Preservation of a bamboo culm in relation to its structure

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Abstract

The low durability of a bamboo culm towards biodeterioration in an exposed environment requires mostly a protection with chemical solutions for long time use. Its anatomical structure, however, makes an efficient treatment difficult as bamboo provides more resistance to penetration than wood.

At its outside the culm is protected by an epidermis as a water-tight seal. No pathways for radial penetration exist, like the ray cells in wood. Also on its inner side towards the lacuna a special tissue acts protective. Main avenues for penetration are the metaxylem vessels of the vascular bundles at the ends of the culm. They are unevenly distributed over the cross-section with only about 8-10% of the total area. Their strongly axial orientation is distorted at the nodes. Access to the vessels is often reduced soon after harvest due to wound reactions filling their lumen The surrounding parenchyma cells as main component of the tissue are connected by small pits and can be reached by diffusion only. Their starch content is the main food for insects and some fungi. Also the protection of the fibres depend on diffusion.

Preservation with chemical solutions is best achieved by using the water-filled vessels of a fresh culm as transportation channels, like by the butt-end treatment as a simple process or by the sap-replacement method on a technical level.The parenchyma tissue and also fibres of a fresh culm can be protected with the Vertical-Soak-Diffusion method. Dipping and soaking works best with moist split culms where the parenchyma is accessible for diffusion.

Technical processes, as water-storage and the smoking of culms are correlated naturally to its structures, especially the parenchyma.

Keywords: Bamboo, culm structures, protection, treatability, preservation methods

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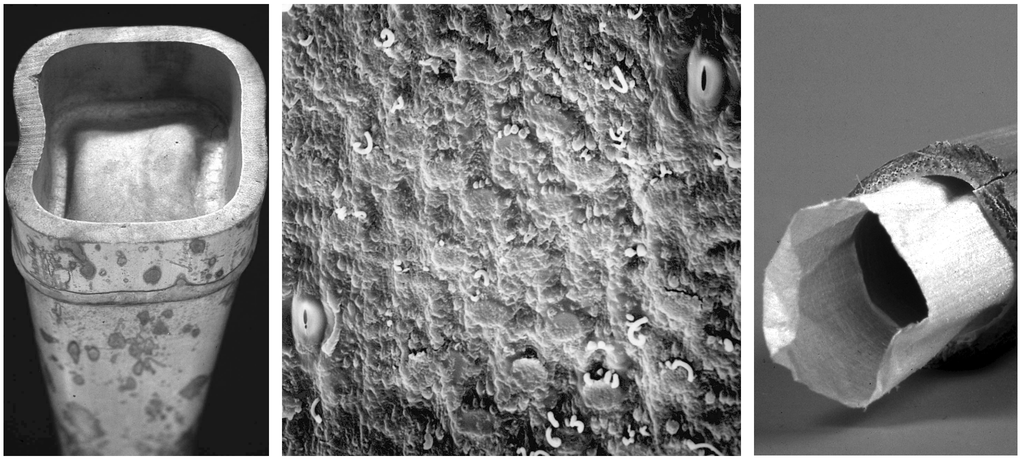


Fig..1: A bamboo culm to be protected; **2**: The cortex with stomata and wax; **3**:Inner layer.

The low durability of bamboo in an exposed environment requires for long time use often preservation with chemicals (Jayanetti & Follett, 1998; Liese & Kumar, 2003). By bamboo preservation the preservative should be introduced into the culm structure as deeply and uniformly as possible. The success is influenced by following factors: the treatability of the bamboo culm, its moisture content, the type of preservative and
the treating process applied.

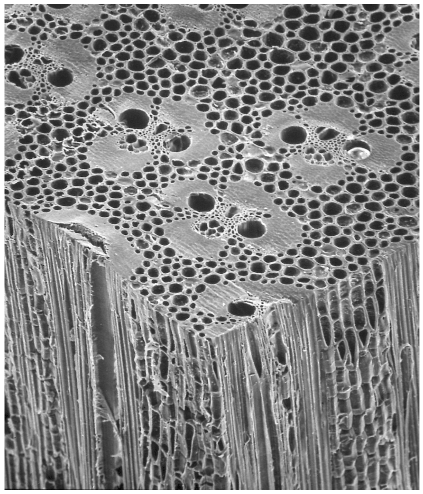
Factors influencing the treatability and preservation of culms

Anatomical factors**:** The treatability of the bamboo tissue is generally low due its anatomical structure which makes the culm considerably more resistant to penetration than wood (Liese, 1993, 1998). Its general structure differs only slightly between species. For the penetration of preservatives the outer and inner culm walls as well as the cross-sections at the end are to be considered (Fig. 1).

