BAMBOO PRESERVATION TECHNIQUES : A REVIEW

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FOREWORD

In June 1993, INBAR convened a planning meeting in Singapore to identify research priorities and set a research agenda that would guide INBAR's activities for the next two years. The meetingwas composed of twelve national programme scientists, along with invited observers from international research and development agencies.

At the networkshop, four INBAR working groups discussed urgent tasks that required attention. The Information, Training, and Technology Transfer Working Group recommended that a handbook should be compiled on bamboo preservation methods. This would assist the process of technology transfer among INBAR's member countries.

Dr. D.N. Tewari, Director-General of the Indian Council of Forestry Research and Education, offered to assign some of his staff the task of collating the available information and providing a review of Indian preservation techniques as an in-kind contribution to INBAR. Subsequently, ICFRE's draft text was reviewed by Prof. Dr. Walter Liese of the Institute of Wood Biology, University of Hamburg, Germany, and Dr. R. Gnanaharan of the Kerala Forest Research Institute. Their comments have been incorporated into the final text. The editorial inputs of Dr. H. C. Bansal of the Indian Agricultural Research Institute are also noted with thanks.

We should note here that other techniques of bamboo preservation are used elsewhere in Asia. INBAR envisages issuing a follow-up handbook that will offer readers an easy-to-use guide to these techniques. The current review is an important first step in this direction.

Paul Stinson
October, 1994 *Manqer, IN BA R*

PREFACE

Bamboo is one of nature's most valuable gifts to mankind. Its remarkable growth rate and versatile properties have made it one of the most sought after materials, especially in tropical countries.

Some of the characteristics of bamboo resemble those of wood. However, its growth characteristics and microstructure make it different from wood; hence the need for specialised techniques for deriving maximum advantage of its diversified uses.

A major drawback with bamboo is that it is not durable against wood degrading organisms. Thus, most bamboos used for structural purposes in rural and tribal housing deteriorate in a couple of years, putting heavy pressure on the resource, owing to increased demands for frequent replacements. This adversely affects the supplies of bamboo, even in bamboo rich regions. Considerable research work has been carried out in bamboo producing countries in the Asian region, as a result of which the service life of bamboo can be increased.

This book attempts to review the information on preservation methods, Our scientists undertook this challenge as a goodwill gesture towards INBAR and their colleagues throughout the Network.

The application of any of the techniques reviewed will depend upon first, whether it is advantageous economically to extend the useful life of the bamboo or whether to regularly replace it; and second, on how suitable strategies can be adopted to relieve pressure on the resource base and lessen over-exploitation. Decision-making, therefore, is not simply on the basis of which techniques are shown to be scientifically sound or environmentally friendly.

The authors are grateful for comments on their draft manuscript by Prof. W. Liese of Germany. Prof. Liese is a recognised expert on bamboo and some of his earlier research was carried out in our institute in Dehra Dun. Comments from Dr. R. Gnanaharan of KFRI are also acknowledged.

It is hoped that the publication will be useful to bamboo scientists in their search for environmentally friendly and effective treatment methods in various situations of supply-demand imbalances.

Dr. D.N. Tewari
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BAMBOO PRESERVATION TECHNIQUES : A REVIEW

INTRODUCTION

Bamboos play a dominant role as woody raw material for a variety of products in the tropical regions. Almost all continents, except Europe, have indigenous bamboo species. Bamboos are, however, more abundant in the tropics, with over 75 genera and 1250 species, ranging from small grasses to giants of over 40 m in height and 0.3 m in diameter (Tewari, 1993).

India, with an annual production of about 3.2 million tonnes of bamboos, ranks second only to China in bamboo production (Pathak, 1989). Over 136 species in 30 genera occur in India (Suri and Chauhan, 1984). The two most widely distributed genera in India are Bambusa and Dendrocalamus. In South and Southeast Asia, the most economically important species for structural uses from the point of view of easy availability are Bambusa balcoa, *Bambusa* bambos, *Bambusa blumeana, Bambusa nutans, Bambusa polymorpha, Bambusa tulda, Barnbusa vulgaris, Dendrocalarmus hamiltonii, Dendrocalarnus strictus, Melocanna barnbusoides, Gigan tochloa spp., Ochlandra travanicorica and Oxytenathera nigroeiliata.* All these species are included in the INBAR priority list (Williams and Rao, 1994)

At least one third of the human race uses bamboo in one way or another. Bamboo is an integral part of the culture in several Asian countries. In India, over one million tonnes of bamboo are used as a long fibre source for the manufacture of pulp and paper. Its unique strength properties, coupled with innovative uses by people, have enabled its versatility to be exploited for many industrial and architectural uses. Bamboo is used for housing construction (as poles, purlins, rafters, trusses), mats (to substitute flat boards), ladders, floating fenders, furniture, handicraft articles, baskets, etc. Its versatile nature and innumerable uses have earned bamboo the name 'green gold of the forest'. Since bamboo is less expensive than construction materials like steel, cement and even wood, it is considered to be 'poor man's timber'.

Unfortunately, like most lignocellulosic materials, bamboo has very low resistance to biological degrading agents. Several techniques to enhance its durability have, therefore, been developed. This review on bamboo preservation has been compiled to consolidate all useful information and to provide helpful guidelines to users.

PROPERTIES OF BAMBOO

Anatomically, bamboo is quite different from wood coming from gynosperms and dicotyledonous angiosperms (Ghosh and Negi, 1959). All the growth in bamboo occurs longitudinally and there is no lateral or radial growth as in trees. Characteristically, bamboo has a hollow stem, or culm (solid in some species only), which is closed at frequent intervals called nodes. The bamboo culm comprises about 50% parenchyma, 40% fibres and 10% vessels and sieve tubes (Liese 1987). Fibre percentage is higher in the outer one- third of the wall and in the upper part of the culm, contributing to its superior slenderness (Grosser and Liese, 1971). Most fibres have a thick polylamellate secondary wall (Parameswaran and Liese, 1976). The typical tertiary wall present in most woody cells of gymnosperms and angiosperms is not present. Similarly, bamboos do not develop reaction wood, which is most common in tree species due to agting.

Fibres in bamboos are grouped in bundles and sheaths around the vessels. The epiderma1 walls consist of an outer and inner layer; the latter is highly lignified. The outer layer contains cellulose and pectin with a wax coating. Silica particles also exist in the peripheral parts of the culm. These anatomical features are responsible for the poor penetration of preservatives into round culms during treatment. Although vessel elements in bamboo are easily permeable, lateral flow is restricted because of the absence of ray cells.

Physical and Mechanical Properties

The density of bamboo varies from 500 to 800 kg/m^3, depending on the anatomical structure, such as the quantity and distribution of fibres around the vascular bundles. Accordingly, it increases from the central (innermost layers) to the peripheral parts of the culm. This variation could be 20-25 percent in thick-walled bamboos like *Dendrocalamus strictus* (Sharma and Mehra, 1970). In thin- walled bamboos, the differences in density are much less (Sekhar and Bhartari, 1960).

Bamboos possess a very high moisture content which is influenced by age, season of felling and species. Season has a greater influence than any other cause. Moisture is at its lowest in the dry season and reaches a maximum during the rainy season. Among the anatomical features, a higher amount of parenchyma increases the water holding capacity (Liese and Grover, 1961). Moisture also varies from the bottom to the top and from the innermost layers to the periphery. Green bamboo may have up to 150% moisture (oven-dry weight basis) and the variation reported is 155% for the innermost layers to 70% for the peripheral layers (Sharma and Mehra, 1970). The variation from the top (82%) to the bottom (110%) is comparatively low. Moisture content decreases with age while the increase in specific gravity is rather limited (Limaye, 1952).

The fibre saturation point (FSP) of bamboo is around 20-22 percent (Jai Kishen et *al.,* 1956; Sharma, 1988), while *Phyllostachys pubescens* has a lower FSP ~13% (Ota, 1955). The FSP is influenced by the chemical/anatomical nature of tissues (Mohmod and Jusuh, 1992). Parenchyma cells, being more hygroscopic, result in raising FSP.

Bamboo shrinks in diameter (10-16%) as well as in wall thickness (15-17%) (Rehman and Ishaq, 1947). Such shrinkage is appreciably higher than encountered in wood. In bamboo, shrinkage, which in fresh culms begins linearly, becomes negative or almost zero as MC falls between 100 and 70 per cent and this continues until fibre saturation point is reached. Below FSP, shrinkage again follows, a linear trend (Sharma *et al.*, 1987.) Tangential shrinkage (6.5-7.5s) in some species is reported to be lower than shrinkage across the wall thickness (1 1- 13%) (Espiloy, 1985). Shrinkage has been related to culm diameter and wall thickness (Mohmod and Jusuh, 1992). Because of differences in anatomical structure and density, there is a large variation in tangential shrinkage from the interior (10%) to the outermost portion (15%) of the wall (Sharma and Mehra, 1970). Such behaviour in shrinkage and density leads to drying defects, such as collapse and cracking, and affects the behaviour of bamboo when pressure treatments are applied.

Bamboos possess excellent strength properties, especially tensile strength. Most properties depend upon the species and the climatic conditions under which they grow (Sekhar and Gulati, 1973). An increase in strength is reported to occur between 2.5 to 4 years. Thereafter, the strength values start falling (Sekhar et al, 1962; Sekhar and Bhartari, 1960,196l; Sattar et al, 1990; Espiloy, 1994; Kabir et al, 1991). To possess optimum strength, there is a 'maturity age'. Thus, only mature bamboos are harvested for structural or other uses.

There is a variation in strength along the culm height as well. Compressive strength tends to increase with height (Espiloy, 1985; Liese, 1986; Sattar et al, 1990; Kabir et al, 1991), while the bending strength shows a decrease (Espiloy, 1985; Janssen, 1985; Limaye, 1952; Kabir et al. The strength increases from the central to the outer part. According to Baumann (Narayanamurti and Bist, 1947), there is more than 100 percent variation in strength from the inner to the outer layers (Table 1).

Although several studies on strength properties have been conducted, the information on strength properties and its corre-

Table 1. *Bending and tensile strength of inner and outer layers of bamboo.*

Property	Inner	Outer
Bending strength (kg/cm^2)	950	2535
Tensile strength (kg/cm^2)	1480-1620	3100-3300

lation with various factors such as moisture, anatomical structure, growth factors, drying and preservation are still lacking for **most** species. Furthermore, there are still no standard methods of evaluation (Liese, 1985). The earliest tests **on** strength were carried out in India on Dendrocalamus strictus (Limaye 1952). A need was felt to standardise the testing methodology (Sekhar and Rawat, 1956). An Indian standard for the same was formulated (Anon., 1973). Most of the reported strength data have, however, been obtained using different test methods with widely varying conditions. Such data on some of the species are reported in Table 2, which shows that bamboo is as strong as wood; some species even exceed the strength of the strongest timbers like sal (Shorea robusta).

