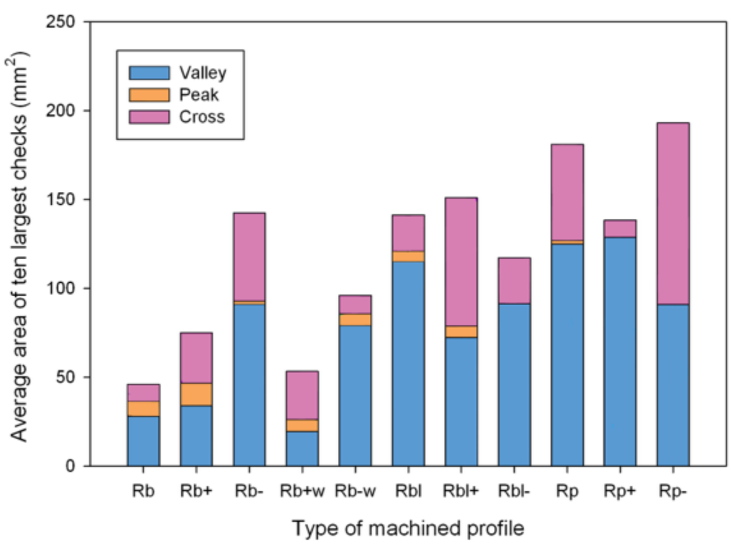


Figure 8. Areas of large checks in profiled samples that developed in grooves, on peaks or crossed peaks in Pacific silver fir decking board samples exposed to natural weathering for 6 months. Note that the short ribble profile (Rbl-) developed some peak checks but they were small (0.5 mm^2) and do not appear on this figure

In addition to the aforementioned large checks, numerous smaller checks developed in the grooves of profiles. This became apparent when we used high resolution confocal profilometry to image the surface of profiled samples (Fig. 7). For example, if you look closely at the grooves in the profilometry images in Fig. 7 you can see a small check in every groove. This observation made us pay closer attention to the smaller checks in the grooves of profiled samples, and we decided, as mentioned above, to quantify their presence or absence in every groove in each of the profiled samples exposed to the weather. The percentage of grooves that contained checks that were visible to a hand lens was very high and varied from a maximum of 98.6% for boards with a rib profile to a minimum of 93.0% for boards with a tall rib profile. Differences in the percentages of grooves in the different profiled boards that contained small checks were not statistically significant ($p = 0.408$). These small checks developed at or near the bottom of grooves and propagated radially into board samples (Fig. 9). Most of the checks could only be seen with a hand lens and therefore they didn't affect the appearance of the boards.

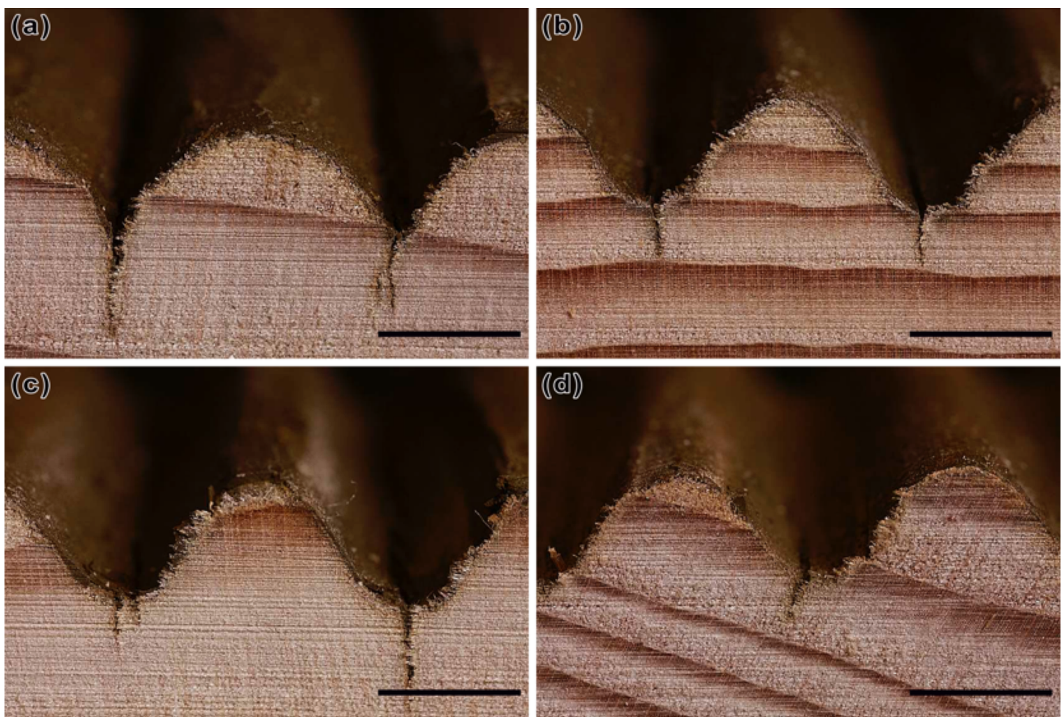


Figure 9. Close-up of peaks and grooves in profiled Pacific silver fir samples after 6 months of weathering. Note the development of checks at the base of grooves in each of the profiled specimens: (a) Standard rib [Rb]; (b) Standard ribble [Rbl]; (c) Standard ripple [Rp]; (d) Standard ribble [Rbl]. Scale bar = 1 mm

Profiling significantly (p = 0.02) increased the cupping of boards exposed outdoors (Fig. 10), but had no significant (p = 0.457) effect on the initial cupping of boards after they were machined and conditioned. Results in Fig. 10 for profiled boards are averaged across the different profiles because there was no significant (p = 0.265) effect of profile type on cupping.

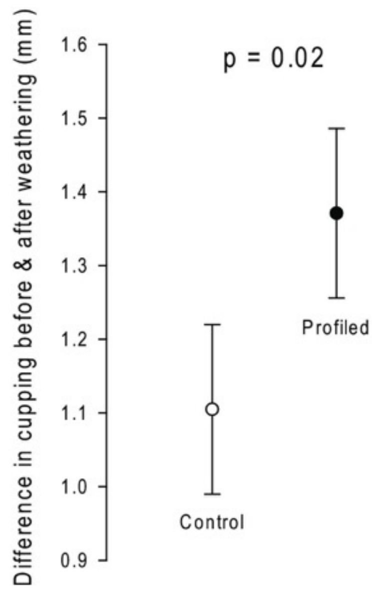


Figure 10. Difference in cupping of Pacific silver fir boards before and after they were exposed to natural weathering for 6 months. Results are averaged across all boards and compared with cupping occurring in the flat (unprofiled) controls

Profiling is interesting because it reduces the negative effects of checking on the appearance of decking boards exposed outdoors. This effect of profiling on appearance is explained by the reduced size of checks that develop in profiled boards and the difficulty of seeing checks that develop within grooves (McFarling *et al.* 2009). Therefore an ideal profile should restrict the size of checks that develop when deck boards are exposed outdoors and confine visible checks to the grooves of profiles. None of the profiles we designed and tested possessed exactly this desirable combination of properties, because none of them confined all large checks to profile grooves. Nevertheless, it seems likely that two of the rib profiles we designed and tested (rib and wide rib) would be better at restricting the size of checks in Pacific silver fir than the ribble profile (profile 17 in Fig. 1 and Table 1) that was used commercially in Canada to profile Pacific silver fir. Our rib profile (Rb) is very similar to one that is being used in Germany to profile larch (*Larix* sp.) deck boards (profile 9 in Fig. 1 and Table 1), but none of the commercial profiles are identical to the wide rib profile we designed and tested, which also performed well.

We hoped that our work would reveal universal trends about the relationship between profile geometry (R1/R2 ratio and H/W ratio) and the ability of profiling to restrict the checking of Pacific silver fir, but no entirely consistent trends of these geometric parameters on check sizes emerged. For example, it is clear that rib profiles (low R1/R2 ratios) were generally better at restricting the size of checks than profiles with higher R1/R2 ratios (ribble and ripple profiles). However, checking of boards with a short rib profile was similar to that of boards with ribble or ripple profiles, despite the fact that the R1/R2 ratio of boards with short rib profiles was similar to that of boards with the other rib profiles.

The effect of profile geometry on the locations of checks was also inconsistent. For example, short rib and short ripple profiles had H/W ratios and groove depths of 30% and 1.5 mm, compared to 40% and 2.0 mm and 50% and 2.5 mm for the corresponding standard and tall profiles, respectively. Both of these short profiles encouraged the formation of checks that crossed profile peaks, but the same effect was not observed in boards with a short ribble profile. Cross-profile checks develop more readily in Pacific silver fir with spiral grain (Evans *et al.* 2010), a defect that is unavoidable in wood used to make decking. Checks that cross profile peaks are very easy to see (Evans *et al.* 2010) and hence profiling should try to reduce their formation. Our results suggest that this desirable outcome may achieved in Pacific silver fir by avoiding rib and ripple profiles with a low H/W ratio (<30%) and grooves less than 1.5 mm deep. Rib and ripple profiles with these characteristics were commonly encountered during our industry survey (profiles 1, 4, 8, and 24 in Fig. 1 and Table 1) and hence it would be worthwhile conducting experiments to see if cross-profile checks can be reduced in other wood species by increasing the H/W ratio and depth of profiles machined into boards.

Profiling increased the tendency of boards to cup when they were exposed outdoors. The same undesirable tendency was noted in profiled (striated) plywood by Bailey (1944a,b), but the profiled plywood cupped away from the profiled face whereas profiled decking here cupped towards the profiled face. Bailey solved the problem of cupping of striated plywood by increasing the thickness of the striated veneer to create a balanced panel which equalized stresses in opposing veneers (Bailey 1944ab). The same approach is clearly not suitable for wooden decking, but it's possible that stress relief grooves that are machined into the undersides of some decking boards (Nystrom 1995) might reduce the tendency of profiled boards to cup when they are exposed outdoors. Further research would be needed to test this hypothesis.

Our results showed that profiling restricted the width of checks that developed when Pacific silver fir deck boards were exposed outdoors to the weather, but was ineffective at restricting large checks from becoming longer. These findings support previous observations (McFarling *et al.* 2009*,* Evans *et al.* 2010). We also found checks at the base of almost <u>every</u> groove in profiled boards, irrespective of profile type. These checks were microscopic and could only be seen with a hand lens. Hence, they did not influence the appearance of boards. Very narrow checks ('slits') also developed at the base of grooved plywood exposed outdoors and it was suggested that they prevented the creation of long wide cracks (Elmendorf 1950). The small microscopic checks we observed cannot account for differences in the ability of profiles to restrict the development of large checks because they were found in all of the different profiled boards. However, their formation and the increased tendency of profiled boards to cup suggest that profiling alters in a very fundamental way the stresses and strains that are responsible for the checking of wooden decking exposed outdoors to weathering. We have confirmed that this is the case using digital image correlation of profiled boards exposed to artificial weathering (Mallett 2012). Our findings on this subject will be the subject of another paper that is being prepared for publication.

4. Conclusions

We developed a method of characterizing the geometry of profiled wooden decking that contains surface grooves and peaks. We conclude that it is possible to classify commercial profiled decking using the ratio of radii of profile grooves (R1) divided by the radii of profile peaks (R2). We identified three different groups of profiled boards and created a new name (ribble) for the profiles whose geometry falls between those of rib (R1/R2<30%) and ripple profiles (R1/R2>60%). Our method of classifying profiles makes it possible to identify different types of profiled decking that are manufactured commercially and systematically compare their properties.

We compared the checking of Pacific silver fir decking with different R1/R2 ratios and height to width (H/W) ratios of profile peaks after profiled boards were exposed outdoors for 6 months. In conclusion, there was no consistent trend of these geometric parameters on checking, but we found that profiles with small R1/R2 ratios (rib profiles) and grooves deeper than 1.5 mm were more effective at restricting checking of Pacific silver fir than profiles with larger R1/R2 ratios (ribble and ripple profiles). Furthermore, the development of unsightly checks that traverse profile peaks in boards with rib and ripple profiles could be reduced by creating grooves that are deeper than 1.5 mm. Profiling increased the undesirable cupping of deck boards exposed outdoors and research is urgently needed to solve this problem.

We have demonstrated that it is possible to reduce surface checking in profiled Pacific silver fir decking by altering the geometry of surface profiles. In principal, the same approach could be used with other commercially important wood species to reduce the negative effects of surface checking on the appearance of wooden decking used outdoors.

Acknowledgements

We thank Dr Alan Preston, Dr Paul Morris and Mr Chris Gaston for their helpful insights into the profiling of decking; Mr Alan Smart, Mr Dallin Brooks, Dr Paul Morris, Dr Makoto Kiguchi and Dr Andreas Krause for giving us samples of commercially profiled wooden decking; the Canadian Foundation for Innovation, British Columbia Knowledge Development Fund and FPInnovations for supporting this research. PDE thanks Viance, Tolko, FP Innovations and UBC Faculty of Forestry for their support of his BC Leadership Chair at UBC. None of these organizations were involved in the design of our experiments, collection, and interpretation of data or the writing of this paper.

5. Literature

Autodesk inc. [Internet]. San Rafael, CA: AutoCAD ®2010 URL: [cited 2013 May 10].
Available from: http://cad.amsystems.com/products/docs/autocad_2010/autocad_2010
_overview_brochure.pdf.

Bailey WC, inventor; United States Plywood Corporation, assignee. Process of making
balanced laminated panels. United States patent US 2363492. 1944a Nov 28.

Bailey WC, inventor; United States Plywood Corporation, assignee. Balanced striated plywood panels. United States patent US 2363927. 1944b Nov 28.

Barber J. Photosynthetic energy conversion: natural and artificial. Chem Soc Rev 2009;38(Renewable energy issue):185-96.

Browne FL, Laughnan DF. Paint performance on forest products. Modification of wood
and plywood to improve paintability. Madison (WI): United States Department of agriculture, Forest Service, Forest Products Laboratory; 1952 May. Report No.: 1926.

Deskey D, inventor; United States Plywood Corporation, assignee. Plywood panel. United
States patent US 2286068. 1942 Jun 9.

