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UPGRADATION OF SMALL TIMBER AND BAMBOO RESOURCES

(Final Report of Project KFRI 407/'03)

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CONTENTS

Outline of the project proposal

Project Number: KFRI 407/'03.

Title of Project: Upgradation of Small Timber and Bamboo Resources

Principal Investigator: Dr. T. K. Dhamodaran

Objectives: Evolve appropriate technology for upgrading quality and service life of small timber and bamboo resources by developing appropriate preservative treatment schedules in order to make them suitable for the manufacture of value-added products.

Programme Outline:

I. Conduct preservative treatment trials
II. Analyze the preservative retention level in the treated material for assessing the conformity with Indian Standards.
III. Arrive at suitable treatment schedules for each resource material.

Funding Agency: KFRI Plan Funds

Budget Outlay: Rs. 6.31 Lakhs.

ACKNOWLEDGEMENTS

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PREFACE

Utilization of small timber and bamboo resources remains to be one of the best solution for facing the issue of timber scarcity and escalating prices. Many of the short rotation timbers like eucalypts, acacias, mahogany and bamboo have the potential to replace a number of the high-cost traditional timbers used. Lack of awareness on the potential of preservative treatment technology and appropriate treatment schedules to be followed for commercial scale operations limits their use till date for making them suitable for structural and non-structural applications. It was in this context, KFRI took the initiative to develop treatment schedules appropriate to commercial scale production of durability enhanced products from these resources. I am happy to release the research results on upgradation of small timber and bamboo resources. KFRI is ready to commercialize the technologies developed for improving the durability of perishable timbers and bamboo.

Dr. K. V. Sankaran
DIRECTOR, KFRI

ABSTRACT

Eucalyptus grandis and *E. tereticornis* wood being non-durable, needs treatment with preservative chemicals. However, both the species are reported to be difficult to treat. A preliminary study was conducted to find out suitable methods of treatment using the eco-friendly and diffusible boron compounds, boric acid and borax. Non-pressure methods like diffusion and hot and cold process could not achieve the required dry salt retention (DSR) (5 kg/m^3, for indoor use) of boron compounds even in 25 mm thick *Eucalyptus grandis* wood.

Vacuum-pressure impregnation (VPI) treatment being more suitable for commercial scale applications in bulk quantity, an economical treatment schedule (15 minutes initial vacuum of - 85 kPa followed by a pressure of 1300 kPa for 15 minutes and a final vacuum of - 85 kPa for 5 minutes, denoted by 15'/15'/5') was developed for treating partially dry *E. grandis* wood with boron chemicals. A pooled mean dry salt retention (DSR) of 7.7 kg. m $^{-3}$ was achieved for wood in partially dried condition using a 6% boric acid equivalent (BAE) solution. The DSR achieved is much higher than the standard specification of many countries. *E. grandis* wood in green condition is found to be effectively treatable using a 6% BAE solution under selected treatment schedules depending on the thickness and moisture level of the wood material.

Wood density and moisture content is found adversely affecting the achievement of required DSR in boron impregnation treatment. It was clear that even *E. tereticornis* wood in green condition could be effectively boron impregnated using appropriate treatment schedule. Only long duration treatment schedules such as application of an initial vacuum of 760 mm Hg (-85 kPa) for 15 minutes followed by a pressure of 1300 kPa for a minimum period of 45 minutes and a final vacuum of 760 mm Hg (- 85 kPa) for 5 minutes (denoted by 15'/45'/5') or a slightly long schedule15'/60/'/5' were found to be capable of achieving the required retention level in *E. tereticornis* wood. A solution concentration of 8% boric acid equivalent (BAE) was found to be required for the VPI treatment of *E. tereticornis* wood. The applicability of long duration schedule (15'/60'/5') is found confirmed even for the treatment of air dry wood of *E.tereticornis,* while employing a 4% copper - chrome - boric (CCB) solution.

The general notion that *Eucalyptus grandis* and *E. tereticornis* woods are difficult to treat is found not true as far as impregnation treatment is concerned. Use a treatment solution of high concentration (6-8% BAE) and selection of the appropriate treatment schedule are the prime factors to be taken care of for achieving the desired DSR level in the treated *Eucalypts* wood.

