TREATABILITY AND FLOW PATH STUDIES IN BAMBOO PART I. *DENDROCALAMUS STRICTUS* NEES.

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ABSTRACT

Bamboo is one of the strongest structural materials used in rural areas of developing countries. Because of its low durability, it often fails prematurely due to fungal, borer, and termite attack. Because of anatomical differences from both hardwoods and softwoods, difficulties in treatment have been encounterd and early failures in preservative treated bamboo often observed. The most important structures for flow of fluids are the vascular bundles. The vascular bundles occurring in the inner zone of the bamboo culm treat better than the vascular bundles at the periphery.

Microscopic studies on the distribution of chemicals in *Dendrocalamus strictus* Nees. indicated that creosote : fuel oil penetrated more uniformly than water-soluble or organic solvent stains. The degree of penetration decreased with the increasing distance of other cells such as fibers and parenchyma tissues from the conducting vessels. At the microscopic level, treatability behavior improved from outer to inner zones along the wall thickness as well as from basal internodes to top internodes.

Keywords: Bamboo, *Dendrocalamus strictus,* structure, penetration index, CCA, treatability.

INTRODUCTION

Bamboo grows widely in India as well as in other tropical and subtropical countries. Whereas wood forms the main building material in most developed countries, bamboos are used extensively for structural purposes in many less developed countries having limited supplies of other building materials. Its adequate strength, easy workability, easy transport, and local availability at low cost make bamboo an excellent material for low cost residential and nonresidential structures.

The natural durability of bamboo is very low and varies between 6 to 24 months depending on the species (Liese 1959). Losses due to biodegradation occur even during storage, if bamboos are not properly protected. Such losses, which may be of the order of 20–30% in terms of wood substance over a 12-month period, can be considerably reduced by suitable prophylactic treatment (Kumar et al. 1985).

There are no systematic data available on the enhancement of performance by different wood preservatives. Nevertheless, there have been several studies on the methods of preservation and the performance of such treated bamboos in actual use. Whereas adequate life has been obtained in the case of out-of-ground contact use, in ground contact, early failures have been observed despite adequate loadings of preservatives equivalent to those recommended for wood. Such treatments have been based on gross absorptions, and no details on distribution in different cell types or reasons for failure have been reported. Penetration patterns with preservatives have been recently

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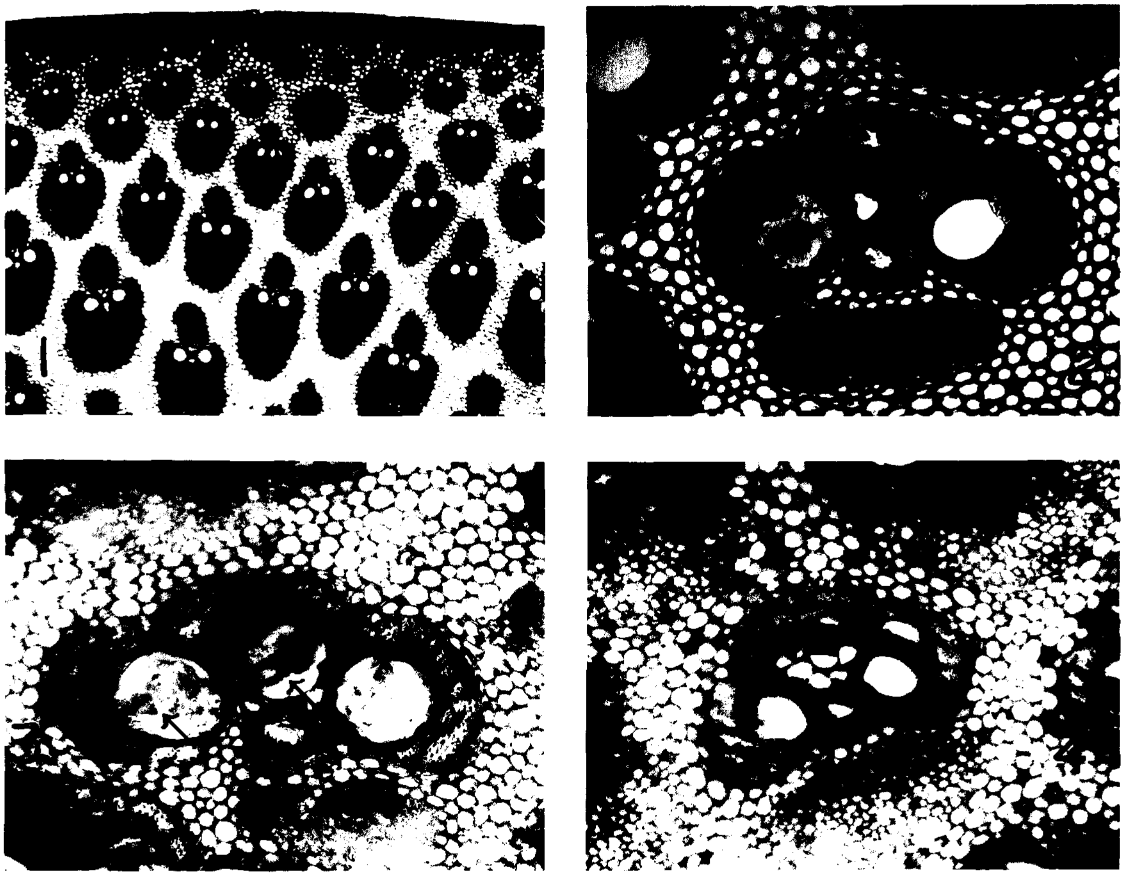

