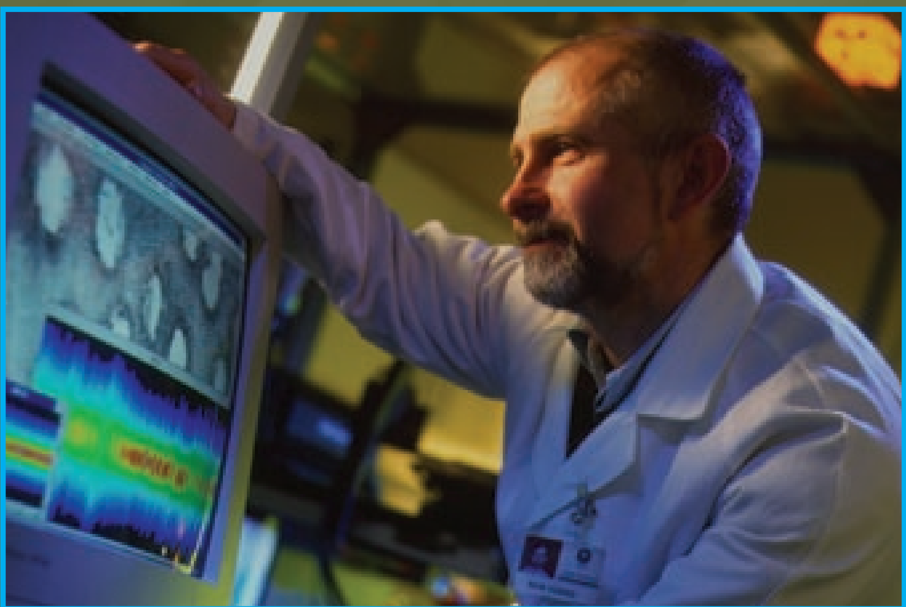
Project No. PN03.1313 Resource Characterisation & Improvement

Australian Government

Forest and Wood Products Research and Development Corporation

Treatment Methods for the Protection of Hardwood Sapwood from Lyctine Borers



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Research and Development
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Publication: Treatment Methods for the Protection of Hardwood Sapwood from Lyctine Borers

Project no: PN03.1313

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Treatment Methods for the Protection of Hardwood Sapwood from Lyctine Borers

Prepared for the

Forest & Wood Products Research & Development Corporation

by

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The FWPRDC is jointly funded by the Australian forest and wood products industry and the Australian Government.

TREATMENT METHODS FOR THE PROTECTION OF HARDWOOD SAPWOOD FROM LYCTINE BORERS

EXECUTIVE SUMMARY

This review examines the various options available to the sawmiller for treating the sapwood of hardwoods against lyctine borers to protect appearance grade products. The treated products should be able to meet the H1 specifications described in AS 1604.1-2000. The hardwood sawmilling industry generally prefers to treat green (unseasoned) timber with water-borne preservatives, to avoid the cost of redrying.

Preservative treatment using copper based preservatives (CCA, ACQ, copper azole) can be performed on seasoned or green timber using vacuum pressure impregnation (VPI). The drawback is that the preservatives may alter timber colour, although the change may not be noticeable due to the low retentions needed for H1. Of these preservatives, ACQ has a number of advantages. CCA is facing the possibility of restrictions in Australia and is restricted in some export countries. CCA treatment of green hardwoods can also produce a sludge problem at the treatment plant. Copper azole (Tanalith E) does not yet have an H1 retention listed in AS 1604.1 and the default H3 retention would be unnecessarily expensive.

The colourless preservatives available are fluoride, pyrethroids and boron in the form of boric acid or various sodium borates. Boron is preferred over fluoride, except within the plywood industry, as it is a cheaper and safer preservative. Pyrethroids can be applied as light organic solvent preservatives (LOSPs) to seasoned timbers in final form, without the need for redrying. This method may suit smaller scale or speciality custom treaters. LOSP treatments will also avoid the problem of producing treated waste for disposal. However, preservative formulation costs will be more expensive than for boron. In the longer term, the Australian LOSP industry may need to adjust practices in the face of possible restrictions due to volatile organic carbon (VOC) emissions. No published information could be found on water borne formulations (emulsions or dispersions) of pyrethroids for H1 specifications. However, such a treatment system for green hardwoods is technically feasible. An advantage for water borne pyrethroids is that when shavings are burnt, the formation of clinker associated with boron treated waste is avoided. A study is needed to demonstrate whether this saving is replaced with another problem, the potential formation of dioxins from the combustion of pyrethroids such as permethrin, which can be classed as organo-chlorine compounds.

Boron has been the traditional and most widely used method of lyctine protection in Australia. Boron is generally considered a safe wood preservative, with a recent exception expressed in Sweden. Boron can be applied using a variety of treatment methods, ranging from relatively inexpensive diffusion, soak or hot and cold bath operations, to VPI. A number of sawmills surveyed were converting from hot and cold bath to VPI, to increase production. VPI also allows timber with a wide range of moisture contents to be treated to specifications, while success for dip diffusion requires timber to be green off the saw. VPI also provides the option of later changing preservative type, as price or environmental issues vary.

