LEACHING OF BORON WOOD PRESERVATIVES - A REAPPRAISAL

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ABSTRACT .

Boron compounds in current use as wood preservatives are susceptible to loss via leaching, under certain conditions. This is because they are not chemically fixed after treatment and remain mobile within the treated wood. Available data on this phenomenon, gathered over forty years, has been reviewed in this paper. It would appear that the significance of this problem has been over-stated for many years.

From the data reviewed it can be concluded that there is no danger of efficacy loss due to external exposure during construction and in fact boron can continue to provide good protection of timber in most practical exposed non-ground contact situations. Loss of these preservatives can only take place to a serious degree when treated timber remains wet throughout its cross section for long periods while at the same time having an external sink for boron migration. Sample size, test methodology, initial over-treatment and sample drying during test, can all be important factors when considering boron loss.

With the advent of suitable standard test methodology and the development of new formulation technology, it will be possible to expand the current use of boron based preservatives. This has already become evident with the increased reliance on boron in many of the recently developed 'fixed' preservative systems designed for exterior and ground contact applications.

KEY WORDS:

Boron; Borate; DOT; Efficacy; Exposure; Leaching; Mobility; Non-ground contact; Review; Tim-bor®.

INTRODUCTION

Boron compounds in current use as wood preservatives are susceptible to leaching under certain conditions, as they are not chemically fixed within the wood. Because of their non-fixed characteristics, boron preservatives are normally recommended for general building use in the protected environment and are not recommended for use in ground contact. This generally equates to the European hazard classes 1 and 2, and hazard class 3 if protected by paint or other such coating (Brookes, 1991; Dickinson, 1991) or equivalent hazard classes in other countries. However, it should also be noted that borates have played a successful role as co-biocides in some 'fixed' formulations for many years such as their use in copper chrome boron (CCB) formulations, which are seen as a suitable alternative to copper chrome arsenic (CCA) products.

The leaching of borates from treated wood has, in the past, been highlighted to its detriment by many authors and these preservatives have taken time to become established in the United States, due to their over-stated leaching problems and subsequent 'branding' as ineffective preservatives (Williams, 1990), even in interior or protected situations. A similar situation has also been observed in some other parts of the world. A review on the use of boron compounds in the preservation of wood, for example, by Cockroft and Levy (1973) suggests that the future of boron preservatives lies in the search to chemically fix them within the treated timber. In the same review, however, Cockroft and Levy conclude that although the leaching of boron compounds from wood has received some study, further work is necessary before these results can be interpreted in practical terms. Other authors have suggested that the loss of these preservatives can only take place to a serious degree when treated timber remains wet throughout its cross-section for long periods of time. Such a condition very rarely occurs in service and temporary exposure of boron treated wood during the construction of a building has never been found in practice to seriously reduce its content (Findlay, 1959; Anon, 1969). In addition to this, commercial experience in New Zealand shows that when boron-treated timber is used according to specification, there has not been a single authenticated case of failure in service since the start of commercial treatment in 1953 (Cross, 1992).

This review of experimental work and commercial experience has been carried out to assess the risk of boron loss and hence efficacy loss when using boron-based wood preservatives in European hazard classes 1, 2 or 3 (protected by a coating) or their equivalent situations. This review was also intended to find any weak areas in the data where additional work might be possible to further test the effectiveness of boron based preservatives.

RESEARCH FINDINGS

There is no doubt that inorganic boron salts used in wood preservation are not chemically fixed within treated timber and that this can result in the loss of boron in certain situations. This has been addressed by many authors in the past. For example, Carr (1955) reported that borax (sodium tetraborate) leached rapidly, and Becker & Buchman (1966) demonstrated that boron leached faster than copper, arsenic or fluorine. Most workers who have readily demonstrated that boron compounds will leach from treated timber, have however, suggested that they remain effective in a non-leaching environment (Findlay, 1960; Jacquiot et al., 1960; Cross, 1992). Unfortunately, the perception of what constitutes a non-leaching situation can differ markedly, from ground contact exposure at one extreme to limited exposure during construction, at the other.

