Remedial treatment: in-situ treatments and treatments of historic structures

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Abstract

In recent years the use of borates for remedial treatments has become more important. Although in-situ treatments do not necessarily use large amounts of chemical in comparison to pretreatment, the associated technology can represent significant developments. The use of different forms of borates especially designed for in-situ treatment are reviewed and illustrated by specific case histories.

Borates have been used as active ingredients in most areas of wood preservation for many years. Early work by Bateman and Baechler, and Cummins pointed the way to the exploitation of borates as wood preservatives (2,12). Several reviews on the use of borates have been published, by Bunn, Carr, and Cockroft and Levy (8,10,11). In recent years interest in borates has gathered momentum in the United Kingdom and the United States and the situation has recently been reviewed by Barnes et al. and Dickinson and Murphy (1,16).

The main areas of interest and the biggest use of borates in wood preservation has been, and probably always will be, the pretreatment of timber. The scope and breadth of papers at this meeting demonstrate this point. There is little doubt that the future of borates as wood preservatives is in the area of pretreatment. The development of application technology and modifications of formulation will be the key to an almost certain greater success in the future.

However, in recent years several interesting applications and forms of borate preservatives, not necessarily for pretreatment, have been studied and reported. Although many of these examples represent a limited specialized market, they serve well to illustrate the special properties of this active ingredient. Borates have time and again proved ideal for specialized preservation requirements, even though the total chemical usage may be limited. In this respect borates can be considered as a tool of the conservation wood technologist, principally involved in remedial and in-situ treatment or in the conservation of wooden structures and artifacts.

These specialized uses of borates often take advantage of several valuable properties of the preservatives — diffusibility, spectrum of biological activity, and ability to formulate borates in a variety of forms — making its application suitable for a range of environments and structures. In addition, the low mammalian toxicity of the inorganic borates is important when the chemical is used in situ and where total chemical containment is not certain.

The examples contained in this paper are not intended to form a comprehensive list of the specialized uses of borates, but they have been chosen to illustrate how the various properties of borates can be utilized. It is hoped that this will stimulate further development and use of borates for specialist wood protection. The author has been personally involved in several of the examples discussed but other examples, which are reported in the literature, are included to illustrate the specific uses of borates in the preservation and conservation of timber and wooden artifacts.

Developments with in-situ treatments

Fused borate rods

Probably the most significant advance in the use of borates for in-situ treatments has been the development and extended use of fused borate rods. In the mid-1970s a major project was conducted in Sweden on the in-situ treatment of railway sleepers with borate pastes (5). This work showed that while injection of the pastes was effective, what was really needed was a highly concentrated borate in a soluble form, but where the solubility was controlled. This led to the development of the fused borate rod. Ironically, their use in railway sleepers was not adopted in Sweden but has since been used in the United Kingdom.

At about the same time in the United Kingdom important work was being carried out on the early stages of decay in window joinery (9). The progress of colonization of painted joinery out of ground contact was characterized by large increases in permeability, progressing along the grain from the joint. These regions become much wetter after rain. The area most at risk from decay was susceptible to wetting up to high levels prior to decay; water was entering the end grains and at some stage at least, moving along the grain (14).

Initial trials in the United Kingdom and major field and laboratory experiments in Sweden clearly showed that the use of fused borate rods in joinery had great potential for the control of decay and successful remedial treatments have been carried out in Sweden since that time (13). The concept has been adopted in many other countries and similar work in the United States is reported at this meeting.

Probably the most important concept that was established in this early work was the principle of establishing the pathways of water entry and intercepting these when inserting the borate rod. Recent work in the United Kingdom has shown that in steady state situations at low moisture contents (MCs) the diffusion of boron from rods is limited, emphasizing the need to establish where water is entering the system (7) and placing the rods to intercept the water and therefore distribute the borates into the timber.

