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RECENT DEVELOPMENTS IN BORATE WOOD PRESERVATION

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Summary

Borates have been used as wood preservatives for over 75 years – providing excellent control of wood destroying organisms such as decay fungi and termites. Because of their water soluble nature, the use of borates have been limited to applications where the wood is used in protected, above-ground applications such as lumber for residential construction. In recent years, lower solubility borates such as Zinc Borate ($2ZnO \cdot 3B_2O_3 \cdot 3.5H_2O$) have been used as preservatives to treat wood- and wood-plastic composites which are used in less protected applications such as exterior siding and above-ground decking. This paper will also highlight the current situation with the use of borates as preservative treatments in the Pacific Rim and in emerging applications such as the dual treatment of railroad crossties to help increase the service life of these commodities.

1. Introduction

Boron containing wood preservatives are all derived from naturally occurring borate minerals. Probably the most commonly used form of boron for the preservative treatment of solid lumber and plywood is the compound Disodium Octaborate Tetrahydrate (DOT, $Na_2 \cdot B_8O_{13} \cdot 4H_2O$), sold under the trademark *Tim-bor*® Industrial (U.S. Borax Inc.). Borates in general, and *Tim-bor* Industrial in particular, possess a number of properties that help to make them unique wood preservatives: they are inorganic salts – stable, odorless and non-volatile. They exhibit low mammalian toxicity while being highly toxic to all wood destroying organisms (termites and decay fungi) and unlike some organic insecticides there has never been any recorded instance of wood destroying insects developing a resistance to borates. They have a near neutral pH, are noncorrosive, colorless and offer no significant impact on strength at preservative levels leaving the wood with strength properties similar to untreated wood.

These factors together with a changing world that has become more focused on the use of environmentally sound and sustainable materials for construction have helped to make borate-treated lumber the optimal choice for residential construction. Building with borates provides a safe, effective and economic solution that allows wood to continue to be used in rigorous environments that might otherwise necessitate the use of alternative materials like steel or concrete.

When used correctly, borates can give effective long-term treatment that is also economical and environmentally sound. Borates possess a very favorable eco-tox profile and they occur naturally in seawater, fresh water, rocks, soils and all plants. The earth consists of trace amounts of more than 200 minerals that contain boron. In trace amounts, they are essential micronutrients for plants and believed to be nutritionally important for humans. Like many trace elements, borates are both essential at low concentrations and toxic at high concentration – allowing them to be effective preservatives against wood destroying organisms.

Boron compounds in current use as wood preservatives are susceptible to leaching under certain conditions, as they are not chemically fixed within the wood. A common misconception is that small amounts of moisture will readily leach boron out of the wood – this is simply not the case. In order for leaching to occur there needs to be a situation where liquid water is entering the wood at one point and then leaving the wood at some other point, also as liquid water.

More recently engineered wood products such as Oriented Strand Board (OSB) have become the preferred choice for structural panel in residential construction, easily surpassing the use of plywood in North America. It is not possible to treat OSB with the waterborne preservatives that are used for lumber and plywood. A safe, economical and effective preservative treatment for OSB is *Borogard*® ZB (U.S. Borax Inc.) which has become the most widely used preservative treatment around the world for strand-based engineered wood building materials and has been in commercial use for more than 15 years. The *Borogard* ZB is added to the composite material during its manufacture. Engineered wood products treated with *Borogard* ZB have been evaluated in severe field tests in Hilo, Hawaii and the Northern Territory of Australia – exhibiting excellent performance against the world's most voracious species of termites. More recently, *Borogard* ZB has become the preferred treatment for wood-plastic composites (WPCs), protecting this emerging class of materials from decay fungi and termites and improving their performance against mold.

2. Health and Safety Update

From a Health & Safety perspective, borate wood preservatives are thought to be environmentally benign and possess low acute mammalian toxicity (similar to that of table salt); they have been used safely as wood preservatives for over 75 years. Unfortunately, even with this excellent profile, borates have recently been classified as a reproductive toxicant by the European Union. This decision was made after more than ten years of debate and has largely been based on animal studies where rats were fed extremely high levels of boron. These levels would never be reached in humans during the normal handling and use of borates. The labeling threshold for borates is 3.1% B_2O_3 (equivalent to 5.5% BAE). Wood preservation formulations containing 5.5% or more of boron expressed as Boric Acid would fall under the new labeling regulations. Typical retentions used for wood preservation are ~2% BAE and less - as such, these treated wood products would not fall under the new labeling regulations. Borates have been listed on Annex 1 of the Biocidal Products Directive (98/8/EC) which confirms that borates (boric acid, sodium tetraborates, DOT and boric oxide) can be used as active ingredients in Wood Preservatives (PT08) in Europe.