Elmendorf A, inventor; Plywood panel. United States patent US 2514318. 1950 Jul 4.

Elmendorf A, Vaughan TW. Means for reducing the checking of Douglas-fir plywood. For
Prod J 1960;10(1):45-7.

Evans PD, Wingate-Hill R, Cunningham RB. Wax and oil emulsion additives: How effective are they at improving the performance of preservative-treated wood. For Prod J 2009;59(1/2):66-70.

Evans PD, Cullis I, Morris PI. Checking of profiled southern pine and Pacific silver fir
deckboards. For Prod J 2010;60(6):501-07.

Evans PD, Gibson SK, Cullis I, Liu C, Sebe G. Photostabilization of wood using low molecular weight phenol formaldehyde resin and hindered amine light stabilizer Polym Deg & Stab 2013;98:158-68.

GenStat (PC/Windows XP). Release 12.1. Hemel Hempstead: VSN International Ltd. 2009.

Government of British Columbia. British Columbia climate action for the 21st century.
[Internet]. 2010 [cited 2013 Aug 17]. Available from: http://www.env.gov .bc.ca/cas/ pdfs/climate_action_21st_century. pdf.

Green C. Synthetic decking takes off. Fine Homebuilding 2005;172(July):44-9.

GripDeck [Internet]. Colchester, Essex, UK: [cited 2013 Aug 17]. Available from: http://www.gripdeck.co.uk/products/slip-resistant-decking.

Hao BY, Avramidis S. Annual ring orientation effect and slope of grain in hemlock timber
drying. For Prod J 2004;54(11):41-49.

Hill MJ, Moss AC, inventors; Stairway & Entrance Safety Products Ltd., assignee. Wooden decking element. UK patent GB 2339437 (A). 2000 Jan 26.

Hislop P. Timber decking. The professionals' manual. 2nd ed. High Wycombe: Trada; 2006.

Johnson FL, inventor. Composite laminated panel and method of its manufacture. United
States patent US 2713014. 1955 Jul 12.

Jonsson O, Lindberg S, Roos A, Hugosson M, Lindström M. Consumer perceptions and
preferences on solid wood, wood-based panels, and composites: A repertory grid study. Wood Fiber Sci 2008;40:663-78.

Lindberg S, Roos A, Kihlstedt A, Lindström M. A product semantic study of the influence
of the sense of touch on the evaluation of wood-based materials. Mat & Design 2013;52:300-07

Mallett J. Full field strain mapping of profiled radiata pine decking boards subjected to
accelerated weathering. [B.Eng. Thesis]. Canberra (ACT): The Australian National University; 2012.

Markarian J. Wood-plastic composites: Current trends in materials and processing. Plast
Addit Compound 2005;7(5):20-6.

McFarling SM, Morris PI, Knudson RM. Extracting greater value from subalpine fir: Profiled decking. For Prod J 2009;59(3):24-8.

Ministry for the Environment. New Zealand's Fifth National Communication under the
United Nations Framework Convention on Climate Change [Internet]. 2009 [cited 2013 Aug 17]. Available from: http://www.mfe.govt.nz/publications/climate/nz-fifth-national-communication/

Morris PI, McFarling S. Field testing of wood products in Canada XVII: High-performance profiled wood decking. Proceedings of the 29th Annual Meeting Canadian Wood Preservers Association [CD-ROM]; 2008, Oct 29-30; Vancouver, BC. Campbellville, Ontario: Canadian Wood Preservers Association; 2009. p. 72-82.

Norlander NE, Knowles RA, inventors; Weyerhaeuser, assignee. Method and apparatus for making simulated hand split shakes. United States patent US 3512562. 1970 May 19.

Nystrom R. Board for use in constructing a flooring surface. United States patent US 5474831. 1995 Dec 12.

Ryan MG, Stape JL, Binkley D, Fonseca S, Loos RA, Takahashi EN, et al. Factors controlling Eucalyptus productivity: How water availability and stand structure alter production and carbon allocation. For Ecol Man 2010;259:1695-703.

Shida S, Ono H, Mikami T, Takahashi H. Utilization and evaluation of exterior wood. IV. Slipperiness of wood decks for floating piers. Mokuzai Gakkaishi 1992;38:835-40.

The Freedonia Group. Wood & competitive decking: United States. Freedonia Focus Reports US Collection. Cleveland (OH): 2012 Oct. 19 p.

FIELD TESTING OF WOOD PRESERVATIVES IN CANADA XXIII: WATER-BASED FIELD-CUT PRESERVATIVES

P. I. Morris, R. Stirling and J.K. Ingram
FPInnovations 2665 East Mall, Vancouver, BC V6T 1Z4

Summary

Field-cut treatments re-seal the envelope of treatment when preservative-treated wood is cross-cut, exposing an untreated core. Many contractors and homeowners do not use the available solvent-based copper naphthenate field-cut preservatives because of their dark colour, unpleasant odour, and persistence on skin and clothing even after washing. FPInnovations therefore approached a number of wood preservatives suppliers to obtain alternative water-based preservatives that could be suitable for field-cut use. Ground-contact and above-ground tests of water-based alternative field-cut preservatives were established at FPInnovations' test site in Maple Ridge, BC in 2008. The decay protection of the field-cut preservatives in this study ranged from poor to excellent. After six years of exposure in ground contact, all control units without preservative applied to the cut ends had failed due to decay. Copper azole containing 2% copper performed the best, better than the reference copper naphthenate. After six years' exposure in an above-ground test, the best performers were copper azole containing 2% copper and two formulations of the reference field-cut preservative, copper naphthenate containing 2% copper in mineral spirits, and copper naphthenate containing 1% copper in water.

1. Introduction

Field-cut treatments are necessary to re-seal the envelope of treatment when preservative-treated wood is cross-cut, exposing an untreated core. Many contractors and homeowners do not do this because they believe the treatment is all the way through, or they are not aware of the need to do so. Above ground, smaller dimensions such as nominal 2-inch lumber treated with preservatives containing mobile bio-available copper, may have adequate protection against spore germination (Morris and Ingram 2013), but there may not be sufficient mobile copper to protect larger dimensions. Furthermore, copper amine based preservatives may not have as much bio-available copper as previously believed (Stirling *et al.* submitted).

A previous study at FPInnovations examined the performance of various field-cut preservatives in ground contact over a period of ten years (Ingram and Morris 1998). However, the majority of residential treated wood is used above ground, and no Canadian field test data on this application are available.

Currently only one preservative is standardized in Canada for application to wood treated with waterborne preservatives – copper naphthenate containing 2% copper in mineral spirits (Canadian Standards Association 2012). A 1% copper formulation is permitted in the USA (AWPA 2014). Disadvantages of copper naphthenate as a field-cut preservative are its unpleasant odour, difficult clean-up, persistence on skin and clothing even after washing, and its bright colour which does not match the colour of most residential preserved wood products. As a result, many contractors and homeowners do not use this product. Zinc naphthenate, though colorless, has the same other disadvantages as copper naphthenate, and is limited to above-ground applications. The ideal field-cut preservative should be waterborne, and colourless, or a colour similar to residential preserved wood products. FPInnovations therefore approached a number of wood preservatives suppliers to obtain alternative water-based preservatives that may be suitable for field-cut use.

Tests of water-based alternative field-cut preservatives applied to the cut ends of coated lumber shell-treated with CCA and exposed under natural conditions in ground contact and above ground were initiated by FPInnovations in September 2008 at our field test site in Maple Ridge, BC. The ground contact test was inspected annually. Due to the slower progress of decay above ground this material was inspected every two years. Previous reports described the tests set-up (Morris and Ingram 2010). The present paper describes the results of inspections after six years of exposure.

2. Materials and Methods

1. Test Unit Preparation

One hundred pieces of green western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) lumber, 105 x 105 mm in dimension, at least 10 ft in length, heavy to heartwood and without antisapstain protection, were obtained from Teal Jones in Surrey, BC, kiln-dried at FPInnovations, and chromated copper arsenate-treated (without incising) at Western Wood Preservers in Aldergrove, BC using their shortest schedule (at our request) and a solution strength of 1.7%. The treated lumber was stored wet for 1 week to ensure maximum fixation prior to drying.

Before cutting into test units, the lumber was pressure-washed to remove the small initial flush of mobile CCA which could be swept onto the freshly cut surface and affect the results of the study. In addition the lumber was sealed with two coats of Supernatural Finish Step 1 (Napier) to further reduce preservative mobility.

For ground contact, end-matched test units were cut to 250 mm in length. Ten replicates were prepared for each preservative (11 for untreated controls), and identified with a numbered stainless steel tag. Both cut faces were brush-coated with two applications of the field-cut preservative. The preservatives to be tested in ground contact are shown in Table 1.

Table 1 Ground contact field-cut preservatives and suppliers

Group	Field-cut preservative	Supplier
1	Copper naphthenate containing 2% Cu in mineral spirits	Kop-Coat
2	Copper naphthenate containing 1% Cu in water	Kop-Coat
3	Copper azole containing 2% Cu	Arch
4	ACQ-D 2% containing Cu	Viance
5	Particulate basic copper carbonate containing 2% Cu	Osmose
6	QT* (5%) + green pigment (0.5%)	Osmose
7	Copper/borate containing 2% Cu	Genics
8	Copper naphthenate containing 1% Cu in mineral spirits	Kop-Coat
9	Micronized copper quat containing 2% Cu	Osmose
10	Control (no field-cut treatment)	N/A

*Quat Tebuconazole

The test unit design chosen for the above-ground study was a "γ-joint" (Figure 1). This was an enlarged post and rail test unit similar to that used by Amburgey et al. (2000) modified with a rebate such that one member is supported by the other. This configuration was chosen because it provides an excellent water trap as well as exposed horizontal and vertical faces.

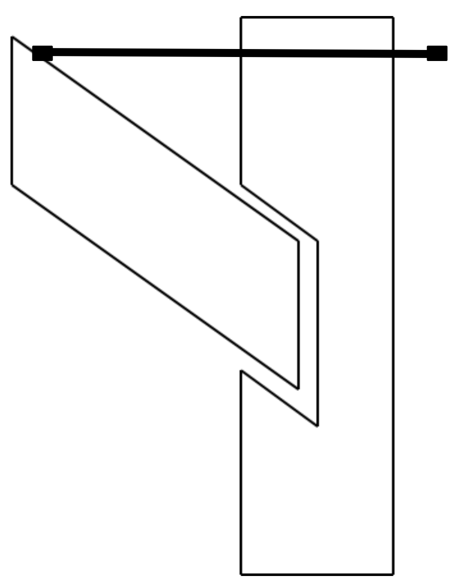


Figure 1 Side view of γ-joint

Pieces were cut to 400 mm in length to form the upright member of the γ-joint, and additional pieces were cut on the diagonal, 250 mm in length, to form the "arm" portion of the joint. The uprights were drilled to accommodate two bolts for fastening the experimental unit to the test racks. Ten replicates were prepared for each preservative (11 for untreated controls), allowing future destructive testing of some samples if desired. The uprights and angled arms of each unit were both identified with a numbered stainless steel tag. Each cut face and bolt hole were brush-coated with two applications of the field-cut preservatives listed in Table 2.

During installation it was suspected that several of the sample components (upright or arm) were actually Douglas-fir rather than western hemlock as intended. These species identifications were confirmed under the microscope. As a result 13 (out of a total of 220) substitute components were installed about 22 months after the initial test. It was also decided to add an additional preservative to the test at the same time.

Table 2 Above-ground field-cut preservatives and suppliers

Group	Field-cut preservative	Supplier
1	Copper naphthenate containing 2% Cu in mineral spirits	Kop-Coat
2	Copper naphthenate containing 1% Cu in water	Kop-Coat
3	Copper azole containing 2% copper	Arch
4	ACQ-D containing 2% copper	Viance
5	Particulate basic copper carbonate containing 2% Cu	Osmose
6	QT* (5%) + green pigment (0.5%)	Osmose
7	Copper/borate containing 2% Cu	Genics
8	0.5% IPBC in water	Kop-Coat
9	0.75% PTQ*	Arch
10	Copper plate (on top and vertical outer angle)	N/A
11	Control (no field-cut treatment)	N/A
12	Borate/glycol plus DDAC***	Sansin

*Quat Tebuconazole
**Propiconazole,Tebuconazole Quat
***Installed approximately 22 months after other material

2. Test Site

The test site at Maple Ridge, BC is located within the University of BC Malcolm Knapp Research Forest. The area is a clearing in second growth coastal western hemlock forest, but was a grass field for decades. It was previously used as a deer pen. The soil is a sandy silt loam to a depth of 0.3 m (12 in). It has a pH around 5.1 and is relatively high in organic matter (15 - 21%). Below this is a layer of fine- to coarse-grained sand with some gravel and silt. In summer, groundwater is between 0.5 and 2.4 m (20-94 in) below grade and flows in a predominantly southwest direction. During the winter months, the groundwater reaches the surface at the southwest end of the site. This site has a rainfall of over 2150 mm (85 in) per year and an average yearly temperature of 9.6°C (49°F) with mean daily maximum and minimum temperatures of 6°C (43°F) and 1°C (34°F) in January, and 23°C (73°F) and 12°C (54°F) in July. It falls within the moderate decay hazard zone for outdoor above-ground exposure using the Scheffer Index (Scheffer 1971; Setliff 1986), with an updated value of 63 based on 30-year climate normals (Morris and Wang 2008). This zone includes most of the major population centres of North America. Soil-inhabiting wood-rotting basidiomycetes including *Leucogyrophana pinastri* (Fries) Ginns & Weresub, *Fibroporia vaillantii* (DC.) Parmasto, *Tapinella sp.*, and *Antrodia serialis* have been found on test material sporadically across the entire site. *Antrodia sordida* Ryvarden & Gilb. has been found on above ground test material.

3. Test Unit Installation

Each ground contact test piece was installed in a plot designated within the Maple Ridge test site in September 2008. Each piece was set lengthwise and buried to half its width in a trench, and separated from adjacent test units by approximately 75 cm. The soil was put back around the test units and a flag was placed to mark each location.