Swietenia mahogany timber is also found treatable under the VPI process using 8% BAE solution under the short duration schedule, 15'/15'/5'. DSR in the range of 7.2-9.5 kg/m^3 is achieved for 25 mm thick mahogany boards. The general notion that mahogany timber is extremely difficult to treat is found not true by the present study.

Acacia mangium is found slightly difficult to treat. VPI treatment of *Acacia mangium* requires the timber in at least partially dry moisture condition; long duration schedules are recommended for achieving effective retention.

Sawn teak thinning sizes containing significant quantity of sapwood is found effectively pressure treatable achieving required DSR as per Indian Standards for perishable timbers, under the short duration schedule 15'/15'/5' using 8% BAE solution. Penetration of boron in the treated juvenile teak thinning wood was found uniform and through and through.

Bamboo is found pressure treatable. An effective schedule capable for commercial scale pressure treatment of bamboo for industrial use was developed. The newly developed

schedule consists of the application of an initial vacuum of - 85 kPa for 15 minutes followed by the application of a pressure of 1200 kPa for 60 minutes and a final vacuum of - 85 kPa for 5 minutes. Employment of this schedule with a minimum solution concentration of 4% CCB or above will found capable to achieve the desired DSR requirements as per Indian Standards for the various end use products, irrespective of the moisture content of bamboo.

Value-addition of bamboo slivers by coloring using natural dyes for handicrafts, mat weaving and basketry work fetches improved income to traditional bamboo workers. Even though many natural dyes are available, lack of information on a standard treatment practice or schedule that can be followed is a bottleneck for the wide application of these dyes for coloring bamboo slivers. A study on this aspect revealed that dyeing in 5% weight/weight basis aqueous dye solution for three hours in boiling condition followed by the required post-treatment with 2% aqueous boiling metallic salt mordants (copper sulphate, potassium dichromate or ferrous sulphate, as the case may be) for an hour is found to be effective practice that needs to be followed for imparting satisfactory color and shades to bamboo slivers. The color development depends on the chemical nature of the dye and the mordants. Some natural dyes yield colors by direct dyeing and do not require any mordanting whereas some other dyes impart a different color after mordanting. Heartwood powder of the locally available plants such as *Acacia catechu* (cutch) and *Caesalpinia sappan* are found to be good dyes that can be used singly or with mordant post-treatments yielding different color and shades. Fruit powder of *Terminalia chebula* (myrobalan) yields a brownish yellow color before mordanting and a very dark gray color after mordanting in ferrous sulphate. Seed pulp of *Bixa orellana*, leaf powder of *Camellia thea* (commercial tea powder), rhizome powder of *Curcuma longa* (commercial turmeric powder), leaf pulp *of Lawsonia alba* and heartwood powder *of Pterocarpus santalinus* are found to offer color directly without mordanting. *Lawsonia alba* is found capable to impart a reddish gray color even at ambient temperature. The color developed is characterized by comparison with a standard color assessment system.

Key words: Preservative treatment; Boron chemicals; CCB; *Eucalyptus grandis*; *Eucalyptus tereticornis*;, *Swietenia mahogany; Acacia mangium; Tectona grandis;* treatment schedule; coloring bamboo; natural dyes; dyeing schedule; mordants.

INTRODUCTION

In the context of shortage of timber, utilization of small timber and bamboo residues has got tremendous importance from the point of view of optimum utilization of forest resources. Juvenile teak wood thinnings from plantations offer one of the small timber resources. Eucalypts, even though primarily grown for pulp wood purpose, is also coming into the local timber depots for structural and non-structural applications. At present, these resources were utilized without any value-addition. Acacias, grown in social forestry and avenue plantations and mahogany from homesteads are also some of the short rotation small dimension timber coming into the timber market. Durability of the sawn wood from many of these small dimension timbers containing sapwood portions is poor; requires preservative treatment for enhancing their service life. Bamboo, another wood substitute, even though perishable, is also currently used without any value-addition. Lack of awareness on the potential of preservative treatment for durability enhancement and information on the treatment schedules to be followed limits their present day commercial utility.

