CWPA Proceedings, 2002, pp 10-24

UPDATE ON BORATE WOOD PRESERVATIVES

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Summary

This paper provides an update on the current status of borate-based wood preservatives, with particular emphasis on the situation in North America. Borates have been used to preserve wood products for over 60 years. The water soluble nature of borates allows them to use the available moisture in wood and penetrate difficult to treat species by the process of diffusion. Currently, in the absence of a 'fixed' borate, the potential applications for wood products treated with boron are limited by their ultimate end-uses. However, with the trend toward the use of more 'environmentally sound' materials there has been a renewed interest in wood preservation with borates. This has been exemplified by the emerging market for treated structural systems in the mainland U.S., utilizing the favorable attributes of borate-treated wood to enhance building durability and sustainability.

1. Introduction

Boron containing wood preservatives are all derived from naturally occurring borate minerals. The mineral borax, $Na_2B_4O_7{\cdot}10H_2O$ is the most significant commercial source of B_2O_3; there are major deposits in both the United States and Turkey. Probably the most commonly used form of boron for wood preservation is the compound Disodium Octaborate Tetrahydrate (DOT, $Na_2B_8O_{13}{\cdot}4H_2O$), sold under the trademark *Tim-bor*® Industrial (U.S. Borax Inc.); it exhibits high water solubility and has a near neutral pH. Borates in general, and DOT in particular, possess a number of properties that help to make them unique wood preservatives:

- Inorganic salts (nonvolatile)
- Low mammalian toxicity
- High toxicity to insects and fungi
- No wood destroying insect resistance
- Odorless
- Near neutral pH
- Noncorrosive
- Colorless

- Strength properties similar to untreated wood
- Compatible with colorants if visual marking is desired

When used correctly they can give effective long-term treatment that is also economical and environmentally sound. Borates possess a very favorable eco-tox profile (Lloyd, 1997). 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.

Borates are members of a class of waterborne chemical preservatives which are diffusible in wood. Using the available moisture in unseasoned wood, the chemical redistributes itself after the treatment – diffusing from areas of high concentration (of chemical) to areas of lower concentration. The water-soluble chemical equilibrates in such a way as to remove the concentration gradient. This capability for the chemical to diffuse after treatment makes it possible to completely penetrate unseasoned wood, thereby allowing effective treatment of refractory species. The subject of diffusible preservatives has been recently reviewed in the context of these systems offering highly effective and flexible options, for both standalone preservatives and as components in more specialized formulations (Manning et al., 1997)

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. This topic is the subject of a recent review (Lloyd, 1995).

Because of this potential for depletion when exposed to significant moisture, borates are normally recommended for general building use in a protected environment and are not recommended for use in ground contact. This particular end-use is delineated in a borate treating standard that has been published by the American Wood-Preservers' Association: AWPA Standard C31-02 (AWPA, 2002), "Lumber Used Out of Contact with the Ground and Continuously Protected from Liquid Water – Treatment by Pressure Processes". More recently, the AWPA has moved to a Use Category System (UCS), utilizing a framework whereby the intended application (end-use) of the treated wood product is used to specify the appropriate standard and preservative retention. Borates are listed in AWPA Use Category UC1 and UC2. UC1 is for wood and wood based materials used in interior construction not in contact with the ground or foundations (e.g.., interior furniture and millwork). UC2 is for wood and wood based materials used for interior construction that are not in contact with ground, but may be subject to dampness – products that are continuously protected from the weather but may be exposed to occasional sources of moisture (e.g., interior framing and sill plates).

A number of recent trends are driving the development of wood preservation activity over the last decade. Among those highlighted have been: changing building practices (wood losing market share to termite resistant building materials such as steel and concrete), increased need for value added production and the emerging area of preservative treatment of wood composites (Vinden, 1990). These issues all have relevance to the current development of boron based wood preservatives in North America and will be discussed in the following section. There have been several reviews published on the use of these preservatives (Barnes et al., 1990; Cockroft and Levy, 1973; Lloyd, 1997) and a review of efficacy data against decay fungi and termites has also been compiled (Drysdale, 1994).