Treatment of railway sleepers

This principle was the main factor influencing the work in a major trial conducted in the United Kingdom on the use of rods in railway sleepers. This trial was conducted by British Rail, Biokil Ltd., and Imperial College (3,4). The initial part of this investigation was concerned with establishing the main pathways of water entry and initiation of decay. By understanding the water relationships and its distribution patterns in the sleeper it was possible to determine the optimum position to place the borate rods. In softwood sleepers this position has been identified as along the central longitudinal axis where checks develop and water entry is initiated. Entry of water at the end grains with subsequent decay initiation was not found to be the case in sleepers. Decay is invariably initiated in the heartwood along the central axis. Application of rods at either side of the central axis along the sleeper length ensures rapid release of the preservative as water enters the sleeper to levels capable of controlling decay within 6 months. The rods continue to dissolve slowly and provide protection for many years, as leaching and water movement through the creosoted shell is limited. Since these trials the use of rods has also been extended to the treatment of large dimensional longitudinal bridge timbers for British Rail.

Treatment of transmission poles

Creosoted softwood transmission poles have given many years of excellent service in the United Kingdom. Their lifetime is often limited by internal heart rot, principally caused by *Lentinus lepideus*. It is arguable whether or not internal decay with sound, treated sapwood is a problem. However where the inner sapwood is poorly treated internal brown rot is very serious. Early trials indicated that borates were slowly redistributed from rods in the heartwood (19). Since then the use of rods as a supplementary treatment for wooden transmission poles in the United Kingdom and Sweden has been further studied (15,17).

After 6 years in the United Kingdom the results looked very promising. At MCs unsuitable for the initiation of decay (below 25%) the distribution of boron was limited up the pole but the groundline region was well treated. In poles where the MC was at least 30 percent the distribution after 6 years was excellent. The insertion of rods has now been optimized to give maximum distribution and minimum strength loss to the pole. Four rods are inserted at the ground line at right angles to each other and sloping down, deep into heartwood, at 45 degrees to the vertical. Initially it was intended to only treat sound poles at inspection but early results indicate that the rods are capable of controlling infection already established in the poles.

The work in Sweden on chromated copper arsenate- (CCA-) treated poles was not so encouraging because losses of boron were high. It would appear that the internal heartwood of creosoted poles does not present a leaching hazard, indicating that the early, prudent insertion of rods into creosoted poles in service will effectively treat the heartwood if it becomes wet and help prevent failure of poles in service due to infection of heartwood by brown rot fungi such as *Lentinus lepideus*. Further extensive trials designed to study the permanence of borates in heartwood of creosoted poles are in progress but already this cheap, effective prophylactic treatment has been adopted by several electricity boards in the United Kingdom. Work is also being initiated to study the insertion of rods at the ground line in new poles.

Most of the work on borate rods has established the need to understand the moisture characteristics of the commodity being treated. Ideally rods should be used prior to the establishment of decay in regions shown to be a risk during inspection. In certain commodities these criteria can be defined but the use of rods in wooden structures generally needs care due to relatively poor distribution at low MCs where established decay may survive. For this reason borate rods need to be supplemented with other treatments where infection at lower MCs is suspected. These situations are discussed and exemplified below.

Case histories of in-situ borate treatment

Certain preservation and conservation projects have necessitated the development of their own specific protocol and clearly demonstrate the versatility of borates for one-time treatments. Probably the most interesting and widely published examples of such treatments have been associated with archaeological artifacts, particularly wooden boats and maritime timbers. In such cases water availability for diffusion has not been limited and therefore allowed the use of simple solutions of inorganic borates.

Wasa

Worldwide interest was aroused in the 1960s by the recovery of the virtually intact Swedish warship *Wasa* which sank on her maiden voyage in August 1628. The Wasa is 180 feet (54.8 m) long and has a displacement of 1,400 tons. When she was raised to the surface her oak timbers were saturated throughout, and there was significant surface softening of those timbers which were not buried in the mud. Problems of restoring old waterlogged timber structures was not new, but the problem with *Wasa* was the sheer size of the structure. The use of polyethylene glycol for conserving small wooden artifacts was well established. Treatment with polyethylene glycol involved spraying over several years, a situation which presented a decay hazard to the vessel. The incorporation of borates into the spray solution proved very effective allowing the timber to be effectively treated by diffusion of the boron salts. Several mixtures of borates were used but eventually seven parts boric acid to three parts borax proved most stable with the polyethylene glycol used. Spraying started in 1962 and finally finished in 1979 (20).

