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THE STRUCTURE OF BAMBOO IN RELATION TO ITS PROPERTIES AND UTILIZATION

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ABSTRACT

An overview is presented on the manifold relations between anatomical, physical and chemical properties of bamboo and the technological properties as well as behavior in processing and product qualities. More research, is needed in order to recognize the prospects and limitations of the various species and to utilize the potentials in the best ways.

Keywords: bamboo - structure - properties - utilization

INTRODUCTION

Bamboos are used for many different purposes. Often only some species are suitable or preferred for certain uses, whereas other species are neglected or even disregarded. What are the criteria for such a selection? It is generally known that restrictions in processing and utilization are often related to unsuitable properties. Therefore a thorough understanding of the relations between structure, properties, behavior in processing and product qualities is necessary for promoting the utilization of bamboo (Liese, 1987). For timber, countless investigations have already dealt with this complex area, but even there many questions are still to be answered.

Fortunately, bamboo is much simpler constructed than wood and the differences among the about 700 species appear relatively small. Nevertheless, a detailed analysis of the reations between structure and properties does hardly exist so far. The few case studies were already starting with the work by Ota (1951). Within the limitation of this presentation some examples will be given with the intention to provide a scenario, which should be supplemented with the experiences of others. This treatise is in a narrow sense not a research paper, but presents an overview to stimulate also further related research.

In comparison with wood the anatomical, chemical and physical-mechanical properties of bamboo exhibit no basic differences among genera and species. Also growth conditions and aging have apparently no significant effect on composition and structure of the tissue. In brief, the total culm comprises of about 60% parenchyma, 40% fibers and 10% conducting tissue (vessels and sieve tubes).

There are some variations between genera and also species, partly related to the types of vascular bundles present (Grosser, Liese 1971, 1974, Wen Taihui, Chou Wenwei 1985). Leptomorph genera, such as *Arundinaria* and *Phyllostachys,* represent the Type I (supporting tissue of the one vascular strand only as sclerenchyma sheaths) and have generally a lower fiber content than pachymorph ...genera, such as *Bambusa. Dendrocalamus* and *Gigantochloa,* especially with Type III and IV (vascular strand with smaller fiber sheaths and one or two isolated fiber bundles). These basic differences in the anatomical make-up must affect a number of properties like density, strength, bending behavior, splitting and shrinkage. A detailed comparison, however, is still to be done, albeit much needed.

Regardless of the type of vascular bundles, all bamboos exhibit striking differences in the distribution of cells within one culm, both horizontally and vertically. The percentage of fibers is distinctly higher in the outer third of the wall than in the inner, as well as in the upper part of the culm compared with the base. Whereas the lower culm contains in its inner part mainly parenchyma with fewer, large vascular bundles, this tissue type is reduced along the culm length. The upper part consists mainly of many smaller vascular bundles with a high portion of fibers, providing the superior slenderness. The higher ratio of fibers viz parenchyma has also significance for pulp production due to its higher yield in comparison with the base. Often this upper part is left as "waste" in the forest. The lower shrinkage of the top portion in comparison with the base is due to the higher amount of parenchyma here.

The fibers contribute 60-70% by weight of the total culm tissue. Their length shows considerable differences between species as well as variations within one culm (Liese, Grosser 1972). Certain species generally have shorter fibers, such as *Phyllostachys edulis* (1.5 mm), *Ph. pubescens* (1.3 mm), other longer ones like *Dendrocalamus giganteus* (3.2 mm), *Oxytenanthera nigrocilliata* (3.6 mm), *D. membranaceus* (4.3 mm). The fiber length is positively and strongly correlated with fiber diameter (11-19m), cell wall thickness (4-6m) and also internode diameter, but not with lumen diameter (2-4m) or internode length. Since the fiber length influences density and strength properties, detailed studies appear worthwhile. The number of vascular bundles per mm2 is closely related to E-modulus, the fiber length to elastic bending stress. So far, fiber length is hardly considered when selecting a bamboo species for a given purpose except pulping, but from practical experience such relations may already be utilized.

Across the culm wall the fiber length often increases from the periphery towards the middle and decreases towards the inner part. Along the culm from base to top no remarkable pattern for the fiber length exists except a slight reduction, whereas a great variation is evident within one internode of up to 100% and more. The shortest fibers are always near the nodes, the largest are in the middle. Thus the nodal part has a reduced strength due to its shorter fibers and marks the breaking point for the standing culm. In service, however, bamboo breaks hardly at the nodes because of a higher fiber portion due to reduced parenchyma and increased lignification.

Furthermore, the irregularity of the grain with an interwoven structure provides more shearing strength than the internodes with their axial arrangement of fibre-sheaths and bundles embedded in homogenous parenchyma. Test samples with nodes, however, exhibit lower bending, compression and shear strength, although a higher specific gravity.
The nodal portion with about 20% of culm or weight basis has shorter fibers, lower holocellulose content, but higher content of extractives, pentosans, lignin and ash than the

internodal portion. Consequently, pulp of the nodal portion has lower strength properties than from the internodal portion, but both portions cannot be separated (Maheshwari, Satpathy 1988).

The ultrastructure of some of the fibers is characterized by thick polylamellate secondary walls. The lamellation consists of alternating broad and narrow layers with differing fibrillar orientation. This polylamellate wall structure is present especially in fibers at che periphery of the culm, and their significance for bending properties appears obvious. Thin walled fibers do not have such a lamellation (Parameswaran, Liese 1976). It remains enigmatic, why only some of che fibers become thick-walled and polylamellated.