Natural Durability of Bamboo

Bamboo consists of 50-70s hemicellulose, 30% pentosans, and 20-25% lignin (Tamolang et al, 1980; Chenef al, 1985). Ninety percent of the hemicellulose is xylan with a structure intermediate between hardwood and softwood xylans (Higuchi, 1980). The lignin present in bamboos is unique, and undergoes changes during the elongation of the culm (Itoh and Shimaji, 1981). Bamboo is known to be rich in silica (0.5 to 4%), but the entire silica is located in the epidermis layers, with hardly any silica in the rest of the wall. Bamboos also have minor amounts of resins, waxes and tannins. None of these, however, have enough toxicity to impart any natural durability. On the other hand, the presence of large amounts of starch makes bamboo highly susceptible to attack by staining fungi and powder-post beetles (Beeson, 1941; Gardener, 1945; Mathew and Nair, 1988; Gnanaharan *et* al, 1993). Laboratory tests have indicated **that** bamboo is more prone to both soft rot and white rot attack than to brown rot (Liese, 1959).

The natural durability of bamboo is very low and depends on species, climatic conditions and type of use. Early observations on durability of bamboo were based on the performance of full-sized structures. Under cover, the untreated bamboo may last 4-

Table 2. *Important strength properties of some bamboo species.*

Species	Country	Sp. gr.	MC %	MOR kg/cm²	MOE kg/cm²	MCS kg/cm²	Ref.
Bambusa bambos	India	.651	15.5	674	65,000	483	Gulati & Singh,1989.
Bambusa bambos	Puerto Rico	.580	10.0	918	1,20,000	367	Heck, 1956
Bambusa bambos	Indonesia	-	15.5	905	-	421	Prawirohatmodjo,1988.
Bambusa blumeana	Philippines	.503	Green	308	86,400	349	Espiloy, 1985.
Bambusa nutans	India	.716	16.0	545	85,000	508	Gulati & Singh,1989.
		.773	(Kiln dry)	1,023	1,57,207	698	Sekhar *et al*, 1962.
Bambusa polymorpha		.659	13.9	355	44,000	-	Gulati & Singh,1989.
Bambusa tulda		.712	14.9	506	82,650	615	Gulati & Singh,1989.
Bambusa tuldoides	South America	.830	11.0	1,547	1,62,000	-	Heck, 1956
Bambusa vulgaris	Puerto Rico	.700	10.0	1,224	1,59,000	584	Heck, 1956
Bambusa vulgaris	Indonesia	-	17.0	860	-	254	Prawirohatmodjo,1990.
Dendrocalamus asper	Indonesia	-	15.0	1,054	-	322	Prawirohatmodjo,1990.
Dendrocalamus strictus	India	.743	12.0	1,407	1,66,777	619	Limaye, 1952.
(New Forest, Dehra Dun)			(Kiln dry)				

Table 2. *Continued*

Dendrocalamus strictus (Average from 10 locations)	India	.719	10.7	1,184	1,59,490	645	Sekhar & Gulati,1973.
Dendrocalamus strictus	Puerto Rico	.620	10.0	1,709	1,77,000	534	Heck, 1956
Gigantochloa apus	Indonesia	-	14.8	893	-	383	Prawirohatmodjo,1990.
Gigantochloa atter	Indonesia	-	14.5	1,219	-	350	Prawirohatmodjo,1990.
Gigantochloa levis	Philippines	.539	Green	228	96,960	396	Espiloy, 1985.
Gigantochloa verticillata	Indonesia	-	14.9	960	-	365	Prawirohatmodjo,1990.
Guadua augustifolia	Puerto Rico	.820	10.0	1,448	1,76,000	-	Heck, 1956
Tectona grandis (teak)	India	.604	12.0	959	1,19,600	532	
Shorea robusta (sal)	India	.707	12.0	1,318	1,62,045	641	

Sp. gr. = Specific gravity
MC = Moisture Content
MOR = Modulus of Rupture (Bending strength)
MOE = Modulus of Elasticity
MCS = Maximum Crushing Strength (compression parallel to grain)

7 years. Under favourable circumstances, trusses and rafters may last 10-15 years. Systematic data on natural durability when there is ground contact and exposed conditions are very limited. Tests conducted in the Philippines indicated variation among species. Dendrocalamus *merillianus* was found perishable while *Schizostachyum* species were found quite resistant. Laboratory exposure to fungal attack showed that some species like Bambusa *blumeana* and *Gigantochloa* showed moderate resistance (Guzman, 1978). Graveyard tests (Fig. 1) completed recently on some important Indianspecies showed that the averagelife of untreated bamboos is less than two years (Table 3). This confirmed the earlier observations on natural durability of bamboo reported by Purushotham et al (1954). According to durability classification (Anon., 1982), bamboos thus fall in class III (non-durable category) with little variation in durability among different species (Fig. 2).

Table 3. *Natural durability of some bamboo species (graveyard test data).*

Bamboo spp.	Maximum life (months)	Minimum life (months)	Average life (months)	Remarks
Dendrocalamus strictus	30	18	19.3	Unpublished data FRI, Dehra Dun
Dendrocalamus membranaceus	21	9	13.0	Unpublished data FRI, Dehra Dun
Bumbusu balcooa			32.0	Purushotham et al, 1954
Bambusa nutans	18	6	9.8	Unpublished data FRI, Dehra Dun
Bambusa polymorpha	84	12	23.4	Unpublished data FRI, Dehra Dun
Bumbusa tulda			41.0	Purushotham *et al,* 1954
Melocanna bumbusoides	24	9	19.9	Unpublished data FRI, Dehra Dun

FIGURE 1. Graveyard tests on treated and untreated bamboos

FIGURE 2. Bamboos removed from graveyard
1. Treated (Sound) 2 & 3 Attacked

Variation in durability has also been observed along the length of the culm and the thickness of the wall. The lower portion of the culm is considered more durable, while the inner part of the wall deteriorates faster than the outer harder portion. This is probably related to the anatomical and chemical nature of the woody cells.

Because of the lack of any toxic constituents, bamboos form a ready food source for a variety of organisms. The presence of considerable quantities of starch in green or dry bamboo makes it more attractive to such organisms, especially stain fungi and borer beetles. Some sap sucking insects have been reported to attack bamboo plantations as well (Chatterjee and Sebastian, 1964,1966; Singh, 1988). The most serious borers of felled bamboos are three species of Dinoderus (celluris, minutes, brevis) and Lyctus, which attack bamboo rich with starch (Casin and Mosteiro, 1970; Sandhu, 1975). They cause immense damage during drying, storage, and subsequent use. Carpenter bees and termites alsoattackbamboo (Beeson, 1938;Sensarma and Mathur, 1957). Bamboos are attacked by marine organisms as well (Anon, 1945).

It is reported that bamboos harvested during summer are more rapidly destroyed than those felled in the rainy season (Liese, 1980). Culms of bamboo plants which have flowered are more resistant tobeetlesbecause of starch depletion. Efforts have also been made to correlate the natural durability of bamboo with phases of the moon (Kirkpatrick and Simmonds, 1958), but it appears to be more of a myth than a scientific fact.

Biodegradation of Bamboo during Storage

Biodegradation is a serious problem in pulp bamboos but is seldom recognised by the pulp mills, as such mills store bamboos in forests/depots for over one year. In earlier investigations, various white rots and brown rots were found to attack the bamboo stacks. No appreciable differences in unbleached and bleached pulp yield were noticed between attacked and sound bamboos, owing to the proportional removal of both lignin and cellulose during fungal attack. (Yields were calculated on the basis of weights of material at the pulping stage, with no allowance made for the weight loss that occurred during storage.) Strength properties of paper from decayed material were, however, appreciably lower (Guha, et al., 1958; Bakshi, et al. 1960). The influence of decay on yield was very striking in studies on flowered bamboos (Bakshi et al, 1960). A 4% decrease in unbleached pulp yield was noticed in bamboos with early stages of white rot attack. Moderate and advanced white rot attack, however, showed an increase in pulp yield on the basis of weight of decayed material charged into digester, because of the simultaneous attack of such fungi on lignin. Advanced brown rot resulted in 25% loss in yield and produced unbleachable pulps.

Decay fungi seriously affect the pulp yield (up to 25% loss over one year storage) and pulp strength is reduced by 15 to 40% (Guha and Chandra, 1979; Bakshi et lal, 1960). In addition, loss of fibrous material due to fungal, borer or termite attack increases chipping losses and reduces digester capacity (Kumar et al, 1980). Fungal attack increases pulping costs, owing to increased alkali demands (because of acidic nature of fungi) and higher bleach consumption (Singh, 1977). While advanced fungal attack produces unbleachable pulps, borer attack in epidemic stages reduces the entire stack to powder, causing losses between 20-40% of volume. Termites also attack bamboo stacks, which in the absence of adequate protection, can suffer losses up to a level. of one metre from the ground during one year of storage (Kumar et al, 1990; Fig. 3a). Protected bamboos remain sound during storage (Fig. 3b).

Any prophylactic treatment of bamboo for pulping should take into account the effect on water quality during processing. Research has shown such treatment is possible but rarely used due to costs.

DRYING OF BAMBOOS

As already mentioned, green bamboos may contain 100-150% moisture content, depending on the species, area of growth and

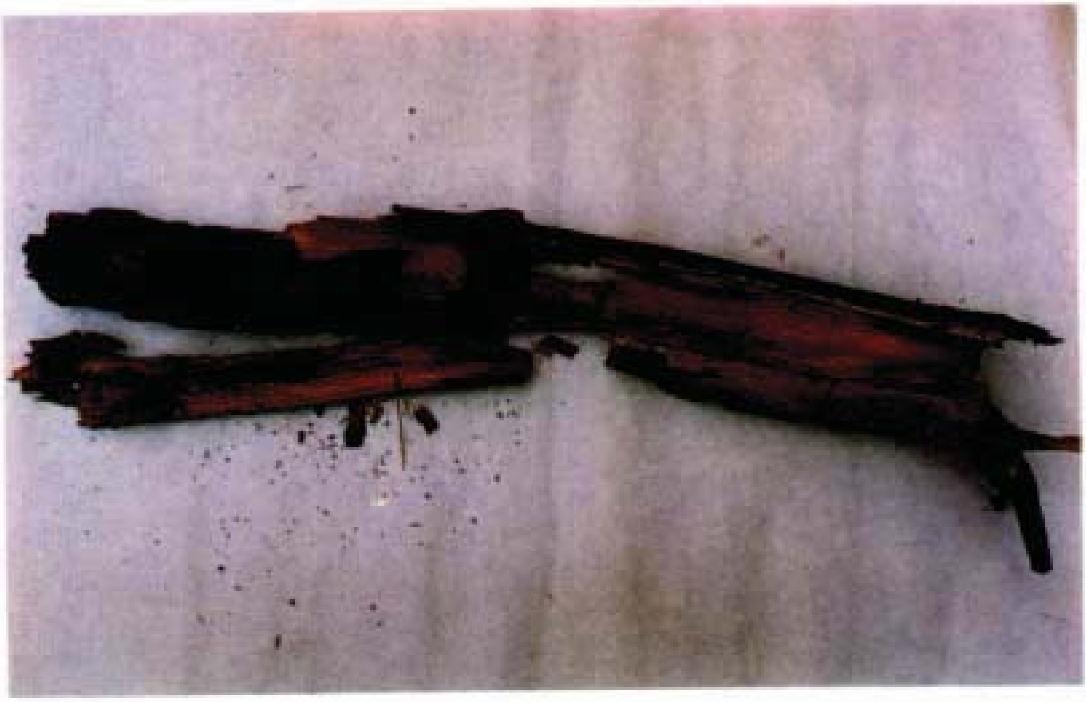

FIGURE 3(a). Advance decay and insect attack in Bamboo.