Mary Rose

Some 400 years ago Henry VIII's flagship *Mary Rose* sank near Portsmouth Harbour. In 1982 she was finally brought to the surface after most of the artifacts she contained had been recovered by divers. The lessons learned from the *Wasa* were well appreciated by staff responsible for the *Mary Rose*. Articles which had been recovered from the ship were treated with polyethylene glycol and borate and stored in cold, humid conditions.

The hull itself was initially kept sprayed with recycled chilled water and constantly checked for biological degradation. When biological activity was confirmed a mixture of 'polybor' and a quaternary ammonium compound was introduced into sprays. It is planned to use polyethylene glycol as the consolidating agent, and borates will play a key role in preventing fungal decay during the treatment. Experimental treatments are presently being conducted to establish the best combination of borates and polyethylene glycols to be used (18).

In raised waterlogged timbers the use of borates in solution seems obvious as diffusion pathways are easily established. However simple borate solutions have also proved very effective in the conservation of other important wooden ships.

Wapama

Bianchini reported in 1988 the use of borates for the in situ treatment of the schooner *Wapama*, a 204-foot-long wooden boat commissioned in 1915 (6). She is currently part of the National Park Service's National Maritime Fleet in San Francisco, Calif. The ship is reported to be suffering from severe brown rot decay.

Multiple applications of aqueous Tim-Bor solutions have been applied to the ship's interior via an elaborate series of piping and valves. Subsequent monitoring of the timbers has confirmed that simple solutions of borates can be used for the preservation of wooden ships giving good chemical penetration where moisture is sufficient for fungal decay. Bianchini goes on to report that similar treatments are being considered in other historic ships in the United States.

R.R.S. Discovery

In the United Kingdom, a very similar chain of events has taken place in the treatment of ships belonging to the Maritime Trust. The application of hot borate solutions to wet, infected timbers has proved highly effective in controlling decay and treating the timber. Protocols are being developed to use borates in several forms depending on the MC, but where the MC is not limiting hot solutions of 30 percent polybor is the preferred method. Current restoration work of the Royal Research Ship *Discovery*, owned by the Maritime Trust but on charter to the City of Dundee Heritage, has played an important role in developing conservation strategies based on the use of diffusible borates. Liberal spraying of water-soaked timbers has given excellent control of decay. Other demanding challenges remain on *Discovery*, but borates will form the basis of treatment and conservation of this important piece of maritime history.

Great Eastern Slipway

In 1850 I.K. Brunel built the massive steel ship *Great Eastern* (12,000 tons). In 1984, the London Docklands Development Corporation discovered the relatively undamaged timbers of the slipway on which she was built and launched into the River Thames. The Corporation decided to retain and restore the most complete portion of the slipway.

Foundations for the slipway were provided by 30-foot piles driven into the river bank. The piles supported horizontal cross heads over which shaped pieces were placed to carry the timbers of the deck at a gradient of 1 in 12 down to the river. Detailed examination showed that all the timbers were pine, probably baltic redwood (*Pinus sylvestris*) imported from Scandinavia. The piles and cross heads had been squared to 12 by 12 inches and were 90 percent heartwood. Surface degrade was slight but any remaining sapwood at the corners was well degraded. Surprisingly, after 130 years burial in the anaerobic mud of the Thames, the bored timbers yielded the sweetly resinous odor of freshly felled pine. The heartwood MC was around 50 percent (i.e., that of freshly felled scots pine). Removal of the mud overfill created a decay hazard to the timber as the pine heartwood has little natural durability. A decision was taken to preserve, as far as possible, the exposed timbers. Conservation and consolidation of the softened outer surfaces and sapwood was considered impractical and so a strategy was devised to preserve the remaining timber as adequately as possible. All the timber that could be removed was transported to a warehouse, carefully dried over a 30-month period, and treated with CCA. This proven effective treatment was not possible for the piles driven into the river bank. It was considered that only the exposed upper ends of the piles merited preservation treatment because of the anaerobic conditions of the mud below.