It was in this context, the present project is formulated with an objective to develop commercial-scale wood preservative treatment schedules for utilizing *Eucalyptus grandis* and *E. tereticornis*, *Acacia mangium* and *Swietenia mahogany*, teak plantation thinning wood (juvenile teak thinnings) and bamboos for the manufacture of value added products by improving their durability. Information on the effect of concentration of treatment solution, treatment schedules, and the moisture content of wood on the achievement of desired dry salt retention (DSR) of the preservatives in the treated wood is scanty in literature. The study was planned to generate basic information needed for successful commercial scale vacuum pressure impregnation (VPI) treatment of *Eucalyptus grandis* and *E. tereticornis* wood.

In the present era of increased environmental concerns, the possibility of utilizing eco-friendly chemicals for preservative treatment has been taken care of in the project. The objective was to evolve appropriate conditions for VPI treatment using boron compounds for end-uses such as joinery and panelling material. Boron compounds are reported to be effective in protecting eucalypt wood (Tambylin and Rosel 1979; Cookson *et al.* 1998). Besides being eco-friendly, the use of boron in the VPI process has the added advantage that it being a diffusible preservative, even after the pressure treatment, diffusion can continue resulting in better distribution of the chemicals within the treated timber.

Bamboo being the fastest grown, sustainable raw material, much interest exists in the products from bamboo, especially in export market. Bamboo being a perishable material needs to be preservative treated for enhanced durability. Treated bamboo has immense potential in its value-added utilization in housing, furniture and fixtures, woven mat and panel products, handicrafts, etc. Due to this reason, the present investigation included study on the preservative treatment of bamboo.

The use of bamboo in sliver form is well known in basket ware, mats and mat-based products, handicrafts, etc. These products act as an important livelihood material for the backward communities in Kerala, India. Quality and value addition in the above products will improve its marketability.

Love for color being a natural instinct, coloration of bamboo slivers for catchy products is a novel approach for value addition. Because of the health risks associated with various synthetic dyes, today, there is a renewed interest in the use of natural dyes. The limitations of the natural dyes such as their availability, color yield, complexity of dyeing process due to their inertness and reproducibility of color shade are responsible for their declined use. It is desirable to have a standard dyeing practice applicable for the different locally available natural dyes for dyeing of bamboo slivers. This is very important, as in India, many of such units are being handled by traditional bamboo working communities. There are only very few studies reported on coloring of bamboo products with natural dyes (IIT 2003, Gulrajani 2004) and they too have not attempted to evolve any uniform treatment condition applicable for the different natural dyes; the present study was oriented mainly to develop a standard treatment condition.

As visual perception of color may vary from person to person, precise characterization of the color developed in comparison to standard color assessment system is another need. Since such an attempt was also not reported so far on bamboo slivers stained by natural dyes, it was planned to look into this aspect. The natural color and hue of a dye can be altered by treatment with metal salts. The possibility of retention of a desirable color on the slivers is also looked into by identifying effective mordents and their appropriate reaction conditions.

REVIEW OF LITERATURE

Eucalyptus is one of the major plantation species in India, mostly grown on a short rotation basis for pulp wood production. For small timber purposes, *Eucalyptus* should be allowed to grow for 15 to 25 years. The natural durability of wood from most of the *Eucalyptus* species is low to poor. According to Tamblyn (1978), the natural durability of *Eucalyptus* heartwood varies greatly between species, the high density timbers (over 800 $kg.m^{-3}$) are generally the most durable. The medium density light coloured eucalypts are suitable for use as timber for housing and other constructions, especially for joinery and panelling. As the wood is heavy and hard, it is difficult to treat and season. *E. grandis and E. tereticornis*, the medium density woods, are non-durable; need to be treated with preservative chemicals (Kauman *et al* 1995). As the wood of *E. tereticornis* being heavy and hard, it is difficult to treat and season.