2. Results and Discussion

As described earlier, borates are referenced in the AWPA Book of Standards. The Standard for Waterborne Preservatives (Standard P5) lists Inorganic Boron (abbreviated as SBX) and the acceptable boron preservatives: DOT, Sodium Tetraborate, Sodium Pentaborate, Boric Acid and FR-1 (a fire retardant system containing boron). The species listed in AWPA Standard C31-02 as well as UC1 and UC2 are: Southern Pine, Hem-fir (Western Hemlock and Amabilis fir), Ponderosa Pine, Red Pine, Spruce-Pine-fir (SPF) and Coastal Douglas fir. The listing of Coastal Douglas fir includes a requirement for incising, while the listing for Hem-fir and SPF does not include an incising requirement. The absence of an incising requirement for these difficult to treat species is due to the diffusible nature of the borate preservative. Borates are also listed for the same species in the Canadian wood preservation standard CSA O80.34 (Canadian Standards Association).

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 (Laks and Manning, 1995 and 1997). 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 (Laks, 1999; Laks et al., 2001). ZB is being used for the preservative treatment of commercial OSB sheathing and siding, MDF trim boards and other exterior products. More recently there have been published reports (Simonsen, et al., 2002; Verhey et al., 2002) evaluating the use of ZB as a preservative for the treatment of Woodfiber-Plastic Composites (WPC). The AWPA has recently expanded its scope and now lists preservatives for nonpressure applications to wood products; ZB is listed in Standard P18, as a Nonpressure Preservative (AWPA, 2002).

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

The excellent performance of borates against decay fungi is highlighted in some L-Joint data developed by Forintek Canada (Morris, 2002). Hem-fir lumber was dip-treated with DOT to an average cross-sectional retention of 0.25% Boric Acid Equivalent (BAE) w/w and was subjected to a conventional L-Joint study (used to evaluate preservatives for exterior joinery; the treated wood is protected with a three coat paint system). A set of 30 treated samples was installed along with a set of 30 untreated samples. The results for average visual ratings after 12 years exposure are displayed in **Figure 1.** The untreated samples had an average rating of 1.5 (23 of the 30 untreated samples had failed) while the treated samples had an average rating of 9.3.

The samples were exposed in Vancouver, B.C. where the average annual rainfall is ~40”. After 5 years exposure a set of five treated samples were removed and chemical assays were carried out; these results showed minimal boron levels (0.02% BAE) in the area of the joint with evidence for a ‘reservoir effect’ with boron being depleted in the area of the joint while being replenished from the ends. Of particular note here is the protection against decay being afforded by the low levels of boron in the area of the joint. The boron is providing protection at retentions significantly below what is normally suggested as a toxic threshold - providing support that low levels of boron may inhibit spore germination. The excellent performance of the borate-treated samples after 12 years is even more noteworthy when one considers that the initial retention was approximately one-quarter of the AWPA Standard of 0.17 pcf B_2O_3.

The performance against termites becomes important when one considers borate-treated building materials as an effective tool in termite-resistant construction (*vide infra*). Until recently, there had been a debate in the AWPA over the appropriate retentions that are effective at controlling damage caused by the Formosan subterranean termite (FST, *Coptotermes formosanus* Shiraki). This led to the establishment of a footnote for the previously accepted retention of 0.17 pcf B_2O_3: "The use of this retention level is not suitable for exposure to the FST". Much of this debate was fueled by conflicting results from different field tests evaluating borates against the FST (Grace, 1997). The classic method of field stake evaluation for performance against termites is obviously not appropriate for borate-treated material and this has led to the development of a variety of other field test methodologies. These different methods share the need to have the borate-treated material in a protected, above-ground exposure to reflect end-use; because the samples are not in ground contact, untreated feeder stakes are typically used to attract termites to the treated specimens.

Integral to the success of any test designed to evaluate the performance of a preservative is the ability to accurately know the chemical retention which is being tested. Typically, chemical assays are carried out on borate-treated samples which are end-matched to the exposed specimens, yielding data on retentions at the start of a test. At the conclusion of the test, chemical assays can be carried out on the exposed specimens, providing verification of the initial loading in addition to checking for any possible redistribution which may have occurred during the test.

Field tests evaluating borate-treated Hem-fir lumber against the FST in a covered, above-ground exposure have been carried out by researchers in Hawaii, Canada and Japan (Grace et al., 1995). This test is still on-going with end-matched samples exposed to active FST colonies: one piece evaluated in Hawaii while the 'sister' piece is exposed to an FST colony in Japan. After five years in Hawaii and six years in Japan, the borate-treated samples are exhibiting performance equivalent to that of the 0.25 pcf CCA (Copper Chrome Arsenate) which is being evaluated as a comparison control in the same test. Results from these tests were instrumental in helping to establish an AWPA borate retention for exposure to the FST: 0.28 pcf B_2O_3.