The culm is covered at its outer as well its inner side towards the lumen by confining layers of special cells. The outer part, the cortex, consists of densely packed cells, often cutinised and with a wax coating (Fig. 2). It provides the necessary water-tight seal for the living culm to prevent any loss of water, like the bark of trees. Consequently it hinders also any later uptake of liquids, thus restricting simple treatments, as by soaking. Liquids will ran easily off from the waxy cortex Rarely the outer part is scrapped of, which may accelerate drying and provide better adhesion of paints.

At the inner culm wall a special layer exists in many species, consisting of compressed and sclerotic parenchyma cells with additional suberin (Fig. 3). A scratching of the inner wall has been suggested for improved penetration, but the anatomical structure and operational difficulties may limit its effect.

The outer and inner layers become more refractory on drying.



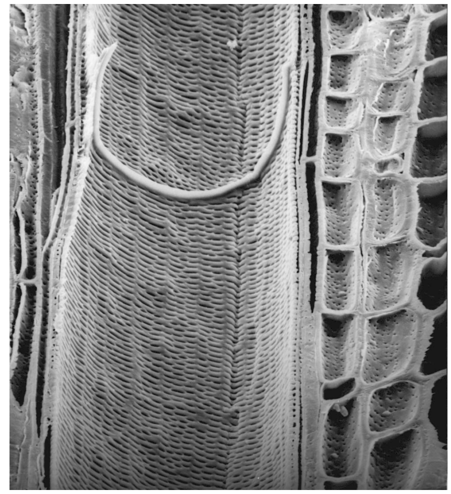


Fig. 4: Culm tissue wíth vascular bundles (2 vessels, phloem, fibre sheaths) embedded in parenchyma. **Fig. 5**: inner vessel side of an internode with pitting towards parenchyma.

The culm tissue consists of parenchyma (~ 50 %), fibres as sheaths, partly with separated strands (~40%) and vascular bundles with two metaxylem vessels and phloem (Fig. 4). Main avenues for any penetration are the vessels at the cut end of a culm. They run strongly axial within an internode, are isolated from each other by surrounding parenchyma (Fig. 5), and become interconnected only at the nodal diaphragm. The vessels are very small at the outer part of the wall and become larger and more dispersed in the middle and inner part. Their lumina on a cross section amounts to only 5-8%, in comparison with 70% in conifers and about 30% in diffuse hardwoods. The internode has no radial pathways for transportation, like the ray cells in wood. The necessary horizontal movement of a preservative solution from the treated vessel into the surrounding main tissue of parenchyma and fibres is only by diffusion and therefore a slow process. The further distribution takes place through the thick parenchyma and fibre cell walls with their numerous lamella, but also through the few simple pits as connecting channels.

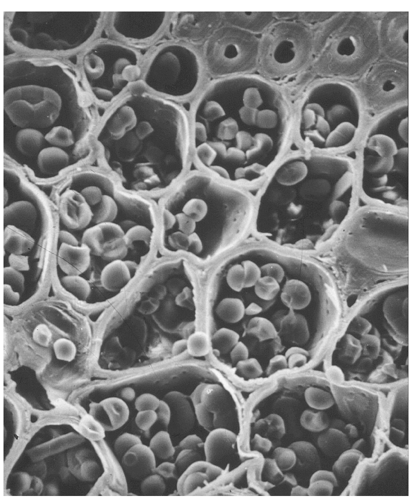
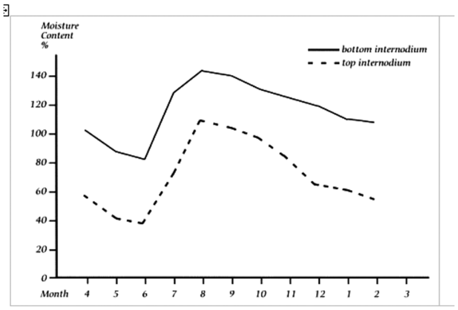


Fig. 6. Parenchyma cell with starch granulae.