Three treatments were employed to preserve the piles. Short-term protection, pending completion of the work, was given by application of Boracal 40 (40% polybor in monoethylene glycol) to exposed surfaces which were then wrapped in polythene to prevent drying out. The piles were excavated to a depth of 4 feet (1.2 m) and the lower 2 feet (0.6 m) were injected with COBRA DFA salts based on bifluorides. This zone was then sealed with bitumen paint. In the section of pile that was to be left exposed, i.e., the top 2 feet (0.6 m), the DFA salts were considered unsafe and so treatment was carried out with borates. Five vertical holes were drilled into the top of the piles 2 feet (0.6 m) down into the pile. The holes were filled with a pumpable 80 percent paste of Tim-Bor. Calculations had shown that if the holes were filled with Tim-Bor, twice the amount of chemical necessary for protection would be present. Smaller horizontal holes were drilled into the vertical holes to allow recharging of the holes in the future maintenance program. The holes were sealed with treated dowels and the end grains of the piles were coated with bitumen. The whole structure has now been rebuilt and the surface is to be treated with an effective water repellent finish. Regular inspections are planned and when necessary the vertical holes will be recharged with polybor paste.

Since then, the paste developed for the piles has been used experimentally to fill voids in transmission poles that have been reinforced with metal trusses. The paste is also being used for void filling at the heads of deck frames in the salt boxes on board *Discovery*. This pumpable paste will undoubtedly prove very valuable in situations where reservoirs of borate are needed in a similar manner to the fused borate rods, but where space and size is not limiting.

In-situ treatment of drier timbers

The major drawback with conventional boron based systems is that they require sufficient moisture to be present in the timber in order to establish a diffusion gradient. It could be argued that if there is insufficient moisture for diffusion then fungal decay will be controlled by lack of water. The main problem is that most decay fungi can remain viable at MCs of around 25 percent where boron diffusion is very slow as shown by Bravery (7). In such situations the use of localized pressure injection of organic solvent based chemicals in the drier region has proved successful in combination with boron based treatments. Imperial College and the Eastern Electricity Board in the United Kingdom are currently investigating other systems compatible with boron rods to treat the drier wood behind reinforcement wraps on transmission poles. Combinations of borate rods with organic solvent pressure injection, fumigants, and fluoride treatments are being investigated.

Solutions of borates in monoethylene glycol as a cosolvent system has also proved very effective for treating the drier areas of timber in situ. The product Boracol 40 is proving very effective for delivering and distributing boric acid in drier timber. Patented multichannel delivery systems have also been developed to give good initial distribution through a single injection point. Boracol has been used in Sweden for several years to treat the drier regions of window joinery such as the center of sills, with boron rods in the wetter regions and near the end grains in joints (13).

Summary and conclusions

The use of borates will undoubtedly increase in wood preservation. Although the bulk chemical use will principally be in pretreatment of timber, specialist use of borates will also continue to gain in importance, particularly for the treatment of old wooden artifacts. At present borates are used in several forms and the user needs to carefully design the treatment protocol to suit the individual situation. Fused borate rods are ideally suited for the localized treatment of very wet areas and for the strategic placement at points of water entry. They can also be inserted into potential danger areas where water ingress is possible and likely to cause decay problems. Such areas are near end grains and joints in structures, or where checks are likely to develop.

Many wooden artifacts are waterlogged and structures like wooden boats often contain large volumes of very wet wood. In such situations the use of simple water solutions, often with repeated applications, can give very effective in-situ diffusion treatments. Research is still in progress to study the use of borates alone, and in combination with other chemicals to treat drier regions of timber, but solutions of borates in monoethylene glycol can give good distribution in drier wood.

The choice and use of borate systems for treatment of artifacts and for in-situ treatments requires care and must always be part of an overall strategy. Scope for other novel formulations exist, e.g., systems to deliver borates to large surface areas in inaccessible situations. Such systems will be developed when the need arises as was the case in the past with the development of existing systems.

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