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INTRODUCTION

Beetle species belonging to the subfamily Lyctinae, within the family Bostrichidae, attack the seasoned sapwood of certain hardwoods. At least one species occurs in each state of Australia, so that the majority of unprotected susceptible timber is attacked within three years of milling. The beetle attacks seasoned timber once it reaches a moisture content of 20-25 % or less (Creffield, 1991). The favoured moisture content is 8-24 %. Kiln drying of timber will kill all stages of lyctines. However, the beetle can easily reinfest susceptible timber when removed from the kiln. In favourable conditions, the life cycle of lyctines can be as short as four to five months, but in Tasmania and Victoria there is generally only one life cycle per year, with the insects spending most of the year as larvae. The larvae pupate, and adult beetles emerge in spring and summer through exit holes that they bore through the wood surface. Other materials such as plasterboard may also be penetrated by beetles when exiting the underlying wood. Brennan (1990) and Peters *et al*. (2002) provide recent reviews on lyctine biology.

The natural susceptibility of timber species to lyctines is listed in AS 5604-2003. Note that ratings were based on information obtained from the mature resource mainly, and that ratings may differ for regrowth or plantation timbers (Creffield *et al*., 1995). The end use where lyctines are the only biological hazard is described as hazard class H1, or, inside above ground exposure (AS 1604.1-2000). Lyctines can also attack timber that is used in hazard class H2, inside above ground, or that is placed outdoors. The additional levels of treatment needed to protect outdoor timber from attack by termites and decay fungi will also protect the timber from lyctine borers. Protecting timber from lyctines allows the greater utilisation of timber containing sapwood in various appearance grade applications. The Timber Utilisation and Marketing Act (1987) (TUMA) in Queensland (Davis and Norton, 1995) and the NSW Timber Marketing Act (1977) restrict the sale and use of lyctine susceptible timber and, in some situations require 'preservative treatment'.

Damage to sapwood is caused by the larvae, which feed on starch and some other nutrients (Creffield, 1991). Heartwood is therefore not attacked. Some timbers such as mountain ash (*Eucalyptus regnans* F. Muell.) are immune because they lack sufficient starch for larval survival. Also, the starch content in sapwood may vary with season, so that immunity can vary with the timing of harvest. An iodine spot test can be used to determine if starch is present in wood at sufficient concentrations to sustain lyctines (AS 1604.1-2000, Appendix A). The other main determinant of susceptibility is pore or vessel diameter. The female beetle must lay its eggs in the pores of sapwood: therefore, those timbers with small pore diameter are naturally immune. The minimum pore size needed in hardwoods for the female ovipositor is approximately 90 microns (Cummins and Wilson, 1934). Similarly, if timber is coated on all endgrain surfaces (including butt joined ends) with paint, varnish, polish or waxes, the timber will be protected from lyctines unless infestation has already occurred. The surface coatings block the pores preventing oviposition. However, this method cannot be relied upon as any checks or breach of the coating will become an opening to infestation.

This review discusses the various preservative options available for protecting timber from lyctine attack. Other methods worth noting, but not discussed further in this review are based on non-chemical wood processing techniques. Sapwood cells in logs or tree trunks may deplete starch if they continue to respire for weeks after felling or girdling (Simpson and Barton, 1991; Peters *et al*., 2002). Starch may also be degraded by microbial activity during water storage. These methods may suit smaller scale production or farm forestry.

PRESERVATION OPTIONS

Copper chromium arsenic

Copper chromium arsenic (CCA) is a cost effective water-borne preservative that was introduced into Australia as a treatment for poles in the late 1950s (Keating, 1961). CCA now dominates the Australian wood preservation market, with some 100-120 treatment plants. It must be noted that CCA is being restricted in a growing number of countries due to environmental and safety concerns primarily about arsenic. The preservative is no longer used to treat timber for the domestic market in the USA. CCA is currently under review by the Australian Pesticides and Veterinary Medicines Authority (APVMA), which is likely to restrict CCA for certain uses such as playground equipment, decking, handrails and picnic tables.

The majority of CCA goes towards the treatment of H3 and H4 commodities, but a number of hardwood mills also use CCA for H1 treatments in place of boron. Then, only one preservative type needs to be stocked at the treatment plant for a wide range of hazard classes. There are many possible variations on copper:chromium:arsenic ratios, and in Australia the best ratio for producing maximum fixation is now the only type specified in AS 1604.1-2000. Around 10-15 years ago the majority of formulations changed from salts to oxides. Humphrey (2002) provides a recent review on the chemistry of CCA.

CCA is a broad acting and durable preservative that is accepted for all hazard classes from H1 to H6. The level required for H1 is 0.035% m/m elemental arsenic (about 0.1% m/m total active elements). The treatment is applied by vacuum pressure impregnation (VPI). As relatively low retentions of CCA are needed for lyctine control, it can be applied to green timber to avoid the step of redrying after treatment. One problem exacerbated by this procedure is that more timber extractives can be washed from wood when green, to react with CCA and produce an insoluble residue frequently referred to as sludge. Also, timber must normally be dressed after treatment, producing treated waste shavings. These can only be burnt in specially constructed incinerators that provide tight control of combustion conditions and are equipped with custom-made scrubbers. This makes the disposal of the waste shavings difficult.

CCA turns timber a light green colour, although the colour change produced from the H1 treatment is often not noticeable. Gluing timber treated to the higher retentions of CCA (H3 to H6) can be difficult (Mengeloglu and Gardner, 2000), while no reference could be found to show whether this problem persisted at the low retention used for lyctine control.

Recommendation

CCA is an effective preservative for protecting timber from lyctine borers, and provides many established treatment plants already using the preservative with the flexibility of treating to a range of hazard classes. Alternatives must be considered for new treatment plants, as CCA is facing restrictions in export markets, and may become restricted in Australia. Its use for the H1 treatment of green hardwoods may also generate some disposal problems relating to sludge and treated waste shavings.