FIGURE 3(b). Stack of prophylactic treated bamboos.

felling season. In addition, bamboos possess hygroscopic materials in the parenchyma and, therefore, take a longer time to dry compared with wood of similar density (Sekhar and Rawat, 1964; Laxmana, 1985). The liability to biological degradation and to deformation owing to excessive shrinkage (which occurs even above the fibre saturation point) necessitates quick drying of bamboo.

Kiln Drying

At the present level of drying technology, kiln drying of round bamboos is not feasible. Even under mild drying conditions, higher temperatures enhance the incidence of cracking and collapse (Rehman and Ishaq, 1947). Split bamboos can, however, be kiln dried.

Air Drying

Air drying takes 6-12 weeks, depending on the initial moisture content and wall thickness. Collapse may be a major problem in some species, owing to excessive and non-uniform shrinkage of the culm. However, problems are mostly seen in drying of immature culms. It is recommended that only mature culms are used (Sharma, 1988).

Split bamboos do not pose any problems in air drying and can be dried even in the open sun. Split bamboos standing upright dry faster than horizontal stacking. Round bamboos can also be dried standing upright or in stacks, using bamboo crossers of appropriate diameter.

PROTECTION OF BAMBOO

Protection of Bamboo Plantations

In India, insect pests of standing bamboo were never considered important and not much work has been done. Some defoliators (Mathur, 1943), bamboo stem beetles (Roonwal, 1977), weevil borers (Chatterjee and Sebastian, 1964, 1966) and sap suckers have been occasionally observed (Beeson, 1941).

Defoliators can be controlled by spraying with 0.2% fenitrothion or 0.1% carbaryl in water with a "sticker". Silvicultural controls work better with weevils, while sap suckers can be controlled by spraying kerosene oil in soap emulsion or folian spray with 0.04% dimacron/rogor or 0.2% fenitrothion.

Dangers from fungal attacks are low in plantations and vigilance is necessary during normal silvicultural practices in the event that some protection/control is needed (Mohanan and Liese, 1990).

Protection of Bamboos during Storage

Pilot-scale trials for short-term protection of bamboos were carried out at three different mills under different climatic conditions in India by the Forest Research Institute, Dehra Dun. Stacks of bamboos were prepared following the pattern adopted by individual mills in a criss-cross arrangement, and were treated by the same chemicals found effective in laboratory trials with minor variation in chemical ratio. Material after different storage periods with/without prophylactic treatment was assessed for incidence of fungal/borer attack (Table 4) and pulp yield and wood substance losses (Table 5, Kumar cl al, 1985).

It should be noted that treatment with Sodium PCP should never be recommended for prophylactic treatment of bamboo destined for pulping.

Prophylactic treatment, including Sodium PCP, resulted in considerable savings in stored bamboos. A long-term protection experiment for storing flowered bamboos up to eight years conducted at Ballarpur Paper Mills, Ballarpur (Maharashtra, India) also gave similar results (Kumar et al,1990).

Laboratory and field trials showed that losses from fungi and insects can be significantly reduced if proper treatments are carried out at the time of stacking, even under open storage. The cost of protection varies from Rs 5 to 10 per tonne (Kumar et al, 1980, 1990).

Table 4. *Incidence of borer/fungal attack on prophylactically treated bamboos with different compositions.*

Treatment	Sound	Fungal attacked only	Fungal borer attacked	No. of borer holes/ bamboo	Remarks
Control	40	35	25	110	Severe stain and fungal attack.
*Sod. PCP 2%	90	-	10	100	No stain fungi.
Boric acid: Borax (1:l) 2%	86	-	14	50	Stain fungi present.
*Sod. PCP: Borax: Boric acid (1:l:l) 3%	83	-	17	70	No stain fungi.

Table 5. *Pulp yield and wood substance losses in bamboos stored with and without prophylactic treatment (average of 3 sites).*

Preservative used	Storage period (months)	Loss in pulp yield (%)	Loss in density (%)
Control	6	6.7	10.5
	12	9.8	13.0
*Sodium PCP 1%	6	4.3	6.0
	12	6.4	7.7
Boric acid: Borax (50:50) 2%	6	4.2	5.7
	12	6.5	7.5
*Sodium PCP : Boric acid : Borax (.5:1:1) 2.5%	6	2.4	4.4
	12	4.7	7.0

* Sodium PCP is shown to be useful experimentally but cannot be used in practice for a number of purposes.

It should be noted that pest attack of stored bamboo may be sporadic. For instance, with beetle attack of reed bamboo, harvesting season, varietal differences and mode of transportation (by water or road) are not important, but maturity of the culms is the key element. A pest management strategy using minimal appiication of pesticide is recommended (Nair et al., 1983).

For protection of structural bamboos (if stored outside), repetition of the treatment after four to six months is recommended. Such bamboos may be treated with any of the compositions above or in Appendix *2.*

For long-term storage of pulp bamboos in the open, it is recommended that the stacks are raised on specially prepared ground (about 10 cm layer of boiler ash, powdered lime sludge containing about 2% BHC) to prevent ttrmi te attack. The stacks should be profusely treated during different stages of stack forming (i.e., at 3,4.5 and 6 metres height) and may be covered with treated bamboo mats or thatch grass. However, treatments must be done in such a way that chemical pollution of the environment is avoided, e.g. fine spray nozzles result in more than 50% of the preserva tive being lost and heavy pollution of the environment.

Stacking methods, and treatments, depend on the incidences of both insect and fungal attacks. For reed bamboos, vertical stacking results in a small gain in pulp yield over horizontal stacking because the former suffers less fungal damage. Monthly treatment with borax-boric acid results in a substantial gain (Gnanaharan *et al., 1982).*

Treatments to Enhance Durability in Service

Generally, the treatment of bamboo is divided into two categories, viz., (a) treatment of green bamboos and (b) treatment of dry bamboos. In addition to the established methods of treatment for wood, some traditional methods are also in use for the treatment of bamboos. Such methods include leaching in water or white washing, and can be carried out without special equipment and technical know- how. Chemical preservation, on the other hand, needs skill and a definite treatment schedule.

Traditional (Non-Chemical) Methods of Protection

Controlling starch content in felled bamboos

In bamboos, soluble sugars are the principal nutrients for parasites. Thus, bamboos with depleted carbohydrates become reasonably resistant to the attack of borers and staining fungi. Methods adopted for lowering the sugar content in bamboos are:

(i) **Felling of bamboo during low-sugar content season:-** Sugar content in almost all plants varies with seasons. In India, for example, it is higher in spring than in winter (Joseph, 1958). Therefore, it is advisable to harvest bamboos between August and December.

(ii) **Felling of bamboo at maturity when sugar content is low:-** Sugar content in bamboos varies with age. It is lowest during the first year but felling of one-year-old bamboo is not desirable because of very low strength and yield. Normally, bamboo matures at 3-4 years.

(iii) **Post-harvesting transpiration of bamboo culm:-** Sugar content in bamboos can also be reduced by keeping , culms upright or leaning them against trees for a few days. Parenchyma cells in plants continue to live for some time, even after felling. During this period, the stored food materials are utilised and, thus, the sugar/ starch content in bamboos is lowered.

(iv) **Water soaking of bamboo:-** In Indonesia, Vietnam and Africa, an easy and widely followed practice for increasing the durability of bamboo is soaking bamboo in water (Sulthoni, 1987). During soaking in water, most of the sap present in bamboo is leached out. Some workers have suggested that a soaking period of 4 to 12 weeks is sufficient.

Experimental work on submerging in mud (Suhirman, 1987; Sulthoni, 1990) and other applications of water soaking have not yet resulted in additional recommendations.

Baking over open fire

Baking over fire after applying oil on the surface is another traditional method for preservation of green round bamboos. This causes rapid drying of the outer shell and induces partial charring and decomposition of starch and other sugars. Moist heating is reported to cause irreversible swelling in bamboo, which probably balances the shrinkage due to moisture loss, thus stabilising bamboo. Baking is recommended over a gentle fire, taking care that the surfaces are rotated constantly. Excessive heating/drying can cause severe collapse (Rehman and Ishaq, 1947). This method is very useful for simultaneous straightening of bamboos in round form.

Lime washing and other coatings

A variety of coatings, such as tar, lime wash, tar and lime wash and tar sprinkled with sand, are used by house builders in Indonesia. These coatings are successful only when continuously applied at cut surfaces, exposed internodes, abrasions and splits.

Chemical Preservative Treatment Methods

Chemical protection ensures a longer life for bamboos. Treatments can be given using a variety of chemicals (Appendix 2), depending upon the culm condition (green or dry) and ultimate use to which the material is to be put. Both non-pressure and pressure treatment processes can be used effectively, the key being thoroughpenetrationand distribution with recommended doses of preservatives. A guide to the various treatments is given in Appendices 3 and 4. Penetration of such chemicals can be checked by simple spot tests (Appendix 5). Assay of preservative can be done by following usual laboratory analysis techniques recommended for different wood preservatives.

Treatability of *Bamboo*

The tissue of bamboos is buil t up ot parenchyma tous cells and vascular bundles (vessels and thick-walled fibres). The vascular bundles are not uniformly distributed inside the culm (Fig. 4) Numerous smaller ones are present towards the outer portion, while larger but fewer bundles are found towards the central part of the culm (Kumar and Dobriyal, 1992). Bamboo has no radial cell elements like the rays in wood. The outer wall is covered by a thin and hard layer and is less permeable than the inner layer. Nutrients are stored in the ground tissue of parenchyma cells, which constitute up to 50%j of the tissue (Liese, 1987). Bamboos behave entirely differently from wood during treatment with preservative.