Work to verify the leachability of borates in various end use situations has involved some extensive laboratory studies and field trials. Probably two of the most significant scientific studies carried out in this area were those by Harrow (1951 & 1960) in New Zealand. In one of these investigations Harrow (1951) suggests that the leaching of preservatives for building timbers could not be a problem, except for the period when it is exposed for air drying or as uncovered framing. He states that treated timber is well protected from leaching effects after installation, by roof and paint. In order to gauge experimentally the extent to which some water soluble preservatives are lost from building timbers during the unprotected period, he treated three timber species by vacuum pressure, with one of three preservatives including borate and exposed them, unprotected for up to six months. His results, some of which are shown in table 1, showed losses from the timber of up to 30% after 26 weeks and 20.55 inches of rain. Although 30 % losses could be considered quite high, it should be noted that even with these losses the boron never falls below an efficacious retention (0.1 - 0.2 % BAE is usually recognized as a retention capable of controlling decay and beetle attack). These results are expressed graphically in figure 1. Heavier losses were gained from the surface of the timber, but this loss did not affect the core concentration after six or fifteen weeks exposure. Harrow concluded from his results that the losses were not of sufficient importance to warrant the application of precautions in anything other than special cases. He suggested that freshly treated timber be covered during air drying and that framing timbers and weather boarding should not be left without roof or paint for weeks at a time. Where this is unavoidable, a safety factor of twice the efficacious boric acid equivalent (BAE) retention is suggested.

The current specification of boron retention, (0.4 % BAE minimum cross-sectional retention) is actually based on Harrow's original work with *Anobium* spp. and the use of this safety factor, in addition to one of four times the efficacious retention to allow for possible variation in treatment (toxic threshold against *Anobium punctatum* = 0.05 % BAE)

Figure 1
Mean Loading of Preservative Determined from Analysis of Timber Exposed to the Weather

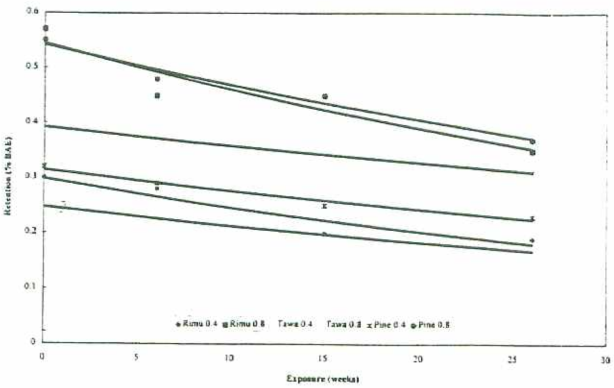


Table 1
Mean Loading of Preservative Determined from Analysis of Timber Exposed to the Weather
(% BAE W/W oven dry wood, five replicates used for each mean)

		Treatment Concentration	
Timber Used	Exposure	0.4% boric acid	0.8% boric acid
Rimu 4" X 1"	Unexposed	0.30	0.57
	Exposed		
	6 weeks	0.28	0.45
	15 weeks	0.20	0.45
	26 weeks	0.19	0.35
Tawa 4" X 1"	Unexposed	0.23	0.40
	Exposed		
	6 weeks	0.24	0.36
	15 weeks	0.21	0.35
	26 weeks	0.16	0.31
Pine 4" X 2"	Unexposed	0.32	0.55
	Exposed		
	6 weeks	0.29	0.48
	15 weeks	0.25	0.45
	26 weeks	0.23	0.37

From Harrow (1951)

In another study reported by Harrow (1960) a fruit store was constructed with exterior walls of treated and painted weather boarding in 1948. Low retentions of boron were used (0.1% BAE), to compare toxic thresholds obtained in the lab with those found in an actual service situation. Over an eleven year period, with the release of several thousand *Anobium* spp. beetles within the building, no loss of efficacy was shown by the presence of bore holes in the boron treated timber. Many bore holes were produced in the untreated timber. Furthermore no appreciable loss of boron seems to have occurred over this time period, even though butt joints in the weather boarding were not protected by metal covers, which is the normal practice for weather board butt joints. After 25 years and a total of 1650 inches (41910 mm) of rainfall, the boron treatment was reported to be still giving good protection against attack (McQuire, 1974). Modern test procedures for coated timber in service have also demonstrated good levels of protection, as illustrated in 'L joint' data developed by Forintek Canada (Morris, 1995). Hemfir lumber that had been dip-treated with borates to a lower than normal retention of 0.25 % BAE were subjected to a conventional 'L joint' study, used to evaluate preservatives for exterior joinery. The wood was additionally protected by a three coat paint system in this test, with the joint broken in the conventional way. After five years exposure in Vancouver, B.C. and an annual precipitation of 40 inches (1016 mm), the thirty treated samples were all free of decay. In contrast, 11 of the thirty untreated joints had failed and 11 others were showing some signs of decay.