The two pieces of the γ-joints were put together, then the upright member was attached using stainless steel bolts to a yellow cedar exposure fence in a randomized array at FPInnovations' test site at Maple Ridge in September 2008, such that the samples were held approximately 1.5 metres above ground level, facing south. Their locations were mapped. It was found that the top of the arm needed to be secured to the upright with a plastic zap-strap ("tie-wrap") see Figure 1.

4. Inspection of Test Material

Annually in late August or early September, each ground contact test unit was removed from the soil and loose grass and dirt were brushed off. The units were then examined visually for indications of decay such as the presence of fungal mycelium or discolouration. If decay was suspected, the area of interest was gently probed with a metal scraper. Each specimen was then assigned a decay rating for each end, based on the AWPA E7 (2008) grading system (Table 3).

Table 3 AWPA decay rating system

Decay Rating	Condition	Description
10	Sound	No sign or evidence of decay, wood softening, or discoloration caused by microorganism attack.
9.5	Trace-suspect	Some areas of discolouration and/or softening associated with superficial microorganism attack.
9	Slight attack	Decay and wood softening is present. Up to 3% of the cross sectional area affected.
8	Moderate attack	Similar to "9" but more extensive attack with 3-10% of cross sectional area affected.

7	Moderate/severe attack	Sample has between 10-30% of cross sectional area decayed.
6	Severe attack	Sample has between 30-50% of cross sectional area decayed.
4	Very severe attack	Sample has between 50-75% of cross sectional area decayed.
0	Failure	Sample has functionally failed. It can either be broken by hand due to decay, or the evaluation probe can penetrate through the sample.

Above ground test units were inspected for decay on a 2-year cycle due to the slower progress of decay anticipated. Each test unit was examined visually for indications of decay such as the presence of fungal mycelium or discolouration at six locations: the horizontal top and bottom of the upright, around the bolt holes, the inner vertical surface of the joint on both the upright and angled piece, and the outer vertical end of the angled piece. If decay was suspected, the area of interest was gently probed with a metal scraper. Each surface was then assigned a decay rating, based on the AWPA E7 grading system.

3. Results and Discussion

3.1 Ground Contact Exposure

After one year decay was found on nine out of eleven controls which had received no field-cut treatment; two of these had failed (Table 4). At the six-year inspection, the controls were severely decayed, with seven of eleven samples having failed (at least one end rated 0) and all individual ends rated less than 9. This indicates that the test method being used in this experiment is an effective technique.

After six years' exposure, the only treatments in which no rating was lower than 9 were copper azole and the reference field-cut preservative, copper naphthenate containing 2% copper in mineral spirits. With ACQ-D, although most surfaces remained sound, three out of ten replicate units had surfaces with ratings of 7 or 8. Similarly, with QT+pigment and copper naphthenate containing 1% copper in mineral spirits, two units had surfaces rated 8. The preservatives in this ground-contact study with 50% or more test units with decay after six years were copper/borate (which is not recommended for ground contact by the manufacturer), micronized copper (with or without quat), and copper naphthenate containing 1% copper in water.

Table 4Decay ratings of test units in ground contact

Group	Field-cut preservative	Mean Decay Ratings						% of boards rated ≤ 9
		1-yr	2-yr	3-yr	4-yr	5-yr	6-yr	
1	Copper naphth with 2% Cu	10.0	10.0	9.8	9.8	9.8	9.8	20

1	in mineral spirits	(0.2)	(0.2)	(0.4)	(0.5)	(0.4)	(0.4)	20
2	Copper naphth with 1% Cu in water	9.8 (0.4)	9.7 (0.4)	9.3 (1.1)	9.4 (0.9)	9.0 (1.1)	8.8 (1.2)	80
3	Copper azole, 2% Cu	10.0 (0.1)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.2)	10.0 (0.0)	0
4	ACQ-D, 2% Cu	9.8 (0.6)	9.8 (0.7)	9.7 (0.8)	9.6 (0.9)	9.6 (0.9)	9.5 (1.0)	30
5	Particulate basic copper carbonate, 2% Cu	9.8 (0.3)	9.4 (1.2)	9.6 (1.1)	9.6 (0.9)	8.9 (1.9)	8.2 (3.0)	60
6	QT (5%) + green pigment (0.5%)	9.8 (0.2)	10.0 (0.2)	9.9 (0.2)	9.9 (0.2)	9.9 (0.3)	9.4 (0.7)	80
7	Copper/borate, 2% Cu	9.1 (1.3)	8.2 (2.1)	7.8 (3.1)	7.7 (3.1)	7.5 (3.0)	6.9 (2.7)	100
8	Copper naphth with 1% Cu in mineral spirits	10.0 (0.1)	9.8 (0.5)	9.9 (0.3)	9.7 (0.7)	9.6 (0.7)	9.6 (0.7)	30
9	Micronized copper quat, 2% Cu	9.9 (0.3)	9.7 (0.9)	9.3 (1.2)	9.4 (1.2)	9.0 (1.6)	8.7 (1.9)	50
10	Control (no field-cut treatment)	7.0 (3.6)	4.5 (4.4)	4.5 (4.4)	3.6 (3.8)	2.8 (3.3)	2.0 (2.8)	100

Standard deviations given in parentheses

3.2 Above-Ground Exposure

Decay on the above-ground test units, where present, was found generally inside the joint, on the vertical faces of the upright and angled members, due to the effect of water trapping and slow drying. The bolt holes and the outer vertical face of the angled member were not decayed, with the exception of some of the test units with copper plate affixed, where again drying would have been delayed.

Early decay was noted in three controls after only two years (Table 5). At the six-year inspection, five of the ten of the untreated control units had confirmed decay, with one unit having failed (one surface rated 0). This indicates that the novel test method being used in this experiment is an effective technique to accelerate above-ground decay.

Groups which received field-cut treatments generally contained early to moderate decay. The only treatments without confirmed decay (ratings of 9 or lower) were copper azole and two formulations of the reference field-cut preservative: copper naphthenate containing 2%

copper in mineral spirits, and copper naphthenate containing 1% copper in water (Table 3).

With ACQ-D, although most surfaces remained sound, one sample contained advanced decay inside the joint, rated 6. In samples with QT+pigment applied, one inner surface was rated 8.

In this above-ground study, after six years of exposure the preservatives found with 20% or more test units showing decay and at least one test unit failed were copper/borate, particulate basic copper carbonate, IPBC, and copper plate.

Table 5Decay ratings of test units exposed above ground

Year	Preservative	Decay ratings: Vertical Top End	Vertical Bottom End	Vertical Inside Joint	Bolt Holes	Angle Inner End	Angle Outer End	% of Samples rated ≤ 9
2	2% Cu naphth in mineral spirits	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	0
4	2% Cu naphth in mineral spirits	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	0
6	2% Cu naphth in mineral spirits	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	0
2	1% Cu naphthenate in water	10.0 (0.0)	10.0 (0.0)	10.0 (0.2)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	0
4	1% Cu naphthenate in water	10.0 (0.0)	10.0 (0.0)	10.0 (0.2)	10.0 (0.0)	10.0 (0.2)	10.0 (0.0)	0
6	1% Cu naphthenate in water	10.0 (0.0)	10.0 (0.0)	10.0 (0.2)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	0
2	Copper azole 2% Cu	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	0
4	Copper azole 2% Cu	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	0
6	Copper azole 2% Cu	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	10.0 (0.0)	0
2	ACQ-D 2% Cu	10.0	10.0	10.0	10.0	10.0	10.0	0

2	ACQ-D 2% Cu							
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	
4	ACQ-D 2% Cu	10.0	10.0	9.8	10.0	9.9	10.0	20
		(0.0)	(0.0)	(0.4)	(0.0)	(0.3)	(0.0)	
6	ACQ-D 2% Cu	10.0	10.0	9.4	10.0	9.4	10.0	10
		(0.0)	(0.0)	(1.4)	(0.0)	(1.4)	(0.0)	
2	Particulate basic copper carbonate 2% Cu	10.0	10.0	10.0	10.0	10.0	10.0	0
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	
4	Particulate basic copper carbonate 2% Cu	10.0	10.0	9.3	10.0	9.7	10.0	20
		(0.0)	(0.0)	(1.5)	(0.0)	(0.9)	(0.0)	
6	Particulate basic copper carbonate 2% Cu	10.0	10.0	8.4	10.0	9.5	10.0	20
		(0.0)	(0.0)	(3.5)	(0.0)	(1.4)	(0.0)	
2	QT 5% + 0.5% pigment	10.0	10.0	10.0	10.0	10.0	10.0	0
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	
4	QT 5% + 0.5% pigment	10.0	10.0	10.0	10.0	10.0	10.0	0
		(0.2)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	
6	QT 5% + 0.5% pigment	10.0	10.0	9.8	10.0	10.0	10.0	10
		(0.0)	(0.0)	(0.7)	(0.0)	(0.0)	(0.0)	
2	Cu/B 2% Cu	10.0	10.0	9.9	10.0	9.9	10.0	10
		(0.0)	(0.0)	(0.3)	(0.0)	(0.3)	(0.0)	
4	Cu/B 2% Cu	10.0	9.8	9.4	10.0	9.3	10.0	30
		(0.0)	(0.6)	(1.9)	(0.0)	(1.9)	(0.0)	
6	Cu/B 2% Cu	10.0	10.0	8.6	10.0	8.7	10.0	30
		(0.0)	(0.0)	(3.3)	(0.0)	(3.3)	(0.0)	
2	0.5% IPBC in water	10.0	10.0	10.0	10.0	9.9	10.0	0
		(0.0)	(0.0)	(0.2)	(0.0)	(0.2)	(0.0)	
4	0.5% IPBC in water	10.0	9.8	9.8	10.0	9.8	10.0	10
		(0.0)	(0.3)	(0.6)	(0.0)	(0.6)	(0.0)	
6	0.5% IPBC in water	10.0	9.9	9.0	10.0	8.9	10.0	30
		(0.0)	(0.2)	(2.0)	(0.0)	(3.3)	(0.0)	
2	0.75% PTQ	10.0	10.0	10.0	10.0	10.0	10.0	0
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	
4	0.75% PTQ	10.0	10.0	9.9	10.0	10.0	10.0	0

4	0.75% PTQ							
		(0.2)	(0.0)	(0.2)	(0.0)	(0.0)	(0.0)	
6	0.75% PTQ	9.9	10.0	9.9	10.0	10.0	10.0	10
		(0.2)	(0.0)	(0.3)	(0.0)	(0.0)	(0.0)	
2	Copper plate	10.0	10.0	10.0	10.0	10.0	10.0	0
		(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	
4	Copper plate	10.0	10.0	9.6	10.0	10.0	10.0	10
		(0.2)	(0.0)	(1.3)	(0.0)	(0.0)	(0.0)	
6	Copper plate	9.9	9.7	8.3	10.0	8.7	9.5	50
		(0.3)	(0.7)	(3.1)	(0.0)	(3.2)	(0.9)	
2	Untreated control	10.0	10.0	9.7	10.0	9.7	9.9	30
		(0.0)	(0.0)	(0.5)	(0.0)	(0.6)	(0.3)	
4	Untreated control	10.0	9.8	8.9	10.0	8.9	10.0	30
		(0.0)	(0.6)	(2.1)	(0.0)	(2.0)	(0.0)	
6	Untreated control	9.9	9.8	8.2	10.0	8.2	10.0	50
		(0.2)	(0.6)	(2.4)	(0.0)	(3.4)	(0.0)	
2	Borate 10% in glycol plus DDAC	10.0	10.0	10.0	10.0	10.0	10.0	0
		(0.0)	(0.0)	(0.2)	(0.0)	(0.0)	(0.0)	
4	Borate 10% in glycol plus DDAC	10.0	10.0	9.8	10.0	10.0	10.0	20
		(0.0)	(0.0)	(0.4)	(0.0)	(0.0)	(0.0)	

Standard deviations given in parentheses

4. Conclusions

After six years of exposure in a ground-contact test of field-cut preservatives at FPInnovations' test site in Maple Ridge, BC, controls without preservative applied to the cut ends had failed due to decay. The decay protection of the field-cut preservatives in this study ranged from poor to excellent, with copper azole containing 2% copper performing the best, better than the reference copper naphthenate.

After six years of exposure in an above-ground test of field cut preservatives at FPInnovations' test site in Maple Ridge, BC, 50% of untreated controls had confirmed decay. The decay protection of the field-cut preservatives in this study ranged from poor to excellent, with the best performers being copper azole containing 2% copper and two formulations of the reference field-cut preservative: copper naphthenate containing 2% copper in mineral spirits, and copper naphthenate containing 1% copper in water.

Acknowledgements

The FPInnovations field test site at Maple Ridge, BC is maintained within and with the assistance of the Malcolm Knapp Research Forest of the University of British Columbia, Faculty of Forestry. The operation and maintenance of FPInnovations' field test sites is supported by the Canadian Forest Service of Natural Resources Canada under a contribution agreement. FPInnovations would like to thank its industry members, Natural Resources Canada (Canadian Forest Service), and the Provinces of British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, Nova Scotia, New Brunswick, and Newfoundland and Labrador for their guidance and financial support for this research.

5. Literature

Amburgey, T.L., H.M. Barnes and M.G. Sanders. 2000. Development of treatments and methods for field treating bridge members. BAA#: DTFH61-97-B-00029. Part 3. Remedial treatments for bridge applications. Forest and Wildlife Research Center. Mississippi Forest Products Laboratory. Mississippi State University. Prepared for Federal Highway Administration Washington DC.

American Wood Protection Association. 2008. AWPA Standard E7-08. Standard method of evaluating wood preservatives by field test with stakes. AWPA. Birmingham, AL. 9 p.

American Wood Protection Association. 2014. AWPA Standard M4-11. Standard for the care of preservative-treated wood products. AWPA. Birmingham, AL. 2 p.

Canadian Standards Association 2012. CSA O80 Series-08 Wood Preservation. CSA, Mississauga Ontario. 117 p.

Ingram, J. and P.I. Morris. 2014. Performance of field-cut preservatives after six years in an above-ground test. Report to Canadian Forest Service. FPInnovations. Vancouver, BC. 25 p.