The **chemical constituents** of the cells with cellulose (~50%), hemicelluloses (~25) and lignin (~25%) are similar to wood. Bamboo, however, does not produce toxic components with ageing, like the durable heartwood of many trees. Its natural durability against biodegradation is generally quite low, with only slight differences among species. The silica content (0.5-4%) has no impact. Important is the presence of a fortifying component, the **starch.** The starch is stored as energy resource in the parenchyma cells (Fig. 6). Its amount of 2-6 %, up to 10 %, is influenced by the age and height of the culm, but more decisively by the season.

Mature culms harvested after the shoots have expanded will have a much lower starch content than just before sprouting resulting in an improved "natural resistance".

Flowered culms contain no starch anymore.



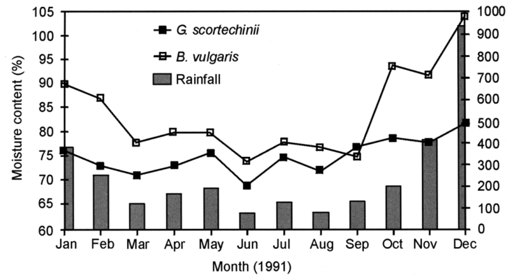


Fig. 7 y 8: Seasonal influence on moisture content of *Dendrocalamus strictus* and Malaysian bamboos.

The **moisture content** of the culm tissue has a decisive influence on the biological resistance, the treatability and thus on the protection effect. It is determined by the water inside the cell lumina, especially the vessels, and the water which is bound in the cell walls When all liquid water has evaporated, the “fibre saturation point” of about 20% of moisture is reached. The moisture content of a green culm ranges between 60-140%. It varies between species, as well as age, culm height and season. Younger culms have a moisture well above 100%, older ones between 60-90%. Within a culm the lower part has a higher moisture content than the upper part, related to the amount of parenchyma present. Most important is the seasonal influence. It is much lower during the drier months than during the rainy season with differences between 50-100%, as shown for the temperate climate of Northern-India, Fig. 7, as well as for the humid tropics of Malaysia, Fig.8 (Liese & Grover, 1961; Latif & Liese, 2002).

Fresh bamboo culms with water-filled vessels are required for the sap-replacement method. Also the Vertical-Diffusion-Soak method needs freshly cut culms. During the beginning of seasoning round and better split bamboos are suitable for soaking and diffusion treatment with water-borne preservatives. With further seasoning the bamboo tissue becomes quite refractory and penetration will depend mainly on the limited internal capillary forces.

For air-dry bamboo penetration by external pressure can be achieved (page 9).

Structural modifications of the culm occur during ageing and by external wounding.

During its first 3-4 years the culm undergoes a maturation process (Liese & Weiner, 1996; Murphy & Alvin, 1997). Its changes some structures and consequently properties and utilization. The one year old “immature” culm has thin cell walls of fibres and also parenchyma with a lower lignin content. The cells do not contain any starch. During the following years fibres and also parenchyma cells exhibit a thickening of their walls by deposition of additional lamellae with subsequent lignification (Fig. 9).

The parenchyma cells are filled with starch as the energy resource for the next year’s sprouting generation. Fibre wall thickening may continue, even above 10 years.

Also the natural senescence of older culms affects the functional efficiency as a partial blocking of the water-conducting vessels, which hinders the treatability.