The vascular bundles play an important role in preservative treatment. The axial flow is quite rapid in green bamboos, because of the end-to-end alignment of vessels. The degree of penetration decreases as the distance from the conducting vessel

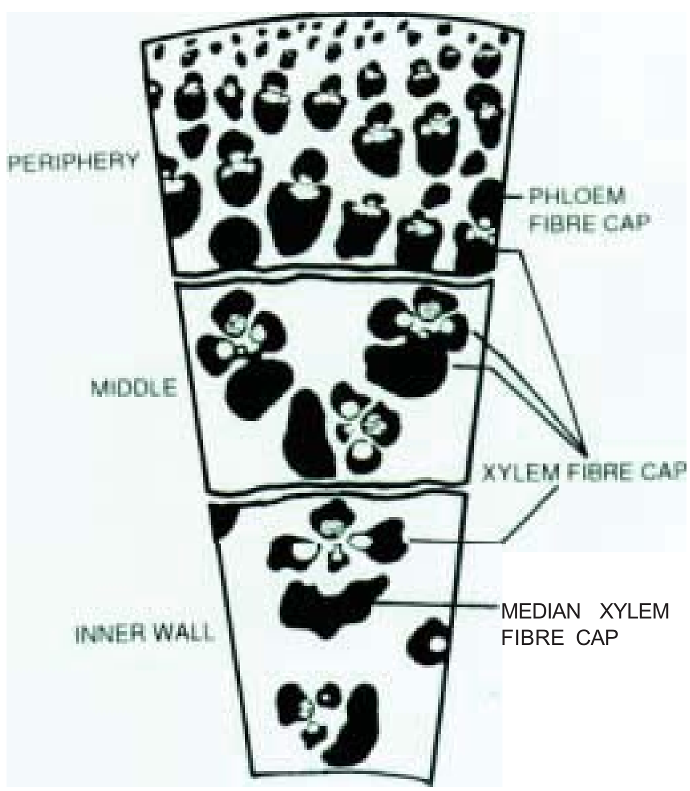

FIGURE 4. Diagramatic sketch of bamboo cross-section

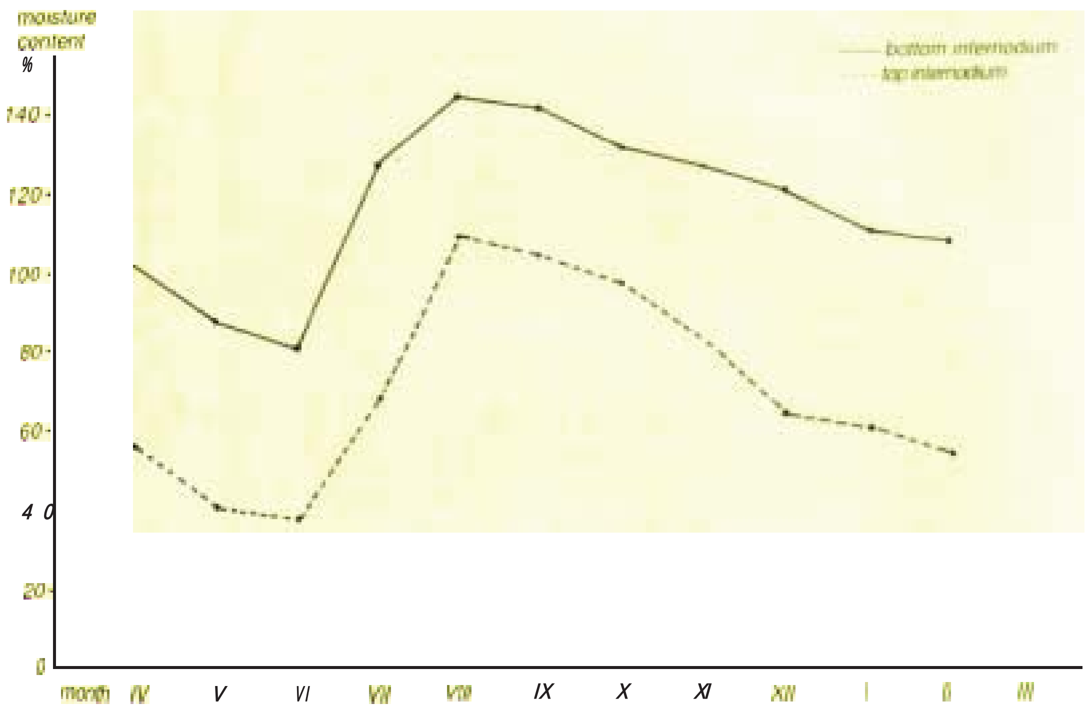

FIGURE 5. Seasonal changes of moisture content in bamboo

increases. The larger vessels tend to get a larger amount of preservative than the smaller vessels. (Both larger and smaller vessels belong to metaxylem whereas the protoxylem consists of tracheid-like elements.) Since vessels occupy a mere 10% of the culm volume, the penetration of preservatives to other tissues surrounding the vessels assumes more importance because untreated pockets, especially in parenchyma tissues, can lead to early destruction by fungi (Licse, 1959).

Moisture has a great influence on treatability of bamboo, especially in the green condition, where the movement of the preservative occurs via diffusion. For a Boucheric treatment, a high moisture content is conditional. Treatability is thus regulated by age (6-Y years old bamboos contain less moisture than young bamboos of 3-4 years), season of telling (maximum moisture is present during the rainy season, Fig. 5, and position (the upper portion of the culm has always a lower moisture content than the bottom). Such differences are of great consequence in uniform and adequate treatment of bamboos by non-pressure methods (Liese, 1959).

During drying, a number of anatomical changes occur, which reduce the treatability of bamboo. In contrast to wood, bamboo starts shrinking from the moment it starts losing water. Sap in the vessels is precipitated, clogging the openings to the adjacent tissues. The pit canals in the parenchyma cells become covered with protoplasmatic substances, rendering them somewhat less permeable to fluids. The entrapped air in various tissues increases the interfacial tension between the penetrating fluids, restricting the flow. The epidermal layers containing waxy and siliceous material repel incoming preservative solutions.

Although the anatomical structure of some bamboos has been well studied, there are not many studies on the flow channels and distribution of the preservative chemicals in different structural parts in dry bamboo. However, it appears that diffusion across the wall decreases with increasing wall thickness. Diffusion rates are highest in the longitudinal and lowest in the radial direction (Bains and Kumar, 1978).

Recently, a study conducted on Dendrocalamus strictus using organic and inorganic chemicals to determine the flow paths showed that creosote was better distributed than water soluble inorganic chemicals (Kumar and Dobriyal, 1992). Similar studies on some other species indicated that parenchyma cells are not easily penetrated in bamboos, owing to deposits of protoplasmatic substances, as mentioned above. Studies have indicated that there is variation in treatability of bamboo along the wall thickness as well as height (Table 6).

Treatment of ***Fresh Bamboo***

Traditional methods increase the resistance of bamboos to borer attack but are ineffective against termites and fungi. Moreover, such methods are best suited to a small-scale user, who is as well a producer. Since bamboos have a large variety of uses and are required throughout the year, traditional methods are of

Table 6. *Preservative (CCA) loading variation along wall thickness and height in* D. strictus.

Bamboo internode	Location along wall thickness	Specific gravity	Split Absorption kg/m’	Solid Absorption kg/m^3
Base	Outer	0.674	9.8	
	Middle	0.567	9.0	8.6
	Inner	0.542	11.4	
	Average	O.594	10.1	
Middle	Outer	0.716	13.2	
	Middle	0.519	15.3	12.8
	Inner	0.522	15.4	
	Average	0.586	14.6	
Top	Outer	0.704	13.7	
	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 hg/m^3

limited value. Alternatives to thesc methods are treatments with chemical preservatives.

(i) **Steeping:-** Freshly cut culms arc immediately placed upright in containers of concentrated solutions of water-borne preservatives (5-10%).. The butt end, up to 25 cm, is kept immersed in the preservative solution. Generally, drops of preservative solutions are observed at the nodes. The treatment takes between 7 and 14 days, depending on the length of the culm. Losses in preservative solution in the container are made up to maintain the initial level of solution. Ramboos can be satistactorily treatedby this method without any equipmcnt and technical skill (Singh and Tcwari, 1980).

(ii) Sap displacement:-Round, half, quarter and 1/8 split fresh bamboos are immersed vertically up to 25 cm, in 10% aqueous solutions of water-borne wood preservatives, i.e. boric-acid-borax, acid-copper-chrome, copper-chrome-arsenic, etc., in suitable containers. The preservative solution rises by wick action as the sap is sucked up. Solution level is maintained by adding fresh quantity at intervals. Adequate loading exceeding 10 kg/m" are obtainable in two metre long bamboos in just six days (Singh and Tewari, 1980). Longer pieces can be treated over a slightly longer period.

In many cases, such treatments are not favoured because of environmental pollution.

(iii) **Diffusion process:-** In the diffusion process, freshly felled culms or bamboos with high moisture content (above 50%) are kept submerged in solution of water-borne preservatives for a period sufficient to attain the required preservative loading. A diffusion period of 10 to 20 days is satisfactory. The absorption and penetration of the chemicals is more in split than in round bamboo. The outer layer of bamboo is more or less impervious and the inner cuticle is permeable to diffusing ions (Singh and Tewari, 1981a). Therefore, boring holes near the nodes or increasing the diffusion time results in better penetration and higher loading. Preservatives that fix slowly, or have high diffusion coefficients like boron-based preservatives, penetrate better. Dip diffusion, steaming-quenching followed by diffusion, and double diffusion are all variations of the diffusion process.

Experiments have shown the effects of dip diffusion. For instance, diffusion with copper sulphate solution (20%) for 96 hours followed by dipping in sodium dichromate solution (20%) for 96 hours, and then storing the bamboos under non- drying conditions for one month, result in over 40% penetration with loading around 13 kg/m^3 in Dendrocalamus strictus (Singh and Tewari, 1981b).

Steaming and quenching, followed by diffusion under drying conditions, is another variation of the diffusion process but this is still only experimental and not yet applied widely. Steaming bamboos at about 100°C for 2.5 hours and quenching in 20% solution of water-borne wood preservatives (CCA), and subsequent storage for about one month, lead to almost complete penetration with very high loading of the preservative. The loading obtained in half split bamboos is 60 percent higher than in round bamboos (Singh and Tewari, 1981b). It is, therefore, recommended that in round bamboos, if this method is to be applied, that either the septa should be punctured, or small notches should be made near the nodes, to allow free access of the solution to the inner epidermis layer of the bamboo, enabling subsequent drainage of the preservative solu tion from the culm. Treatment with 8-10% solution of CCA, ACC or CCB following the above schedule would give a retention of about 10-12 kg/m^3 in most bamboo species.

