FUSED BORON ROD TREATMENT OF HERITAGE STRUCTURES.

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Introduction

Public Works Canada is responsible for the maintenance of wooden structures owned by the Canadian Parks Service, including wooden buildings of heritage value. Control of the cost of maintaining these structures is being addressed through appropriate use of preservative-treated wood. However, for structures already in place, techniques for eliminating localized decay are required. Such decay may arise because of building design or because checking of large treated timbers has exposed untreated wood. In 1990 a project was intitiated by Public Works Canada to evaluate fused borate rods for remedial treatment of heritage structures. The study reported here is part of that project and describes the evaluation of fused rod treatment for preventing or eliminating decay in wood in service.

The potential of boron compounds as wood protecting agents has long been recognised (2). In 1979 research in Sweden identified the benefits of using boron based pastes for the remedial treatment of railway ties, to extend their service life (5). However, the study also highlighted the need for a highly concentrated source of boron for use in remedial treatment. The fused borate rod (IMPEL™ rod) was developed in response to this need. Much of the early experimentation focused on the use of the borate rods for the protection of window joinery (7). These researchers showed that the boron diffused rapidly from the site of deposition when the moisture content exceeded 25 to 30 percent. The target inhibition dose of 1.5 kg/m^3 boric acid equivalent (BAE) was reached at 11 to 12 cm from the treatment point in approximately 9 months. Complete eradication of all fungi was achieved in about 40 percent of the windows examined.

The remedial treatment of railway ties with borate rods was first described by Beauford and Morris in 1986 (3). They noted that decay in the Douglas-fir (*Pseudotsuga menziesii*) and European redwood (*Pinus sylvestris*) ties was most commonly associated with the major check on the upper surface. Distribution of the boric acid was good, particularly along the central core adjacent to the check. Examination of the most probable pathways of water entry into the commodity, enabled the placement of the rods to be optimised. This is most important if the maximum

effectiveness of the rods is to be realized. Further research has confirmed the value of borate rod treatment of railway ties (4, 15) as well as extended the application to poles (9, 10, 12).

The movement of boron in wood is clearly influenced by both water movement and the moisture content (13, 16). Morrell and coworkers have reported the diffusion of boron from rods placed in Douglas-fir heartwood. At moisture contents above 40 percent the boron diffused well, particularly in the longitudinal direction, with substantial quantities at 7 cm from the injection point.

However, very little research has been published on borate rod remedial treatment in heritage structures. Dickinson (8) at the First International Conference on Wood Protection with Diffusible Preservatives, described the use of borate rods and boron pastes to treat several ships of historic interest. They included the Mary Rose and the Wasa, two wooden ships which sank over 400 years ago and were recovered from the sea, as well as two more recent naval vessels the Wapama and the R.R.S. Discovery.

The objective of the study reported here was a) to confirm in a controlled laboratory investigation that borate rod treatment could erradicate or prevent decay in pine; and b) to demonstrate the effectiveness of fused rod treatments in eliminating decay in wooden structures under Canadian climatic conditions.

Materials and Methods

(i). Laboratory study using selected decay fungi.

Fifty ponderosa pine (*Pinus ponderosa* Ait.) sapwood test samples, 150 mm x 25 mm x 25 mm, were prepared and sorted into five groups. One of these groups was retained as test controls. The variables to be studied were: the decay fungi; and the sequencing of the innoculation with the decay fungi and the remedial treatment with borate rods. The fungi selected for the study were *Postia placenta, Gloeophyllum trabeum* and *Coniophora puteana*. All three fungi are commonly used in laboratory evaluations of preservative effectiveness in softwoods and have been isolated from wooden structures. The *C. puteana* species (#31095) included in the investigation was isolated from the McLean's Mill on Vancouver Island and was identified by the Biosystematics Research Centre, Ottawa.

Following preparation of the test samples from the kiln dried lumber, three holes 6 mm diameter and 15 mm in depth, were drilled in one face of each piece. All the holes were aligned along the central axis of the face, with two of the

holes located 10 mm from each end, while the third hole was centred on the face, (ie. 75 mm from each end). Thirty two test samples were pressure impregnated with water to raise their moisture content to approximately 100%. They were allowed to condition in the laboratory until the moisture content decreased to approximately 50 percent, based upon their weight. The samples were sealed in plastic bags and sterilized by 2.5 Gy of gamma irradiation.