Ingram, J. and P.I. Morris. 2014. Performance of field-cut preservatives after six years in ground-contact. Report to Canadian Forest Service. FPInnovations. Vancouver, BC. 16 p.

Morris, P.I. and J. Ingram. 1998. A ten-year evaluation of field-cut preservatives. Report to Canadian Forest Service. Forintek Canada Corp. Vancouver, BC. 5 p.

Morris, P.I. and J. Ingram. 2010. Initiation of a ground-contact field test of field-cut preservatives. Report to Canadian Forest Service. FPInnovations - Forintek Division. Vancouver, BC. 10 p.

Morris, P.I. and J. Ingram. 2010. Initiation of an above-ground test of field-cut preservatives. Report to Canadian Forest Service. FPInnovations - Forintek Division. Vancouver, BC. 4 p.

Morris, P. I., and J. K. Ingram 2013. Twenty-year performance of decking with two levels of preservative penetration. Forest Products Journal 62 (7/8): 566-570

Morris, P.I. and J. Wang. 2008. A new decay hazard map for North America using the Scheffer index. The international research group on wood preservation, Document No. IRG/WP 08-10672, IRG Secretariat, Stockholm, Sweden. 13 p.

Scheffer, T.C. 1971. A climate index for estimating potential decay in wood structure above ground. For. Prod. J. 21(10): 29-31.

Setliff, E.C. 1986. Wood decay hazard in Canada based on Scheffer's climate index formula. For. Chron. 62(5): 456-459.

Stirling, R, J.N.R. Ruddick, W. Xue, P. I Morris and P. Kennepohl. Submitted. Characterizatoin of copper in leachates from ACQ- and MCQ-treated wood and its effects on basidiospore germination. Wood and Fiber Sci.

EFFECT OF PIGMENTED PHOTO-PROTECTIVE PRE-COATS ON THE SERVICE LIFE OF TRANSPARENT AND SEMI-TRANSPARENT COATINGS

Rod Stirling and Paul I. Morris
FPInnovations
2665 East Mall, Vancouver, BC V6T 1Z4

Summary

The need for frequent maintenance of clear wood coatings reduces the competitiveness of wood products in exterior appearance applications. Application of protective pre-coats containing organic UV absorbers and hindered amine light stabilizers has been shown to improve coating performance. It was hypothesized that addition of transparent iron oxide pigments to these protective pre-coats would further enhance the performance of transparent and semi-transparent coatings. Field tests were set up in Maple Ridge, BC and Saucier, MS to evaluate the effect of unpigmented and pigmented protective pre-coats on the performance of transparent and semi-transparent coatings. After two years of exposure coatings were in fair to good condition. While improved performance was associated with the use of protective pre-coats, there was no evidence that the added pigment improved performance at the two-year inspection.

1. Introduction

The need for frequent maintenance of clear and semi-transparent wood coatings reduces the competitiveness of wood products in exterior appearance applications. To provide long-term performance they must protect wood against light, water, and disfiguring fungal growth which interact to cause the process we term weathering (Figure 1). Even if they are resistant to UV, these coatings are to some degree transparent, and visible light wavelengths can penetrate to the wood surface and degrade lignin present in the outer layer of the wood. This results in substrate degradation, loss of coating adhesion (Evans *et al*. 1996), and the formation of low molecular weight lignin photo-degradation products that serve as a carbon source for black stain fungi (Sharpe and Dickinson 1993).

Recent attempts to improve the photo-stability of wood, and thereby improve the performance of clear coatings, have focused on adding carbon-based UV absorbers (UVA) and hindered amine light stabilizers (HALS) to wood coatings and as protective pre-coats (Hayoz *et al*. 2003; Morris and McFarling 2006; Schaller and Rogez 2007; Vollmer and Evans 2013; Stirling and Morris 2013a). UVA and HALS have been shown to significantly improve coating longevity, but not to the degree demanded by the market. Performance of carbon-based UVAs tends to decrease over time as they are vulnerable to photo-degradation (Pickett and Moore 1993). Pigments (inorganic UV absorbers) offer longer lasting protection (Blanchard and Blanchet 2011), and extend protection into the visible region, which is critical to protect wood against the more damaging wavelengths of visible light (Kataoka *et al*. 2007). Red iron oxide pigments have been associated with improved colour stability of wood (Schauwecker *et al*. 2009) and reduced lignin photo-degradation (Schauwecker *et a*l. 2013). Larger iron oxide particles have been associated with greater opacity and greater photo-protection (Schauwecker *et al*. 2014). However, these pigments also lead to changes in wood colour (Aloui *et al*. 2007). This must be carefully controlled to obtain the desired appearance of the wood, and not completely obscure the grain. Combining UVA, HALS, and pigments in coatings is recommended to maximize surface protection (Joint Coatings/Forest Products Committee 2000). The present work evaluates the effect of adding transparent iron oxides to protective pre-coats containing UVA and HALS.

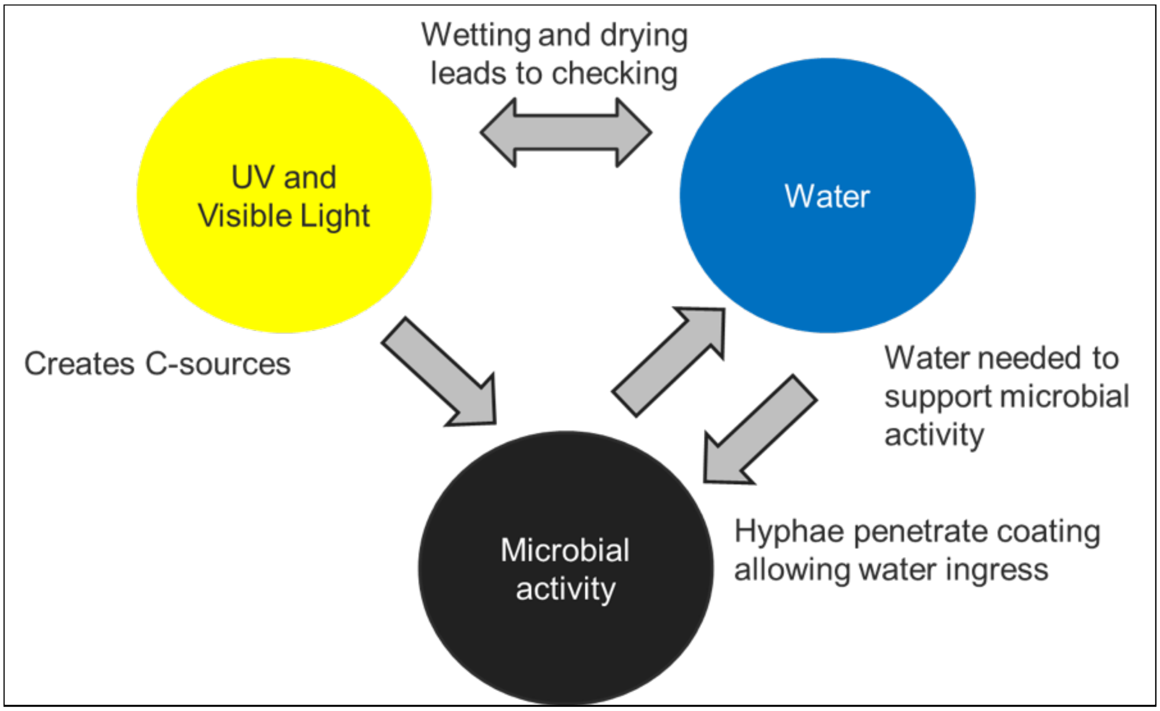


Figure 1: Relationship between environmental factors that result in the degradation of wood surfaces.

Materials and Methods

White spruce (*Picea glauca* (Moench) Voss) was selected as a substrate because it has few available nutrients and few heartwood extractives that may support the growth of black-stain fungi. The spruce wood was cut into 144 test samples (142 x 19 x 200 mm). Edges were eased and end grain sealed with two coats of epoxy resin (Intergard 740, International Marine Coatings). Seventy-two samples were pressure-treated with CBP2, a proprietary carbon-based preservative previously associated with improved coating performance (Stirling and Morris 2013b); the remainder were not preservative-treated.

The wood surface of all samples was lightly sanded with 280 grit sandpaper. Each protective pre-coat was applied by brush to 24 untreated samples and 24 preservative-treated samples. The unpigmented protective pre-coat consisted of 5.0% Tinuvin 1130 (BASF, formerly Ciba) and 2.5% Lignostab 1198 (BASF, formerly Ciba) in a mixture of 36% 2-butoxyethanol in water. The pigmented protective pre-coat included an additional 1% mixture of red and yellow transparent iron oxide pigments (Elementis Specialties). Twelve samples from each treatment group were coated with a water-based two-step semi-transparent film former (three coats of step 1 and one coat of step 2). The remaining 12 samples from each treatment group were coated by brush with three coats of a water-based transparent urethane film former. The backs of each sample were coated with one coat of alkyd primer. Six samples from each treatment group were installed on south facing exposure racks at 45° to the horizontal at FPInnovations' field test site at the University of British Columbia's Malcolm Knapp Research Forest in Maple Ridge, BC on November 1, 2011. The remaining samples were installed at the USDA Forest Products Laboratory field test site at the Harrison Experimental Forest near Saucier, Mississippi on April 11, 2012. This method was developed as an improvement on the previous approach of coating short segments of longer pieces with different systems, in order to eliminate growth of black stain fungi that had penetrated one system into the wood under adjacent systems. The attachment was via screws from the back surface to avoid penetrating the test coatings.

Samples were inspected after one and two years of exposure as described by Stirling and Morris (2013a). Subjective ratings, on a 10 (perfect) to 1 (maximum possible degradation) scale, were given for substrate degradation (ASTM D660), discolouration (ASTM D3274), coating degradation (the lowest value for flaking, cracking, or erosion (ASTM D772, ASTM D662, ASTM D661)), and an overall general rating. In addition, the colour coordinates (L*a*b*) of the exposed surface of each sample were measured using a Konica Minolta CM 700d spectrophotometer.

2. Results and Discussion

During the one-year inspection it was observed that a great deal of coating degradation and black stain fungal growth was clustered above where the screws penetrated the backs of the samples. The screws penetrated the sample to just below the exposed surface. This may have put some mechanical stress on the surface of the wood and the wood coating, leading to this early failure. As a consequence, areas directly above the screw holes were not considered when determining the subjective ratings. After two years of exposure the damage associated with the presence of the underlying screws was still apparent (Figures 2 and 3). However, coating degradation and black stain colonization did not appear to progress far from the screw holes, so evaluations limited to the centre of each sample were likely still an accurate reflection of coating performance.

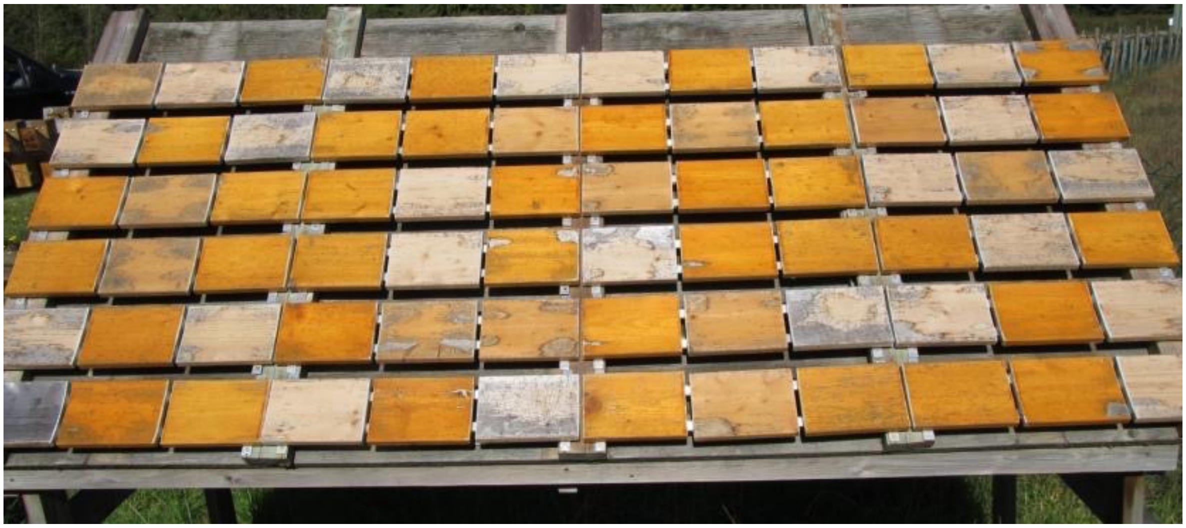


Figure 2: Samples after two years of exposure in Maple Ridge, BC

Figure 3: Samples after two years of exposure in Saucier, MS

Very little substrate degradation was observed at either test site after two years of exposure (Figures 4 and 5). The presence of either pre-coat was not associated with improved substrate ratings. This is consistent with Schauwecker *et al*. (2014) who reported that application of iron oxides did not reduce surface checking.