Ammoniacal copper quaternary compounds

The ammoniacal copper quaternary compounds referred to collectively as ACQ were developed by Chemical Specialties Inc (Jin and Archer, 1991; Preston *et al*., 1994). ACQ is a copper-based preservative that lacks arsenic and chromium, so is rising in favour as an alternative to CCA. It is manufactured from copper carbonate and quaternary ammonium compounds (quats) such as didecyldimethylammonium chloride (DDAC) or benzalkonium chloride (BAC). Retentions are expressed in terms of copper oxide, allowing easier comparison with other copper-based preservatives. The ratio of actives in ACQ should be close to 67% copper oxide and 33% quat. The quats are added as a co-biocide to improve performance against copper tolerant fungi. The first formulation included ammonia and DDAC. However, variations have appeared in an attempt to reduce ammonia odour at the treatment plant, and to reduce the cost of the formulation. The forms are ACQ-B with ammonia and DDAC, ACQ-C with ammonia or ethanolamine and BAC, and ACQ-D with ethanolamine and DDAC.

The retention of ACQ required for H1 treatment is 0.17% m/m. ACQ is a more expensive preservative than CCA, however, there should be limited price differential at the H1 retention levels. As with CCA, ACQ can be applied by VPI to green timber and still meet H1 requirements. An added benefit with this preservative is the reported avoidance of the sludge problem noted for CCA. There are some 14 ACQ treatment plants in Australia, and most are CCA hardwood treatment plants converted to avoid the sludge problem. Also, ACQ treated waste shavings are less hazardous than CCA treated waste shavings, so will be easier to dispose of, although disposal by burning is still not recommended.

As with CCA, ACQ H1 treatment will colour the timber slightly. ACQ is more corrosive than CCA, so when a treatment plant converts from CCA to ACQ some valves and fittings require upgrading to more corrosion resistant metals. Fasteners used for ACQ treated timbers placed outdoors must be hot dip galvanised or stainless steel. Corrosion would be much less of a problem for interior timbers treated to the lower H1 ACQ retentions. Unlike CCA, ACQ treated timber can be regularly and reproducibly glued. This feature is demonstrated by the commercialisation of ACQ treated laminated veneer lumber (LVL) pine crossarms, that are produced by gluing treated veneers (Anon., 2002).

ACQ is a relatively safe wood preservative, and does not contain any known carcinogens. In the longer term, any wood preservative containing heavy metals may face restrictions, with concern about copper currently expressed in some European countries.

Recommendation

ACQ is a better alternative to CCA for H1 treatments, and would suit those sawmills wishing to treat for a range of hazard classes. If the sawmill is only interested in H1 treatment, then boron or a pyrethroid should be used, as they are colourless or cheaper.

Copper azole

Copper azole or Tanalith E is an alternative water-borne preservative to CCA and is safer because it lacks arsenic and chromium (Fox and Williams, 1995; Drysdale and Braithwaite, 1995). This coloured preservative contains copper, tebuconazole and boron. The boron is not fixed, but under H1 conditions would remain an active ingredient in wood. Copper azole is accepted in AS 1604.1 for H3 and H4, and H5 for softwoods. Currently, a retention for copper azole is not listed for H1 or H2 in AS 1604.1, although the H3 specified loadings could be used. As with CCA and ACQ, it seems likely that copper azole could be used to treat green hardwoods. It should also avoid the sludge problems associated with CCA. Copper azole is less corrosive than ACQ, but timber treated to H3 and H4 retention levels can suffer from surface contamination by moulds.

Copper azole is a relatively safe wood preservative, and does not contain any known carcinogens. In the longer term, any heavy metal containing wood preservative may face restrictions, with concern about copper being expressed in some European countries.

Recommendation

Copper azole is a suitable alternative to CCA. However, for H1 lyctine control, commercial use should wait until a suitable retention is determined and specified for H1 in AS 1604.1. The default is to treat to the H3 retention, but this would add significantly to cost, and noticeably colour the timber. Also, no reference was found to demonstrate that the H3 retention could be achieved in unseasoned hardwood.

Fluoride

Fluoride is one of the oldest wood preservatives known (Anon., 1935; Tamblyn, 1945) and is generally applied as sodium fluoride. Fluoride is highly effective against termites and decay fungi, although like boron it leaches so is not listed for exterior use in AS 1604.1. Its use is virtually restricted to diffusible formulations in the remedial preservative market (Johanson, 1974), or as a veneer dip for the protection of plywood (Booth and Edwards, 1962). Fluoride diffuses more rapidly than boron, so in diffusible preservatives is often formulated to provide a quick kill ahead of boron.

Amongst the advantages of fluoride is that it is a colourless preservative. Also, because fluoride treated veneers can be glued, it generally replaced boron for veneer treatments some 30-40 years ago. Currently, most plywood mills have changed further from using fluoride to dipping veneers in pyrethroids before gluing. Fluoride is not as safe as boron, and ingestion in excessive amounts can lead to a number of problems such as the bone disease fluorosis (Pillai and Stanley, 2002).

Recommendation

Fluoride is not recommended for the treatment of solid wood for lyctine control, as boron, and the synthetic pyrethroids, are cheaper and more environmentally friendly alternative.