Eucalyptus timber is refractory in nature and is difficult to treat. Dip diffusion and the hot and cold process are the two non-pressure methods suggested for refractory timbers. The success of dip diffusion using Rentosol preservative for eucalypts as building timber was reported by Farquhar (1973). Tambyln and Rosel (1979) reported that dip diffusion using boron solution was effective against *Lyctus* borer attack in eucalypts timber for building purposes in Australia. Cookson *et al* (1998) also reported that dip diffusion process using boron compounds was effective in protecting *E. obliqua*. Abdurrohim and Martawijaya (1987) reported the failure of 5-10% BFCA preservative in the hot and cold process for the treatment of *Eucalyptus deglupta*.

Vacuum-pressure-impregnation (VPI) is the most effective method for getting higher preservative loadings. Treatability of eucalypts timber under the VPI process is in much dispute. Banerjee (1974) reported that *E. grandis* can be pressure treated with creosote leading to fairly extensive penetration; whereas Kohli and Kumar (1989) reported the untreatability of *E. teriticornis* with creosote even under the highest pressure used. Donoso and Manriquez (1978) also reported the untreatability of *E. globulus* under VPI method using CCA preservative.

In a review paper on the treatment of *Eucalyptus* hybrid, which is closer to *E. tereticornis*, Dev (1997) reported it as less resistant to bio deteriorating agencies and very refractory to treatment. Even though the species is generally reported to be a difficult to treat by the vacuum - pressure impregnation (VPI) process using creosote - fuel oil mixture and CCA (Sud and Sharma 1976; Kohli and Kumar 1988, 1989), successful VPI treatment of *E. tereticornis* by full cell method employing 5.9% CCA and 4% CCB was reported by Sharma *et al.* (1988).

Published research papers on the treatability of *Swietenia mahogany*, *Acacia mangium*, Tectona *grandis* (teak) juvenile thinning wood, are found scanty in literature.

Bamboo is reported to be non-durable and difficult to treat. Its treatability is poor due to the presence of a waxy cutenous outside surface, presence of impermeable nodes, thin culm wall, absence of ray cells, etc. A detailed review of bamboo preservation were given by Kumar et al (1994), Gnanaharan (2000), and of late by Liese and Kumar (2003) and National Mission on Bamboo Applications (NMBA) (2006). Indian Standards 9096 and 1902 detail the code of practice for preservation of bamboo for structural and non-structural purposes respectively (BIS, 1979, 1993).

A preliminary attempt on the coloring of bamboo products with natural dyes has been reported by IIT Mumbai (2003) and Gulrajani (2004). However, these studies also did not evolve any uniform treatment condition applicable for the different natural dyes.

MATERIALS AND METHODS

Non-pressure treatments

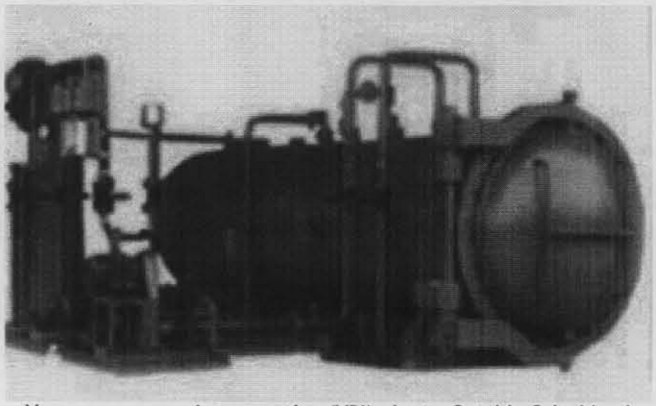
Dip diffusion and the hot and cold process were the non-pressure processes attempted.

An empty oil drum cut lengthwise was used as the treatment tank. Ten wood samples of 25 x 25 x 500 mm dimensions, of known moisture content, volume and weight were kept dipped in the preservative solution and borax took in the ratio 1: 1.5 for a specified duration chosen from the relationship between concentration of treatment solution, dipping duration, DSR and the thickness of wood (Dhamodaran and Gnanaharan 1984). After the treatment, the samples were drained off the solution, weighed, and block-stacked under cover for diffusion storage.

In the hot and cold treatment, the samples were kept immersed in a hot solution (60^0 C) for 40 minutes and then transferred to a cold solution (about 30^0 C) and left for another 40 minutes. Then samples were drained off the solution, weighed and stored under cover.