Diffusion rates almost double with every 10-20°C rise in temperature (Kumar and Bains, 1979). However, CCA, ACC, or CCB solutions start precipitating on heating. Diffusion rates also depend on thenature of the diffusing ion and its interaction with the diffusion media. Preservatives based on ammoniacal solutions not only diffuse faster, but can also be heated to get better penetration and loading in shorter periods (Dev et al, 1991). Ammoniacal-copper-arsenite can be used for treating green bamboos by diffusion, taking advantage of better penetration of the ammonium ions.

Results of investigations, summarised in Table 7, have demonstrated that diffusion processes are perhaps the best and simplest for treatment of green, split and round bamboos. In fact, these could be universally specified as preservative treatments of bamboos for all purposes.

(v) Boucherie process:- This is a widely recognised process which does not require detailed description here. It is suitable for freshly felled green bamboos with branches and leaves intact. Even one-day-old bamboos can be treated by just chopping off about 15 cm from the butt end. In the process, the preservative is pushed through the bamboo by gravity from a container placed at a height. This method has been modified to use a simple hand pump by means of which air pressures of 1 .0 to 1.4 kg/cm′ could

Table 7. *Treatment of green* Dendrocalamus strictus *by different non-pressure methods (Singh and Tewari, 1979; 1981).*

Specimen type	Method	Preservative	Duration	Absorption kg/m^3*
Round	Diffusion	ACC 6%	10 Days	7.76
Half-split	"	"		11.16
Round	"	"	"	10.65
Half-split	"	"		15.53
Round	"	"	30 Days	15.65
Half-split	"	"	"	19.77
Round	"	Boric acid Borax 6%	10 Days	7.73
Half-split	"	"	"	11.32
Round	"	"	20 Days	10.86
Half-split	"	"		20.16
Round	Osmo-paste diffusion	CCA paste	30 Days	10.74
Half-split	"	"		14.66
Round	"	"	60 Days	20.38
Half-split	"	"		31.76
Round	"	ACC paste	30 Days	12.04
Half-split	"	"		18.51
Round	"	"	60 Days	26.25
Half-split	"	"	"	31.56
Round	Steam quenching	CCA 20%	4h/0.5 h	5.26
Half-split	"	"	"	5.84
Round	"	"	4h/48 h	18.34
Half-split	"	"	"	30.46

* ascertained by chemical analysis

FIGURE 6. Boucherie treatment of green bamboo using foot pump for creating pressure.

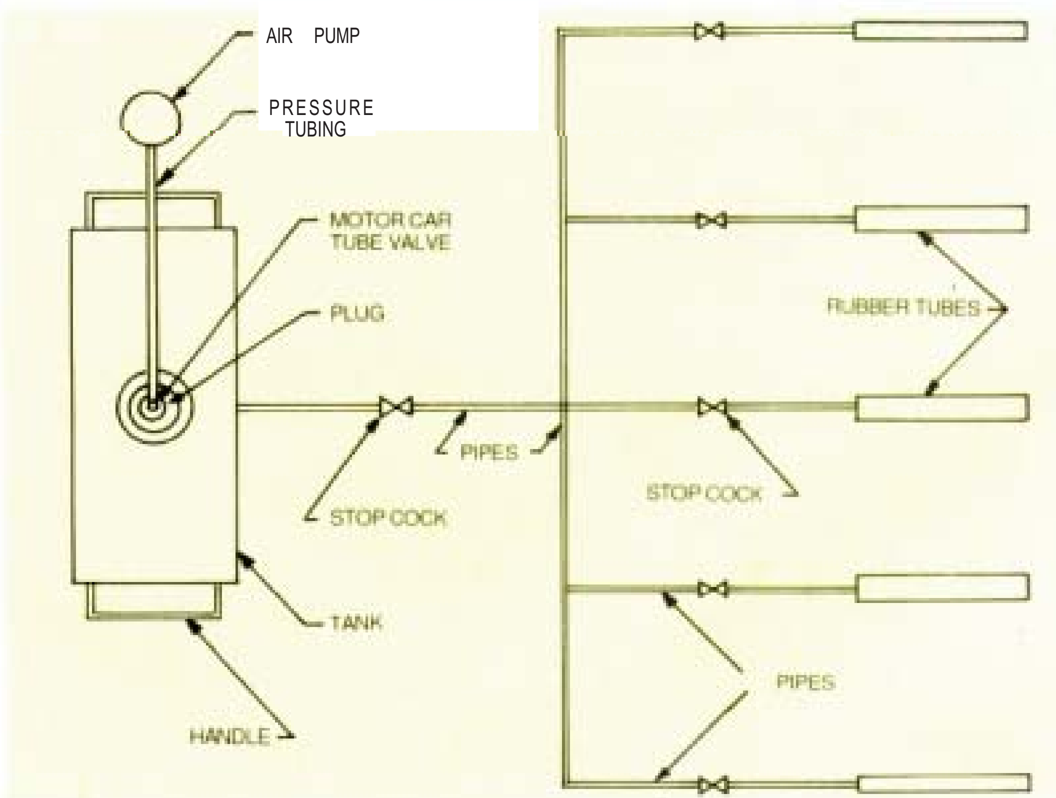

FIGURE 7. Schematic diagram of modified Boucherie treatment plant.

be applied to the preservative in a suitable container kept at the ground level (Purushotham et al, 1954). This reduces the period of treatment significantly. The penetration and absorption of the preservative depend upon several factors like concentration of solution, treatment time, nature of chemicals used, dimensions of bamboo, its age and moisture content.

It usually takes 30-60 min to treat short bamboo lengths using pressures up to 2 kg/cm^2 The equipment at the Forest Research Institute, Dehra Dun, and used for the past 35 years, is shown in Fig. 6. A schematic diagram, in Fig. 7, shows the potential to increase the pressure during the process. Earlier studies on a number of bamboo species indicated that treatability of green bamboos with non-pressure methods was highly variable. The modified Boucherie process is a process which can be used with confidence (Purushotham et al, 1954).

In order to get more uniform distribution of preservative from bottom to top, it is possible to use initially a concentrated solution (- 6%) until the solution appears at the dripping end. This should be followed by pumping in a solution of a lower concentration (- 2%) for the same period (Shukla et al, 1979).

Treatment of Dry Bamboo

(i) Soaking:-Air-dried bamboos have only to be submerged in the preservative solution (oil or solvent type) for a period depending upon the species, age, thickness and absorption required. Such treatments are used in India, but not elsewhere. The penetration is predominantly by capillarity. The soaking method requires little equipment and technical knowledge, provided the schedule of treatment, such as type of preservative, its concentration and the period of dipping, is worked out. Nonetheless, there are dangers of pollution due to spillage.

If water-borne preservatives are used, the process is called "Steeping". Results of investigations using specimens of D. strictus and B. polymorpha soaked in water-soluble preservatives (5% CCA composition) indicated that the penetration of the solution was fast in the initial stages and gradually slowed with time. Adequate amounts of preservative, however, were absorbed in all the specimens in about two weeks. The absorption of preservative was more in half-round specimens in comparison to round ones (Table 8).

Table 8. *Absorption of preservative in air-dried specimens of* Dendrocalamus strictus *and* Bambusa polymorpha *treated by steeping in 5% CCA composition.*

Species	Type of sample	Dry salt absorbed (kg/m' after different immersion period (days) 6	12
Dendrocalamus strictus	Round	9.75	13.15
	Half-split	9.71	14.43
Bambusa polymorpha	Round	6.93	10.01
	Half-split	13.44	17.92

Soaking treatments with organic solvent type preservatives, suchaspentachlorophenol, copper/zincnapthenates/ abietates, work better than steeping in water-soluble preservatives. Such treatments may, however; be more expensive in some countries because of the cost of the solvents. Cold soaking in diesel oil for 7 days, reported to prevent borer attack, works out to be cheaper than treatment with copper- sulphate solution in Indonesia (Sulthoni, 1990).

Results above are experimental and if the process becomes more widespread, practical applications such as moisture contents and length of samples need to be worked out.

(ii) Hot-cold process:- At FRl, Dehra Dun, a hot-cold tank process has been developed. However, it is not widely in use elsewhere due to the economic aspects. Air dried material is loaded in the tank fitted with steam coils or some other heating arrangement. The tank is then filled with a hot creosote : fuel oil mixture and heating is continued to raise the temperature to about 90°C, which is maintained for a period of about 3-6 hours.

The preservative is then allowed to cool, after which oil is drained out. The round bamboos with holes are then kept inverted in the tank, to allow the preservative to flow out from the hollow portions of the bamboo. Split bamboos do not require such a practice.

Typical loading of creosote: fuel oil obtained following different heating schedules are reported in Table 9.

Table 9. *Hot-cold tank treatment of bamboos (without holes) with creosote : fuel oil (1:1) (Singh and Tewari, 1979).*

Species	Heating time (h)	Absorption (kg/m) Round	Half-split
Dendrocalamus strictus	3	54	57
	4	69	72
	6	72	74
Bambusa yolymoryha	3	42	45
	4	49	57
	6	67	72

(iii) Pressure treatment:- It is theoretically possible to use pressure treatments (Purushotham, 1963; Kumar and Dobriyal, 1992), but general applicability in a number of countries has not yet been developed. Species of bamboos having thin walls are susceptible to cracking, even when treated under low pressure (5-7 kg/cm^2) (Singh, 1976). Round and half split bamboos of thick walled species like Dendrocalamus strictus can be treated with creosote: fuel oil (1:1) under hydraulic pressures of 14 kg/cm^2. Retentions ranging between 88 and 92 kg/m^3 are obtainable in round or half split bamboos (Singh and Tewari 1980).

