Structural use of bamboo: Part 2: Durability and preservation

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Structural use of bamboo
Part 2: Durability and preservation

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Synopsis
Bamboo is a strong, fast growing and very sustainable material, having been used structurally for thousands of years in many parts of the world. In modern times, it has the potential to be an aesthetically pleasing and low-cost alternative to more conventional materials, such as timber, as demonstrated by some visually impressive recent structures.

This five-part technical series, aimed at both developed- and developing-world contexts, will bring together current knowledge and best practice on the structural use of bamboo, covering:

• an introduction to bamboo (part 1)
• durability and preservation (part 2)
• design values (part 3)
• element design equations (part 4)
• connections (part 5)

This second article presents the main causes of decay of bamboo and the different methods of protection and preservation available.

Introduction
Bamboo is more susceptible to decay than timber, due to a lack of natural toxins[1] and its typically thin walls, which means that a small amount of decay can mean a significant percentage change in capacity.

There are three causes of decay: beetle attack, termite attack and fungal attack (rot).

Beetle attack
Certain beetles are attracted to the starch in bamboo and lay their eggs inside the culm. When the eggs hatch, the larvae eat along the culm and eventually through the culm walls to escape, leaving small round or oval exit holes (about 1–6mm in diameter).

Powderpost beetles (which leave 1–2mm exit holes) are the most common (Figure 1).

The rate of attack is fastest with fresh green bamboo (which is more susceptible), but even dry bamboo can be attacked in warm humid climates where the equilibrium moisture content of the bamboo outside...
Termites attack
Termites are small ant-like insects which live in colonies and feed on plant material. They are also attracted to the starch in bamboo but, unlike beetles, have enzymes which also enable them to break down the cellulose. Because they live in large colonies, they can cause rapid damage (Figures 2 and 3). There are two generic types of termite: subterranean and drywood. The former live in the (preferably damp) ground, whereas the latter make their nests in the timber itself. Subterranean termites are translucent so build tunnels or find hidden paths to avoid sunlight (Figure 4).

Fungal attack (rot)
Rot is caused by a fungus. For the fungus to survive, the bamboo needs to be relatively wet with at least 20% moisture content, which essentially means the bamboo must be exposed to rain or ground moisture (Figure 5).

Protection against decay
As with timber, the most effective ways to protect bamboo from decay are by drying before use and by appropriate design and detailing (Figure 6)\textsuperscript{3,5}:

- The bamboo should be kept dry under a roof with a good overhang to protect against wind-blown/driving rain. Water traps, particularly at the bases of columns, should be avoided. This will prevent rot and also decrease the rate of beetle and termite attack. Walls formed from bamboo should be protected with a waterproof layer. Bamboo walls encased in only cement mortar, relatively common as a modern form of “engineered” bamboo housing, have shown evidence of deterioration when they are fully exposed to driving rain\textsuperscript{4} (Figure 7).

Single-storey bamboo buildings are likely to experience less rot damage than multistorey buildings because less of the wall is exposed to rain.
- The bamboo should be separated from the ground with a good barrier, preferably a concrete ground slab, thereby forcing the termites out into the open. This will make it harder for subterranean termites to attack the bamboo. Maintenance will still be required to remove any shelter tubes, which the termites build to protect themselves against light. Never cast bamboo direct into concrete as the bamboo cannot breathe and is likely to rot.

In colder climates, such as Europe, these measures will often be adequate, but in warmer humid climates, where there is the risk of beetle and drywood termite attack, structural bamboo must be preservative-treated if a reasonable design life is required. Although this will slightly increase the initial cost of the bamboo, the whole-life...
cost of the structure will be less.

Non-structural members, decay of which will not pose a safety risk, may be left untreated if it is accepted that they will need to be replaced regularly. However, they will lose their attractive appearance as they start to degrade, and beetles leave significant amounts of dust from the exit holes, which can be a nuisance inside the building. The length of time bamboo will last before it needs to be replaced will depend on the environment in which it is used and the treatment type. Table 1 presents a guide for suggested approximate timings in a warm aggressive environment. It indicates clearly why bamboo should preferably only be used in a dry internal environment, and also why it should be treated. Note that the variation in time depends on the prevalence of termites nearby.