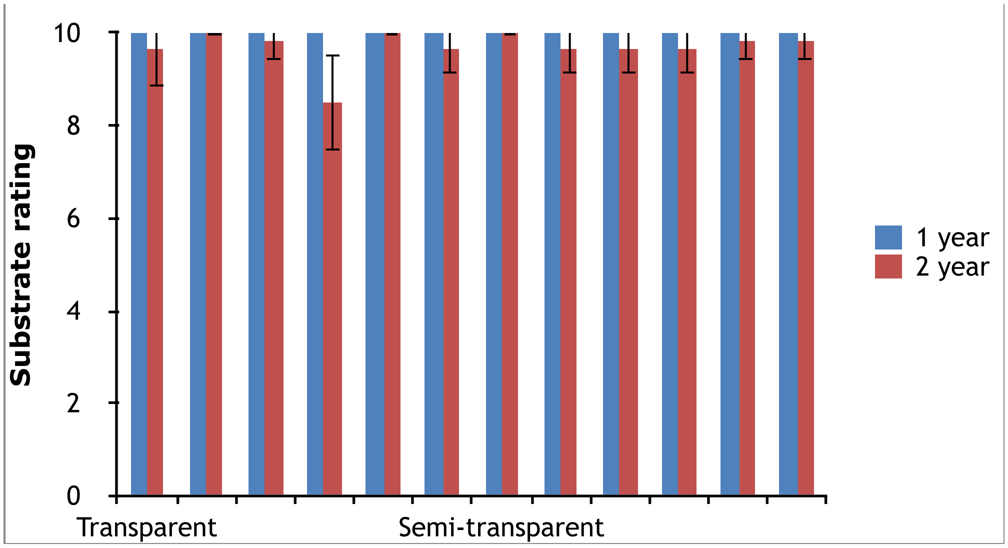


Figure 4: Average substrate degradation after one and two years of exposure in Maple Ridge, BC

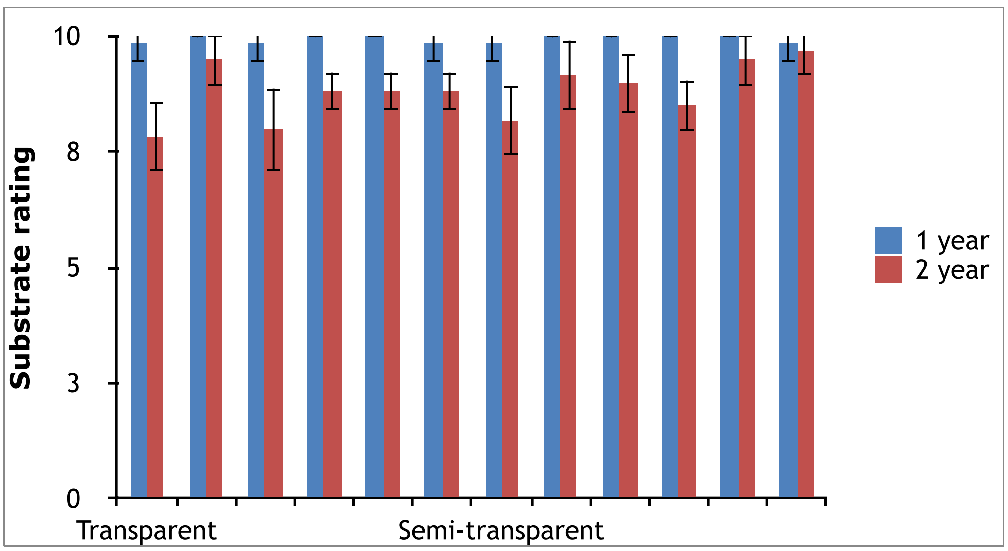


Figure 5: Average substrate degradation after one and two years of exposure in Saucier, MS

After two years of exposure many samples were severely discoloured due to colonization by black stain fungi (Figures 6 and 7). There was little differentiation between treatments at Maple Ridge. However, there was less discolouration associated with the semi-transparent finish, and with both protective pre-coats in samples exposed in Mississippi. There were few differences between pigmented and unpigmented pre-coats at either site.

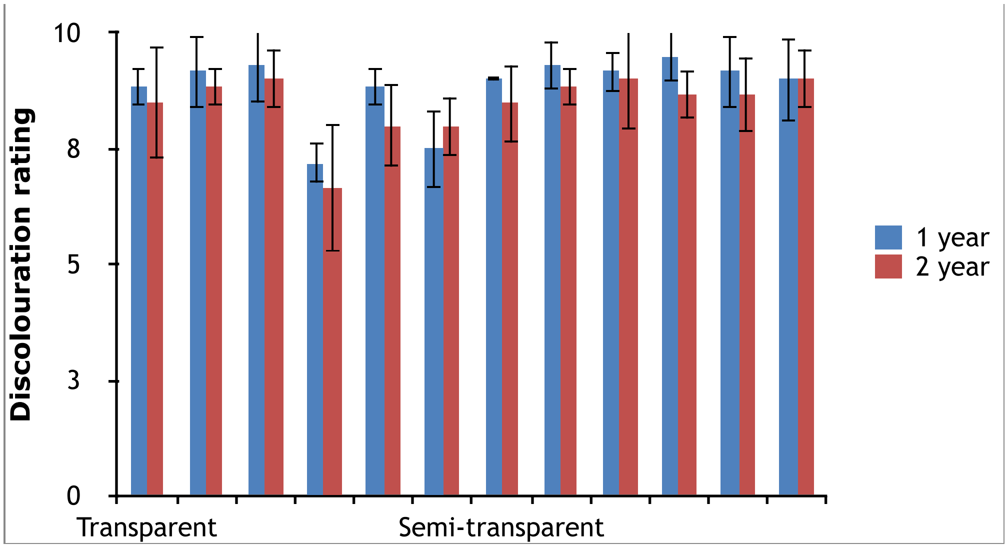


Figure 6: Average discolouration after one and two years of exposure in Maple Ridge, BC

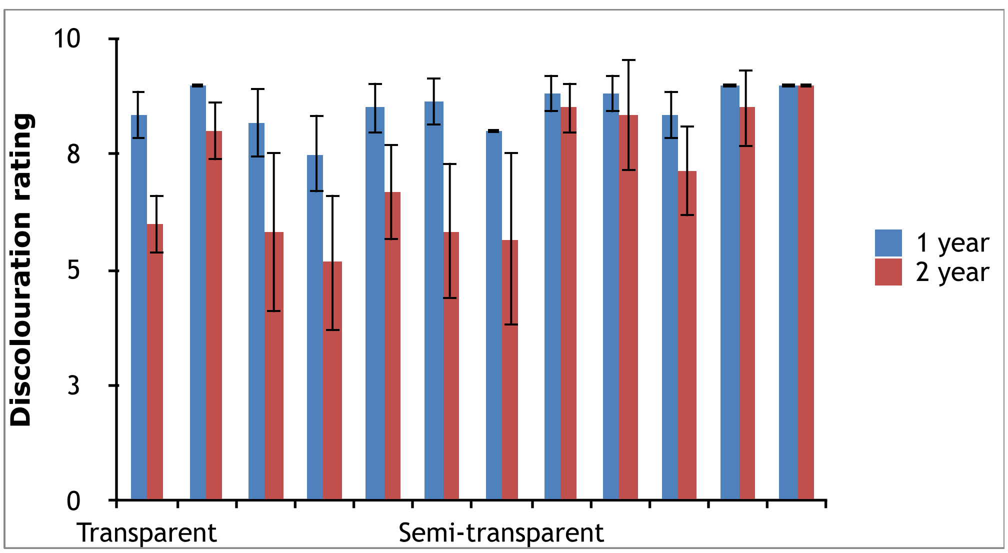


Figure 7: Average discolouration after one and two years of exposure in Saucier, MS

A moderate degree of coating degradation was observed at both sites after two years of exposure (Figures 8 and 9). Both protective pre-coats were associated with similar or improved coatings performance. There were no apparent differences between pigmented and unpigmented protective pre-coats.

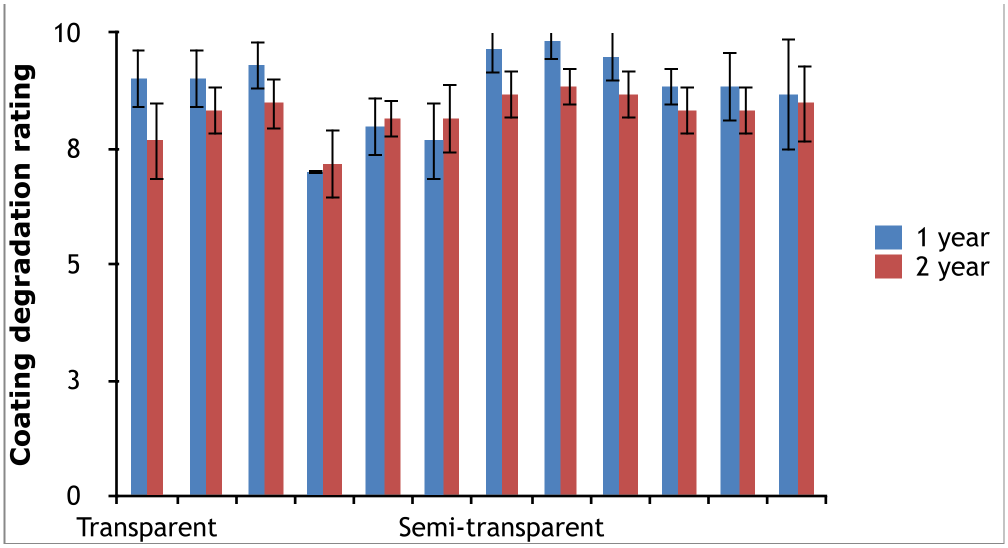


Figure 8: Average coating degradation after one and two years of exposure in Maple Ridge, BC

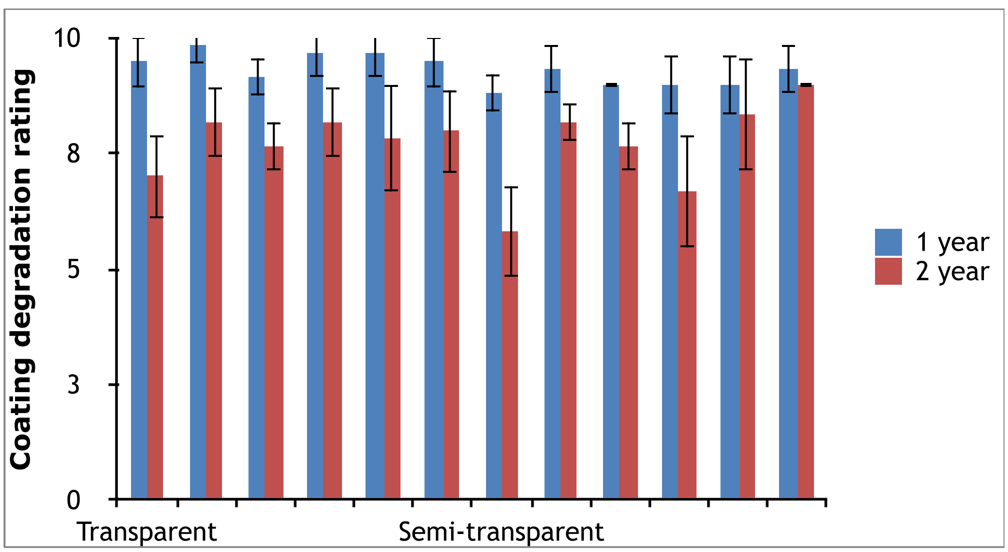


Figure 9: Average coating degradation after one and two years of exposure in Saucier, BC

General ratings indicated fair to good performance for all test coatings groups (Figures 10 and 11). There were slight improvements associated with the use of protective pre-coats, but no statistically significant improvement associated with protective pre-coat pigmentation at the two-year inspection.

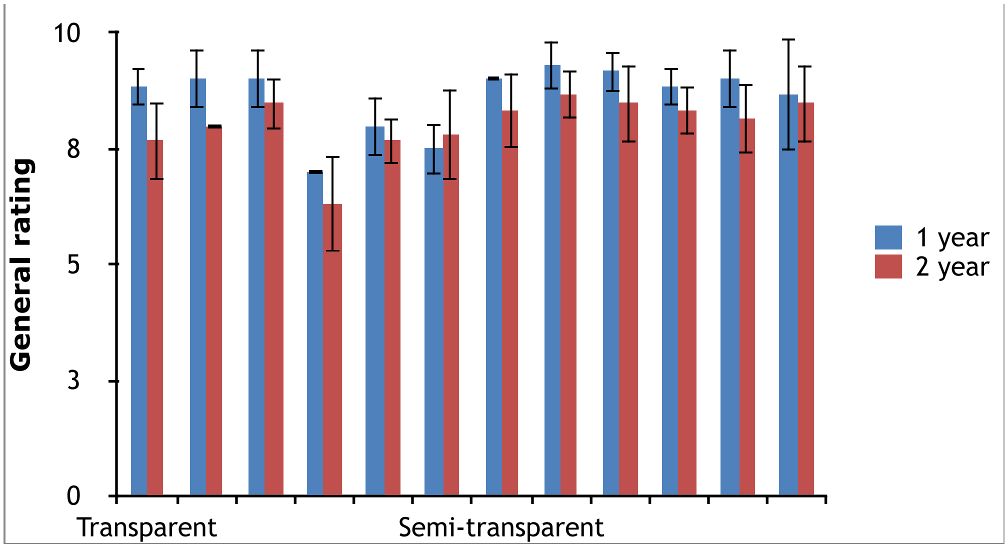


Figure 10: Average general ratings after one and two years of exposure in Maple Ridge, BC

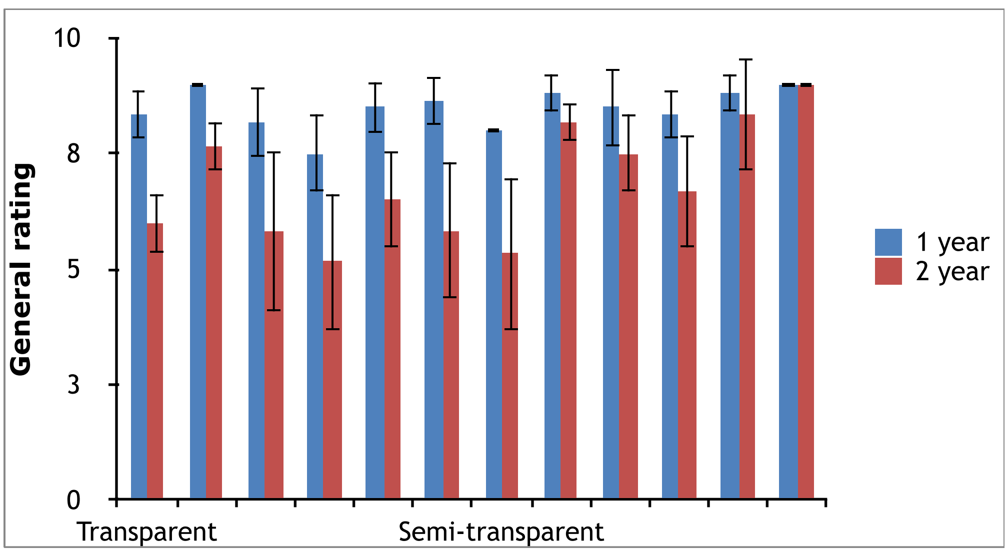


Figure 11: Average general ratings after one and two years of exposure in Saucier, MS

Colorimetric data are summarized in Figures 12-14. An analysis of variance was used to determine the factors associated with variation in each colour coordinate (Tables 1-3). For lightness (L*), time, coating type and the use of protective pre-coats were significant factors. Treatment and site were not associated with change in lightness. For a* (green-red), time, coating type, the use of protective pre-coats and preservative treatment were significant factors, while site was not. For b* (blue-yellow), time, coating type, the use of protective pre-coats, and site were significant factors, while preservative treatment was not. Overall, the use of protective pre-coats was associated with enhanced colour stability, particularly for the samples coated with the semi-transparent finish. However, pigmented pre-coats were no more colour stable than unpigmented pre-coats.