Small ponderosa pine sapwood cores (5 mm in diameter and 5 mm in length) were placed for ten days on an agar medium in prepared petri plates containing actively growing cultures of each of the of the fungi. The infected cores were used to innoculate the test samples.

Nine test samples were selected and borate rods placed in the centre hole and fungal inoculum (infected cores) placed in each of the outer holes (figure 1). The amount of boron rod added to each sample was 1.0 g of Boric Acid Equivalent (B.A.E.) which corresponds to approximately 0.7 g of rod. Three replicates were used for each fungus. An additional eighteen samples were infected with the decay fungi, but had no borate rods installed. These were the samples in which rods were to be installed at 4 and 8 week intervals following inoculation with the fungi. The objective of this last test variation, was to evaluate how well the boron will control decay fungi at different stages of fungal colonization. As before there were three replicates for each fungus. Finally, six samples were prepared with either only fungi or only borate rods. These were the reference controls for the experiment.

Nine samples innoculated with the same fungal species were placed together in a sterile container with vermiculite wetted to 100% water holding capacity. The containers were sealed with lids in which six holes 5 mm in diameter had been drilled and then each fitted with a 25 mm 2 micron Millipore filter. The moisture content of the vermiculite was monitored by weighing the containers every three weeks. When necessary, sterile water was added to maintain the moisture level in the vermiculite.

After 12 weeks the test samples were taken from the containers. The end 10 mm section was removed from each sample, to measure the final moisture content of wood. A 10 mm slice was then sawn horizontally from the upper surface of each test sample. The freshly exposed surface of this slice was sprayed with circumin reagent to display the longitudinal movement of the boron. At the same time a small piece of wood was removed at 5 mm intervals from the matching surface of the test sample for re-isolation of the test fungus to establish its viability (Figure 1). Each sample was then cross cut at 10 mm intervals and the cross sectional surface sprayed with the reagent to show the

radial and tangential movement of the boron. From the matching face which was not sprayed with reagent three samples for fungal isolation were removed preferentially from regions failing to respond to the indicator, where these were present.

(ii). Field Study to evaluate decay at McLean's Mill.

An initial examination of several structures was made to determine those to be used in the project. McLean's Mill a sawmill located at Port Alberni, was selected as a suitable field location to demonstrate the ability of IMPEL™ fused borate rods, to control active decay in timber. It is no longer operational and is being considered for conversion to an industrial museum. A preliminary examination of the structure was made, during which the Douglas-fir timbers in a section of the sub floor were cored in an attempt to isolate active decay fungi. The presence of decay was indicated by mycelium covering the wood surface. Five cores were removed from each of three locations. They were brought back to laboratory and placed on specially prepared 2% malt extract agar (containing 100 ppm of benomyl), to facilitate the growth of decay fungi. Following sub-culturing two decay fungi were isolated. These were identified by the Biosystematics Research Centre, Ottawa as *Coniophora* sp. with one being further identified as *C. puteana*, an active wood destroying fungus often found in wooden structures.

The section of the floor at the McLean's Mill, where these decay fungi were found, was selected for the evaluation of the remedial treatment. A matrix of borate rod treatment sites was drawn at each of the three locations and holes drilled into the sub floor to allow the placement of the rods (figure 2). At each location the separation of the holes within each row was 10 cm. while the rows were placed approximately 8 cm. apart. Following insertion of borate rods (18 mm in diameter and 75 mm in length containing 57.4 g B.A.E.), the holes were sealed with rubber stoppers.

After three months 15 cores from each location were removed to determine the viability of the decay fungi. Cores were taken from three zones:- between borate rods, and at 50 mm and 100 mm intervals from the outer line of the rods (figure 2). The cores were placed on a malt agar medium as described above and incubated at 24°C for two weeks. The presence or absence of fungal growth was recorded, and cores were removed from the medium and sprayed with curcumin indicator to determine distribution of boron. The fungi isolated from the wood were examined under the microscope to confirm that they were the *Coniophora* sp. isolated earlier.

Results and Discussion

(i). Laboratory study to control selected decay fungi.

At the end of the twelve week test period the moisture content of all the samples ranged from 39% to 42%. At these moisture levels rapid diffusion of the boron would be expected. They would also support vigorous fungal attack of the samples so that the objective to assess the ability of the borate treatment to eradicate selected decay fungi present in wood will be confirmed.