FIGS. 1–4. *Dendrocalamus strictus* Nees. 1—Cross view showing distribution of vascular bundles from periphery to the central zone (×12); 2—Creosote: fuel oil penetrated regions (×30); 3—Vascular bundles filled with wax dye (×30) and 4—Penetration of silver nitrate (×30).

recognized to play an important role in proper and uniform treatment of wood (Kumar et al. 1990).

Bamboo is a typical treelike grass having no lateral growth. A single stem of bamboo, called a culm, shoots out from the ground attaining maturity in 3–4 years. Bamboo structure is fundamentally different from wood in the organization of tissues (Ghosh and Negi 1959). The tissue is built up of parenchyma cells, fibers, and vascular bundles. The nutrients are stored in the ground tissue called the parenchyma cells, which constitute up to 50% of the tissue (Liese 1987).

The vascular bundles are nonuniformly distributed inside the culm, vessels with a narrow lumen but large in number being present nearer to the outer wall, and wider lumen but less in number located in the inner part of the wall (Fig. 1). Fibers near the outer wall are thick walled, narrow lumened but large in proportion (Grosser and Liese 1974). This heterogeneity in structure is expected to lead to variation during treatment. Although longitudinal movement of preservative solution through the vessels is expected to be rapid and more or less uniform, lateral movement to fibers may vary because of the variation in vessel-fiber ratio from outer to inner wall. The delay in such flow can be detrimental in protection especially in case of rapidly fixing preservative.

The objective of the present study is to identify tissues transacting flow, and study the penetrability of different tissues in *Dendrocalamus strictus*, a most widely used bamboo species in India.

EXPERIMENTAL PROCEDURE

Penetration studies

A green mature bamboo culm (*Dendrocalamus strictus* Nees.) was obtained from New Forest, Dehra Dun. Bamboo strips 35 mm long, 15 mm wide covering the total wall thickness (5 mm approx.) were obtained from a single internode, selected from the base. Samples were air-dried to about 15% moisture content. In the first set, impregnation was carried out by immersing the blocks in a 5% solution of silver nitrate and evacuating the blocks for 30 min. A pressure of 350 kpa for 1 h was applied following the vacuum. The blocks were further treated with a 2% solution of hydrazine dihydrochloride and kept in bright sunlight for 2–3 h for the fixation of silver ions. The reaction produced a reddish orange stain, which turned blackish under the sunlight. The second and third sets of blocks were treated with creosote : fuel oil (50:50) mixture and hot molten wax containing a red dye, respectively. The treatment procedure followed was the same as described earlier (Kumar and Dobriyal 1983).