Treatment with water-borne preservatives like CCA can also be done effectively. A pressure of 3.5 kg/cm^2 for one hour is sufficient to achieve retention of more than 8 kg/m^3(dry salt) in split bamboos. (Kumar and Dobriyal, 1990). The preservative loading varies significantly from bottom to top (increase) and

FIGURE 8. Use of treated bamboo (erected 1989)

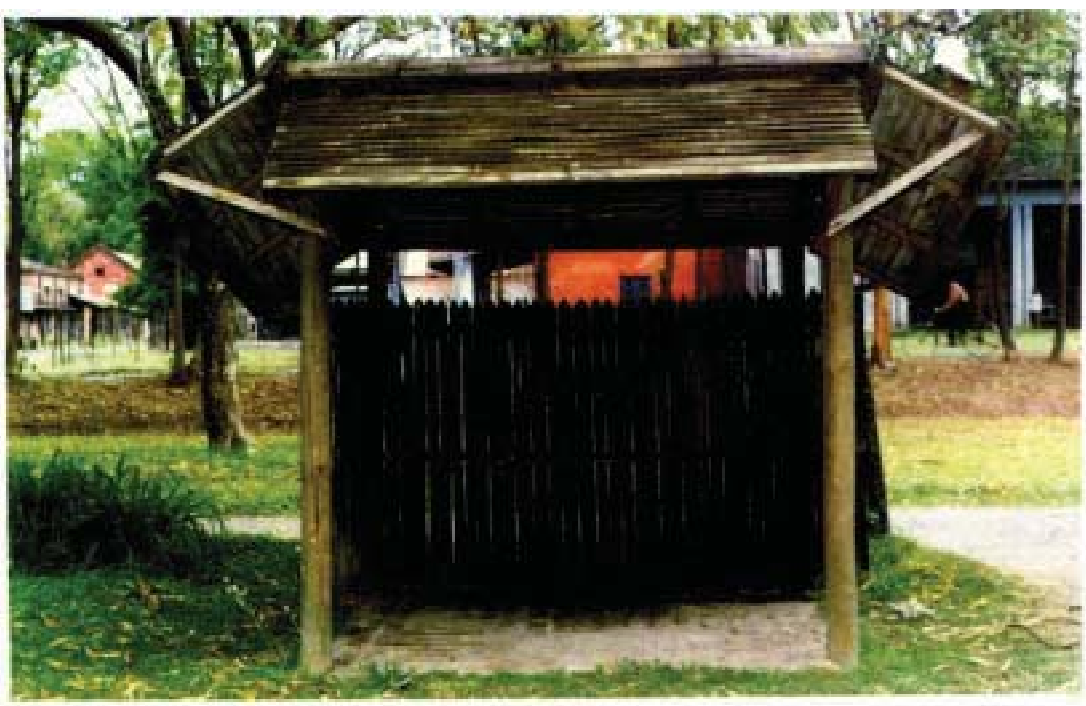

FIGURE 9. CCA treated bamboo shed (erected 1978)

FIGURE 10. Treated bamboos for reinforcing mud walls for storage godowns (erected 1959)

FIGURE11. . Bamboo-mat (CCA treated) for protection against wind and rain in storage pIowns (erected 1971)

from inner layers to outer layers (decrease). Treatment with 6% CCA under 7 kg/cm^2 yielded absorptions between 14-18 kg/m^3 (Singh and Tewari 1980).

The problem of collapse of round bamboos under pressure treatment can be solved by drilling holes or notches between septa (Sonti, 1990), but this leads to considerable spillage. Drilling holes not only equilibrates the pressure on both sides of the bamboo wall, but also ensures better treatment from both surfaces. A vacuum/pressure schedule helps to ensure more uniform penetration.

Performance of treated bamboos in service

Trials with treated bamboos have indicated varied durability depending upon the location of use. CCA treated bamboos in partially protected areas give a fresh appearance even after five years of service (Fig. 8), and in exposed conditions showed some decay after 15 years (Fig. 9). Treated bamboos used for reinforcement of mud walls decayed up to about 50 cm from the ground level (Fig. 10) in 15 years, while the rest of the structure was sound. The performance in partially exposed or under cover was much better (Fig. 11). Practically no damage to CCA treated bamboo used as a roofing support (Fig. 12a) for a thatched hut and as exterior cladding in low cost huts was noticed, even after 40 years of service (Fig. 12b).

ENVIRONMENTA1 ASPECTS OF TREATING BAMBOOS WITH PRESERVATIVES

Methods described under non-conventional techniques are absolutely safe and pose no threat of environmental pollution. At the same time, these methods have limited scope in extending bamboo’s service life. Chemical preservation strategies employ chemicals toxic to fungi and insects and are invariably toxic to mammals. Slight carelessness in the use of such chemicals can endanger the safety of workers handling the chemicals or freshly treated materials. A useful reference book has been issued by

UNEP (Anon., 1994).

Although the preservatives recommended in Appendix 2 have long safety records, these chemicals are under constant scrutiny by various pollution control agencies. The very name of arsenic in preservative formulations raises an alarm in the minds of environmentalists. Formulations containing arsenic and chromium have been rigorously tested for leaching in labora tory and under service conditions, and meet current safety standards. CCA treated material is considered absolutely safe and has been recommended for the treatment of playground equipment. Such formulations make complexes with wood substances and are rendered immobile to cause any toxicity concern. Pollution hazards do exist at formulation as well as impregnation sites. It is suggested that ready-to-use premixed formulations be used to eliminate such hazards and necessary safety precautions as suggested by the manufacturers be followed. Treatment effluents, if generated on a large scale, should be adequately treated before disposal.

Pentachlorophenol is another chemical being viewed cautiously. The present technology of manufacture of this compound claims that no dioxins are produced in the process. Nevertheless, disposal of all treated wood products and residues have to meet the toxicity characteristic leaching procedure limits (TCLP) proposed by the Environmental Protection Agency (EPA) of the USA.

Guidelines for tropical timber are recorded in Willeitner and Liese (1992) and provide useful pointers for institutes engaged in developing such programs.

Boric-acid: borax, Cu/Zn naphthenates/abietates are among the safest wood preservatives being promoted the world over. Many new chemicals considered to be environmentally safe such as Tebuconazole, IPBC (3-iodo 2-propanyl butyl carbamate), chloro-thalonil, isothiozolones and synthetic pyrethroides are under various stages of adoption as wood preservatives. Apart from being expensive, such chemicals need to be tested for their

FIGURE 12 (a). Round and split bamboos used under thatch roof (erected 1955)

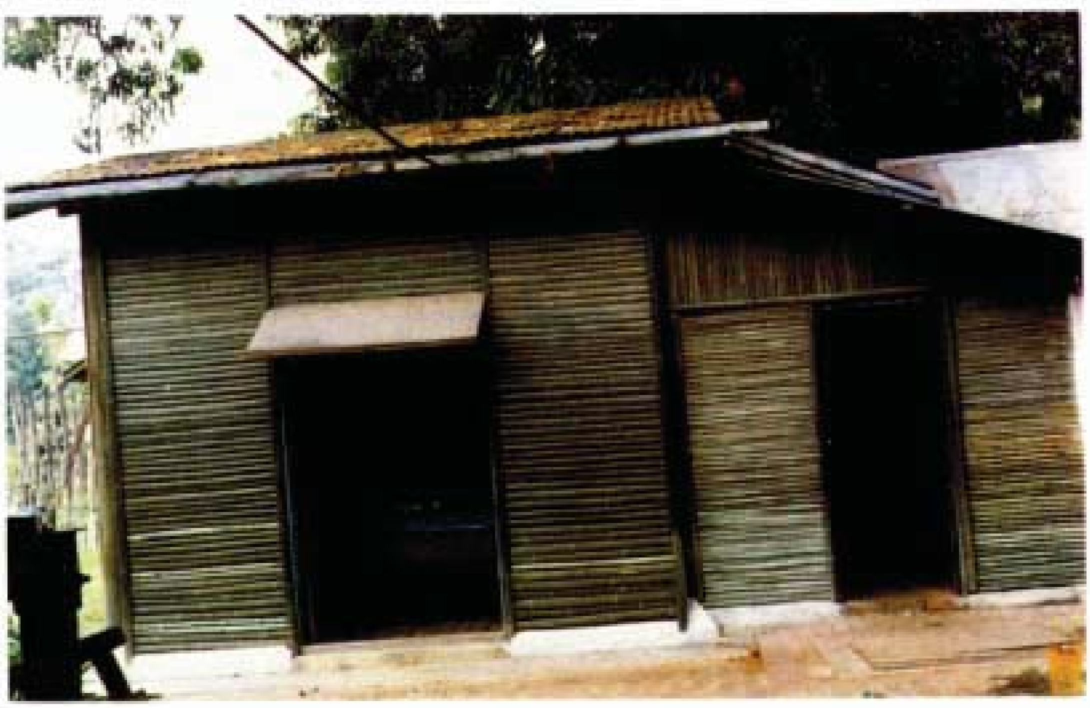

FIGURE 12 (b). Low cost hut made out of CCA treated bamboos (erected 1955) efficacy on bamboos.

Disposal of preservative treated bamboo after prolonged service causes problems in several countries. In some, it is not considered a hazardous waste, but in others it has to be brought to special dumping places.

Proper safety garments such as gloves, aprons, and eye protective glasses should be used while handling preservative solutions or freshly treated material. Any spillage of chemicals should be immediately attended to by soaking in wood dust and disposed appropriately. Freshly treated material should be stored under cover during drying to avoid rain leaching of chemicals.

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APPENDIX 1

GUIDELINES FOR PRESERVATIVE TREATMENT OF BAMBOOS

A. Steps in the Treatment of Bamboo Strips

Preparation of material

(a) Cut mature culms at least three years old.

(b) Make strips using appropriate tools (Fig. 13).

Treatment of strips

(a) When strips have high moisture and there is not sufficient time for seasoning, treat the strips by steeping or diffusion process.

(b) When strips are dry, treat strips by either cold soaking, open-tank or pressure process.

B. Steps in the Treatment of Freshly Felled Whole Round Bamboo

Preparation of material

(a) Cut mature culms at least three years old. These should be cut at least 30 cm above the ground. Keep the branches and leaves on.

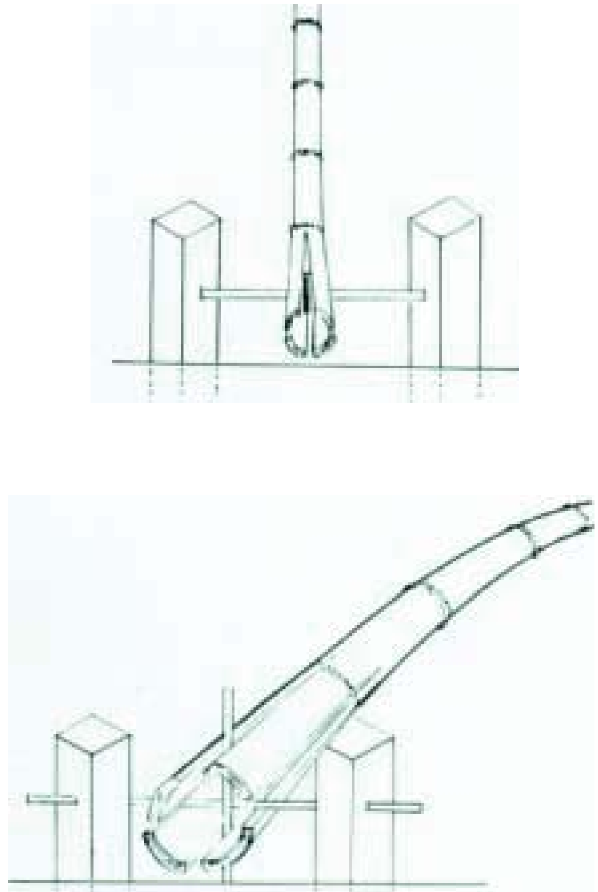
(b) Cut the culm from the top at a portion above which the culm is unsuitable for the purpose for which it is being treated.

