Structural use of bamboo. Part 2: Durability and preservation

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Technical Note Series: Structural Use of Bamboo

Technical Note 2: Durability and Preservation

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Synopsis

Bamboo is a strong, fast growing and 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 recent, visually impressive structures.

This Technical Note Series brings together current knowledge and best practice on the structural use of bamboo, covering:

1. Introduction to bamboo
2. Durability and preservation
3. Design values
4. Element design equations
5. Connections

The series is aimed at both developed and developing world contexts. This second Technical Note 2 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 have a significant percentage change in capacity. There are three causes of decay:

1. **Beetle attack**

Certain beetles are attracted to the starch in bamboo and lay their eggs inside the culm, after which the eggs hatch and the larvae eat along the culm and eventually through the culm walls to escape, leaving small round or oval exit holes (about 1mm–6mm diameter). Powderpost beetles (which leave 1mm–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 (but under cover) will often be higher than in more temperate climates[2].

Figure 1: Beetle damage in bamboo – exit holes are clearly visible[3]

2. Termite 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 beetle have enzymes which also enable them to break down the cellulose. Because they live in large colonies they can cause rapid damage (Figure 2 and 3). There are two generic types of termites: 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[4] (Figure 4).

Figure 2: Severe termite damage in bamboo[3]

Figure 3: Cross-section through termite-damaged bamboo[5]

Figure 4: Subterranean termite shelter tube emerging from crack[3]

3. 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[6] (Figure 5).


Figure 5: Fungal damage, splitting and bleaching of boron-treated bamboo exposed to the sun and rain after around 10 years[3]

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):

a) 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[7] (Figure 7). Single storey bamboo buildings are likely to experience less rot damage than multiple storey buildings because less of the wall is exposed to rain.

b) 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 termite shelter tubes, which the termites build to protect themselves against light. Never cast bamboo direct into concrete.

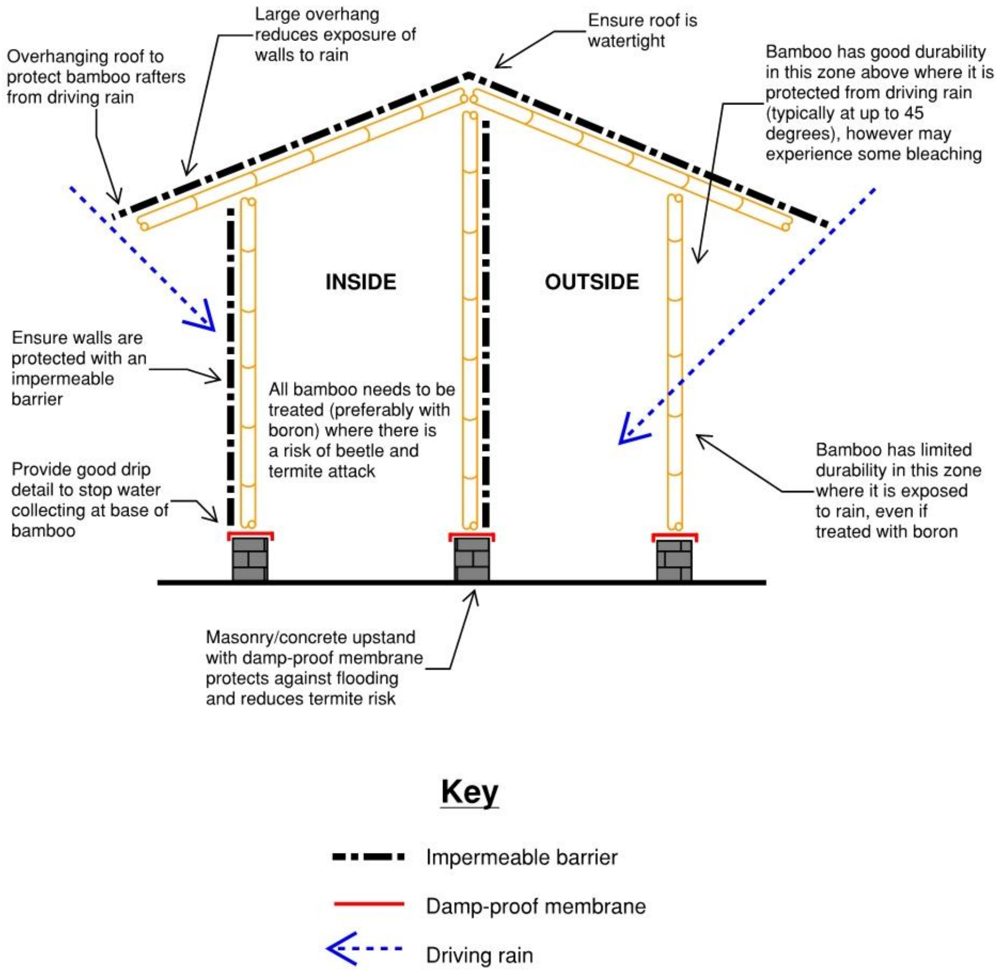

Figure 6: Recommendations for detailing bamboo structures to protect against rot and insects (based on good practice timber detailing, Kaminski (2013)[7] and Trujillo et al. (2013)[8]

Figure 7: Cane and cement mortar wall, showing signs of significant rot damage to cane due to rain[3]

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. For non-structural members, decay of which will not pose a safety risk, it is possible to leave them untreated and accept that the members will need to be regularly replaced. 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 and indicates clearly why bamboo should preferably be only 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.