Pressure treatment

M/s. Wood-Tech Industries, Irinjalakuda, Kerala, India permitted the use of their commercial-scale pressure treatment cylinder (1.2 m diameter and 3 m length) for conducting the vacuum-pressure impregnation (VPI) trials.



Vacuum pressure Impregnation (VPI) plant - Outside & inside views

The cylinder was fully loaded with wood of various sizes (while commercial runs) including marked samples (of known moisture content, and weight and volume) of different thickness category. The treatment schedule for all trials consisted of the application of an initial vacuum of - 85 kPa for a specified period, fully flooding the cylinder with the preservative solution followed by the application of a pressure of 1200 kPa for specified period. After draining out the preservative solution from the treatment cylinder to the storage tank, a final vacuum of -85 kPa was applied for 5 minutes (in all the different schedules/trials) in all charges to prevent any possible bleeding of solution from the treated material. In order to see the effect of different schedules on the achievement of the desired retention (DSR) level in the treated material, the duration of the initial vacuum and pressure period were varied in the different trials. The marked samples were taken out after the treatment, drained and weighed again.

Preservative chemicals used

Commercial formulation of copper-chrome-arsenic (CCA) and copper-chrome-boron (CCB) and boric acid and borax (BA-BX) wood preservatives as per Indian Standard 401 (BIS 2001) were selected for the treatment trials. 20% boric acid equivalent (BAE) solution of boric acid and borax in the ratio 1: 1.5 was employed for non-pressure processes. CCA and CCB as well as BA-BX solutions of different lower concentrations were employed for the pressure (VPI) process. Boron impregnation has the additional advantage that it being a diffusible chemical, can continue to diffuse even after the pressure treatment is over, resulting in even distribution of the chemical in the treated wood.

Determination of preservative retention in the treated material

The solution pick up was calculated from the weight difference due to treatment and volume of individual samples; dry salt retention (DSR) (kg/m^3) was calculated by multiplying the solution pick up with concentration of the treatment solution. From DSR and density, retention in terms of per cent was calculated.

Determination of preservative penetration

The penetration of boron in the treated wood was tested as per Indian Standard 2753 or 401 (BIS 1991, 2001). CCA penetration was determined using a solution of 0.5 % chrome azurol S solution containing 5 % sodium acetate; spraying of the reagent solution in cross cut surface will turn CCA/CCB treated areas blue while untreated areas will remain red. Penetration of boron in boric acid - borax treated material was tested by spraying an alcoholic extract of turmeric powder followed by spraying a saturated solution of salicylic acid in dilute hydrochloric acid (13 g/100 ml) on cut surface of treated material. Boron treated surfaces will turn to red while untreated surface will remain yellow.

Moisture content (MC) and Density determination

Moisture content was determined by oven drying method and density by water displacement method.

Assessment of success of the treatment schedule employed

The success of the schedule employed was ascertained by comparing the retention of preservative (in terms of DSR, kg/m^3) achieved in the treated timber against the standard value suggested as per the Indian Standards (BIS 2001) for perishable timbers; for bamboos, the threshold reference retentions were as per Indian Standards 9096 and 1902 (BIS 1979, 1993). Assessment of the penetration of preservative in the treated timber and bamboo material was also used as an index of the success of the treatment schedule developed.

Wood materials treated

Logs from *Eucalyptus grandis*, *Eucalyptus tereticornis*, *Swietenia mahogany*, *Acacia mangium*, *Tectona grandis* (teak) juvenile thinning wood, were sawn into boards of various sizes, sampled for treatment, density and moisture content determination. *Bambusa bambos* was selected for the investigations on the preservative treatment of bamboo.

Eucalyptus grandis

As *Eucalyptus grandis* wood was available in plenty, it was decided to use this for the interior panelling of the auditorium at the Kerala Forest Research Institute. As this necessitated using large quantity of treated wood, and boron chemicals are being more environmentally friendly in terms low mammalian toxicity, a study was conducted on the boron treatability of *E. grandis* wood. *E. grandis* wood was subjected to both non-pressure (dip diffusion and the hot and cold method) and pressure processes (VPI) of treatment.