Synthetic pyrethroids

The light organic solvent preservatives (LOSPs) have been used in Australia since the late 1970s, and formulations can be designed to suit a range of conditions from H1 to H3. After de-registration of organochlorine insecticides, such as dieldrin, in 1995 the LOSP industry switched to the synthetic pyrethroids, with permethrin most widely used. Pyrethroids first appeared in AS 1604 in 1993. Currently, permethrin, cypermethrin, deltamethrin and bifenthrin are accepted for H1 in AS 1604.1. Unlike boron, the preservative formulations are leach resistant. However, for H1 conditions, this is not a particular advantage. Pyrethroids can slowly degrade under UV exposure (Oliveira, 1994), while boron remains stable. It is unclear whether this degradation might cause any significant long term reduction in efficacy. Some safety margin occurs as timber is normally treated to levels well above the toxic threshold required for lyctine control. It is also unclear whether starch in wood degrades to any significant extent over the long term.

Pyrethroids are organic insecticides that can be used alone for H1 and H2 treatments, or combined with a fungicide for H3 exposure. The actives are dissolved in organic solvents such as white spirit, and for H3 formulations may also incorporate resins and waxes to increase water repellency. These additives are not normally added to H1 or H2 formulations, as water repellency is unnecessary. Pyrethroids are generally compatible with tributyl tin naphthenate but not tributyl tin oxide (Blunden and Hill, 1987).

LOSP formulations in white spirit have the advantage of not swelling wood after treatment, so were originally designed for window joinery that could be assembled soon after treatment (Taylor, 1980). Commercial treatments mainly use a double vacuum impregnation schedule, sometimes in combination with a low pressure phase up to 150 kPa (compared to 1380 kPa for CCA or boron treatments). Penetration into eucalypt heartwood using these schedules is minimal (Cookson and Trajstman, 1996), while full sapwood penetration can normally be achieved. Some smaller scale window manufacturers in Australia apply LOSP by brushing. In the USA, a three-minute dip is normally used to treat windows with LOSP. However, both brushing and the three-minute dip will produce only surface penetration. Such an envelope treatment may be adequate for window joinery that is already cut to final length and form. However, these methods would not suit products such as hardwood flooring that is docked after treatment, as the protective envelope will be breached. AS 1604.1-2000 requires full sapwood treatment.

The pyrethroids do not colour timber, unless a dye is added to the formulation to aid the identification of treated timber at the mill. LOSP does not affect most paints and adhesives, once the solvent has dried.

An advantage of LOSP treatment for lyctine control is convenience, in that timber can be treated when ready in seasoned final form. This feature also avoids the generation of treated waste shavings, and allows timber to be sold within 1-2 weeks of treatment. However, LOSP formulations are relatively expensive, and do not necessarily suit the production line of a sawmill where treatment of timber in the green state is generally preferred.

In Europe particularly, the LOSP industry is under pressure to reduce its volatile organic compound (VOC) emissions. This problem has led to research aimed at altering the solvent system. The pyrethroids may now be formulated as microemulsions or dispersions in water. For window joinery, these technologies must find a balance between replacing organic solvent with water, while not causing the timber to alter dimensions after treatment. An alternative method for managing VOC emissions may be to recover and recycle evaporating solvent at the treatment plant.

The water-borne pyrethroid formulations are more suited to lyctine treatments at the sawmill as timber could be treated while still green. No publicly available information could be found on the use of water-borne pyrethroid formulations for this purpose, apart from the protection of logs in storage. The superficial treatment applied to logs would be largely lost upon milling. For sawn green hardwood, VPI treatment is technically feasible, and is being practiced by some hardwood mills. The pyrethroids would not diffuse, but may have sufficient repellency to protect all sapwood.

Pyrethroids are considered to be relatively safe wood preservatives in Australia. In Europe, some concerns have been raised about dust from permethrin treated carpets (Boge *et al.*, 1996).

An advantage of water-borne pyrethroid treatments is that the treated waste shavings will not produce clinker if burnt. Clinker is a hard glass-like product often left from burning boron treated waste.

One aspect that needs further investigation is whether dioxins are formed when pyrethroid treated wood waste is burnt, as can occur during the incineration of a number of other chlorine containing molecules (Strecker and Marutzky, 1994; Oehme and Muller, 1995).

Recommendation

Treatment with pyrethroids formulated as LOSP would suit the treatment of seasoned timbers in final form, and would avoid the generation of treated wood waste.

A cheaper option more suited to a sawmill would be to treat green hardwoods with water-borne formulations of the pyrethroids. This practice would avoid the clinker problem experienced at some boron treatment plants, although whether a potentially more serious problem of producing dioxins from burnt pyrethroid treated wood waste would occur should be determined. A trial should be conducted and published to demonstrate efficacy after the treatment of green timber by this method (rather than trials on the treatment of seasoned timber).

Boron

Introduction

Boron treatments for timber were invented and commercialised in Australia following research at Commonwealth Scientific and Industrial Research (forebear of CSIRO) (Cummins, 1939). Since that time, there have been a number of reviews on boron in wood preservation (eg. Bunn, 1974; Cockcroft and Levy, 1973; Greaves, 1990; Drysdale, 1994; Lloyd and Manning, 1995).

In Australia, because the first veneers peeled from a log contain all sapwood, research began with the aim of protecting hardwood veneers. At first, dry veneers were soaked in hot boric acid solution (1.25% at 93^{o}C for 10-40 minutes). However, this method required heating equipment, the veneers to be separated individually in 'finger crates', and lifting gear. Also, there was rapid dilution of the boric acid solution as boric acid was selectively absorbed by the wood (Tamblyn, 1949).

A commercial improvement for veneer treatment was momentary dipping of individual sheets in cold boric acid (2-4%) or borax (3-6%) followed by block stacking (stacking without stickers) of the veneers for at least 2-4 hours (Tamblyn, 1949).