The treated blocks were split at the middle and 12–15-micron-thick sections were prepared with a sliding microtome. These sections were mounted in glycerol for examination under a microscope and photographed at various magnifications to assess areas and cell types showing penetration.

Determination of penetration index

Penetration index was computed from degree of penetration of the different cell types by assigning them weight factors as detailed below:

a) Vessels constituting the main flow paths were given a weight factor of three.
b) Fibers contribute to strength and were given a weight factor of three.
c) Parenchyma cells constitute a major volume and may act as decay centers if not penetrated and were given a weight factor of two.

The composite penetration index was calculated as below:

$$PI = \sum_{1}^{3} W_1P_1/24$$

where W is the weight factor and P is the degree of penetration of each cell type (Table 1).

Studies on variation in treatability

Three internodes, one each from the base, middle, and top of the same culm of *Dendrocalamus strictus*, were selected and each internode was cut into two halves; one half was kept as a solid (round) and the other half was split into 9 equal strips of 150-mm length and 15-mm width with full wall thickness. Each strip was again split into three sections (outer, middle, and inner strips) across the wall thickness. Volumes of all the 81 specimens were measured with the help of vernier callipers. Each sample was individually weighed. All the specimens were immersed in 4% aqueous solution of CCA (copper-chrome-arsenic) and evacuated for 30 min. A pressure of 350 kpa for 1 h was then applied in the laboratory treatment cylinder. Post-treatment weights were recorded to obtain gross retentions of the chemicals.

Specific gravity of different zones along the bamboo wall thickness was determined by the water displacement method on oven-dry weight swollen-volume basis.

RESULTS AND DISCUSSION

Gross penetration on pattern

Data on penetrability of various cell types occurring in bamboo are reported in Table 1. As may be seen, vessels are the most heavily penetrated tissues either with oil or aqueous solutions. Parenchyma in bamboos are reported to be unpenetrable (Liese 1988). However, in the present study, parenchyma have been observed to be reasonably penetrated with creosote resulting in heavy penetration of fi-

TABLE 1. *Degree of penetration in various tissues of* D. strictus.

Treatment	Vessels (meta and protoxylem)	Parenchyma	Fibers	Penetration factor	Penetration index
Creosote	+++	+	+++	9 + 2 + 9	0.83
Wax dye	+++	+	+	9 + 2 + 3	0.52
$AgNO_3$	+++	–	++	9 + 0 + 6	0.63

+++ Heavily penetrated, almost all cells showed penetration.
++ Moderately penetrated.
+ Scarcely penetrated, only a few cells showed penetration.

bers as well (Fig. 2) Entry of wax solutions was limited to the vessel lumens as shown by colored deposits (Fig. 3), resulting in sparse penetration of parenchyma and fibers. Silver nitrate also stained the vessel walls, but parenchyma cells did not show much stain, although the fibers contiguous to vessels showed good penetration (Fig. 4). The composite penetration indices for creosote, wax-dye solution and silver nitrate solution, computed by the following method come to 0.92, 0.52, and 0.63 (Table 1).

Based on these data, bamboo can be classified as easily treatable with creosote but only moderately treatable with water-soluble salts. This nonuniform distribution of water-soluble salts is probably the reason for the early failure of even well-treated bamboos in service (unpublished data).

Variation in penetration along the wall thickness

Because of the variation in structure from outer wall to inner wall, there is considerable variation in penetration pattern along the wall thickness.

The examination of sections showed that the fibro-vascular bundles occurring in the inner zone of the bamboo culm were treated better with creosote : fuel oil mixture than the vascular bundles occurring at the periphery below the outermost layer of epidermal cells, which is very hard, waxy by nature, and less permeable than the inner layer (Liese 1959). The large vessels (metaxylem) tended to conduct better than the smaller vessels (protoxylem) (Fig. 2). In the case of fibers, their distribution is typical in bamboos, as these are found in xylem, phloem, and median xylem fiber caps made up of the sclerenchymatous tissue appearing in cross section. These groups of fibers showed considerable variation in shape and size affecting the flow of oil (Fig. 2). Fibers associated with the metaxylem were penetrated better than the fibers associated with the phloem and protoxylem. The ground tissue consisting of parenchyma cells showed varied penetration. The parenchyma cells contiguous to vascular bundles although lignified showed good penetration of creosote.