More recent studies, with un-coated systems, than those of Harrow, include those by Williams & Mitchoff (1990) and Roff (1984). Williams & Mitchoff examined the loss of boron and efficacy against termites. Feeding and survival of the termite *Reticulitermes flavipes* was prevented on disodium octaborate tetrahydrate (DOT - available commercially as Tim-bor® wood preservative) treated pine (*Pinus* spp.) and oak (*Quercus* spp.) after a 30 month (2.5 years), above ground weathering period. The total rainfall over this period was 145 inches (3683 mm). The pine and oak (2 X 6 X 120" boards) were treated by dip immersion for 1 minute in heated 29 and 50.6% BAE concentrations respectively, followed by 8 weeks diffusion. Although some loss of boron did occur during exposure, sufficient DOT remained in the timber to allow only a negligible weight loss (< 4 %) of the wood.

Roff (1984) in a similar situation, reports that utility grade Hem-fir lumber treated with DOT by diffusion remained protected against decay, when stored exposed to the weather, over a 2 year period. Untreated control lumber showed significant signs of decay after 12 months. It was also found that the treated timber had retained more than half the initial loading and that the 1/9 central core still retained 75 % of the original loading. Also unlike the untreated controls, the DOT treated lumber was protected against infestation by the damp wood termite *Zootermopsis angusticallis*.

In pre-creosote treatment applications of DOT carried out to utility pole material, superficial spray application lead to the protection of the material from both insects and decay fungi for 18 months and longer (Dickinson & Murphy, 1991; Lloyd, 1994a). This material, treated and left exposed for this amount of time has also shown rather remarkable levels of penetration, with the DOT appearing to wash into the timber and being mobilized to treat newly exposed areas, exposed as a result of checking during drying (Lloyd, 1994a; 1994b).

A similar phenomenon has been demonstrated by the work of Barlow & Robinson (Robinson, 1995). They carried out superficial *in situ* spray applications of 10 % DOT to dry pine which left nearly all the loading on the surface of the timber. This timber was then exposed to 0.25 inches (6.35 mm) of simulated rainfall per day for a period of 28 days (178 mm total). This exposure resulted in a redistribution of DOT to deeper levels within the wood. However, based on the total level of boron left in the three zones, exposure also resulted in a 37 % and 48 % boron loss in the two applications investigated. Although efficacious levels of boron were still maintained, even at this level of loss, such superficial applications with such high losses would clearly be frowned upon by the pre-treatment industry. Their results are shown in table 2. This work is of particular interest, however, as it shows clearly the ability of borates to redistribute *in situ* and the importance of total sample analysis when carrying out boron depletion work.

Table 2
Amount of Boron (ppm) in Wood at the Surface and at Four Depths Below the Treated Surface of Pine 24 hours after Treatment and after Exposure to Simulated Rainfall (total 178 mm)

Wood m/c (initial)	Surface	1 mm	2 mm	2.5 mm	3 mm
Unexposed					
10 %	13918	2326	456	282	81
20%	14201	1068	219	96	78
Exposed					
10 %	2348	2417	2038	1119	886
20 %	1724	1526	2540	1503	2663

From Robinson (1995)

An interesting study on DOT treated wood in a ground contact situation has been reported by Arthur (1967). In 1961 the Forest Research Institute of the Forest Department, Federation of Malaya, initiated long term durability tests on keruing railway sleepers double treated with DOT and 50/50 creosote diesel fuel. A total of 180 treated railway sleepers were laid in the main line of the Malayan railway between Gemas and Batu Anam with the object of observing their performance in service. In addition to the above test a further twelve sleepers containing DOT of which only six were additionally treated with the creosote/diesel mixture, were prepared in order to determine boron losses as a result of in service exposure over a five year period.

These ties were treated by a full cell vacuum pressure process to retentions of the order of 0.7 to 1.7 % BAE and were found to contain about 0.3 to 0.5 % after the five years exposure. The rates of boron loss, initially fairly rapid at higher retentions, showed a marked tendency to diminish with time. The application of the creosote/diesel mixture to half of the sleepers was found to reduce the rate of boron loss, so that after the five year exposure period the boron loading remained some 20 - 25 % higher than the sleepers treated with DOT alone. The actual results for each sleeper analyzed are given in table 3 and have been shown graphically in figure 2.