Around the same time, work began in New Zealand to dip green radiata pine for protection against common furniture beetle, *Anobium punctatum* de Geer, (Spiller, 1948). However, first commercial production in New Zealand was to treat the hardwood tawa in 1949-50 against lyctines (Harrow, 1955). A New Zealand Government Committee of Enquiry approved boron treatment of green framing timber in 1952, and treatment of *Pinus radiata* D. Don began soon after (Harrow, 1955). The most common method of treatment was to dip timber in a highly concentrated boron solution (e.g. Tim-bor®) and allow diffusion to occur for 6-8 weeks. Until about 1986, 99% of boron treated timber in New Zealand was by the dip and block stack method (Vinden, 1990). A move away from boron treated framing in New Zealand, coupled with some practices that lead to 'leaky buildings', has seen a rise in damage caused by decay fungi.

In Australia, further research was aimed at treating sawn hardwoods. The most widespread technique was the hot and cold bath, which is still one of the main methods used today (Cookson *et al*., 1998). Other methods included soaking timber in hot solution for some hours (Bootle, 1971). A steam and cold quench method was also adopted by some Australian mills (Tamblyn, 1956), but seems no longer in use.

A major expansion for boron treatments arose from the need to preserve rubber wood as it is of low natural durability and vulnerable to insect attack. The rubber tree (*Hevea brasiliensis* (Willd.) Muell.-Arg.), grown in south east Asia, has a latex producing life of about 25 years.

After that time, the tree is felled and new plantations established. The timber had low commercial value as it is non-durable, and was often wasted. After examining a variety of treatment methods, large volumes of rubber wood are now treated using a vacuum pressure/diffusion process (Tan, 1991). Currently however, the rubber wood industry is facing problems exporting to Sweden due to claims that boron is a 'dangerous substance' (Anon., 2003), a suggestion contrary to most other considerations on boron.

Until now, borates were not widely used in the USA. However, a coordinated research effort on boron treatments began in 1984 between several research organisations (Barnes *et al*., 1989). The importation of lyctine susceptible *Virola* spp. (banak) from Brazil also boosted research into boron diffusion in the USA (Williams and Mauldin, 1985). Expanded commercialisation in the USA of boron treatments for softwoods will depend upon resolution of the problem of boron effectiveness against termites.

Boron has a number of advantages as a wood preservative, especially for H1 type exposure conditions. Borates are relatively inexpensive, colourless, non-flammable, and can be applied by a variety of methods, ranging from cheap dip tanks to sophisticated VPI plants. Boron also has sound health, safety and environmental credentials (not withstanding the directive from Sweden mentioned above), as it has low toxicity to mammals, and low environmental impact (Currie, 1997).

Formulation

There are a wide variety of boron formulations available. The various sodium containing formulations are most common, and are generally referred to as borates. Woods (1994) gives an outline of boron formulations and uses. Borates can be used in glass manufacture, detergents and bleaches, fire retardants, fertiliser additives, corrosion inhibitors and buffers. Boron-containing wood preservatives are derived from naturally occurring borate minerals (Lloyd and Manning, 1995). The main mineral is tincal (borax). Large deposits are found in the USA and Turkey. Some of the common wood preservative formulations are:

Boric acid or H_3BO_3 (17.5% boron). Boric acid has relatively low water solubility. A 4% concentration can give crystals at room temperature. Therefore, the solution must be heated to obtain higher concentrations. Boric acid should also be kept away from iron as it causes blue-black discolouration or iron tannate, when it reacts with extractives from or within wood. Boric acid cannot be used in ferrous vats (Cokley, 1948). Some mouldicides are not compatible with boric acid. It is customary in research articles to compare the various borate formulations back to their standard boric acid equivalent (**BAE**) contents.

Borax = sodium tetraborate or $Na_2B_4O_7.10H_20$ (11.4% boron) or $Na_2B_4O_7.5H_20$ (14.9% boron). Borax is available as both the hydrated (decahydrate) form and as pentahydrate. Borax pentahydrate appears to be the most common boron formulation used in Australia. A trade name for sodium tetraborate pentahydrate is **Neobor**. About 5% borax is soluble in water at room temperature. In other industries, borax is used in detergents and bleaches, and has been a laundry additive since 1900 (Woods, 1994). Borax is slightly alkaline (pH 7-8). When impregnated into wood, the alkaline condition penetrates only 0.8 mm, and then returns to a pH 4-4.5. Therefore, the borax must convert into boric acid within a short distance in the wood (Cokley, 1948). The main advantage of borax over boric acid is that it is non-corrosive.

Tim-bor® = Polybor = disodium octaborate tetrahydrate (**DOT**). Composition approximates $Na_2B_8O_{13}.4H_2O$ (21.0% boron). This product can be made by mixing 100 parts (by mass) boric acid with 117.5 parts of borax pentahydrate. Tim-bor® is highly soluble. At 20^oC about 10% m/m will dissolve, and solubility increases greatly with warming. At 60^oC, 35% Tim-bor® will dissolve. Tim-bor® is mildly alkaline (7-8 pH). This product is used widely in New Zealand, USA and other countries.

Diffusol® is a DOT-type formulation that contains thickening agents designed to leave a larger film coating on dipped wood surfaces. It also contains a mouldicide (isothiazolone). Diffusol® is manufactured by Koppers Arch. It is delivered as a solution rather than a dry powder. Solutions for dipping usually contain about 10-13% BAE at room temperature. Unlike the common practice for Tim-bor®, Diffusol® is not heated because it can deliver sufficient boron to the timber surface upon dipping when cold.