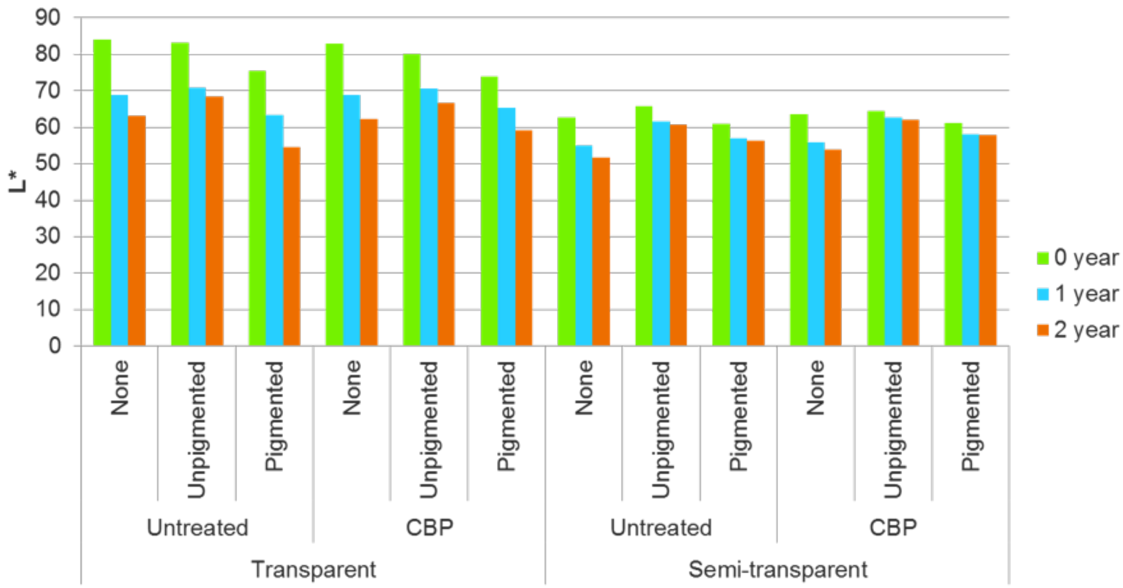


Figure 12: Average lightness (L*) values of coated samples after zero, one, and two years of exposure

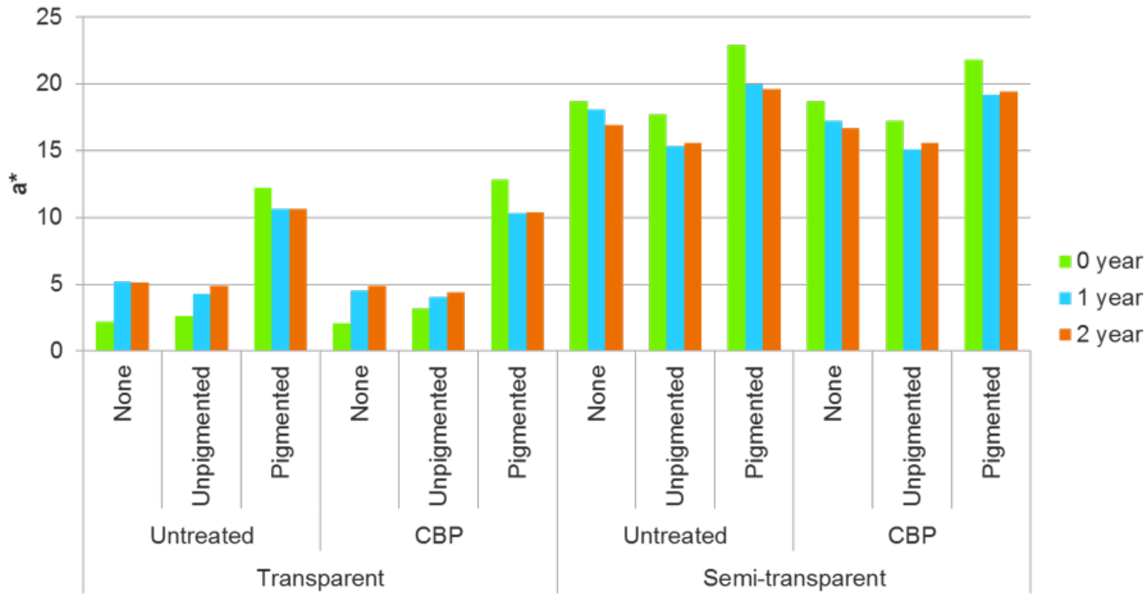


Figure 13: Average green-magenta (a*) values of coated samples after zero, one, and two years of exposure

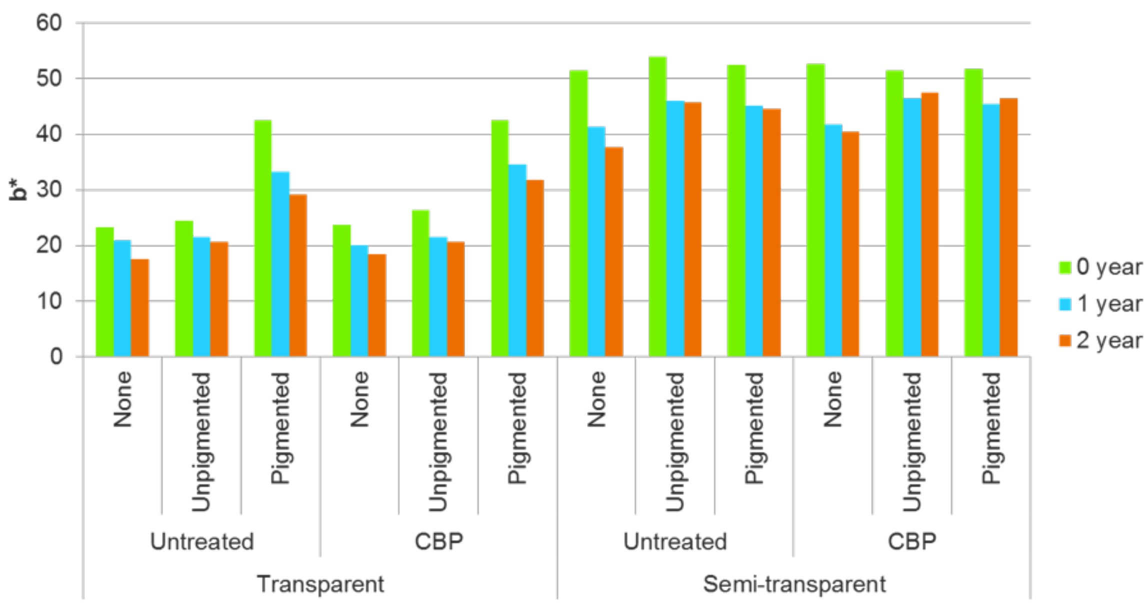


Figure 14: Average blue-yellow (b*) values of coated samples after zero, one, and two years of exposure

Table 1:Analysis of Variance for L*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	24150.478	24	1006.270	83.121	.000
Intercept	869057.720	1	869057.720	71786.865	.000
TIME	10193.064	1	10193.064	841.979	.000
COATING	10532.209	1	10532.209	869.993	.000
TREATMENT	.036	1	.036	.003	.956
PRECOAT	2217.264	2	1108.632	91.576	.000
SITE	23.316	1	23.316	1.926	.166
COATING * TREATMENT	31.607	1	31.607	2.611	.107
COATING * PRECOAT	856.956	2	428.478	35.394	.000
TREATMENT * PRECOAT	26.621	2	13.310	1.099	.334
COATING * TREATMENT * PRECOAT	44.025	2	22.013	1.818	.164
COATING * SITE	50.112	1	50.112	4.139	.043
TREATMENT * SITE	10.173	1	10.173	.840	.360
COATING * TREATMENT * SITE	.004	1	.004	.000	.986
PRECOAT * SITE	144.988	2	72.494	5.988	.003
COATING * PRECOAT * SITE	18.413	2	9.206	.760	.468
TREATMENT * PRECOAT * SITE	12.326	2	6.163	.509	.601
COATING * TREATMENT * PRECOAT * SITE	2.205	2	1.103	.091	.913
Error	4915.070	406	12.106		
Total	1849354.212	431			
Corrected Total	29065.547	430			

R Squared = .831 (Adjusted R Squared = .821)

Table 2:Analysis of Variance for a*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	17623.895	24	734.329	378.767	.000
Intercept	27058.830	1	27058.830	13956.966	.000
TIME	38.435	1	38.435	19.825	.000
COATING	14113.784	1	14113.784	7279.901	.000
TREATMENT	20.843	1	20.843	10.751	.001
PRECOAT	3009.618	2	1504.809	776.182	.000
SITE	1.394	1	1.394	.719	.397
COATING * TREATMENT	1.292	1	1.292	.666	.415
COATING * PRECOAT	436.714	2	218.357	112.629	.000
TREATMENT * PRECOAT	1.093	2	.546	.282	.755
COATING * TREATMENT * PRECOAT	2.312	2	1.156	.596	.551
COATING * SITE	8.949	1	8.949	4.616	.032
TREATMENT * SITE	3.081	1	3.081	1.589	.208
COATING * TREATMENT * SITE	.205	1	.205	.106	.745
PRECOAT * SITE	23.588	2	11.794	6.083	.002
COATING * PRECOAT * SITE	6.384	2	3.192	1.647	.194
TREATMENT * PRECOAT * SITE	.059	2	.030	.015	.985
COATING * TREATMENT * PRECOAT * SITE	.047	2	.024	.012	.988
Error	787.126	406	1.939		
Total	82303.899	431			
Corrected Total	18411.021	430			

R Squared = .957 (Adjusted R Squared = .955)

Table 3:Analysis of Variance for b*

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	61328.597	24	2555.358	483.240	.000
Intercept	289509.230	1	289509.230	54748.706	.000
TIME	5081.076	1	5081.076	960.876	.000
COATING	45336.846	1	45336.846	8573.591	.000
TREATMENT	.232	1	.232	.044	.834
PRECOAT	6377.888	2	3188.944	603.057	.000
SITE	21.107	1	21.107	3.992	.046
COATING * TREATMENT	.923	1	.923	.175	.676
COATING * PRECOAT	4489.882	2	2244.941	424.538	.000
TREATMENT * PRECOAT	4.056	2	2.028	.384	.682
COATING * TREATMENT * PRECOAT	34.438	2	17.219	3.256	.040
COATING * SITE	.003	1	.003	.001	.980
TREATMENT * SITE	44.188	1	44.188	8.356	.004
COATING * TREATMENT * SITE	1.290	1	1.290	.244	.622
PRECOAT * SITE	6.289	2	3.145	.595	.552
COATING * PRECOAT * SITE	86.216	2	43.108	8.152	.000
TREATMENT * PRECOAT * SITE	12.826	2	6.413	1.213	.298
COATING * TREATMENT * PRECOAT * SITE	.609	2	.304	.058	.944
Error	2146.914	406	5.288		
Total	646890.964	431			
Corrected Total	63475.511	430			

R Squared = .966 (Adjusted R Squared = .964)

3. Conclusions

Addition of transparent iron oxides did not improve the performance of protective pre-coats under transparent or semi-transparent coatings after two years of exposure at two test sites.

Acknowledgements

This project was financially supported by the Canadian Forest Service under the Contribution Agreement existing between the Government of Canada and FPInnovations.

The FPInnovations field test site at Maple Ridge, BC is maintained within and with the assistance of the Malcolm Knapp Research Forest of the University of British Columbia, Faculty of Forestry.

The operation and maintenance of FPInnovations' field test sites is supported by the Canadian Forest Service of Natural Resources Canada under a contribution agreement.

The authors would also like to thank Greg Schueneman of the USDA Forest Products Laboratory for access to the Saucier, Mississippi test site.

4. Literature

Aloui, F., Ahajji, A., Irmouli, Y., George, B., Charrier, B., Merlin, A., 2007. Inorganic UV absorbers for the photostabilisation of wood-clearcoating systems: Comparison with organic UV absorbers. Applied Surface Science. 253: 3737-3745.

Blanchard, V., Blanchet, P., 2011. Color stability for wood products during use: Effects of inorganic nanoparticles. BioResources. 6(2):1219–1229.

Evans, P.D., Thay, P.D., Schmalzl K.J., 1996. Degradation of wood surfaces during natural weathering. Effects on lignin and cellulose and adhesion of acrylic latex primers. Wood Science and Technology. 30: 411-422.

Hayoz, P., Peter, W., Rogez, D., 2003. A new innovative stabilization method for the protection of natural wood. Progress in Organic Coatings. 48: 297-309.

Joint Coatings/Forest Products Committee, 2000. Best of both worlds – clear exterior finishes. American Painting Contractor. 77: 47-49.

Kataoka, Y., Kiguchi, M., Williams, R.S., Evans, P.D., 2007. Violet light causes photodegradation of wood beyond the zone affected by UV radiation. Holzforschung. 61: 23-27.

Morris, P.I., McFarling, S.M., 2006. Enhancing the performance of transparent coatings by UV protective pre-treatments. International Research Group on Wood Protection, Stockholm, Sweden. Document No. IRG/WP/06-30399. 10p.

Pickett, J.E., Moore, J.E., 1993. Photodegradation of UV screeners. Polymer Degradation and Stability. 42: 231-244.