In the United States, the Environmental Protection Agency (EPA) has extensively reviewed borates. The National Center for Environmental Assessment (NCEA) conducted a multi-year assessment under their IRIS program of more than 200 studies on borate's health effects and concluded that people can safely consume more than twice the amount of boron previously considered harmless – increasing its allowable daily dose of boron from 6.3 mg to 14 mg per day. In fact, people's greatest exposure to borates is the one to three milligrams they eat every day as part of a healthy diet of fruits and vegetables, nuts and grains, wine and coffee. The EPA has recently conducted a TRED on Boric Acid and concluded there was no need for changes involving wood preservation uses.

Borates are essential to plants, and research shows that they are biologically important in animals and humans. As mentioned earlier, they are about as acutely toxic as table salt – in fact, most people's greatest exposure to borates is through a balanced diet. The decision to classify borates was primarily based on research conducted with animals forced fed borates at levels 1,000 times greater than dietary levels.

Both DOT and ZB are registered as wood preservatives in the United States (EPA) and Canada (PMRA):

- *Tim-bor*® Industrial
  EPA Reg. No. 1624-39
  PCP Reg. No. 18879

- *Borogard*® ZB
  EPA Reg. No. 1624-120
  PCP Reg. No. 23283

3. The New Zealand Experience

Radiata Pine was first introduced into New Zealand in the early 19th Century and its ability for fast, vigorous growth led to extensive use as a plantation species to help supply the domestic market for residential construction. It quickly became apparent that the sapwood of this material was susceptible to significant attack by the *Lyctus* species of wood boring beetles. In the 1940s, inspired by the initial effort in Australia, researchers in New Zealand identified boron diffusion treatment as an effective and economic treatment for Radiata pine used in residential construction and in 1953 the Timber Preservation Authority mandated the use of boron treatment as one of the approved options for protecting *Lyctus* susceptible building materials. Boron treatments received widespread use, supported by excellent performance and reasonable cost. In 1990 it was estimated that a borate treated framing package would add only ~NZ$100 to the cost of a typical three bedroom home in New Zealand.

In the mid-1990s some building code changes were implemented and it became acceptable to use kiln-dried lumber as an alternative to treated framing, removing the requirement for preservative treatment that had been in place for some 40 years. In less than 5 years time, the 'leaky building crisis' evolved and new construction that was built using untreated framing became susceptible to significant deterioration from fungal decay leading to a widespread problem with estimated damages in excess of NZ$ 1 Billion. This unfortunate episode served to highlight the decay protection which had been provided by the boron treatment and eventually led to a new set of building practices where, once again, preservative treatment became the preferred option. Boron treatments are once again the leading treatment for interior framing used in residential construction in New Zealand.

4. Use of Borate-treated Framing in Hawaii and California

Like many idyllic destinations, Hawaii offers a paradise-like environment that attracts visitors who travel there to enjoy the year-round warmth and tropical surroundings. Unfortunately, the environment in Hawaii challenges wood products with one of the more demanding exposure hazards found anywhere in the world. The same conditions that prove so enticing to both local residents and the several million annual tourists, also provide a near-perfect environment for the Formosan subterranean termite (FST - *Coptotermes formosanus*), a non-native pest that has wreaked havoc on wooden structures in Hawaii for over 100 years. Because of the threat afforded by the FST, local building codes have mandated the use of strategies aimed at protecting wooden structures from damage caused by the formidable Formosan. One of most important and widely used strategies has involved the use of wooden building materials that have been treated with preservatives to provide protection against wood destroying organisms such as decay fungi and the FST. The use of treated framing lumber in Hawaii has allowed wood to continue being utilized as a building material for residential construction, capable of competing with termite-resistant alternative materials such as steel and concrete. Borate-treated framing was first introduced into Hawaii in 1992 and within 2 years became the preferred treatment for the Douglas fir lumber that is used there – gaining a market share in excess of 90%, a figure that is still accurate today. Several thousand borate-treated homes have been built in Hawaii and, to date, there has still not been a single documented case of failure in service for wood that was adequately treated and properly used.

Like Hawaii, the residential construction industry in California prefers the use of Douglas fir lumber – a species that is extremely difficult to treat with most waterborne preservatives like CCA, and more recently ACQ and Copper Azole. The diffusible nature of borate preservatives allows for complete penetration of Douglas fir lumber. Since its introduction there in 1995, borate-treated sill plates have become the most widely used in the western region of the United States and once CCA was phased out in 2004 they became the preferred sill plate treatment for all of North America. Local building codes as well as the major model code (2006 International Residential Code, IRC) and the American Wood Protection Association (AWPA) recognize and approve the use of borate-treated lumber in accordance with all sections that require the use of preservative treated wood as sill plate (Dodai).

5. Borate-treated wood for durable construction in Japan

Durable wood-frame construction has become an area of increasing focus in Japan and the concept of a "100 year home" has been recently discussed. The successful use of borate-treated wood in areas of the world with similar exposure hazards suggest that integration into Japanese residential construction would provide a safe, effective and economical alternative to currently available building materials.