Wood is a common structural material, used for building most homes and some commercial buildings in North America. This widespread use is due to wood's desirable performance properties, abundance, cost effectiveness, ease of use, and favorable environmental attributes. However, wood can be degraded by various wood-destroying organisms (WDO) such as termites and decay. The remainder of this paper highlights the use of treated wood structural systems to enhance building durability and sustainability.

Wood destroying organisms (WDO) such as termites and decay fungi have an indispensable presence within the earth's ecosystem; they recycle dead trees and other plant materials into elements essential to life. Their presence is ubiquitous and large; for example, it is estimated that termites have a biomass of one thousand pounds for every person on earth (Conniff, 1998).

Building codes recognize that the termite infestation potential is highest in California, the southeastern U.S., Hawaii and Puerto Rico, whereas the decay potential is highest in the southeast and along both coasts (**Figures 2 and 3**). Additionally, highly destructive species of non-native termites such as the Formosan subterranean termite are increasing in population and range (**Figure 4**). As of January 2001, over ninety counties/parishes have been confirmed to have active infestations of the Formosan Subterranean termite (FST).

Comparing the termite and decay hazard profiles with new home building activity shows that nearly half of all new homes are built in areas of significant termite and decay hazard (U.S. Dept. of Commerce, 1999). As a result we find that many new homes are suffering damage from WDO. At a national level, it has been estimated by the Wood Protection Council of the National Institute of Building Sciences that the annual cost to replace wood severely damaged by decay and termites increased from $750 million in 1988 to over $2 billion in 1993 (NIBS, 1993). The economic loss continues to grow with some estimates indicating that Florida and Louisiana each spend $1 billion per year to repair and treat damage caused by WDO.

The desire to protect buildings from WDO is well established and evident in mandates by building codes in many regions of the United States as well as in standards required by home mortgage lenders. The predominant method of protecting homes requires establishing a barrier against subterranean termites by treating the soil under and around homes prior to construction and treating in and around existing homes when termites are detected. Additionally, treated wood is used for selected building elements such as sill plates. This approach provides some relief, but even perfect barriers don’t protect structures against airborne termites such as Formosan and drywood termites, carpenter ants, or from wood decay. Chemical barriers degrade over time and are often destroyed in the construction process or by simple homeowner activities such as landscaping.

Historically, organochlorine pesticides such as chlordane, aldrin, and heptachlor were used to place a chemical barrier at the soil level. These materials were long lasting (30 to 50 year life) and the vapor pressure from these materials would “fill in” any missed or disturbed areas to provide a continuous layer of protection. These properties, while functionally desirable in a termiticide, were environmentally unacceptable. As a result, chlordane and other organochlorine pesticides were removed from the market in the late-1980s. The current termiticides are less persistent (effective working lives of about 5 years) and much less forgiving of applicator error and physical disturbances.

The inadequacy of the current mitigation method for WDO has become apparent in many areas of the continental U.S. In Florida, for example, a statewide commission of entomologists, builders, architects, pest control operators, and government officials found that in 1993, 72% of pest control operators (PCOs) had pre-construction treatment failures within 5 years of treatment and that the failure rate was 92% for post-construction treatment (Florida Dept. of Agriculture, 1994). In Louisiana, PCOs are enduring significantly more liability claims from ineffective termite treatments (Ring, 2000). The consequences to the homeowner are increased risk of property damage, increased maintenance expenses, and the constant stress of worrying about what's happening behind the walls.