Treatment with preservatives

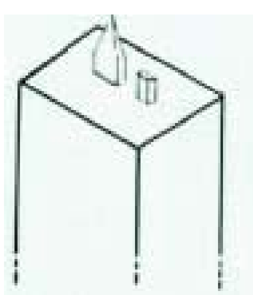
(a) Treat the culm by the modified Boucherie process using water-borne preservative solutions.

(b) Branches should be cut immediately after the treatment is completed. If this is not done, a part of the preservative

Tool for splitting bamboo into two half



Tool for splitting bamboo into four quarters



Tool for making strips of equal-breadth

Cross cutting hand saw

FIGURE 13.

is likely to be sucked into the branches, since the evaporation of moisture through the leaves facilitates the conduction of the preservative.

(c) Treated bamboos should then be stored under shade to facilitatefurtherdiffusionand fixationof thepreservative.

(d) Cuttings and boring done on treated bamboos are likely to expose untreated surfaces. Therefore, such surfaces should be brushed, sprayed or flooded with the same preservative solution.

C. Steps in the Treatment of Round Bamboos of Short Lengths

Preparation of bamboo posts

(a) Cut culms that are at least 2-3 years old.

(b) Cut culms in required length. It is best if the top node is at least 8-10 cm below the top of the post. Cut posts from the lower two-thirds of the culms, since the upper part of the culm usually splits during seasoning.

(c) Knock all nodes but the top one with an iron bar. Then bore 6 mm diameter holes for fastening wire on the post at the appropriate height. It may not be possible to knock all nodes (either because of irregular shape of the bamboo or smaller internal diameter due to greater wall thickness or the nature of the bamboo species). In that case, bore 6 mm holes as given in Figs. 14 and 15 (a &b) in such a way that the holes remain on the upper side of the post when grouted in the ground. Culms intended for use as tent poles or scaffolding should also be bored in the above manner, keeping the bore position just above the node when grouted.

Treatment with preservatives

When bamboos have sufficiently high moisture content, preferably almost green

(i) Treat the bamboo with water soluble preserva tives by the diffusion process.

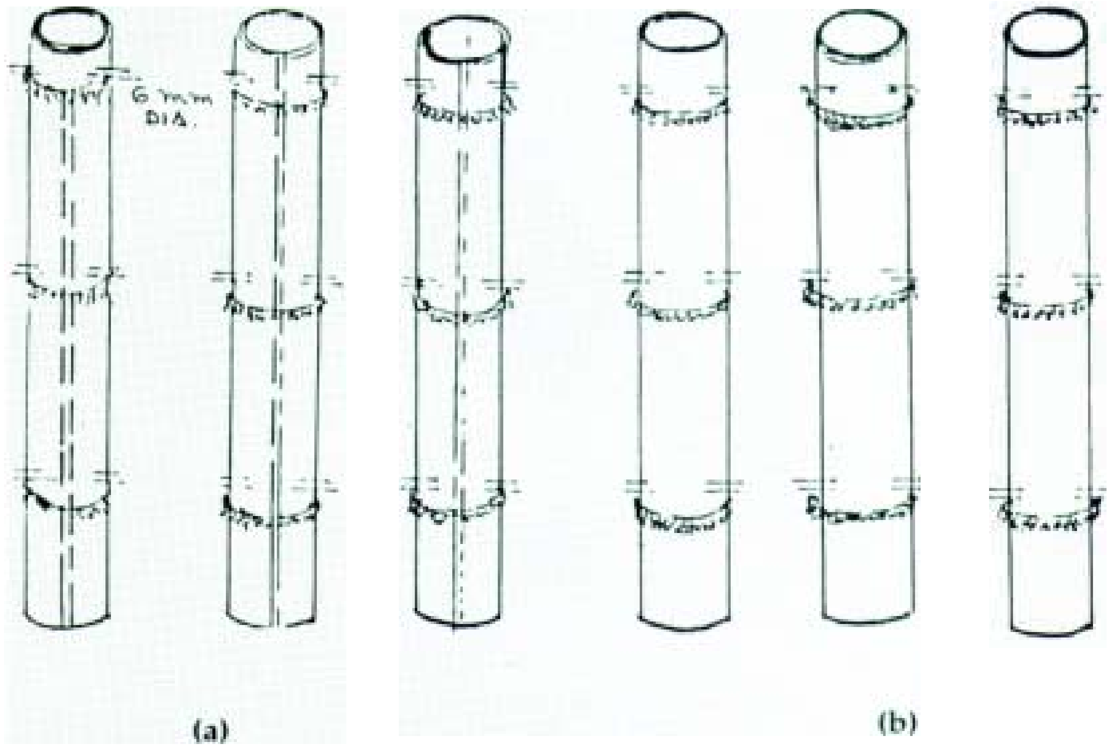


FIGURE 14 : Boring pattern for bamboo with punctured septa tor fence posts.

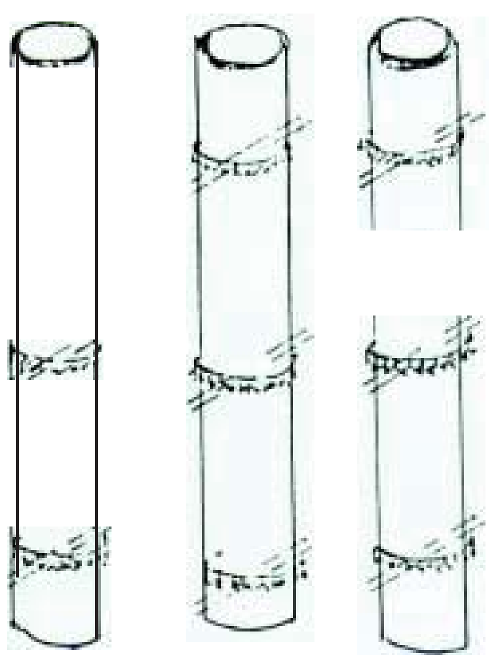


FIGURE 15 (a) : Boring pattern with punctured septa for better trentment of bamboo to ensure penetration of inner wall

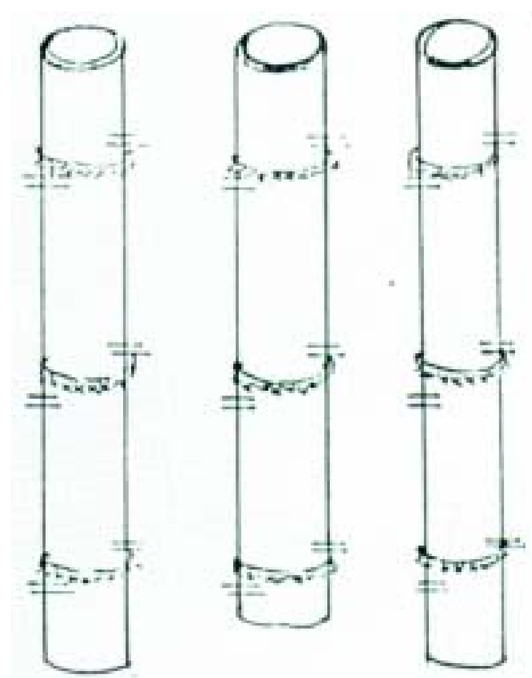


FIGURE 15 (b) : Alternate boring pattern with holes near nodes to ensure access of preservative solutions to inner walls of bamboo

(ii) Drain out the preservative from the tank after achieving the requirements of treatment.

(iii) Take out the treated bamboos from the preservative tank and put them up right over a fixed support to allow the preservative to drip out from the bamboo culms. Collect the left-over preservatives for safe disposal.

(iv) Stack the bamboo under shade and allow to air dry.

When bamboo is partially dry and there is sufficient time for drying

(i) Pile the material for air drying, as green bamboos or bamboos with high moisture content will not absorb preservative solution. First, place two or more bamboos across each block and then place the material cross-wise. Season the material for 4-5 weeks in dry weather and 8-10 weeks in wet weather, or until the material reaches a moisture level of 15-20%.

(ii) Give prophylactic treatment, either by dipping or spraying, to prevent stain/fungus/powder-post beetle attack during drying.

(iii) The material can be treated when dry. This can be done by either cold soaking, hot and cold bath treatment or pressure processes.

(iv) After draining the cylinder, take out the treated material and keep it up right, resting on some fixed support, so as to allow the preservative to drain out. Collect and safely dipose to left-over preservative.

APPENDIX 2

LIST OF PRESERVATIVES RECOMMENDED FOR TREATMENT OF BAMBOOS

Note : Some chemicals are banned in some countries.

(a) Coal tar creosote and fuel oil (50:50) by weight. In high termite-infested areas, it is preferable to add 1% dieldrin. Coal tar creosote should meet the relevant standard specification for preservation purposes (Anon. 1961).

(b) Copper-chrome-arsenic composition containing copper sulphate (Cu SO, $5H_2O$), sodium or potassium dichromate (Na_2 Cr_2O_7, $2H_2O$ or K_2 Cr_2O_7, and arsenic pentoxide (As_2O_5 $2H_2O$) in the proportion of 3:4:1 (Anon. 1981b). In some countries, CCA of different formulations are also used.

(c) Borated-copper-chrome-arsenic (SBOR) composition conforming to Forest Research Institute, Dchra Dun composition (Patent pending).

(d) Acid-copper-chrome composition containing copper sulphate ($CuSO_4$ $2H_2O$) 50 parts, sodium dichromate ($Na_2Cr_2O_7$ $2H_2O$ 47.5) parts, chromic acid (CrO_3 1.68) parts (equivalent to 2.5 parts of sodium dichromate (Anon. 1981a).

(e) Copper-chrome-boron composition containing boric acid (H_3BO_3), copper sulphate ($CuSO_45H_2O$) and sodium or potassium dichromate ($Na_2Cr_2O_7$ $2H_2O$) or (K_2 Cr_2O_7) in the proportions of 1.5:3:4 (Anon. 1981c).

(f) Ammoniacal-copper-arsenite composition containing copper- sulphate, arsenic trioxide dissolved in ammonia (Dev et al, 1990).

(g) Boric acid:borax (1:1.54).

(h) Copper naphthenate/abietate and zinc naphthenate/ abietate containing 0.5% copper or 1% zinc.

(i) Sodium-penta-chlorophenate: Boric acid: Borax (.5:1: 1) 2.5% solution for prophylactic treatment.

(j) Sodium-penta-chlorophenate: CCA (0.5:2) 2.5% solution for prophylactic treatment.