Use in Japan is supported by an extensive 10 year field test which was conducted by researchers from Kyoto University, Forintek Canada Corp. and the University of Hawaii. Samples of borate-treated Dodai were evaluated against the Formosan subterranean termite in covered, above-ground test units which were designed to simulate Dodai usage in a "worst-case" unventilated and humid Japanese crawlspace. The test units were placed directly on top of active FST colonies in Kagoshima Pref., Japan and in Hawaii. The 10 sets of replicates were inspected annually over the course of 10 years. Unlike typical residential construction, termite activity was encouraged and untreated feeder stakes were used to attract the termites into the test units. Comparative controls such as CCA and untreated Hinoki were also included in the study.

Borate-treated Hem-fir samples from the same 'mother' boards were exposed for 10 years at the test sites and at the end of the exposure were shown to have equivalent performance to CCA – the accepted industry standard at the time the test was initiated. The termite pressure was found to be more intense in Hawaii (~3x), such that 10 years of exposure there could be considered equivalent to ~30 years in Japan. After 10 years of exposure in Japan, there was no evidence for decay on any of the borate-treated samples while decay was found on 9 of the untreated Hem-fir samples and 6 of the untreated Hinoki. Both the untreated Hem-fir and Hinoki showed progressive termite attack in the first year at the Kagoshima site and were heavily attacked by the end of the exposure.

These results represent the longest running Formosan termite field test using full size material that has ever been carried out anywhere in the world and clearly demonstrate that Borate treated lumber would be suitable for use as Dodai in Japanese residential construction. Borate-treated wood can provide a safe, effective and economical solution to the challenges of durable residential construction in Japan.

6. Emerging Applications

The species, size and quality of standing timber available for harvest is changing world-wide and this is promoting the development and extended use of wood composites in applications which require resistance to wood destroying insects and decay fungi. Traditionally, solid wood products are pressure treated with solutions of preservative chemicals. However, the nature of a composite makes it possible to incorporate a preservative into the product during its manufacture. This decreases total production costs and yields a superior product in which the composite can achieve a constant loading of preservative throughout its thickness.

Both DOT and Zinc Borate (ZB, $2ZnO^{\cdot}3B_2O_3^{\cdot}3.5H_2O$) are suitable for incorporation into wood composites, although ZB has been used almost exclusively for exterior composite products where there is a perceived risk of leaching. Zinc Borate is a white odorless powder (median particle size of 9 microns) and is typically mixed in the blender with the wood furnish, adhesive and wax. ZB is manufactured by U.S. Borax Inc. and sold under the trade name *Borogard*® ZB (registered trademark of U.S. Borax Inc.). ZB exhibits low water solubility at room temperature (<0.28%, w/w) and provides efficacy, even after rigorous standard leaching tests. It is also relatively simple to incorporate ZB powder into a wood composite during blending.

Zinc Borate (ZB) currently dominates the in-process treatment (preservative added during manufacture) of engineered wood products in the United States and Canada. ZB is being used for the preservative treatment of commercial OSB sheathing and siding, MDF trim boards and other exterior products. More recently the manufacturers of Woodfiber-Plastic Composites (WPC) have recognized the susceptibility of these materials to wood destroying organisms and have begun treating these materials with *Borogard* ZB. In 2010, in excess of 50% of these materials will be preservative treated with *Borogard* ZB.

Railroad crossties have historically been preservative treated with creosote. When creosote is used to treat refractory hardwoods such as white oak, the preservative will not completely penetrate the crosstie and leaves a shell treatment. Untreated zones can be exposed when checks and cracks develop in-service, potentially allowing for decay to be established and reducing the effective service life of the crosstie. Recently, some railroads in North America have begun specifying the use of 'dual-treated crossties' to help protect these untreated zones and increase the service life. This concept of 'dual treatment' follows on from work established by Prof. Terry Amburgey of Mississippi State University and involves pre-treating the crosstie with *Tim-bor* during the air seasoning process and then following this with a conventional creosote treatment. The borate is allowed to diffuse into the heartwood during the seasoning process, providing protection throughout the cross-section and minimizing the potential for untreated zones following creosote treatment. The follow-up treatment with creosote also serves to help 'seal in' the borate preservative and reduce the potential for leaching. In 2009, greater than one million crossties (>5% of treated crossties) were dual-treated in this fashion – providing greater protection for the crosstie and helping to increase the service life in high hazard areas such as the Southeastern United States.

7. Conclusions

Wood is a cost effective and environmentally desirable material for construction. However, wood destroying organisms such as termites, carpenter ants, and decay fungi can challenge the durability and sustainability of wood framed structures. Borates are used to provide protection against wood destroying organisms. Borate wood preservatives have an excellent reputation for safety and performance – and this reputation has been built over many years of safe and effective use in various wood products. Borate-treated wood is an excellent fit with integrated pest management (IPM) approaches for controlling wood destroying organisms. The use of lumber and OSB panel that has been industrially pre-treated with borates provides a means to build homes that are durable, cost effective, and sustainable. The use of borates as preservative treatments for wood-composites and WPCs illustrates how these materials can provide protection to building products which would be difficult to treat using other preservative systems. The dual treatment of railroad crossties highlights the effective combination of borates and creosote to improve service life in high hazard areas.