Efficacy and performance

Boron has broad spectrum activity against a range of wood destroying organisms, however boron is listed in AS 1604.1 only for H1 conditions.

Cummins (1939) found that 0.14% boric acid (based on air dry weight of wood) controlled lyctines. Gregory (1942) therefore aimed to treat timber to a loading of 0.2% BAE to give a slight tolerance or safety margin. AS 1604.1 requires at least 0.047% m/m elemental boron (=0.27% m/m BAE) based on oven dry treated sapwood for H1. The 0.27% loading is for the whole cross section of susceptible sapwood. Earlier requirements in AS 1604-1980 were for 0.2% BAE with not less than two-thirds of this amount permitted in the timbers sampled. TUMA (1987) retentions were based on 0.2% BAE for the inner one third of the susceptible sapwood section. The more recent 0.27% loading assumes a retention gradient of 75% (0.27 x 0.75 = 0.2%).

Boron is also effective against basidiomycete fungi, as might be encountered in both interior and exterior above ground applications. Cookson and Pham (1995) provide recent data, and found that all brown and white rotting fungi examined were controlled by 2.0 kg/m^3 boric acid in *P. radiata* sapwood (= 0.42% BAE m/m) and *E. regnans* sapwood (= 0.36% m/m). Lloyd *et al*. (1990) examined the mechanism by which boron might affect fungi. Boron is not accepted in AS 1604 for H3 to H5 conditions because it can leach, but may be formulated in diffusible preservatives as remedial treatments to control decay fungi.

The efficacy of boron compounds against lower fungi and soft rotting fungi is less clear. Borates are generally effective against sapstain fungi. However, at the levels normally used commercially, borates do not protect timber from surface moulds. Borates actually stimulate the growth of some moulds (Amburgey, 1990). Mould growth may also be encouraged if the method of boron treatment requires a lengthy period of diffusion where timbers are wrapped.

Mouldicides are often included in borate formulations to control surface moulds, especially in warm humid regions. However, mould inhibitors do not always prevent mould growth.

The ability of commercial loadings of various borates to protect timber from termites is still a matter of debate and research (Kennedy *et al*., 1996). The results and conclusions vary with country, termite species, and the method of assessment. Boron is not accepted in AS 1604 for H2 conditions because the level needed to control termites under Australian conditions has yet to be proven conclusively and submitted for review.

While fresh borate solutions do not colour wood, colour may result from using aged solutions that accumulate wood extractives. However, gauging timber after treatment usually removes stained surface layers of wood. Boron treatment has no significant effect on the strength of timber (Anon., 1994). Boron treated timber will blunt saw blades more quickly than untreated timber (Davis and Norton, 1995). Provided the treated timber is dried to a moisture content below 18%, borate treatment should have no adverse effect on painting (Anon.., 1994).

Borate treated wood can affect phenol formaldehyde glues, but most other glues seem to be compatible. Boron treatments are no longer used in Australia to treat veneers, due mainly to gluing problems (K. Lyngcoln, pers. comm., 1996). They were largely replaced with sodium fluoride dip diffusion treatments and, more recently, permethrin has become the preservative of choice. Veneers are dipped in the permethrin emulsion, which probably does not diffuse, but loads the fine peeler checks present in all veneers with insecticide, sufficient to prevent lyctine attack.

Treatment methods

There are generally two stages involved in boron treatments. Firstly, the boron is applied to green or partially seasoned timber and, secondly, the boron must move more deeply and evenly into the wood during a diffusion period. In its simplest form, diffusion treatment is a natural process where molecules of the preservative migrate though wood. Diffusion is based on the tendency of certain compounds to equalise their differences in concentration (Williams, 1991).

The borate may be applied to the timber using a variety of methods, such as dipping, spraying, or brushing with hot or cold solutions. The borate is applied momentarily as a surface film, so that sufficient boron concentration must be present in the surface film to give the desired loading within wood upon diffusion. To complete the treatment, a diffusion period of 4-8 weeks is usually required. Alternatively, timber may be left to soak in borate solutions, either cold or hot, so that diffusion and replenishment of boron continues during submergence over several days or weeks. Other methods of applying borate solution are the hot and cold bath, steam and cold quench and VPI. These later processes force solution into the timber structure upon application, so that less diffusion time is required to complete the treatment. The diffusion period required after such treatments may be 1-7 days, and often the timber can be sold almost immediately after preservative application.

Temperature has a major influence on the concentration of boron in solution, which in turn affects the amount of boron contained in the surface film of dipped timbers that will be available for diffusion. According to Findlay (1960), the film of liquid left on timber after dipping is about 0.2 mm (this film would be thicker for Diffusol®). Timber is usually dipped rough sawn, so that more solution is held to the timber surface, providing a reservoir of preservative for diffusion. Unheated solutions of boric acid or borax might only contain 4% BAE. Cold solutions of Tim-bor® or sodium pentaborate have higher BAE. Heated solutions can contain up to about 35% BAE.

Boron is mostly applied to green timber. Scantling does not usually need to be dressed after seasoning, however, appearance grade products must be dressed. This produces boron treated wood shavings, and also wastes chemical. This waste is disposed in a variety of ways. Most often, it is burnt in boilers to produce steam. Boron treated wood does not produce highly toxic by-products when burnt (Williams, 1990). However, if boron concentrations in the wood waste mixture are high, it can fuse to produce ‘clinker’, which may need to be chipped off the walls and grates of furnaces every 1-2 weeks. One method of reducing the problem is to use a very hot fire fuelled with wood that has not been treated with boron, which melts the glass but promotes corrosion and accelerates decay of the furnace walls (Neely, 1990). Another method is to add lime (Young, 1947).