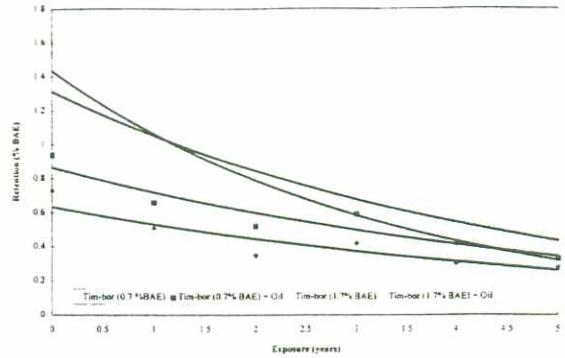
Table 3
Mean Annual DOT Loading Within Each Set of Sleepers (second and third set over treated with oil)

Boric Acid Equivalent, % (ODW)						
Sleepers	Initial	1st year	2nd year	3rd year	4th year	5th year
T181-3	0.73	0.51	0.35	0.42	0.30	0.28
T184-6	0.94	0.66	0.52	0.59	0.42	0.33
T187-9	1.64	0.94	0.63	0.84	0.44	0.52
T190-2	1.68	1.02	0.62	0.69	0.34	0.39

From Arthur (1967)

In another more rigorous ground contact stake test carried out by Orsler & Holland (1993), some relatively high DOT retentions were observed after exposure. In this test, Scots pine stakes measuring 50 x 50 x 500 mm were vacuum treated prior to exposure. The data obtained (tables 4, 5 & 6) demonstrated that as much as 40 % of the calculated retention was lost in the first six months but that this level then remained reasonably constant at efficacious loadings with further exposure (The data actually

Figure 2
Mean Annual Loading of Tim-bor Determined from Analysis in Each Set of Sleepers



shows only a 35 % loss at the 12 month determination). It should also be noted that the 0 time figure already shows only 88 % of the original loading, which suggests that this retention determined by analysis should be taken as the starting retention and that the overall losses are therefore lower (26% at 12 months). The results have also been expressed graphically in figures 3 to 5.

Table 4
DOT Content (kg/m-3 BAE) In Successive Increments From the Radial Face of an Above Ground Portion of Stakes After Periods of Exposure Half Buried in the Ground

Distance from surface (mm)									
Months	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18
0	9.28	4.7	3.74	3.15	3.02	3.15	3.31	2.74	3.08
1	3.51	3.3	3.57	3.04	3.28	3.44	3.35	3.1	1.55
2	5.44	3.31	3.59	5.01	3.96	3.73	3.95	3.61	1.58
3	4.37	3.51	4.18	4.03	4.23	4.69	4.16	3.49	3.84
6	7.04	3.93	2.32	2.72	1.65	1.51	1.25	1.31	1.02

From Orsler & Holland (1993)

Figure 3
Boron Content In Increments From the Radial Face Of An Above Ground Portion of Half Buried Stakes

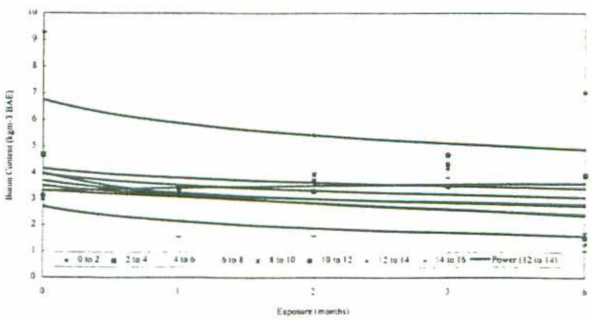


Figure 4
Boron Content In Increments from the Radial Surface of a Below Gorund Portion of Half Buried Stakes

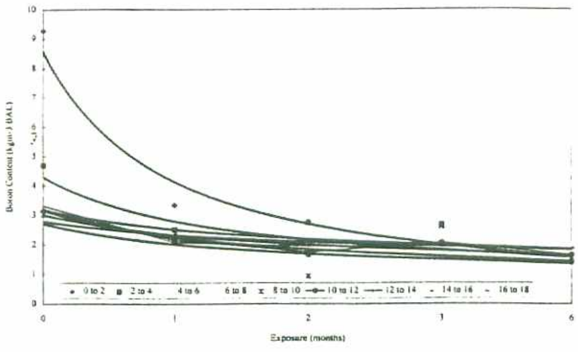


Table 5
DOT Content (kg/m-3 BAE) In Successive Increments From the Radial Face of a Below Ground Portion of Stakes After Periods of Exposure Half Buried in the Ground