Table 1: Suggested approximate length of time before bamboo will need to be replaced (assuming a warm aggressive environment with a risk of termite and beetle attack)

	Untreated	**Treated with boron**	**Treatment with fixed preservatives ***
Internal	2–6 years	30+ years	30+ years
External above ground	0.5–4 years	2–15 years	30+ years
External in ground contact	<0.5 years	< 1 year	15+ years

***Note: 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[9]

Introduction to treatment options

When selecting a treatment type or chemical and application method, the following considerations are important[2]:

- quantity of bamboo to be treated
- availability of treatment facilities
- availability of chemicals
- intended use of bamboo: inside or outside
- country legislation
- species: some species are more readily treatable than others
- transport time from harvest location to treatment facility: some treatment methods require very freshly cut bamboo
- budget
- effectiveness of treatment type or chemical and application method
- whether the chemical affects the structure of the bamboo or any metal fastenings
- toxicity of chemical to humans throughout whole life (treatment, use and disposal)

- toxicity of chemical to environment throughout whole life (treatment, use and disposal).

Traditional treatment options
Several traditional and simple treatment options commonly used in developing countries exist[10], 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). Unfortunately these all have limited effect and hence are not normally recommended for permanent structural bamboo – they may be appropriate only for marginally prolonging the life of non-structural bamboo or in temporary shelters. Painting or varnishing for example firstly does not adhere well to bamboo due to its smooth silica outer skin, secondly 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 also exist other traditional treatment methods using naturally-found chemicals, however these are also not recommended 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 (such as: older copper-based preservatives including copper-chrome-arsenic (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:

1. **Boron:** cheap to apply, effective, but soluble, so elements treated with boron cannot be used externally.
2. **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[10] and has a good track record[7]. Boron has insecticidal (poisonous to insects) and fungicidal properties. It generally has a low mammalian toxicity, although in higher concentrations can irritate the skin and eyes, and if ingested is moderately toxic[11,12]. 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 be much lower than this). Boron treatment is also 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 ($Na_2B_8O_{13}.4H_20$) (trade names *Tim-bor* or *Solubor*).

Although significant research has been conducted to see whether a boron-containing compound can be fixed into bamboo/timber[2], so far there has been no success and 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 below), in practice only the modified Boucherie method avoids the need to rupture the diaphragms (note maintaining a solid diaphragm improves the ability to reliably infill the internode with grout/mortar/epoxy which is typically essential for good structural connections (see Technical Note 4), and may also play an important 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[10] (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.

Figure 8: Bath method with boron, Colombia[3]

Vertical soak diffusion
This method involves placing the bamboo culms upright and pouring chemicals into them from the top[10] (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 done in Indonesia.

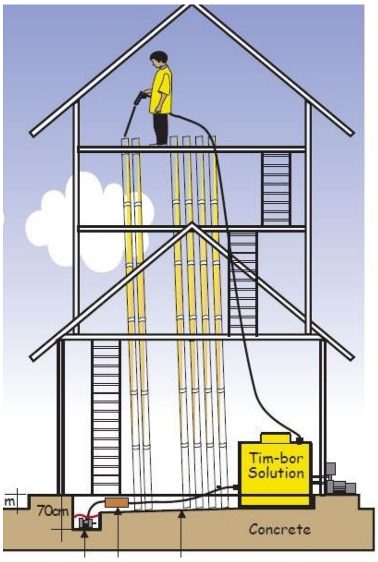

Figure 9: Vertical soak diffusion treatment tower[13]

Modified boucherie method

This is a sap-displacement/replacement method whereby the treatment chemical is pushed through the bamboo under pressure, replacing the sap[10] (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.

Figure 10: Modified Boucherie treatment equipment, Costa Rica[3]

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, and instead 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 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 type 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 end of 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 by kiln drying or natural drying.

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[14]. 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.

Figure 11: Seasoning of bamboo in Colombia[15]

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 also exist a number of simple and effective methods to apply boron. However, because of its high solubility in water, it can be easily 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, by 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 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 paper in this Technical Note series will cover design values and variation coefficients for using bamboo structurally.

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