It is generally acknowledged that total eradication of WDO is not a realistic goal and that pest control efforts should be focused on limiting the risk to buildings through an integrated pest management (IPM) approach involving proper design, construction, building materials, and the judicious use of pesticides. An often discussed IPM approach for WDO is the Six "S" strategy (Morris, 2000), involving:

- Suppression
- Site management
- Soil barriers
- Slab and foundation details
- Structural protection
- Surveillance and remediation

Suppression involves programs to reduce termite populations over large areas. This typically involves government-sponsored initiative such as Operation Full Stop to reduce Formosan termites in the French Quarter in Louisiana. In most locales, however, there are no area-wide suppression programs. Site management is essential to good design and construction practices. It involves grading the site to ensure that water drains away from the structure and clearing the site to ensure that there is no wood debris or tree stumps buried on-site to attract termites. It also involves ensuring that there is no wood-to-soil contact for untreated wood. Soil barriers involve placing a chemical or physical layer at the foot of the structure. With the current soil termiticides, chemical barriers must be reapplied over and over. Physical barriers are a new approach and they can include such items as 4" thick layer of precisely sized sand or crushed stone or stainless steel termite mesh. Slab foundation details involve using the physical structure of the slab as a physical barrier. Subterranean termites can pass through cracks that are as narrow as 1/25" and subterranean termites build earthen, shelter tubes to pass from the soil into building. Hence, slabs and foundations should include details so that shrinkage cracks and other openings are less than 1/25", metal termite shield are placed between the foundation and the sill plate, and exterior wall coverings such as stucco, brick veneer, or siding does not extend below grade to provide a hidden passageway for termites. Structural protection requires building wall and roof assemblies with materials that are resistant to WDO and designed to properly manage moisture. Even with these mitigation methods working, regular inspections should be performed to identify any problems and to take corrective actions while the problems are manageable.

Structural protection for WDO involves two basic elements: 1) managing moisture within the building assemblies and 2) choosing materials that are protected against WDO. Sometimes, non-wood building materials are chosen solely because they are resistant to decay and insect attack, when wood products would otherwise be the material of choice. However, common building materials such as steel and concrete can increase the water loading in the building envelopes, providing a more favorable environment for wood destroying organisms. Water can condense on the steel frame members, creating problems of corrosion, decay and insects. Concrete is a porous material and allows moisture to migrate and accumulate on the cool side of the block wall, creating a condition for WDO to prosper.

Wood that has been industrially pre-treated with borates has been successfully used for structural systems in various parts of the world where termites, decay, and other wood destroying organisms pose significant problems. This has resulted from the realization that it is far more cost effective and environmentally responsible to provide lasting, built-in protection to the very building components and systems that are susceptible to degradation than to provide remedial protection year after year.

In New Zealand, for example, the use of borate-treated lumber and panel for the entire structure has been standard practice for over 50 years. New Zealand is a country where the weather is often wet and the homes are commonly wood-framed. As a result buildings are at risk from decay fungi, as well as wood boring beetles. Borate treated wood has shown excellent performance as a building material in the wet environment encountered by builders in New Zealand. There is virtually no remedial treatment industry in New Zealand (Vinden, 1990); this is in marked contrast to the situation in the United States, where there are significant expenditures every year to treat and repair damage caused by WDO.

In Hawaii, the use of treated wood for structural systems has been standard construction practice for decades. The practice was embodied into the building codes in the mid-1980s and all wood framing was required to be constructed with pressure treated wood. When borate-treated wood was introduced into the Hawaiian market in 1992, it quickly became the most widely used framing material. Hawaii is believed to have the highest Formosan termite pressure in the United States as the FST was present in Hawaii for several decades before they were introduced into the mainland U.S. Formosan termites are the most voracious, destructive and difficult to control among all economically important wood destroying organisms in the U.S.. In this very tough environment, borate treated wood has performed well in field tests and structural systems built with borate treated wood have an exemplary record in real world use.

The success in the use of borate wood preservatives for treating structural materials is due to its many performance attributes. Borates have a well-established record of performance against a broad spectrum of wood destroying organisms. Borates are cost effective and easy to use for the preservative treatment of solid sawn lumber, plywood, and wood composites such as oriented strand board (OSB). Lumber and plywood is pressure treated with waterborne borates such as DOT, whereas with OSB the borates (ZB) are added to the wood composite during the manufacturing process. In treated wood, borates are colorless (although a dye is often added); non-volatile and robust so they don't evaporate, degrade or produce an odor during service; and are non-corrosive, requiring no special fasteners. The implication to builders and designers is that significant protection against termites and decay can be built into the structure without having to make drastic changes in design or to the construction process.

3. 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.