In the untreated control samples the decay fungi were able to completely penetrate the wood during the twelve week test period indicated by the success in re-isolating the test fungi at all locations in the samples (Table 1). At the same time, in uninoculated controls boron diffused from the rods to fully pentrate the wood. The presence of boron was even indicated by curcumin on the cross sectional ends of the test samples, 70 mm from the treatment site. The holes in which the rods had been placed were empty, indicating 100% depletion of the boron. If the boron had been distributed uniformly throughout the sample the retention would be 10.7 kg/m^3 B.A.E. This is above the target retention of 6 kg/m^3 usually suggested for field treatments using fused borate rods. However it is likely that the distribution will be non-uniform particularly in those samples where the borate diffusion time was restricted to four weeks.

Based upon a visual examination of the exposed surface of the 10 mm horizontal slice removed and sprayed with the circumin, the samples which were innoculated with decay fungi and treated with boron showed distinctly different degrees of boron penetration, which depended on the duration of boron treatment. Samples in which borate rods had 12 or 8 week diffusion periods were generally almost completely penetrated, although the colour intensity varied, particularly near to the innoculation point. Those with only a four week diffusion period following the eight week fungal incubation, showed a strong red colour up to 45 mm distant from the treatment site. However, the cautionary comments of Edlund (11), and Carey and Bravery (6), concerning the sensitivity of the curcumin reagent on decayed wood should be noted. They reported that even wood which did not respond to the circumin reagent contained measurable amounts of boron. Thus the lack of a red colour in the test samples can not be taken to indicate the absence of boron. It has been suggested that the curcumin reagent has a detection threshold of 0.3 % B.A.E., which in these ponderosa pine samples would translate to a retention of 1.3 kg/m^3. The actual boron retentions achieved in the samples can only be identified by chemical analysis and these are planned.

Cross-sections removed at each isolation location when

sprayed with indicator showed full boron penetration among samples decayed by *P. placenta*, in which borate rods were placed either at the same time as the fungus or four weeks after fungal innoculation. Samples which had been incubated for eight weeks prior to borate rod treatment showed almost no colour near to the surface. However, attempts to re-isolate the fungus from those parts of the cross section failing to react to the indicator were unsuccessful. A similar analysis on the test samples infected with *G. trabeum* showed less marked colour changes due to the presence of boron, after spraying with the curcumin reagent. Nevertheless, subculture with inoculum taken from every 5 mm cross-sections was only successful with three sections taken close to the point of innoculation (Table 1). These were the located at 45, 55 and 60 mm from the boron treatment site, in samples where the diffusion period for the boron was limited to the final four weeks of the twelve week test.

Samples innoculated with *C. puteana* showed the same trends of a limited boron diffusion with the shorter diffusion periods, and a general failure to re-isolate the fungus after boron diffusion, except for those located close to the innoculation point (Table 1).

It is of interest to compare the relative resistance of the three fungi tested to the borate treatment. There were clear indications from the degree of survival of the fungus that *C. puteana* is more tolerant to boron than either *P. placenta* or *G. trabeum*, and that *P. placenta* is easily controlled by boron. This is consitent with results reported by Baechler and Roth (1) who showed that the toxic limits of *G. trabeum* were 0.80 to 1.24 kg/m^3 B.A.E., while those of *P. placenta* were 0.38 to 0.80 kg/m^3. It should also be noted that the toxic thresholds reported by these authors for fungi are below the 1.3 kg/m^3 detection threshold for the curcumin reagent. This may explain the failure to re-isolate the fungus in some regions which did not react to the reagent.

(ii). Field Study at the McLean's Mill.

The results from the decay evaluation and borate rod treatment of the sub floor at the McLeans Mill, are shown in Table 2. Moisture content measurements made during the initial site visit were above 40 percent and remained at this level when evaluated three months after treatment. Thus good diffusion of boron can be anticipated. Active decay fungi were isolated from all five cores taken from two of the three test locations in the sub-floor prior to boron treatment (I and III). Three of the five cores in the remaining test location (II) produced decay isolates during the preliminary examination. Thus all three test locations contained active decay fungi prior to treatment.

When the procedure was repeated, some three months after the

fused borate rod treatment, no decay fungi could be isolated from cores removed between the rows of rods at two of the three treatment sites. Since the rows were spaced 8 cm. apart, this would suggest that the boron had successfully diffused laterally a distance of 4 cm. The remaining test location (III) yielded one isolate for an 80% success rate in eliminating the decay fungus.