	Distance from surface (mm)								
Months	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18
0	9.28	4.7	3.74	3.15	3.02	3.15	3.31	2.74	3.08
1	3.35	2.52	2.14	2.2	2.15	2.16	2.08	2.37	2.41
2	2.78	1.66	0.98	1.63	0.93	1.75	1.95	2.19	2.67
3	2.53	2.67	2.5	2.56	2	2.06	1.97	1.81	1.9
6	1.39	1.43	1.54	1.43	1.55	1.65	1.6	1.88	1.71

From Orsler & Holland (1993)

Figure 5
Total Boron Recovered from the Stakes after Exposure Half Buried in the Ground

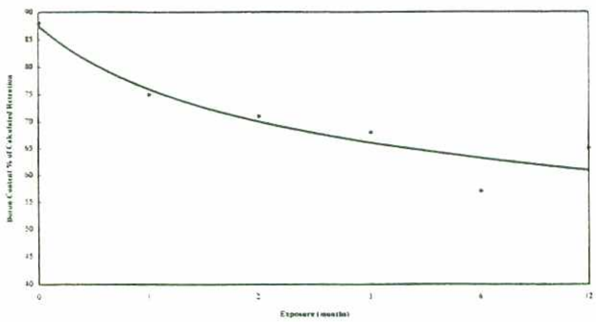


Table 6
Total DOT Recovered From Stakes After Exposure Half Buried In The Ground

Exposure (months)	0	1	2	3	6	12
Recovery (% of calculated retention)	88	75	71	68	57	65

From Orsler & Holland (1993)

Table 7
% Boric Acid equivalent remaining after exposure to different rainfall intervals

Rainfall Interval (mm)	Dry Wood Samples % BAE Remaining										Ave	Std	Cov (%)	Confidence -95	Confidence +95
0	0.9	1.0	0.9	0.8	0.7	0.8	0.9	0.9	0.8	0.5	0.85	0.13	16.45	0.764	0.936
10	1.1	1.4	0.8	1.1	0.8	1.1	1.4	0.9	1.2	0.8	1.06	0.22	21.06	0.92	1.19
25	1.0	1.1	1.0	0.9	0.8	0.9	1.0	1.0	0.9	0.6	0.92	0.13	13.73	0.84	0.99
50	1.2	1.1	1.1	1.1	1.1	1.0	1.0	1.0	0.8	1.0	1.03	011	10.81	0.96	1.10
75	0.8	0.7	0.6	0.7	0.8	0.9	0.8	0.7	0.8	0.7	0.75	0.08	11.05	0.70	0.80
100	0.9	0.9	1.0	0.8	0.9	1.0	1.0	0.6			0.89	0.12	13.23	0.80	0.97
150	1.1	0.9	0.9	0.9	1.0	1.0	0.9	0.9			0.93	0.07	7.03	0.88	0.97

Table 8

Rainfall Interval (mm)	Wet Wood Samples % BAE Remaining										Ave	Std	Cov (%)	Confidence	
														-95	+95
0	1.0	0.8	0.7	0.7	0.6	1.0	0.7	0.6	0.6	0.7	0.77	0.14	19.55	0.684	0.856
10	0.9	0.7	0.6	0.6	0.6	0.9	0.6	0.5	0.5	0.6	0.64	0.14	22.13	0.55	0.73
25	1.4	0.7	0.7	0.7	0.7	0.9	0.6	0.5	0.6	0.7	0.73	0.25	34.27	0.58	0.89
50	0.7	0.8	0.7	1.1	0.1	0.9	0.8	0.9	1.0	0.9	0.79	0.25	31.68	0.63	0.94
75	0.8	0.6	1.2	0.6	0.8	0.9	0.7	0.7	0.6	0.9	0.79	0.17	21.57	0.68	0.89
100	0.9	0.5	0.8	0.9	1.0	0.6	0.9	0.8			0.79	0.16	20.14	0.68	0.90
150	1.0	0.5	0.8	1.2	0.6	0.9					0.81	0.24	29.17	0.62	1.00