APPENDIX 3

PRESERVATIVES, RETENTION, SUGGESTED CONCENTRATIONS OF TREATING SOLUTIONS AND METHODS OF TREATMENT OF BAMBOO FOR STRUCTURAL PURPOSES*

Structural uses of treated bamboo	Recommend preservatives**	Concentration of preservatives	Absorption of preservatives kg/m^3	Method of treatment
Posts, pole fencing, etc., exposed to weather and in contact with ground:				
a) Dry bamboos	a		80 to 128	Open tank or pressure
	b,c,f	6 to 8%	8 to 12	Pressure
	d,e	8 to 10%	10 to 16	Pressure
b) Green bamboos	b,c,f	8 to 10%	8 to12	Diffusion
	d,e	10 to 12%	10 to 16	
Bridges, scaffolding, ladders, etc., exposed to weather but not in contact with ground:				
a) Dry bamboos	a		48 to 80	Hot dipping or open tank or pressure
	b,c,f	6%	5 to 8	
	d,e	8%	6 to 10	
b) Green bamboos	b,c,f	6 to 8%	5 to 8	Modified Boucherie or diffusion or sap displacement
	d,e	8%	6 to 10	

House building, walls trusses, purlins, rafters, tent poles, etc., under cover:				
a) Dry bamboos	a		4-8	Hot dipping or open tank or pressure/ steeping
	b,c,f	4%	4	Pressure
	d,e,g	6 %	6	Pressure/ steeping
	h 3 %	2% cu Zn (in mineral oil)	0.4 as Cu 0.6 as Zn	Soaking
b) Green bamboos	b,c,f	6 %	4	Modified Boucherie or diffusion
	d,e,g	8 %	6	
Ceilingdoor and door paneling:				
a) Dry bamboos	b,c,f	3 %	3.5	Steeping/ Pressure
	d,e,h	5%	4	Steeping/ Pressure
	h	2% cu 3% Zn (in mineral oil)	0.4 as Cu 0.6 as Zn	Soaking
b) Green bamboos	b,c,f	4 %	3.5	Modified Boucherie or diffusion
	d,e,g	5 %	4	

* A code of practice for preservation of bamboo for structural purposes (IS: 9096) was formulated by FRI, Dehra Dun and Bureau of Indian Standards, New Delhi. This Appendix incorporates some new additions.

** Letters refer to list of preservatives given in Appendix 2.

PRESERVATIVES, RETENTION, SUGGESTEDCONCENTRATIONS FOR TREATING SOLUTIONSAND METHODS OF TREATMENT FOR BAMBOO FOR DIVERSE SURPOSES (NON-STRUCTURAL USES) *

Diverse (non-structural) uses of treated bamboo	Recom-mended preser-vatives**	Concentration of preser-vative	Absorption of preser-vative kg/m^3	Method of treatment
Window blinds and **mats** exposed to the weather.				
a) Green split bamboos	b,c,f	4 to 6%	5	Diffusion
	d,e	5 to 8%	8	
b) Dry split bamboos	b,c,f	4 to 6%	5	Steeping
	d,e	5 to 8%	8	
	h	1% Cu	0.5 as Cu	Dipping
		2% Zn (in mineral oil)	0.8 as Zn	Dipping
Furniture exposed to the weather.				
a) Whole green bamboos	b,c,f	4 to 6 %	5	Modified Boucherie/ Diffusion for legs and arms.
	d,e	5 to 8 %	8	
b) Split bamboos for parts other than those in a) above	b,c,f	4 to 6 %	5	If green, diff-usion process
	d,e	5 to 8 %	8	
	h	1% cu	0.4 as Cu	if dry painting/
		2% Zn (in mineral oil)	0.6 as Zn	soaking

c) Indoor furniture	g	2 to 4%	5	If green, diffusion process if dry painting/ soaking
Basketware				
a) Agricultural	a		4-8	Hot and cold
use other than in (c) below	b,c,d,e,f	4 to 6%	5	Diffusion/ soaking/ steeping
b) Household use including window blinds, mats and furniture under cover.	d,e,h	4 to 5%	4	Diffusion
	h	1%Cu	0.4 as Cu	soaking/ steeping
		2%Zn (in mineral oil)	0.6 as Zn	
c) packing of edible material including fresh fruits and vegetables.	g	2 to 4%	4	Diffusion
	h	1% Cu in mineral oil 2% Zn in mineral oil		Brushing/ - spraying

* A code of practice for preservation of bamboo for non-structural purposes (IS 1902) was formulated in 1961 by FRI, Dehra Dun and Bureau of Indian Standards, New Delhi. This appendix incorporates some new additions.

** Letters refer to list of preservatives given in Appendix 2.

APPENDIX 5

STANDARD METHODS FOR DETERMINING PENETRATION OF PRESERVATIVES

***Note**: The following relates to specialist institutes with the capacity to conduct the tests.*

Method For Determining Penetration of Arsenic-Containing Preservatives

Reagents

Solution 1. Dissolve 3.5 g ammonium molybdate in 90 ml distilled water; then add 9 ml concentrated nitric acid.

Solution2. Dissolve 0.07 g benzidine dihydrochloride in 10 ml concentrated acetic acid and add the solution to 90 ml distilled water.

Solution 3. Dissolve 30 g stannous chloride in 100 ml of I:1 hydrochloric acid (one part concentrated hydrochloric acid added to one part distilled water).

Best results are obtained with freshly prepared solutions. Agitate the solution until all chemicals are dissolved. Solution 1 is clear and colourless; solution 2 (benzidine is difficult to dissolve) is clear and light violet in colour; solution 3 is colourless or slightly turbid. Solution 1 must be prepared for each day's testing; solutions 2 and 3 will keep in clean, glass-stoppered, brown-glass bottles for one week.

Method of Application

Solution 1 is first applied by dipping the boring or cross section in a flat glass dish containing the solution or pouring the solution over the cross-section or boring. The entire wood surface must be saturated. After waiting two minutes, shake off the excess solution and allow to dry for about one minute.

Solution 2 is next applied in the same manner as solution 1. After waiting two minutes, shake off excess solution and allow to dry for about one minute.

Solution 3 is applied last by pouring the solution on the cross-section or boring, beginning at the untreated part. The entire wood surface will immediately turn bluish; hence, it is necessary to wait several minutes for the reaction to bring about the maximum colour contrast. Untreated portions will fade to a bright red or reddish orange, while treated portions will be light bluish-green to dark bluish-green. Usually thecolour differences are more distinct when the specimens are observed at arm's length.

After about one hour, the stain fades; the colours may then be renewed by another application of solution 3.

Method for Determining Penetration of Boron-Containing Preservatives

Reagents

Solution 1. Extract 10 g turmeric with 90 gm ethyl alcohol. Decant or filter to obtain clear solution.

Solution 2. Dilute 20 ml of concentrated hydrochloric acid diluted to 100 ml with ethyl alcohol and then saturate with salicylic acid (about 13 g per 100 ml).

Procedure

A smooth surface shows the results of the spot test better than a rough surface. The surface must be dry; otherwise, the test will not be satisfactory.

Solution 1 is applied, preferably by spraying, or with a dropper, to the surface to be treated. The surface being treated is then allowed a few minutes to dry.

Solution 2 is then applied in a similar manner to the areas that have been coloured yellow by the application of solution 1. The color changes should be observed carefully and will show up a few minutes after application of the second solution. In the presence of boron, the yellow colour of the turmeric solution is turned red.

After reagent application, placing bamboo in a warm oven accelerates and intensifies the colour reaction to better differentiate between treated and untreated bamboo.

Method for Determining Penetration of Copper-Containing Preservatives

Reagent

Dissolve 0.5 g Chrome Azurol S concentrate and 5 g sodium acetate in 80 ml water and dilute to 100 ml.

Procedure

Spray the solution over split borings or freshly cut surfaces of treated bamboo. A deep blue colour reveals the presence of copper.

Method for Determining Penetration of Chromium

Reagent

Dissolve 0.5 g diphenyl carbazide in 50 ml of isopropyl alcohol and 50 ml distilled water.

Procedure

The boring or cross-section of bamboo to be tested shall be reasonably dry, dipped into or sprayed with the solution of diphenyl carbazide. The treated wood quickly turns purple, while the untreated wood retains nearly its original colour.

Method for Determining Penetration of Pentachlorophenol using a Silver-Copper Complex known as Penta-check

Penta-check is a special blend of copper and silver ions for the determination of pentachlorophenol and distribution in wood.

Reddish coloured copper pentachlorophenate is formed where pentachlorophenol is present, thus indicating the exact location of pentachlorophenol.

The exact mechanism of the silver ions is not known, but in their presence, a redder colour is formed more than with copper alone.

Reagents

Cupric acetate $Cu(CH_3COO)_2\ 2H_2O$
Silver acetate $CH_3COO\ Ag$
Tergitol XD
Distilled water
Isopropyl alcohol (99%)

Stock Blends

I		II	
Cupric Acetate	- 4.015	Silver Acetate -	0.4 g
Tergitol XD	- 0.5 g	Distilled water -	100.0 g
Distilled water	- 100.0 g		

Mix cupric acetate and distilled water until dissolved and then add Tergitol XD. The XD is a semi-solid at normal temperatures, and it is best to heat this until liquid, and then add to the blend with mixing until solution clears. Reserve as Blend I.

Penta-Check Ready to Use	**Percent by Volume**
Blend I	25
Blend II	25
Distilled water	25
Isopropyl Alcohol (99%) -	25
	100

Mix together in the order indicated in the above formulation.

Apply to cross-sections or borings of penta-treated surface and observe rapid formation of red copper pentachlorophenate. Excessively dark penta treatments tend to obscure the colour. Applications may be by brush, flow-on or spray.

Note:-Tergitol XD is manufactured by Union Carbide Chemical Company. Cupric acetate and silver acetate should be reagent grade. Commercial isopropyl alcohol (99%) is satisfactory.

Method for Determining Penetration of Zinc-Containing Preservatives

Reagents

1. 1 g of potassium ferricyanide in 100 ml of water.
2. 1 g of potassium iodide in 100 ml of water.
3. Starch indicator solution. Make a paste of 1 gm of soluble starch in about 5 ml of distilled water, add 100 ml of distilled water, and boil for one minute with constant stirring. Cool. This solution is subject to decomposition, and therefore, should not be used longer than three days before a new batch is prepared.

Method of Application

The boring or cross-section of bamboo to be tested should be reasonably dry. Mix 10 ml each of the three stock solutions and pour into a good atomizer. Spray the boring or cross-section of wood evenly. The reaction between the zinc chloride and the spraying solution will cause the treated wood to turn a deep blue instantly, while the untreated part will retain its original colour. This method is a positive test. Should the colour fade, repeat the process.