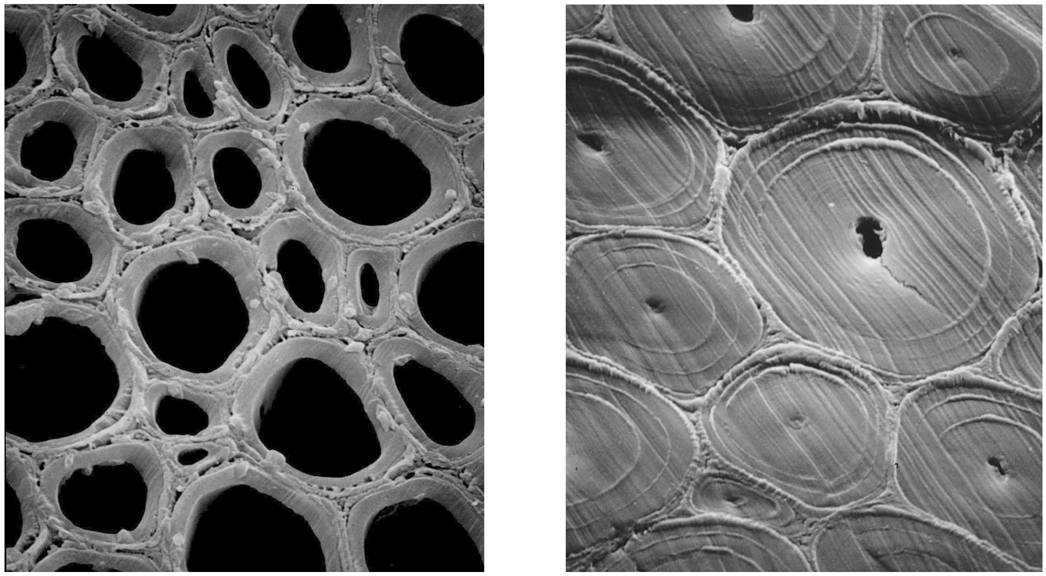
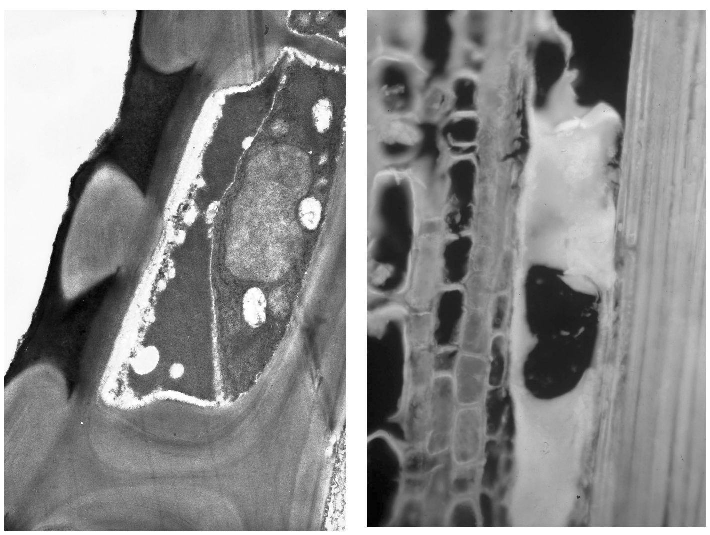


Fig. 9: Fibres of a 1-year and a 12-year old culm of *Phyllostachys viridiglaucescens.*



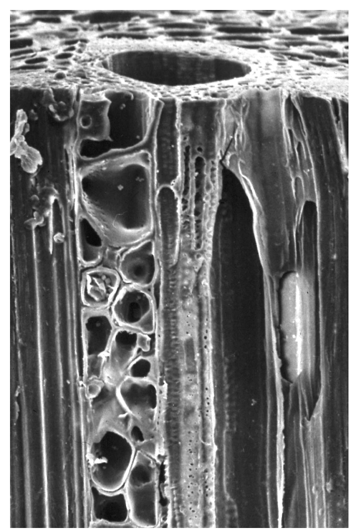
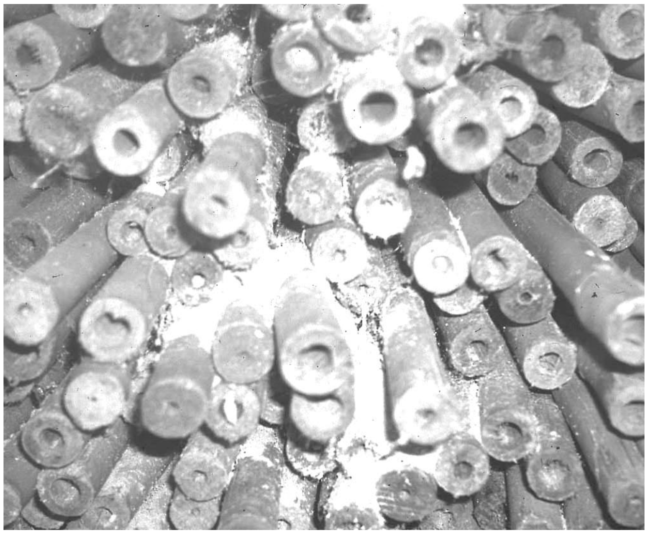