### Introduction to treatment options

When selecting a treatment type or chemical and application method, it is important to consider:

- the quantity of bamboo to be treated
- the availability of treatment facilities
- the availability of chemicals
- the intended use of the bamboo: inside or outside
- any country-specific legislation
- the species of bamboo: some species are more readily treatable than others
- the transport time from harvest location to treatment facility: some treatment methods require very freshly cut bamboo

### Traditional treatment options

There are several traditional and simple treatment options which are commonly used in developing countries, including soaking for several weeks in water (which washes out some of the starch), smoking (which provides a light protective layer and partially heat-treats the surface) and painting (which provides some protection against water).

If we consider the example of painting or varnishing: firstly, it does not adhere well to bamboo due to its smooth silica outer skin; secondly, it tends to break down rapidly under UV light; and thirdly, as the bamboo changes size under different moisture conditions, the paint will crack and allow water in.

There are also other traditional treatment

<table>
<thead>
<tr>
<th>Table 1: Suggested approximate length of time before bamboo will need to be replaced (assuming warm aggressive environment with risk of termite and beetle attack)</th>
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<tr>
<td>Internal</td>
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<td>External above ground</td>
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<td>External in ground contact</td>
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* This is an inferred estimate based on a combination of limited testing conducted so far using fixed preservatives in bamboo, and on evidence from stake tests of timber. It is not yet known whether severe exposure to rain increases the likelihood of splitting, which would weaken the culm and its connections, and allow further water ingress.
methods using naturally found chemicals; however, these are not recommended either as their effectiveness is limited and some may be harmful to humans.

**Preservative treatment options**

Preservatives are essentially toxins which are added to the bamboo to deter fungal and insect attack. Although numerous types of treatment are available, many have limited effectiveness or are unsuitable because they pose major health-and-safety risks (e.g. older copper-based preservatives including chromated copper arsenate (CCA) and ammoniacal copper arsenate (ACA), and other chemicals such as creosote and chlorpyrifos). This leaves just two basic types of preservative that are widely considered to be by far the most appropriate for bamboo:

- **Boron** – cheap to apply, effective, but soluble, so elements treated with boron cannot be used externally
- **Modern copper-based wood preservatives** – expensive to apply, effective, but reasonably well fixed against leaching, so can be used externally

**Treatment using boron**

In nearly all cases, boron is by far the most appropriate chemical with which to treat bamboo and has a good track record. Boron has insecticidal and fungicidal properties. It generally has a low mammalian toxicity, although in higher concentrations it can irritate the skin and eyes, and if ingested is moderately toxic. Boron-treated bamboo is safe to touch; however, there are differing views on whether it is hazardous when burnt (data sheets say as a general rule that boron-treated timber/bamboo should not be burnt, but some research has suggested that the risks may in fact be very low). Boron treatment also has a relatively low cost.

Boron is normally used in compound form, typically as a salt. These compounds are readily available in most countries as relatively cheap fertilisers that just need to be added to water. The mixture is sometimes also heated to assist in the treatment process. In all treatment methods, the boron solution can be reused multiple times (but not indefinitely), and any residual solution can be safely diluted down and used as a fertiliser. The most commonly used boron-containing compound is disodium octaborate tetrahydrate (Na₂B₈O₁₃·4H₂O) (trade names Tim-bor® or Solubor®).

Although considerable research has been conducted to see whether a boron-containing compound can be fixed into bamboo/timber, so far there has been no success; hence, all boron-containing compounds will eventually have their boron leached out when exposed to rain.

While there are many different ways of treating with boron (as discussed further on), in practice only the modified Boucherie method avoids the need to rupture the diaphragms. Maintaining a solid diaphragm is beneficial as it: (a) improves the ability to reliably infill the internode with grout/mortar/epoxy (which is typically essential for good structural connections; this will be discussed in more detail in the fourth article in the series), and (b) may also play an important role.
role in controlling splitting and buckling of the culm wall. Where other methods are used, consider the impact of poorer grout/mortar/epoxy compaction in the internode.

**Bath/soaking**

This method involves soaking the bamboo in a bath of the chemical (Figure 8). Split bamboo may require only a week, whereas round culms need 10–14 days. The nodal diaphragm needs to be punctured to allow the chemical to access the inside of the internodes; the chemical can be heated to speed up the process. This requires fresh or almost fresh culms (up to seven days since harvesting); otherwise the cell walls will start to close. Bamboo should be stored upright for a minimum of one week after treatment to allow the boron to diffuse throughout the culm, followed by a further period of one to two weeks to partly season the bamboo. The bath liquid can be reused multiple times. Bath treatment is the cheapest and simplest of the boron treatment methods, but it takes the most time.