Figure 6
DOT Remaining After Exposure to Rainfall (Dry Wood)

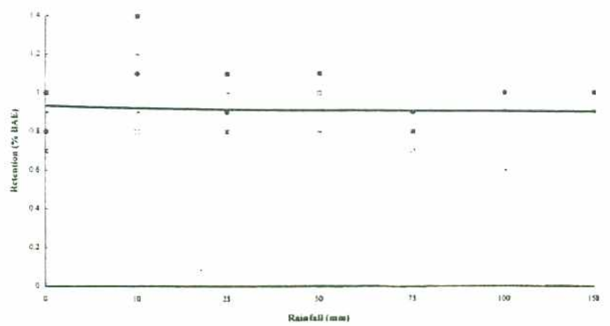
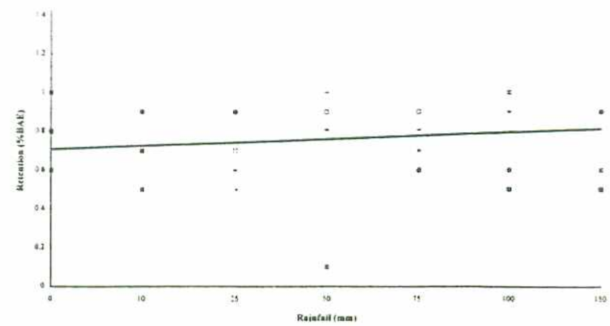


Figure 7
DOT Remaining After Exposure to Rainfall (Wet Wood)



The most recent study, using an accelerated leaching test has been carried out by the CSIR to asses the rate of boron loss from sawn lumber pressure treated with DOT to termite control retentions (5 kgm-3 BAE) in South Africa. This work was primarily carried out to determine whether short term external storage of timber would have a deleterious effect on its durability performance (Turner & Conradie, 1994). One set of the pressure treated timber (pine) was exposed immediately after treatment, as it was argued that freshly treated timber may be more susceptible to boron losses than treated and subsequently dried material. A second set was dried prior to exposure to the same leaching regime. Both were exposed to incremental rainfall levels, up to a total of 150 mm, which represents up to 2 months rainfall in South Africa and would complement the results of Harrow (1951) which supplied data for exposure starting from 140 mm. The results gained have been shown in tables 7 & 8. No trend for boron losses emerged from either set in this study (figures 6 & 7) and the results showed no significant difference between those gained for exposed and unexposed samples, even at these higher loadings. From these results the authors concluded that exposure to rainfall levels of less than 150 mm poses no threat to the durability of performance of the DOT treated wood. The results also corroborate the work of Harrow (1951) which shows no significant losses at 140 mm (figure 1).

Discussion

The analysis of the data and conclusions reviewed here which have been produced by many authors over many years has been both a useful and interesting exercise. Whilst it of course remains true that boron compounds can be removed from treated timber under certain conditions we now have a much clearer picture of these conditions and the levels of loss which can occur in certain situations. Leaching is actually defined as 'causing a liquid to percolate through some material with the view of removing the soluble constituents'. Clearly, such a situation can only be generated in very severe test situations and the passage of water through treated timber rarely occurs in commercial use. The process by which boron may be lost from treated timber actually appears to be much more one of diffusion rather than that of the general perception of leaching. It is necessary for the boron to diffuse to the surface of the treated timber, if any loss is to occur to the surroundings. Diffusion is, of course, a function of concentration, temperature and moisture content. On the basis of this, the depth of penetration of liquid water and subsequent sample re-drying become very important factors.