Efficacy of borate rod activity 50 mm beyond the outer line of treatment was slightly lower. In one location one of five cores (20%) yielded the decay fungus, while in the second site two cores (40%) contained an active decay fungus. The third location was again clearly less well treated since four of the five cores (80%) produced active fungal growth on the medium. The lower success rate at 50 mm beyond the lines of treatment can be explained by the observation that boron from only one row of sites can migrate to the evaluation point. Thus it is clear that while some boron has diffused to re-isolation point the retention achieved is clearly insufficient to completely erradicate the fungi. Since some boron rod remained in the treatment hole after the three month test period, it may be anticipated that further diffusion will take place, and a more effective performance may be found if the sub-floor was resampled after a longer time period, eg. 12 months. The lower effectiveness in eliminating fungi at test location III (table 2) may indicate either a lower moisture content in the timber at this location, or the presence of less permeable heartwood.

Cores taken 10 cm from the row of rod treatment sites (at sampling location 3 in table 2), showed lower success in eliminating the fungus. Even so in two locations two of the five cores failed to yield an active decay fungus. This would indicate that the diffusion of the has been effective up to 5 cm from the treatment site, and some boron has diffused to almost 10 cm.

It is of interest to note that the decay fungus present in the McLean's Mill is a *Coniophora* sp., since *C. puteana* is known to be tolerant to boron. A laboratory study using 50 x 100 mm western hemlock (*Tsuga heterophylla*) boards showed that approximately 4 kg/m3 BAE were required to eliminate decay (14).

The examination of cores removed from the test site after three months for presence of boron using the curcumin reagent gave variable results. All sites where the fungi were re-isolated failed to react to the reagent. However, some cores failed to react with curcumin even though no fungi could be isolated.

Conclusions

It may be concluded from the study that:

- fused borate rod treatment of heritage timber structures can erradicate active decay fungi.

- borate rod treatment of above ground timber in service can prevent decay fungi becoming established.

Acknowledgements

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Table 1. Success in re-isolating the test fungi after borate rod treatment at 0, 4, and 8 weeks following fungal innoculation. Sampling locations for re-isolation are at various distances (mm) from the treatment site (*).

	Distance (mm) of isolation point from treatment site												
	60	50	40	30	20	10	*	5	15	25	35	45	55
G. trabeum	Y	N	N	N	N	N	*	N	N	N	N	Y	Y
C. puteana	Y	Y	Y	N	N	N	*	N	N	N	N	Y	Y

Note: All untreated controls re-isolated at every sampling point for all three fungi.

P. placenta could not be re-isolated with boron rod treatment at 0, 4 or 8 weeks.

G. trabeum could not be re-isolated with boron rod treatment at 0 or 4 weeks.

C. puteana could not be re-isolated with boron rod treatment at 0 or 4 weeks.

Table 2. Isolation of *Coniophora sp.* from timbers at McLean's Mill.

Isolation before treatment		Location	Re-isolation Frequency	
No.	%		No.	%
Sampling site I				
5	100	1	0	0
		2	1	20
		3	3	60
Sampling site II				
3	60	1	0	0
		2	2	40
		3	3	60
Sampling site III				
5	100	1	1	20
		2	4	80
		3	5	100

Locations: 1 is located between treatment sites, 5 cm. from treatment site.
2 is located 5 cm. from line of treatment sites.
3 is located 10 cm. from line of treatment sites.