A recent survey of 20 hardwood sawmills (Cookson *et al*., 1998) registered to treat with boron showed that eight used the hot and cold bath method, ten used VPI of unseasoned timber, one used dip diffusion with Diffusol®, and one small operation used a cold soak method. Some of the sawmills using VPI had used the hot and cold bath method previously, but found VPI more convenient and suited to their larger scale production.

Some of the treatment methods are listed below:

Dip diffusion using cold solution

Tamblyn (1975) described research by CSIRO in 1952-54 that examined the dipping of green sawn *Eucalyptus obliqua* L'Herit. and *E. dives* Schau. with cold (25^{o}C) concentrated sodium pentaborate (about 17% w/w). The dip was for one minute. The sapwood needed to be block stacked for 25 days at ambient temperature to achieve the sapwood core retention of 0.2% BAE. At the time, this system of treatment was not introduced because the hot and cold bath method gave faster results.

Improved results in cold solutions can be expected by dipping in Diffusol®. Diffusol® was developed for *P. radiata* in New Zealand by the Forest Research Institute in a joint project with Hickson Timber Preservatives. It is a thickened borate solution that leaves more boron on the surfaces of dipped timber than conventional treatments. It allows the use of solutions containing 10-13% BAE at ambient temperature, rather than solutions with 16-18% BAE that must be heated (Vinden *et al*., 1990). Some of the advantages over conventional dipping in heated baths in New Zealand were more even distribution of preservative within timber, ability to treat gauged timber, energy savings and the avoidance of chemical dust as Diffusol® is a liquid (Vinden and Drysdale, 1990). Best results are obtained if the timber is dipped green off the saw (Cookson *et al*., 1998).

Plant equipment required to set up the Diffusol® cold dip system is less expensive than for the hot and cold bath or VPI methods. Greater throughput is allowed compared to the hot and cold bath process and throughput may be comparable to VPI. A block stacked pack of timber can be dipped and then held over the dip tank to drain every 30-45 minutes. The main disadvantage is the diffusion holding time, which requires storage space in the sawmill yard, and some forward planning or expectation of treated timber stock requirements. Freshly treated timber packs need to be covered as soon as possible after treatment. If white deposits of chemical (borates) form on the timber surface during diffusion, then the timber is drying too rapidly (Anon., 1956).

Cold soaking

Cold soaking is suited to small volume or occasional treaters, who can afford to have the treatment vat tied up by the same pack of timber for weeks at a time. The cold soak method is used on a small scale in the industry in NSW. It usually involves soaking in 3 to 4.5% borax for 12-14 days (Johnstone and Humphreys, 1972). The length of time needed to treat timber by soaking depends on timber species and thickness. As a general rule for 4.5% borax solutions at 18^{o}C, timber of 2.54 cm thickness requires seven days soaking, while timber of 3.81 cm thickness requires 14 days soaking (Davis and Norton, 1995). One sawmill surveyed (Cookson *et al*., 1998) treated about 20 m^3/year comprising tallowwood, spotted gum, blue gum and red mahogany. It generally tries to cut out the sapwood, so as to avoid treatment. The sapwood is easy to distinguish from the heartwood in these species, and lengths are put aside over several weeks to produce a sling ready for dipping. Therefore, some of the timber is partially seasoned. The sling is stickered at each layer, submerged, and left to soak in the solution for one week. The sling is then removed, and left to air dry and season without covers.

Brush application

Creffield *et al*. (1983) describe the remedial and/or preventative treatment of partially seasoned (16% mc) *E. obliqua* using Boracol 40 (40% Tim-bor®, 51% ethylene glycol, 9% water). A brush application gave almost complete protection to the sapwood from lyctines. Brush application would not be a commercial option for large scale production. Depth of penetration appears to be limited. However, the work described by Creffield *et al*. (1983) for the small scale treatment of seasoned hardwoods could be investigated further. It may be possible to brush treat gauged timber with Boracol 40, and thereby avoid the production of treated waste shavings.

Soak in heated solutions

Dipping in heated boron was a common practice in New Zealand for the treatment of radiata pine against *Anobium* (Arthur, 1993), but is little used in Australia. Johnstone and Humphreys (1972) examined hot soaking in an effort to avoid the heat losses of the hot and cold bath process. The hot soak method gave adequate retentions for some timbers and sizes.

However, they found that the hot and cold bath method still gave generally higher retentions than this hot soak method.

One of the sawmills surveyed had previously treated spotted gum (*Corymbia maculata* (Hook.) K.D. Hill & L.A.S. Johnson) in a dip tank by hot soaking. The borax solution was kept hot, just short of boiling, and during the course of the day it would immerse three slings of timber. Near the end of the day, the slings were raised by forklift, left to drain for 30 minutes, and then placed uncovered in the yard to dry. However, the penetration was not always good, and the sawmill converted to VPI.

Hot and cold bath

In Australia, the hot and cold bath has been the main method used to treat sawn timber with boron (Gregory, 1942; Young, 1946). The cooling of heated wood produces a suction effect that forces treating solution into the wood. Eight of the twenty sawmills surveyed were using this method, treating 1-5 m^3/day. Timber is dipped rough sawn and green, or partially seasoned. One mill also treats dressed timber. The stickered slings are generally submerged in the tank in the morning, 2-5% borax solution heated to 80-92^{o}C (one mill to about 60^{o}C), and the solution allowed to cool overnight. Timber can be sold within days of treatment, or air dried and dressed.