4. Literature

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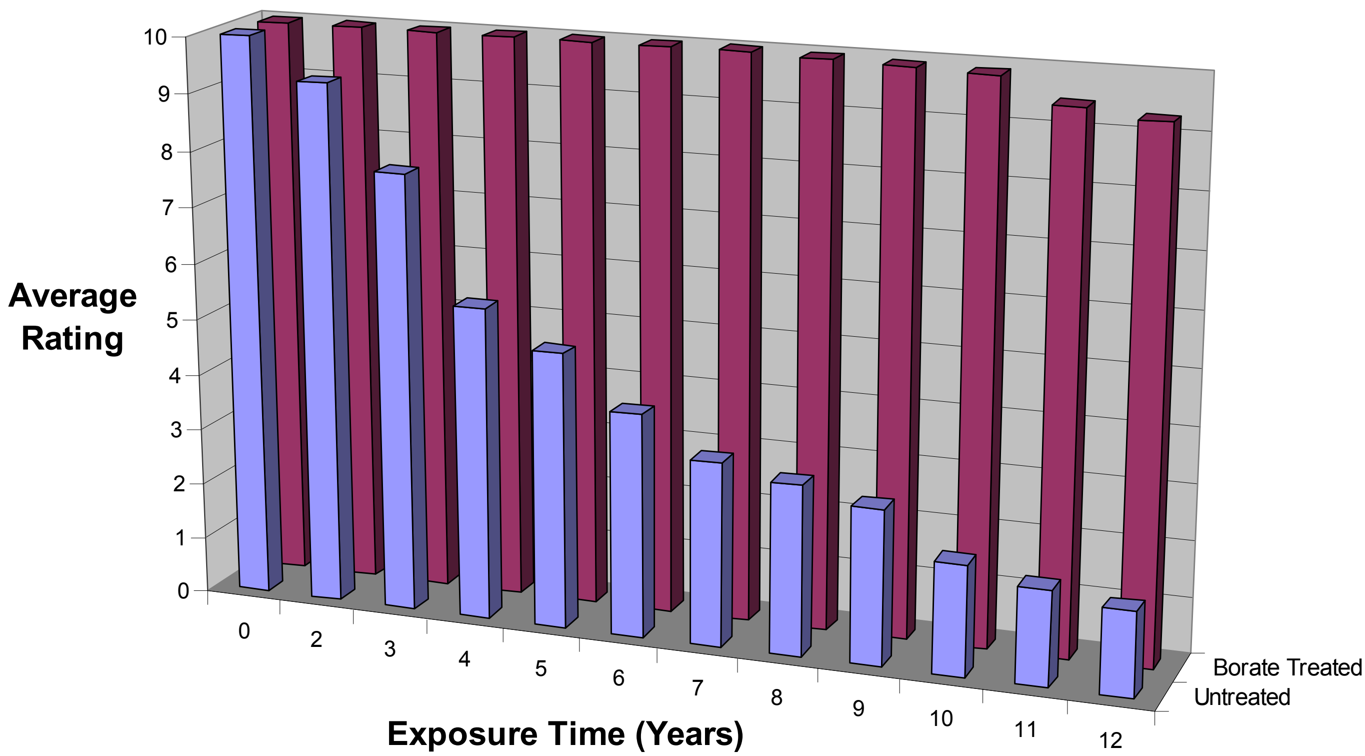


Figure 1. Average visual ratings for L-Joint samples exposed for 12 years in Vancouver, B.C.