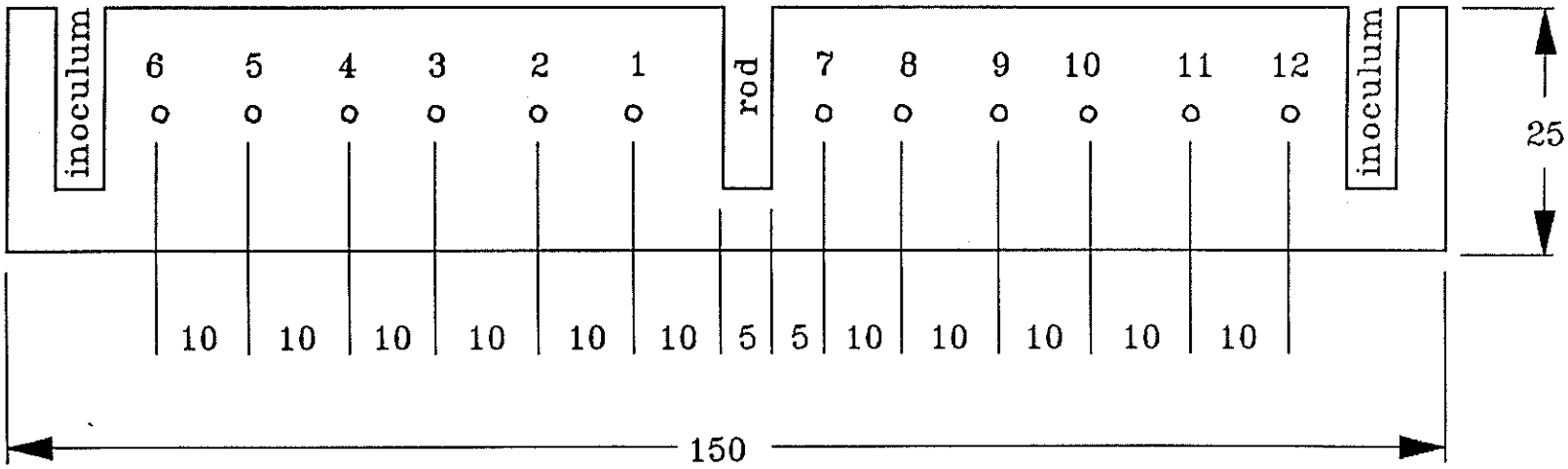

Figure 1. Diagram showing location of treatment and fungal inoculation sites and sampling points for fungal re-isolations.

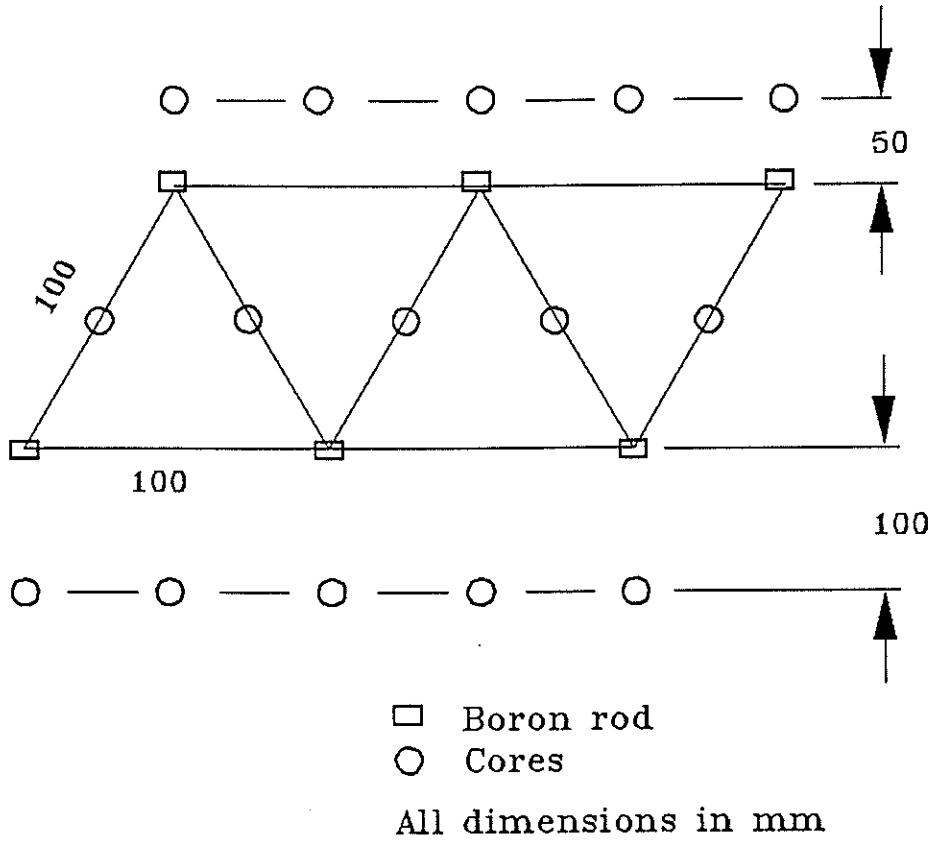

Figure 2. Location of boron rod treatment sites and core removal for fungal isolation.