Schaller, C., Rogez, D., 2007. New approaches in wood coating stabilization. Journal of Coatings Technology Research. 4(4): 401-409.

Schauwecker, C.F., McDonald, A.G., Morrell, J.J., 2013. Performance of wood treated with prospective organic surface protectants upon outdoor exposure: FTIR spectroscopic analysis of weathered surfaces. Holzforschung. 67(2): 227-235.

Schauwecker, C.F., McDonald, A.G., Preston, A.F., Morrell, J.J., 2014. Use of iron oxides to influence the weathering characteristics of wood surfaces: a systematic survey of particle size, crystal shape and concentration. European Journal of Wood and Wood Products. 72(5): 669-680.

Schauwecker, C., Preston, A., Morrell, J.J., 2009. A new look at the weathering performance of solid-wood decking materials. JCT Coatings Tech. 6(9): 32-38.

Sharpe, P.R., Dickinson, D.J., 1993. Blue stain in service on wood surface coatings part 3. The nutritional capability of Aureobasidium pullulans compared to other fungi commonly isolated from wood surface coatings. International Research Group on Wood Preservation, Stockholm, Sweden. Document No. IRG/WP/93-10035. 10p.

Stirling, R., Morris, P.I., 2013a. Improved Coating Performance on Wood Treated with Carbon-Based Preservatives and an Ultraviolet/Visible Light Protective Precoat. Forest Products Journal. 63(3/4): 95-100.

Stirling, R., Morris, P.I., 2013b. Performance of coatings on wood treated with carbon-based preservatives. International Research Group on Wood Protection. Document No. IRG/WP/13-40638. 11p.

Vollmer, S., Evans, P.D., 2013. Performance of clear coatings on modified wood exposed to the weather for 2 years in Australia. International Wood Products Journal. 4(3): 177-182.

OUTDOOR LIVING

Mary-Anne Dalkowski
Timber Specialties Co., 35 Crawford Crescent, Campbellvile, ON. L0P1B0

No recent industry market study has been conducted on volumes of treated wood produced for the residential market in Canada. However, from polling a wide range of producers and retailers across the country, we at Timber Specialties estimate the production of consumer pressure treated wood in Canada to be around 800 million board feet for 2014. That's up only slightly from the 790 million board feet we had estimated for 2011. These of course are not hard numbers, but they do give you some idea about just how important the residential market is to the wood preservation industry in Canada.

Wood treated for the consumer market does not have to meet the rigid, defined spec of a pole, a pile or a bridge. These products aren't even strictly utilitarian, but they do present challenges. Producers have had to create appearance grades for decking and fencing. In the past couple of years we've seen a rapid take-up of coloured treated wood in parts of the country where it has never been accepted in the past. The market is changing. However, it's at the mercy of what retailers think consumers want and what media are telling them need. It's a tough market in its own way – keeping up with these ever-changing wants and needs.

One focus that's been with us for a while and shows no sign of fading is outdoor living: the outdoor space as an extension of the home, taking the indoors outdoors, bringing the outdoor indoors, and Staycations. How is this translating into actual projects? How are we doing this? Let's look at some of the trends.

Tracking Outdoor Living Trends

To track trends in outdoor living, I focused on three lines of information, none of which unfortunately is Canadian. But trends cross borders, driven by traditional and online media, so we are or will be feeling their influence here as well. The first group I looked at was the design professionals: the architects and the landscape architects. Both the American Institute of Architects (AIA) and the American Society of Landscape Architects (ASLA) use their membership to rate the popularity of residential projects, including many that fall under outdoor living. The second approach was a private US trend study by Metaphor IIc focused on outdoor products. And finally, I went where everyone else goes, to find out just what was going on – the worldwide web. I chose two platforms, Houzz.com and Freshome.com.

AIA 2014 Home Design Trends Survey

The AIA Home Design Trend Survey is conducted quarterly with a panel of over 500 architecture firms that concentrate their practice in the residential sector. These are the design leaders that shape how homes function and look, and this survey helps to identify emerging trends in the housing marketplace.

The trend they are seeing is what's being called "right sizing". Home sizes are increasing only modestly, if at all, and households are investing more attention in exterior and property improvements, including decks, outdoor kitchens and fully furnished outdoor living rooms. 69% of residential architects reported outdoor living to be increasing in popularity (up from 63% in 2013 and only 49% in 2012).

ASLA 2014 Trends Survey

Landscape architects who specialize in residential design were asked to rate the expected popularity of a variety of residential outdoor design elements in 2014. Gardens and landscaped spaces received a 94% rating as somewhat or very popular. Following closely, outdoor living spaces, defined as kitchen and entertainment spaces, were second most popular at 92%. Outdoor recreation came in third at 76%. I'll cite more of these popularity numbers as we get into specifics of projects; but, overall, consumer demand appears to remain strong for attractively designed landscapes for entertaining and relaxing.

Metaphor IIc

Metaphor IIc is a US product development company that specializes in outdoor building and decorating products. They recently published a professional report "Color, Design and Market Trends in Residential Outdoor Products" that examines design, style and colour as it relates to house styles, regional styles and current trends in exterior building products and outdoor décor.

The Metaphor IIc group expects outdoor living to not only sustain popularity over the next five years but also increase. They predict that "outdoor living spaces will not be viewed as a trend or movement but as a staple of the American home". They see outdoor living spaces as providing lots of opportunity for outdoor building products and décor. I've peppered some of their predictions throughout the paper.

Houzz

Houzz.com is a web site and online community about architecture, interior design and decorating, landscape design and home improvement. It started simply as a side project of a California couple renovating their home who were tired of pulling pages out of design magazines. When they launched in February 2009, CNN named Houzz the App of the Week, calling it "The Wikipedia of interior and exterior design sites".

The website and mobile apps feature photos, articles written by architects, interior designers and home design experts, product recommendations and a user forum. Over 2 million home improvement professionals use the site to connect with homeowners. Over 4,500 users responded to the 2014 Spring Houzz Landscaping Survey. And I was able to illustrate all the trends discussed below with images from Houzz.

Freshome

Freshome is an online magazine focusing on interior design and architecture, with over 3.8 million unique visitors every month. It is rated in the top blogs and regularly picked up by Yahoo News, CNET and The Huffington Post. Freshome features an archive of 7,000 posts and 9,000 images of interior products and architectural projects.

Major Trends

The trends all these sources are reporting fall into five categories: outdoor entertaining (by far the largest), recreation, sustainability, extended use, and low maintenance.

Entertaining Outdoors

What began with all-weather cushions and an umbrella over the table has evolved into "exterior decorating". Sofas and dining suites, table and floor lamps, rugs – all are available in a wide array of colours and styles, good enough to duplicate inside. We're used to bringing in the outdoors with stone, brick, wood and concrete. Now the indoors is moving out. Consumers are creating outdoor entertainment spaces that have come to resemble outdoor rooms.

The deck overall continues to be a popular feature in new construction at 82%, creating the foot print for today's outdoor room. 98% of ASLA respondents reported building terraces, patios and decks for seating and dining, large enough to define specific entertaining areas and accommodate comfortable furniture.

Today's consumer perceives less disconnection between indoor and outdoor living. Homeowners look at porches and decks as extensions of their living space, so they're quick to embrace anything that helps create a seamless transition. Enter transitional decking – outdoor durability and performance with the design aesthetics of indoor flooring.

90% of landscape designers reported that installed seating has become popular among homeowners. Benches, ledges, boulders and seawalls provide extra seating when entertaining. Done right, installed seating is a high-end touch that creates the illusion that the outdoor space is larger than it is by eliminating bulky seating.

Outdoor furniture is so popular at 84% that indoor furniture manufacturers are starting to compete for this market. Whether contemporary or Euro country, full lines are available with weather resistant frames, engineered foam cushions and material in a range of stylish colours. Interior design can now be translated into outdoor living with no sacrifice in design or quality.

A professionally appointed gourmet kitchen is becoming the social hub of the great outdoors. Today's aspirational outdoor kitchen has a granite topped stainless steel cooking centre with dual fuel grills and burners, pizza ovens, ice makers, sinks, refrigerators, bars, beer on tap and wine storage. The materials commonly used are stone, brick, masonry and stainless steel to withstand natural elements of changing weather and UV exposure.

Pergolas score a high 83% among popular projects. They can give the feeling of a ceiling, to complete the outdoor room concept. And they're almost always constructed out of wood. Covers in marine grade fabrics are also being added to moderate sun and protect against rain.

Recreation

Swimming pools are still very popular at 74%, with kidney and oval shaped pools replacing rectangular shares. As features like waterfalls and splash pools grow in demand, the backyard is starting to emulate a luxury resort.

Running water is being used to provide visual and audible tranquility and relaxation in the backyard. Decorative water elements (ornamental pools, grottos, water runnels or bubblers) rated 86% in popularity among landscape customers. In the same restorative vein, spa features, such as hot tubs, whirlpools and saunas are popular outdoor recreation amenities at 76%. The garden is increasingly being designed as a great place to reduce stress.

Sustainability

The concept of "farm to table" is coming out of the restaurant and into the backyard. TV chefs have influenced consumers who want to grow their own produce, both for the taste and the bragging rights. It has to be convenient and make the most of available space, so homeowners are opting for containers and raised beds, ranked at 76.4%. What they're planting is vegetables and herbs to grow more of their own food.

Under landscape garden elements, low maintenance landscapes rated 95%. Synthetic lawns are growing in popularity because they are low maintenance, earth friendly, eliminate the need for pesticides and fertilizers and save water. Turf lawns are also popular in places where grass is difficult to grow.

Extended Use

Exterior lighting was one of the highest rated exterior projects of 2014, rated at 98% popularity, as better lighting extends backyard enjoyment into the night. Today's lighting is much more sophisticated, available in a wide range of formats with dimmers, colour changes and other features previously only available indoors.

Fire pits and fireplaces were rated at 95% in popularity by the landscape architects. Metaphor reports that business in fire pits has tripled in the past 2 to 3 years as they have become available to consumers as DIY kits.

The North American Deck and Railing Association estimates that with lighting and fire pits, homeowners are now using their decks 30% more than they ever have.

Low Maintenance

Homeowners are increasingly turning to low-maintenance, carefree choices for both their indoor and outdoor spaces. They want furnishings that can be left outdoors and won't fade, and plants that don't have to be constantly watered, fertilized and pruned. This is where treated wood is particularly challenged. Although there have been advances in coatings and sealers, maintaining the colour and the surface of treated wood is still an issue and takes time from the enjoyment of the outdoor room.

Professional Deck Builder magazine, with a circulation of 18,000 professionals in the deck, dock and railing industry, recently surveyed its readers as to what decking material they use most frequently. Wood plastic composite continues to take a larger and larger share of the decking market. On the sales side, 42% of vendors expect plastics and composite sales to increase in the next 24 months, while only 19% of vendors anticipate sales growth for treated wood.

A recent study by the Freedonia Group also suggests that although wood decking will continue to account for the majority of demand in volume and value, it is forecast to grow much more slowly than composite and plastic lumber. However, they foresee that the demand for wood decking will be supported by the material's low cost and consumer reluctance to switch materials when renovating the large base of already installed wood decks.

Conclusions

As the sophistication of outdoor living increases, so too will the bar be raised for residential treated wood. While treated wood has historically been unchallenged on price, competitively priced composite and plastic decking are now appearing in the marketplace, bringing a low-maintenance option within reach of more consumers. Although significant efforts have been made to improve the appearance of treated decking and fencing, dimensional lumber falls short of the standards set by indoor hardwood and laminate flooring. Looking at the whole outdoor room, treated wood railings and accessories have not kept pace with new styles and the growing sophistication of exterior decorating. Some new interest in treated wood has recently been revived with the introduction of a more natural brown colour, but the longer term care associated with exterior wood remains an issue.

Mary-Anne Dalkowski, Vice President Marketing of Timber Specialties Co**.** has worked closely with wood treaters and Canadian building material retailers for almost 24 years, marketing pressure treated wood to consumers and contractors. She represents the wood preservation industry as a Director of the Canadian Wood Council and serves on the editorial board of Wood Design & Building magazine.

DESIGN AND CONSTRUCTION OF TALL WOOD BUILDINGS: BUILDING ENCLOSURE AND LONG-TERM DURABILITY

Jieying Wang
FPInnovations – 2665 East Mall, Vancouver, BC V6T 1W5

Summary

FPInnovations published the "Technical Guide for the Design and Construction of Tall Wood Buildings in Canada' in 2014 to assist early adopters in construction of tall wood buildings. This article briefly covers related considerations and recommendations on designing durable and energy efficient enclosures.

1. Introduction

The "Technical Guide for the Design and Construction of Tall Wood Buildings in Canada" (1st edition) was published by FPInnovations in 2014 based on collaborative work with a large team of experts with funding provided by Natural Resources Canada. "Tall wood building" is defined as a wood-based or hybrid building that is significantly higher than currently permitted by the National Building Code of Canada, and what was permitted in the past using traditional sawn timber members, i.e., with a height of 10 storeys or more. This guide was intended to be used initially by the design teams participating in the "2013 Tall Wood Structure Demonstration Projects" initiative, led by the Canadian Wood Council and supported by Natural Resources Canada. The guide has nine chapters covering building systems, sustainability, structural and serviceability, fire safety and protection, building enclosure, prefabrication, costing, performance monitoring, and maintenance. Chapter 6, Building Enclosure Design, led by RDH Building Engineering in the development, was considered an essential component of this technical guide due to the importance of building enclosure and long-term durability. The chapter covers aspects unique to design and construction of building enclosures of tall wood buildings, while heavily referencing existing best practice guides (CMHC 1999a, 1999b; HPO 2011; Finch et al. 2013; Gagnon and Pirvu 2011; Karacabeyli and Douglas 2013).