Fig. 10, 11: Slime secreted by the parenchyma is pushed into a vessel *Phyllostachys viriglaucescens.* **Fig. 12**: Tyloses blocking a vessel, *Phyllostachys viridiglaucescens.*

Wounding of a living culm, either by borers or mechanically, produces structural defence reactions to protect the water-conducting system against air blockage. The same reactions will be activated by the harvesting of a culm, which "it considers" as a threat to the safety of water conduction. The vessels will be filled by slime developed from the surrounding parenchyma and pushed through their pit fields (Figs. 4, 10, 11). Also balloon-like protrusions, called tyloses, contribute to the blocking of the vessel lumina (Fig. 12), (Weiner & Liese, 1996). The axial penetration will thus be hindered considerably. Especially for the sap-replacement method a fresh cut at the ends has to ensure the access to the water-filled vessels.

Biodegradation by insects and fungi



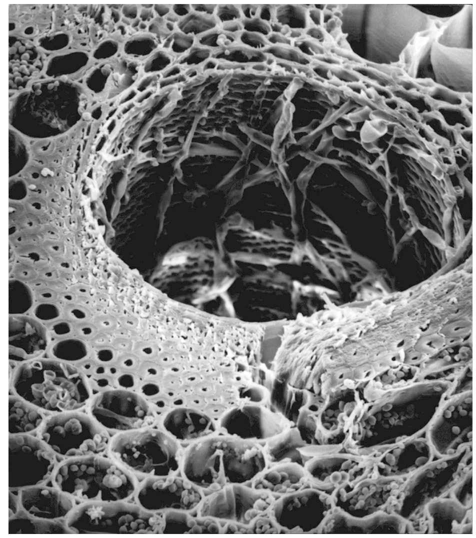


Fig. 13: Culm degradation by powder-post beetles.
Fig. 14: Fungal hyphae deteriorating parenchyma and fibers.

Bamboo constructions can be attacked by **insects** and fungi. Most common is the "powder-post" beetle in stored and manufactured bamboo which can reduce the tissue to a flour-like powder (Fig. 13). Larval attack depends on the starch and soluble carbohydrates in the parenchyma, present preferable at the inner culm part whereas the more fibrous outer part is mainly mechanically damaged by gnawing through. In thick-walled bamboos, like the Guaduas, the larvae will demolish the inner starchy tissue and exit without much structural damage because the strength is maintained by the thick outer fibrous tissue.

Termites are most destructive

Fungi can cause discolouration and decay. Their requirement for life is a sufficient moisture content and oxygen for respiration, so that water soaked and especially air-dry bamboo with moisture below 20% will be "protected". The colourful moulds are confined to the surface and nourish from impurities. They cannot penetrate and degrade, but may cause shallow blemishes. Blue stain fungi do penetrate the culm with their pigmented hyphae and use the starch in the parenchyma. They do not have enzymes for cell wall degradation and thus do not degrade the tissue.

The true destroying fungi grow in the cell lumina and degrade with their enzymes either only the celluloses and hemicelluloses with lignin remaining (brown-rot) or all wall substances (white-rot) (Fig.14). Bamboo is mainly destroyed by white-rot fungi, e.g. *Schizophyllum commune*, leading finally to a fibrous mass. Before slight colour change or weight loss indicate fungal action the strength properties are much reduced. Incipient decay is often overlooked.

Lesser common are soft-rot fungi which grow inside the cell wall and degrade its carbohydrates. They are tolerant to less oxygen, a high moisture and may resist the toxic concentration of many chemical preservatives. Culms in ground contact are generally attacked by this fungal group.