Variation in treatability along the culm length and wall thickness

Data on CCA retention (after treatment with 4% CCA) are reported in Table 2. Data were collected for three internodes at base, middle, and top of the bamboo. There was consider-

TABLE 2. *Preservative (CCA) loading variation along wall thickness and height in* D. strictus.

Bamboo internode	Split specimen: Location along wall thickness	Split specimen: Specific gravity	Split specimen: Average absorption kg/m^3	Solid specimen absorption (kg/m^3)
Base	Outer	0.674	9.8	8.6
	Middle	0.567	9.0	
	Inner	0.542	11.4	
	Average	0.594	10.1	
Middle	Outer	0.716	13.2	12.8
	Middle	0.519	15.3	
	Inner	0.522	15.4	
	Average	0.586	14.6	
Top	Outer	0.704	13.7	13.6
	Middle	0.482	15.7	
	Inner	0.450	15.3	
	Average	0.545	14.9	

Variation along wall thickness
Outer 12.2 kg/m^3
Middle 13.3 kg/m^3
Inner 14.0 kg/m^3

TABLE 3. *Variation in vessel diameter and frequency of distribution along the wall thickness observed in a single bamboo culm of* D. strictus.

Location in the wall thickness		Average vessel diameter (μm)	Average number of vessels/mm^2	Vessel area (%)
Outer	⅓	60.0	21	6.06
Middle	⅓	85.0	15	8.51
Inner	⅓	100.0	9	7.07

able variation in treatability from bottom to top. The total salts loaded in the basal section were 8.6 kg/m^3, whereas middle and top internodes absorbed 12.8 and 13.6 kg/m^3 respectively. A similar pattern was observed with bamboo strips obtained along the thickness in the same three internodes. The differences in absorption between ring and strip sections indicate that the outer skin of bamboo is responsible for the refractory nature of bamboo. This is further supported by the fact that the outer layers absorbed much less preservative, although these differences tend to narrow with height. Overall differences between outer, middle, and inner sections along the wall thickness of bamboo are, however, much less than the differences observed between basal and top internodes.

Vessel diameter variation, frequency of vessel distribution, and volume occupied by them are reported in Table 3. Despite the existence of a lesser number of vessels in the inner layer, this layer exhibits highest permeability and tends to retain the highest amount of preservative. The frequency of vessels increases considerably from the inner layer to the outer layer, but the vessel area decreases because of narrow lumen in the outermost layer. This results in lower loadings of preservative solutions because of less volume availability as vessels are the easiest and first to get filled. Moreover the narrow lumen would require a higher pressure to overcome interfacial tension of the penetrating solution. For better penetration and uniform loadings in all layers, higher pressures for longer durations may be required.

REFERENCES

GHOSH, S. S., AND B. S. NEGI. 1959. Anatomical features of bamboo used for paper manufacture. Cellulose and Research. A symposium, C.S.I.R. New Delhi.

GROSSER, D., AND W. LIESE. 1974. Verteilung derleitbundel und Zellarten in sprobachsen verschieldener Bambusarten. Holz. Roh-Werkst. 32:473–482.

KUMAR, S., AND P. B. DOBRIYAL. 1983. Flow path in selected softwoods and hardwoods. J. Timb. Dev. Assoc. (India) 29(3):26–33.

———, K. K. KATRA, AND P. B. DOBRIYAL. 1985. Protection of pulp bamboo in outside storage. J. Timb. Dov. Assam (India). 31(4):5–12.

———, R. P. SHARMA, P. B. DOBRIYAL, AND B. B. CHAUBEY. 1990. Pressure impregnation of hardwoods: Treatment schedules for easy-to-treat Indian hardwoods. Wood Fiber Sci 22(1):3–9.

LIESE, W. 1959. Bamboo preservation and softrot. F.A.O. Rep. No. 1106 to Govt. of India, 1959.

———. 1987. Research on bamboo. Wood Sci. Technol. 21:189–209.

———. 1988. Personal discussion.