Probably the most interesting point to have come out of this exercise is the reduced rate of boron loss which occurs with time. This may be as a result of the retention approaching a level too low to continue to actively drive the diffusion process. This appears to occur well above the toxic limit with regard to decay and beetle attack, at between 0.2 to 0.4 % BAE. A loading of 0.4 % is actually the normal recommended target retention, so one could conceivably ask why so many workers have observed losses in exterior trials. This can probably be answered because most investigations on the leachability of borates have actually been carried out using significantly over-treated timber (where the diffusion pressure, related to concentration, encourages artificially high losses), severe test situations and small test samples. This is seen clearly in the work carried out by Harrow (1951), Becker & Buchman (1966), Arthur (1967), Orsler & Holland (1993). Some tests are quite extreme, such as the 'shower test' of Esser *et al.* (1995) where 70 litres of water per day were passed through another 'L joint' for a period of 10 days. The real life significance of this work is surely questionable. Boron retentions in many tests are often as high as 2% BAE but even in these situations the rate of loss is dramatically reduced at a loading of about 0.4 %. This can be seen for example, if the graphs of the data produced in the ground contact exposure tests of Arthur (1967) (figure 2) or the stake tests of Orsler & Holland (1993) (figures 3 to 5) are extrapolated. It could be envisaged that depletion rate will be reduced further and that the loading within the wood will remain high enough to maintain efficacy over very many years. It could perhaps be hypothesized that if timber is treated to a starting retention of only 0.4 % by a penetrating process, the losses which will then occur in a hazard class 3 situation (un-coated) will be negligible and long term protection could be expected.

In a review given by Carr (1962) he states that: "commercial experience with borates over a period of about 20 years in Australia and about 10 years in New Zealand has shown that boron compounds can be safely recommended for preservation of building construction materials that will be used under conditions that do not involve direct contact with the ground and where protection by roof and/or paint is ensured." He goes on to state that: "for boron leaching to occur wood must be thoroughly wetted throughout its cross-section and must be in constant contact with water or moist medium into which diffusion of the boron can occur. Hence, thorough wetting of wood cannot by itself cause leaching; a protracted process permitting the continued removal of boron is also required. Therefore, damaged roofs or burst water pipes can seldom cause severe leaching of boron unless neglected for years." More than 50 years of commercial experience now supports these words of Carr (1962) and the findings of many previous authors.

By way of illustration, a further truly commercial example is given in the form of a housing complex in Wellington, New Zealand (Anon., 1994). This demonstrates the possible extremes of 'exposure during construction'. Unfortunately the construction company involved in this example went into liquidation in 1990, prior to completion of the property and failed to install the walls or roof. The boron treated framing has remained in this condition for a period of five years and has effectively become a long term boron exposure test site. The annual average rainfall in this area is 50 - 60 inches per year and the severity of this 'test' situation was apparent by the pooling of water and growth of algae in many parts of the building.

Analytical tests carried out on samples taken from the building show that efficacious boron loadings still remain (0.2 - 0.4 % BAE in the samples analyzed to date) and a physical inspection confirmed that these loadings are still actually providing protection. There was no apparent fungal decay or insect damage in the boron treated framing which could not be said of the untreated OSB flooring, which showed signs of physical decay and a proliferation of basidiomycete mycelium and fruit bodies.

The mobility of inorganic boron based preservative systems should be considered a major asset in many areas of current application. Borate remains one of the only preservative active ingredients that is able to provide deep penetration and hence full protection of refractory species such as spruce and hemfir. Even when not applied throughout the cross-section initially, boron compounds can usually be relied upon to provide full cross-sectional protection when exposed to hazard. With a continuing increase in environmental concern, the ability to remove a preservative from a timber commodity at the end of its desired service life, through extraction processes without burning (such as hot aqueous extraction of wood chips), may become an additional asset in the future.

Conclusions

The following conclusions can been drawn from the data reviewed in this paper.

- Treatment specifications to ensure application by a penetrating process and a minimum cross-sectional retention of 0.4 % BAE counter any actual or perceived potential loss of efficacy due to exposure of un-coated timber during construction.
- Boron treated timber for general building use in a European hazard class 1, 2 or protected 3 situations (or their equivalents in other countries) can be used on the basis of existing data and will provide long term protection.
- Exposure after treatment or on site of construction for more than a few months should not be recommended, as with any construction timber, but would not have any deleterious effect on efficacy.
- Even in a worst case scenario during construction, with exposure over many years, usually recommended boron retentions will not be reduced to below efficacious levels.
- The rate of boron loss due to exterior exposure is significantly reduced at retentions below 0.4 % BAE, to a point where it appears to become negligible.
- Boron treated timber could possibly be used on the basis of efficacy and potential boron loss, in an unprotected above ground situation.

The nature and extent of previous work carried out in this area has demonstrated the need for the development of additional studies in the area of long term boron performance in exterior situations and the possibility of expanding the current applications specified for borates. The advent of suitable exterior above ground-contact tests, such as the lap joint test is certain to increase the latest wave of interest in boron based wood preservatives and will hopefully expand our knowledge and use of this most remarkable group of preservative systems.

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