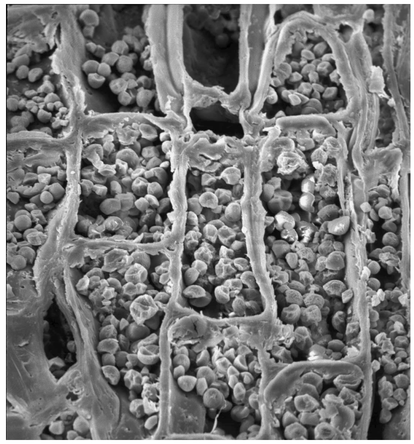
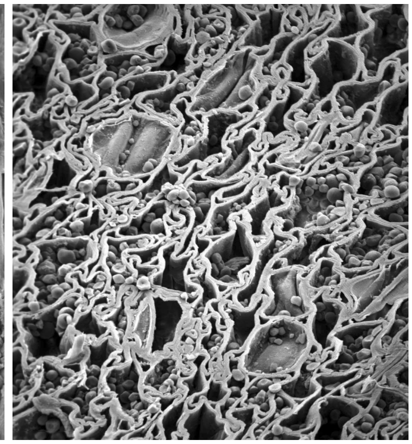




Fig. 15: Clump curing, *Bambusa blumeana,* Philippines
Fig. 16, 17: Structural effects in smoked treated *Guadua angustifolia.*

Influences on non-chemical treatments

The non-chemical treatment methods for bamboo, also called traditional methods, are widely applied, also in Latin America (Moran, 2002). Although often of limited effect they should be used to the extent possible to avoid the handling with toxic preservatives in rural areas..

Culm selection influences considerably the starch content and thus the resistance to biodegradation. The culms should be " mature", as recognizable by external factors, and cut in a season when starch content is lowest. An influence of the moon phase and preferred hours for cutting, at night or during dawn, is a common belief.

For **clump-curing** the culms are cut at the base, placed off ground as on a stone and left leaning against neighbouring stems (Fig.15). As transpiration by the leaves and respiration by parenchyma continues, the moisture content is reduced as is the starch, thus enhancing reducing attractiveness against borers.

Water-soaking of culms is an easy and widely adopted practice for improving resistance against borers and bluestain fungi. For short-term the culms are kept fresh, like for easy splitting or sap-displacement, for long-term the starch is degraded and permeability is improved due to disintegration of pit membranes by bacteria. The **smoking treatment** has been developed in Japan as a drying method which also improves dimensional stability. The partly charring forms a dark protective layer on the surface by adhesion of soot and other pyrolysis chemical components (Nomura, 2002). The system has been further developed especially in Colombia at a large-scale for commercial operation to exclude chemical preservatives for larger bamboo constructions (Villeges, 2000). The ZERI Pavilion at the EXPO 2000 in Hannover with 3.500 smoked-treated Guadua culms is a magnificent example. Samples have shown collapsed parenchyma cells, but partly filled with starch, so that biodegradation was not excluded (Figs.16, 17).

The **heat treatment** as applied for timber has also been tried for bamboo (Leithoff & Peek, 2001). Split bamboo samples in a bath of vegetable oil above 210°C caused enhanced durability against fungal attack, but resulted also in structural changes and reduced mechanical properties.

Influences on chemical treatments

For chemical treatment of bamboo two main **types of preservatives** can be applied. Their choice depends on its state, round or split, the moisture content, intended use and the facilities available. All preservatives are toxic also to human beings and animals, so that special care before, during and after treatment is mandatory, and even more in rural areas.

Mostly used are water-borne types, especially non-fixing salts, as they can diffuse the fresh/ moist culms for complete penetration of the ground tissue. Boron compounds are most common for culms and products. Their use is limited for covered situations due to possible leaching out. Fixing types are chemically bound by the bamboo tissue and can be applied also for outside use. However the long-time used CCA salt-types with their excellent properties are in most countries forbidden due to their toxic side-effects to mammals. Because of their limited diffusion deposits may remain on the surface.

Oil-based preservatives, such as creosote, require air-dry bamboo with no water pockets inside the cells. They are only to be applied by the pressure process to achieve sufficient penetration and inside distribution. Treating round bamboo the creosote may easily drop off from their smooth skin, the cortex, leading to environmental damage.