**Vertical soak diffusion**

This method involves placing the bamboo culms upright and pouring chemicals into them from the top (Figure 9). Holes will need to be punched through all but the last of the nodes. The culms are then left for 10–14 days while the solution diffuses through the bamboo walls outwards; the solution should be topped up periodically. Finally the base nodes are punctured and the chemical drained out. A dye can be added to the chemical which will show on the outside of the culm when diffusion is complete. This method requires fresh or almost fresh culms (less than seven days since harvesting) otherwise the cell walls will start to close. The chemical can be reused several times. Vertical soak diffusion is cheap and is commonly performed in Indonesia.

**Modified Boucherie method**

This is a sap-displacement/replacement method whereby the treatment chemical is pushed through the bamboo under pressure, replacing the sap (Figure 10). It is therefore one of the fastest methods, taking as little as 30 minutes per culm (including setting-up time). The equipment needed can generally be sourced locally; however, experience is normally necessary to ensure the process is effective. The chemical can be reused several times.

To be effective, the bamboo will need to be treated within 12 hours of being cut, otherwise the cell walls start to close. If this is not possible, the bamboo should be kept in a tank of water to keep it moist. During transportation, the ends of the culms should be covered with a damp cloth, and immediately before treatment these should be trimmed off to remove any length that has begun to dry. This method is used extensively in Costa Rica and Nepal. It is one of the fastest and most effective treatment methods; however, the required freshness of the culms and the technology required are drawbacks.

**Treatment using modern copper-based preservatives**

Modern forms of copper-based preservatives are significantly less toxic to humans than older forms because they no longer use arsenic and chromium; instead, they contain a mixture of copper, biocides and sometimes boric acid. They are very effective against fungi, termites and beetles, and are chemically relatively well fixed into the bamboo (with the exception of any boric acid component); hence, they can be used externally and in contact with the ground.

Copper-based preservatives are somewhat corrosive to steel; hence, galvanised or even stainless-steel fixings may need to be considered. The corrosive potential will depend on the percentage retention of the active chemical. The recommended forms of modern copper-based preservatives that could be used for bamboo are copper azole types B and C (CA-B and CA-C), because they do not contain boron (which will leach out over time) and are less corrosive to steel than other forms. These copper-based preservatives are safe in use as the toxic chemical is fixed into the bamboo; however, the treated bamboo should not be burnt at the end of its life because this may release hazardous chemicals.

In general, copper-based preservative treatments are significantly more expensive than boron-based treatments because they all require semi-industrial pressure treatment, and also because the bamboo must be fully kiln-dried before treatment.
After treating, the bamboo needs to be re-dried either in a kiln or naturally. It is important to note that limited work and testing has been conducted on the use of copper-based preservatives for treatment of bamboo; however, indications so far suggest that it could be very successful. Testing would need to be conducted to determine the required percentage retention of the active chemical to be effective and exactly what pressure treatment process would be suitable for this.

**Seasoning**

Seasoning (drying) of bamboo is important in order to carefully bring down its moisture content to levels closer to the equilibrium moisture content in service. Seasoning improves bamboo's resistance to fungi and insect attack and is especially important before transporting. It also limits the amount of drying shrinkage in service, which would otherwise affect the connections, and as a general rule it is better to work with dry bamboo.

Seasoning should be done slowly enough for the bamboo to shrink uniformly, otherwise cracks and splits can occur. Seasoning of large-diameter culms by just storing takes a long time (several months) (Figure 11), so often solar or heated kilns are used to speed up the process.

**Summary**

Bamboo is a particularly vulnerable natural building material and, without proper consideration of insect attack or rot, can deteriorate very rapidly. To protect against insects, in nearly all scenarios boron should be regarded as the treatment chemical of choice due to its efficacy, low cost, low mammalian toxicity and ease of use. There exist a number of simple and effective methods to apply boron. However, because of its high solubility in water, it can easily be washed out, and hence must be used in areas protected from rain.

To protect against rot, good practice detailing (durability by design) should be used: protecting the bamboo from rain and water by keeping it indoors, elevated and covered.

When these measures are successfully combined, bamboo can have a lifespan of over 30 years.

As a possible alternative to boron, copper-based chemically-fixed preservatives have shown some promise, and in theory these would allow bamboo to be used externally. However, further research in this field is still required.

The next article in the series will cover design values for using bamboo structurally.

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**References**