The occurrence and distribution of such fibers will influence certain properties and processing qualities, so that detailed studies with technological superior and inferior bamboo species about che fiber type present appear useful. Considering in this respect the parenchyma it can be noted that all elongated cells have apparently a polylamellate wall structure with up to 15 alternating lamellae (Parameswaran, Liese 1975). Since these cells have a length of generally only 0,1 mm and are thus only 1/30 as long as fibers, a property related significance of this wall structure remains obscure.

The specific gravity determines to a large extent the mechanical properties of the culm. It depends mainly on the fiber content, as well as fiber diameter, and cell wall thickness. Along che culm the specific gravity augments with the increase of the fiber percentage. Many investigations have proved this close relationship. A different behavior of species often results from a different anatomical make-up, as it has been shown for some Philippine bamboos by Espiloy (1987) for Indonesian bamboos by Widjaja and Risyad (1987) and for Malaysian bamboo by Abd. Latif et al. (1990). Mathematical calculations about the interdependence between anatomical structures and mechanical properties were provided by Janssen (1981).

For trees, aging has considerable influence on the cellular make-up and thus on technological properties, since the cambium produces modified cells, and heartwood is being formed. In bamboo aging effects are restricted to the primary tissue. The numerous investigations on strength properties in relation to culm age have not shown corresponding results (Abd. Latif 1991). Whereas some reports show higher strength values for one year old bamboo than for older ones, other tests revealed a general increase with age up to 6-8 years, followed by a decrease in all strength properties in culms of ten years (e.g. Zhou 1981) or at maximum around 3 years (Espiloy 1991).

Sporadic observations about an increase in lamellation for fibers with age (Alwin, Murphy 1988) are enlightening and should be extended on a broader scale. Especia1Iy the relation between cell wall lamellation and density must be investigated. Dying culms become brittle and are often bent down and break. There must be a structural/chemical basis for such drastic changes in properties (Kitamura 1975) so more as fungal degradation appears unlikely. In spite of its considerable importance, the relations within a dying culm are still much concealed.

Regarding the influence of growth conditions it has been found that marked differences in technological properties exist among individual culms from the same stand and even more among those from different localities. For example, *Gigantochloa pseudoarundinacea*, growing on the slope, showed higher specific gravity, bending and tensile strength than those growing in the valley (Soeprayitno et al. 1987). The structural basis for such variations should be investigated.

Fertilization of bamboo stands is increasingly applied, not only for shoot production but also for culm wood. As a consequence of fertilization, the number of shoots is increased, e.g. the yield, culm diameter and height may expand, but the structural composition remains apparently unchanged and thus the technological properties. This is unlike wood, where an increased cambial growth of conifer trees results in a lower density.

Chemical composition

Of the many relations between the chemical composition and utilization only few examples may be mentioned: Bamboo consists of about 50-70% holocellulose, 30% pentosans and 20-25% lignin. There are some differences in these main constituents between species, but any influence on technological properties remains uncertain. The silica content amounts to 0.5-5% according to species and affects their cutting and pulping quality. Most silica appears to be situated in the epidermis, but more knowledge about its location would be useful for processing technologies.
The increasing utilization of bamboo shoots provides healthy food due to their richness with essential amino-acids -besides their delicacy. Quite a number of species, however, contain also toxic or irritating substances, like lethal amounts of cyanogens. The nutritional composition (sugar, protein, fat, free amino acids, vitamins etc.) decreases with the growth of che shoot. To enlarge further shoot production, an inventory about the various substances present, is needed. Many of rhese substances are transported with the sap in che vessel of the growing shoot. Only for one species, *Oxytenanthera braunii* in Tanzania, its large-scale collection and fermentation to a powerful drink is known. Why not for others? Have they been tried, and what are the results?
For timber, organic and inorganic by-products, like polyphenols, resin, waxes, influence many properties, like shrinkage, durability, gluability. Nothing like that is known for bamboo, the more as such substances are apparently hardly produced by the metabolic processes of the parenchyma cells. Apparent differences of certain species in the natural resistance against fungi cannot be explained so far. Liability for the attack by powderpost beetles, especially Dinoderus spp depends on the amount of starch present. It changes with the growing season, but the often mentioned possible influence of the moon-phase on the resistance and thus either on the chemical substances or on the vitality of the borers remains so for a belief. Few species like *Bambusa textilis,* are said to be less vulnerable due to a general lower starch content. The sugar content of the parenchyma cells can influence the setting of cement for cement-bamboo structures. Since for cement bamboo particle boards pretreatment and chemical additives are needed, seasonal changes of the carbohydrates may be considered.

The potential of certain bamboo species for extractives to be used in the cosmetic and pharmaceutical industry can only be mentioned briefly. The species used so far belong mainly to the genera *Bambusa, Dendrocalamus, Gigantochloa* and *Phyllostachys* - is this due to lucky chances or systematic screening?
The preservation of bamboo respectively its penetrability is another area where the anatomical structure determines the possibilities for treatment. The culm is covered at its outer and inner side by an impermeable skin. Also the absence of ray cells as radial pathways determine the need for an axial penetration through the long and wide vessels. In green condition the natural easy flow of water can be used by the so-called sap replacement treatment. It is only necessary to fill the vessels with a suitable preservative, so that during the following resting period the salt components can diffuse into the surrounding tissue. Treatment time depends much on the vessel area of the bamboo. Generally around the metaxylem comprises of 6-8%, but differences exist between the lower and upper part of a culm and also between species.

As a last example surface decoration of the culm may be mentioned. This improvement of appearance due to application of lac or dyes is much hindered by the chemical composition of the culm-epidermis so that special treatments are often necessary (Kawamura, Katani 1990).

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