Several **treatment methods** could be applied for bamboo preservation. Their choice depends mainly on the moisture content, beside the factors mentioned above. The "butt end treatment" is common whereby the base of fresh culms, with foliage (disposal !) or without, is kept immersed in a container or trough for several days for the uptake by capillary and diffusion (Fig. 18). This simple process without much skill can save much material for supports of fruit trees or in vineyards. The "dip-diffusion" for about 30 seconds in a high concentrated boron solution has been successfully applied for split bamboo and mats. A sufficient storage time under tight cover is required for adequate penetration (Fig. 19). For the soaking method fresh culms are submerged in a boron- containing solution for 7-10 days. To ease penetration bore holes should be made on opposite sides in each internode and/or the solid nodal wall punctured with a long stick to provide protection for the inner culms tissue (Fig. 20).

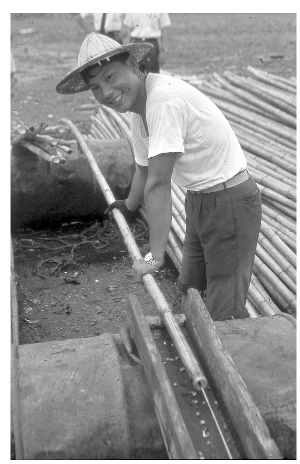
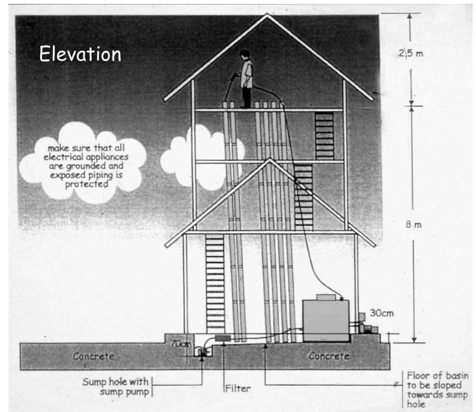


Fig. 18: Butt-end treatment of poles, Thailand. **Fig. 19**: Dip-diffusion treatment, Bali
Fig. 20. Puncturing the nodal walls to ease penetration from inside.

For the “Vertical-Soak-Diffusion” process fresh culms are vertically stacked in a basin with all nodal walls ruptured, except the lowest one. The inner part is frequently filled with a boron-preservative and serves as a reservoir for the diffusion into the wall (EBF, 2003), (Fig. 21). The diffusion capacity is influenced by the structure of the inner wall layer (Figs. 3).



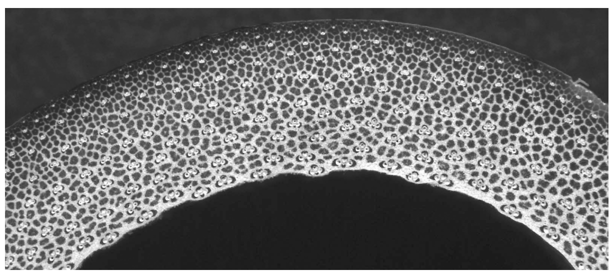


Fig. 21.: Vertical-Soak-Diffusion method, for diffusion from inside, EBF, Bali.

Special attention merits the “sap-replacement-method”, as a modified Boucherie method. The preservative is pushed into the butt end of a fresh culm, where after a few minutes the liquid drops from the top. Culms of 9 m length can be treated within 30-50 minutes with a pressure of 1.0-1.3 bar (Figs. 22, 23). It is a reliable and environmental friendly method, the more as the preservative remains entirely inside the culm (Liese *et al.*, 2002).

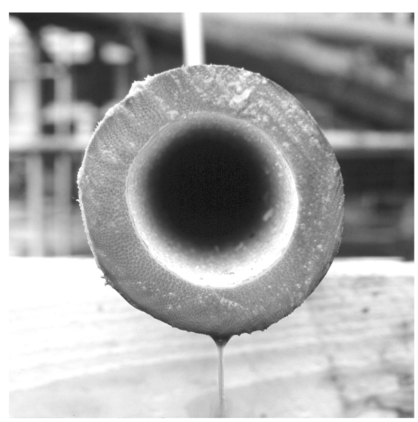


Fig. 22. Sap-replacement of fresh bamboo, Bamboo Village, Hawai.
Fig. 23. Preservative solution dripping from the top.

The **pressure methods** provides the best protection, but require costly technical installations and special handling for culms; thinner walls have to be perforated for each internode to avoid cracks and collaps. Spillage of preservatives is common.

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