2. Increased Loads on Enclosure

Environmental and structural loads acting on building enclosures increase with building height. A tall building is generally more exposed, greatly increasing the wind and the wind-driven rain loads experienced by the roof, exterior walls, windows, balconies, and various interfaces. There is also greater runoff on the exterior walls of the bottom storeys. These all require robust enclosure systems and detailing to prevent rain penetration. A tall building typically uses mass timber products, such as cross-laminated timber (CLT), glulam, build-up members, and various structural composite products. It typically needs a prolonged construction period, though this may be shortened by prefabrication. These factors usually increase moisture risk resulting from on-site wetting and reduced drying ability, particularly in the rainy coastal climates. The increased wind load along with the increased stack effects inside a tall building requires robust air barrier systems. In addition, the enclosures bear larger structural loads, particularly at lower levels, requiring heavier and denser structural members, increasing the thermal bridging potential. The exterior walls also bear heavier cladding, typically through exterior insulation. They also need to accommodate larger differential movement occurring between structural and enclosure components, resulting from wood shrinkage and load-induced deformation. A tall building also incurs increased difficulty and costs associated with long-term maintenance and repair. Therefore, a tall wood building requires much more robust building enclosure systems, compared with lower-height wood-frame buildings.

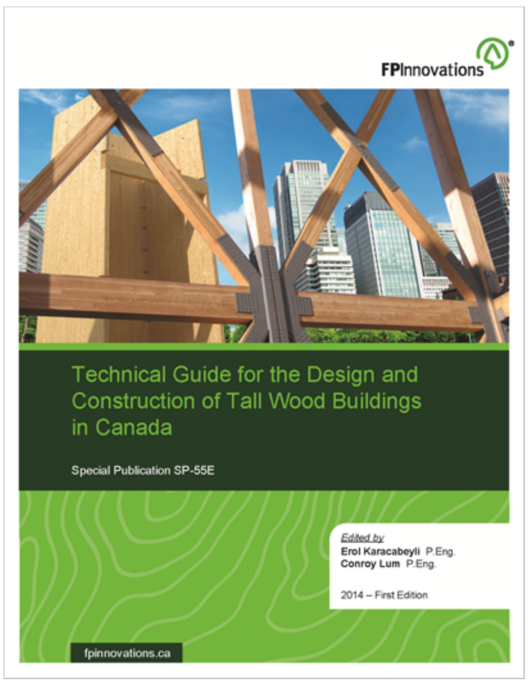


Figure 1 Cover page of FPInnovations' tall wood building guide

3. Exterior Wall Systems

The enclosure system of a tall building is determined by the structural system to a large degree. Figures 2 illustrate five types of exterior walls and structural systems that may be used in a tall wood or wood hybrid building. Light platform frame exterior walls (a) are most commonly used in low- to mid-rise wood-frame buildings in North America. This system represents a structurally adequate and cost-effective option for the top floors of a taller wood building. Prefabricated framing or assemblies are often used to speed up construction, replacing stick-built framing.

When light platform framing system cannot effectively meet the structural requirements of a tall building, non-bearing wood-frame infill walls can be used in a mass timber structure (b); or in a concrete building (c), utilizing similar wood-frame exterior wall assemblies. For such infill wall applications, attention must be paid to the interfaces between the structural members and the infill walls to accommodate potential deflection of structural members, prevent water penetration, reduce thermal bridging, and to ensure airtightness. Wood-based infill walls in mid- and high-rise concrete or steel buildings have been used in northern Europe for a few decades. They often improve thermal performance relative to the traditional steel-stud or concrete block infill walls, making it easier to meet increasingly stringent energy efficiency requirements using thin wall assemblies. Other wood-based systems and materials, such as structurally insulated panels, could also be used for non-bearing exterior walls.

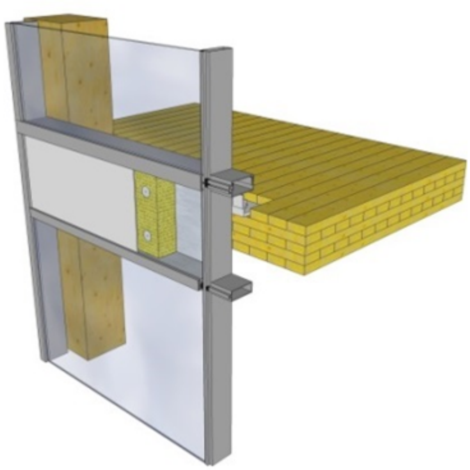
Exterior wall systems based on mass timber plates (d), such as CLT, laminated veneer lumber, laminated strand lumber, and parallel strand lumber, provide another option for exterior walls, particularly when the exterior walls are designed to be shear walls. In addition to these four approaches, a curtain wall (e) is a common option, especially for commercial and institutional buildings.

a. Platform framing

b. Wood-frame infill in a mass timber structure

c. Wood-frame infill in a concrete structure

d. Mass timber construction (e.g., CLT)



e. Curtain wall assembly in a mass timber building

Figure 2 Five types of building enclosure systems

4. Building Enclosure Design

A building enclosure is expected to control environmental loads by managing heat, air, moisture, and vapour transfer through the assemblies. The assemblies and all interfaces must be properly designed, built, and maintained to achieve long-term durability and thermal efficiency. In particular, multiple lines of defence should be provided to prevent water ingress through the building enclosure.

The most critical control layers of an exterior wall include cladding, water-resistive barrier

(WRB), air barrier, thermal insulation, and vapour control layer. The opaque wall assemblies of a tall wood building should be rainscreened walls, properly designed and built to meet durability and thermal performance requirements, depending on the climate and local building codes. Rainscreen construction generally improves moisture performance by providing a capillary break between the cladding and the WRB, a continuous path for drainage, improved drying capacity and a degree of pressure moderation across the cladding. For the WRB to perform adequately, the continuity of the WRB must be maintained over the service life, particularly at various interfaces, such as between roof and wall, window and wall, and balcony and wall. In most wood wall assemblies, the WRB should be vapour permeable to facilitate drying towards the exterior. The cladding of a tall wood building must be durable and made from low-maintenance materials. It is typically required by fire regulations to be non-combustible.

In terms of thermal performance, a traditional wood-frame wall, for example a wall built with 2 by 6 in. dimensional lumber with fibreglass batt insulation in the stud cavities, will likely not meet the insulation requirements in most climates based on the 2011 National Energy Code for Buildings, or the ASHRAE 90.1 standard in some jurisdictions in Canada. Exterior insulation (Fig. 3, 4) is strongly recommended to achieve continuous insulation and to keep the structural members warm. When exterior insulation is used, attention must be paid to cladding attachment to prevent excessive long-term deflection and to reduce thermal bridging. Potential impacts of exterior insulation on durability performance (e.g., vapour permeability) and fire performance should also be assessed. Closely associated with thermal performance, air flow control becomes more important due to the increased loads on the enclosure of a tall building relative to a low-rise building. Airtightness is more critically important for thermally efficient building enclosure assemblies to achieve long-term durability due to the increased vapour condensation potential and reduced drying capacity resulting from high thermal insulation levels. See detailed air barrier design in the guide.

Tall buildings typically use low-slope roof and roof-deck assemblies, often built with mass timber beams/columns (e.g., glulam) and mass timber plates (e.g., CLT), with built-up assemblies. Either a conventional or protected membrane roofing assembly (also called "inverted" roofing) can be used (Fig. 5, 6). Comparing these two options, the protected membrane roof provides greater protection of the roofing membrane and is recommended for a roof deck or a roof anticipated to have high foot traffic and other surface loads. A low-slope roof must provide a good slope to drains, recommended to be a minimum of 2%, by taking into consideration factors such as material dimensional stability and settlement. The use of mass timber products for the roof structure of a tall building requires special considerations, including on-site moisture management (Wang 2015), to reduce wetting and promote drying, particularly in a rainy climate. Water leaks through a roof could lead to deterioration and compromise of the underlying structure. However, immediately finding leaks may become challenging when leakage occurs above mass timber assemblies. To mitigate these risks, the roof structure may be designed to integrate interior ventilation cavities to improve drying performance. Preservative-treated wood may be specified for vulnerable locations. When there is a desire or even requirement for installing a green roof, the costs and benefits must be carefully assessed, considering life span, long-term maintenance costs, and probability of leaks.

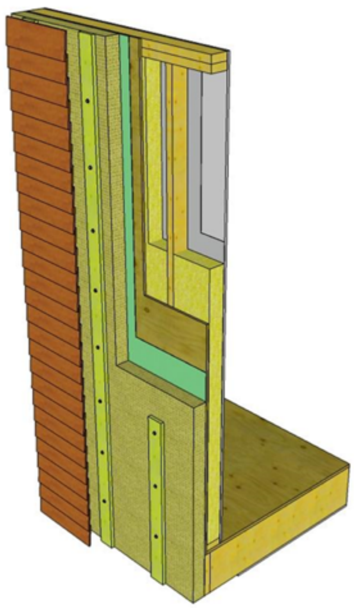


Figure 3 Split-insulated wood-frame wall assembly with exterior rigid mineral insulation

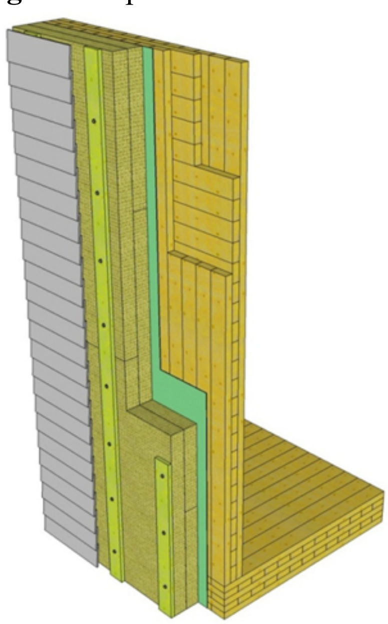


Figure 4 Exterior-insulated CLT wall assembly

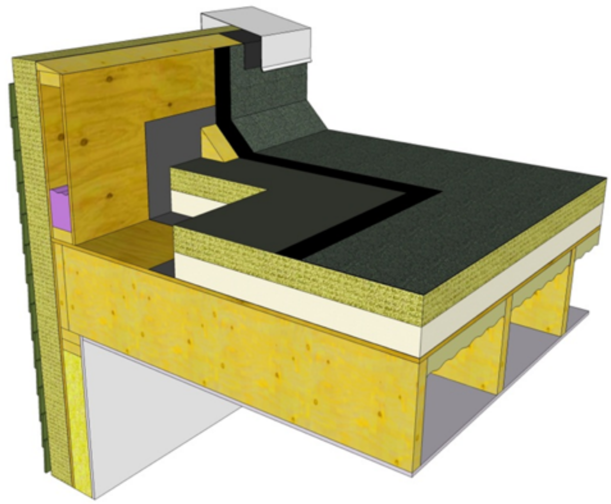


Figure 5 Low-slope roof with conventional roof assembly

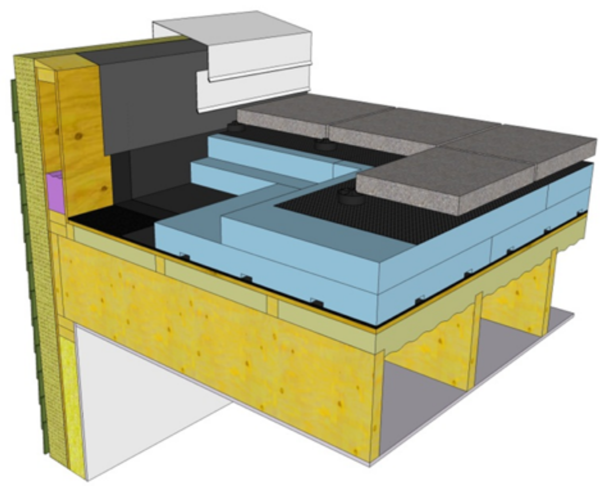


Figure 6 Low-slope roof with inverted (i.e., protected membrane) roof assembly

5. Conclusions

The "Technical Guide for the Design and Construction of Tall Wood Buildings in Canada" is a multi-discipline, peer-reviewed document. It has been well received in the construction industry since its release, not only in Canada, but worldwide. Two trophies were awarded to FPInnovations at the 2014 Contech Building Exposition in Montreal, in the Housing-Innovative Practices category, for the development of this technical guide. This article covers only briefly the major considerations for designing durable and energy efficient building enclosures. More information about building enclosure design, on-site moisture management, and exterior wood application is provided in the technical guide. Other aspects related to the design and construction of a tall wood building can be found in other chapters of this guide. Note such a guide is not intended to substitute for input of professional engineers for any specific construction project.

Acknowledgments

Development of the building enclosure chapter of the "Technical Guide for the Design and Construction of Tall Wood Buildings in Canada" was led by Dave Ricketts and Graham Finch, with co-authors including Michael Lacasse, John Straube, and Jieying Wang. The chapter was peer reviewed by Mark Lawton, Leslie Peer, Constance Thivierge, Paul Morris, Robert Jonkman, Angela Lai, and Andrew Harmsworth. FPInnovations would like to thank its industry members, Natural Resources Canada, and the Provinces of British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, Nova Scotia, New Brunswick, and Newfoundland and Labrador for their guidance and financial support.

6. Literature

Canadian Mortgage and Housing Corporation (CMHC). 1999a. Best Practice Guide on Wood-Frame Envelopes. Canadian Mortgage and Housing Corporation, Ottawa, Canada.

Canadian Mortgage and Housing Corporation (CMHC). 1999b. Best Practice Guide on Wood-Frame Envelopes in the Coastal Climate of British Columbia. Canadian Mortgage and Housing Corporation, Ottawa, Canada.

Homeowner Protection Office (HPO). 2011. Building Enclosure Design Guide–Wood Frame Multi-Unit Residential Buildings. Homeowner Protection Office, Branch of BC Housing, Vancouver, Canada.

Gagnon, S. and C. Pirvu (editors). 2011. CLT Handbook (Canadian Edition). Special Publication SP-528E. FPInnovations, Point Claire, Quebec.

Karacabeyli, E. and B. Douglas (editors). 2013. CLT Handbook (U.S. Edition). Special Publication SP-529E. FPInnovations, Point Claire, Quebec.

Finch, G., J. Wang, and D. Ricketts. 2013. Guide for Designing Energy-Efficient Building Enclosures for Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climate Zones in North America. FPInnovations, Vancouver, BC.

Wang, J. 2015. On-site moisture management of wood construction. FPInnovations, Vancouver, BC. Available on: www.durable-wood.com.