Davis and Norton (1995) provide further details: The treatment solution typically used for the hot and cold bath method is 4.5% borax (45 kg in 1000 litres water). There may be a need to warm the solution in a mixing tank to help dissolve the borax. Cover the dip tank and treatment solution, to avoid dilution by rain. Plant design should prevent spillage and run-off, and minimise the chance of pollution. Tanks can be built of steel, concrete or brick. Heat the solution to just under boiling, and maintain temperature near 100^{o}C for two hours for 2.54 cm thick timber, or four hours for 3.81 cm thick timber. Allow the bath to cool overnight, so that the temperature drop is at least 40^{o}C. Take the pack out of the cooled solution in the morning. Add fresh packs of timber to the tank, and reheat. After treatment, the timber can be air dried or kiln dried (at temperatures less than 70^{o}C). If mould or staining occurs, antisapstain chemicals can be added. Top up the treatment solution after each treatment with 4.5% borax. The solution should be stirred during treatment, and after top ups. Stirring is best accomplished with a circulating pump, but in smaller plants manual stirring with a paddle should be enough.

The hot and cold bath systems are mostly used on a small scale where outlay for vacuum pressure impregnation plant is not warranted, and excess steam is available (Johnstone and Humphreys, 1972). The recent industry trend, especially by larger producers, is to move away from the hot and cold bath method towards VPI. The hot and cold bath treatment cycle could be accelerated by transferring timber between two baths (one hot, one cold), and would reduce heat loss and subsequent reheating of solution. Timber packs for dipping are usually stickered, while timber packs for VPI can be mostly block stacked.

Steam and cold quench

Steam and cold quench is a modification of the hot and cold bath method, where timber is steamed for three to four hours, and then flooded with a cold weak solution of boric acid or borax for the remainder of the standard 24 hour period (Tamblyn, 1956). Some diffusion will continue until the timber dries. However, this method does tend to encourage surface checking in some species (Bootle, 1971). The survey suggests that the method is no longer used in Australia.

Vacuum pressure impregnation

Boron can be used to treat green or partially seasoned timber, thereby avoiding the need to season timber before treatment. Treatment of seasoned timber on a regular basis for lyctine control would be better achieved using LOSP, to avoid redrying costs.

The levels of boron needed to control lyctines are relatively low, so that green or partially seasoned hardwoods can be treated by VPI. Vessels usually empty of fluid soon after a tree is felled so can be filled with boron treating solution while the timber is still green, and the boron can then diffuse into the surrounding damp timber. VPI is probably the most effective, easiest and most widely adopted method for shortening diffusion times (Lloyd and Manning, 1995). It has been used extensively to treat rubber wood (Salamah *et al*., 1988; Tan, 1991), and was successful in the treatment of *E. obliqua* and *Acacia melanoxylon* R. Br. (Cookson *et al*., 1998).

Ten sawmills surveyed treated 4-30 m^3/day using VPI. Three of the sawmills had been using VPI for 25-30 years. Hardwood timbers treated are local eucalypts such as spotted gum, and the occasional rainforest timber. One sawmill had three different work tanks connected to a 16,500 litre treatment cylinder, containing low concentration CCA, high concentration CCA and 3% borax pentahydrate. The ten litres of preservative trapped in the lines did not seem to create a sludge problem upon mixing of the CCA and borax. The mill used low concentration CCA to treat coloured hardwoods for H1 conditions, and borax only for the pale rainforest timbers. The preference was to treat with CCA even for H1, as CCA did not give mould problems.

Most plants used a 3% borax solution and Bethell treatment schedules to 1380 kPa pressure. Antisapstain chemicals were reported to be more stable in the cold VPI solutions than in the hot and cold bath. However, a number of VPI and hot and cold bath sawmills still could not fully control the mould problem even with antimould agents added. Some sawmillers had changed operations from hot and cold bath to VPI. They reported that timber checking, which could occur after the hot and cold bath process, did not occur after VPI. Most of the sawmills treated timber within one week of sawing. One mill that normally treated timber green off the saw reported that only white cheesewood (*Alstonia scholaris* (L.) R. Br.) was difficult to treat this way, so it allowed it to partially air dry before treatment. Treated timber could normally be sold three to seven days after treatment.

Recommendation

Boron treatment is a tried and tested method for lyctine control. Relatively low capital investment and simple dip or soak methods can be used. Treatment can also occur by VPI, which offers a number of advantages:

1. Timber at a range of moisture contents can be treated by VPI. It is less important to treat timber green off the saw, than it is for dip diffusion treatment.

2. Timber can be sold or seasoned soon after treatment. This advantage also applies to timber treated by the hot and cold bath method.

3. Although checking does not seem to be a problem with most hot and cold bath treatments, the lower temperatures used in VPI treatments should reduce any potential problem. Also, solutions at the lower temperature would be slower to remove extractives from timber than the heated solutions in the hot and cold bath method.

4. Timber packs do not have to be stickered for VPI treatment (perhaps a fillet every 4-5 layers).

5. The cylinder could be used to treat timber with either CCA or boron. However, plant operators would need to ensure that boron and CCA solutions did not mix, to prevent sludge formation.

6. VPI allows greater flexibility in the preservatives that can be used, so that if desired, the preservative could be changed from boron to a copper-based preservative or the pyrethroids.

The main disadvantage of the pressure cylinder system is that it is more expensive to install than either the dip diffusion or the hot and cold bath systems. Also, plant operators require more training to operate the pressure plant system safely.

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