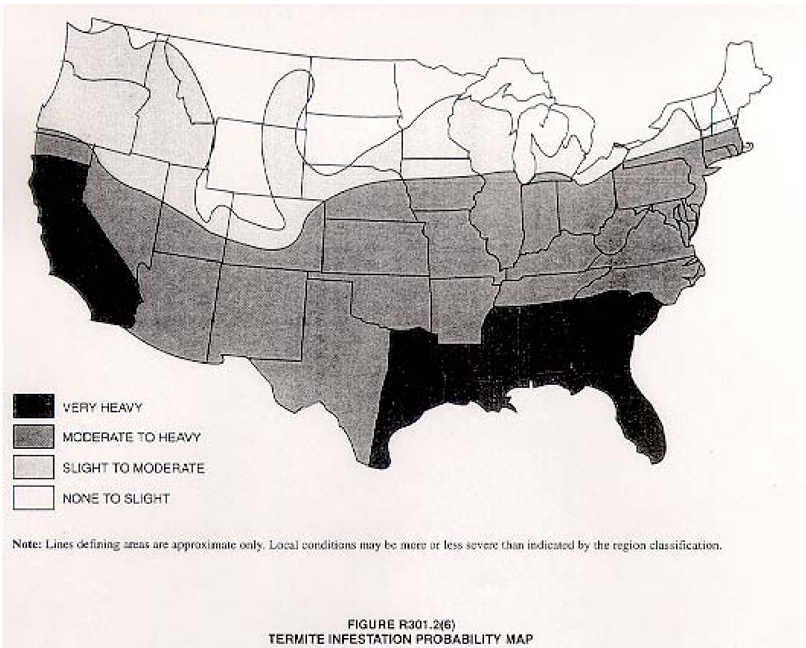
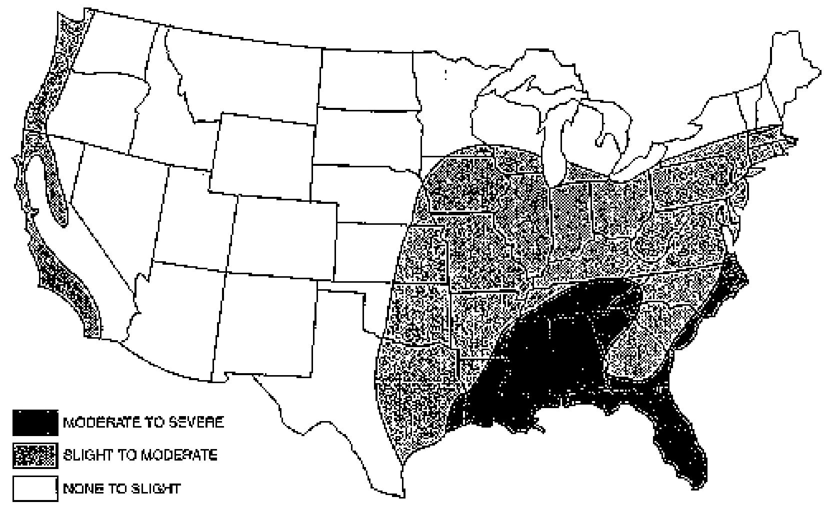


Figure 2. Termite Probability Map (Source: 2000 International Residential Code)



Notes: Lines defining areas are approximate only. Local conditions may be more or less severe than indicated by the region classification.

FIGURE R301.2(7)
DECAY PROBABILITY MAP

Figure 3. Decay probability map (Source: 2000 International Residential Code)

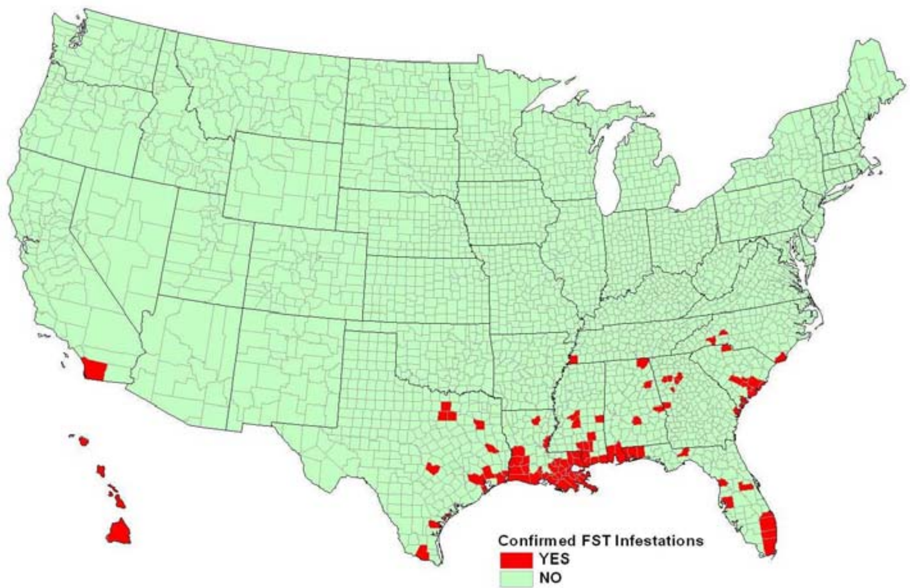


Figure 4. Confirmed FST infestations (Source: Woodson et al., 2001)