As *E. grandis* wood was supposed to be difficult to treat, in order to get desired retention of the preservative in the treated timber, it was decided to use a boron solution of slightly high concentration; a 20% BAE solution for the non-pressure process (dip diffusion and the hot and cold process) and a 6% BAE solution was for the VPI treatment trials. The selection of a comparatively higher concentration (20% BAE) for the non-pressure treatment was due to the assumption that eucalypts being reported to be difficult to treat and especially in the non-pressure process as the maximum solution pick up is always limited due to the lack of application of any external pressure, it was thought that a comparatively higher concentration of treatment solution will yield better retention in terms of DSR (kg/m^3).

A study was conducted to determine an efficient method of boron treatment for *E. grandis* wood and the efficacy of diffusion, hot and cold and vacuum-pressure impregnation (VPI) treatments was compared. *Eucalyptus grandis* wood, 15- years- old from the plantations of Kerala Forest Development Corporation at Vandiperiyar, Kerala were used for non-pressure treatment trials. For the VPI treatment of green wood, material from trees of 30 years age was used; whereas for the pressure treatment of the partially dry material, wood from trees of 15 years age was used.

For the diffusion treatment of *E. grandis* wood using 20% BAE solution, a dipping duration of 40 minutes was chosen, from the relationship between concentration of treatment solution, dipping duration, DSR and the thickness of wood (Dhamodaran and Gnanaharan 1984). After the treatment, the samples were drained off the solution, weighed, and block-stacked under cover for diffusion storage. In the hot and cold treatment, the samples were kept immersed in a hot solution (60^0 C) for 40 minutes and then transferred to a cold solution (about 30^0 C) and kept it there for another 40 minutes. Then samples were drained off the solution, weighed and stored under cover.

As *E. grandis* wood was supposed to be difficult to treat, in order to get desired retention of the preservative in the treated timber, it was decided to use a boron solution of slightly high concentration; a 6% BAE solution was employed for the treatment trials with *Eucalyptus grandis* wood. DSR and penetration of preservative in the treated wood was determined as mentioned earlier.

The details of sample sizes and their moisture content, the different treatment schedules employed, respective concentration of the boron solution used on the green and partially dry materials were as given in Table 1.

Eucalyptus tereticornis

The *Eucalyptus tereticornis* wood used for the treatment trials (pressure treatment only) was from trees of 15 and 30 years of age; the 15 - year old trees were from the Kerala Forest Development Corporation's plantations at Punalur and Thiruvananthapuram and the trees of 30 years age were from Kozhikode, Kerala.

E. tereticornis wood is supposed to be more difficult to treat than *E. grandis wood*. Due to this reason, *E. tereticornis* wood was treated under the pressure process with 8 per cent BAE solution. For comparison, it was also subjected to treatment with a low concentrated (4% BAE) solution too.

The details of the different treatment schedules tested on green and partially dry *E. tereticornis* wood are as shown in table 1.

Air dry *E. tereticornis* wood samples of dimension 25 x 25 x 500 mm were also subjected for a preliminary VPI trial using 4% copper - chrome - boric (CCB) preservative formulation solution employing a long duration schedule, 15'/60'/5' (not included in Table 1). The DSR and penetration of preservative were determined.

Swietenia mahogany

Partially dry Mahogany wood was pressure treated with 8% BAE solution employing the short duration schedule, 15'/15'/5'. Sawn Mahogany wood of size 1250 x 25 x150 mm and 800 x 25 x 75 mm was treated and the DSR and penetration of preservative achieved were checked.

Acacia mangium

Acacia mangium wood planks of thickness 25-30 mm were subjected to VPI treatment with 8% BAE solution employing the short duration schedule, 15'/15'/5'. The DSR and penetration of preservative were assessed.

***Tectona grandis* (Teak) thinning wood**

Partially dry juvenile teak thinning wood sawn sizes of dimension 1700 x 70 x 30 mm were pressure treated using 8% BAE solution under the short duration schedule 15'/15'/5'/ by following the methods mentioned earlier and the DSR and penetration of preservative achieved were compared with the retention requirements as per Indian Standards.

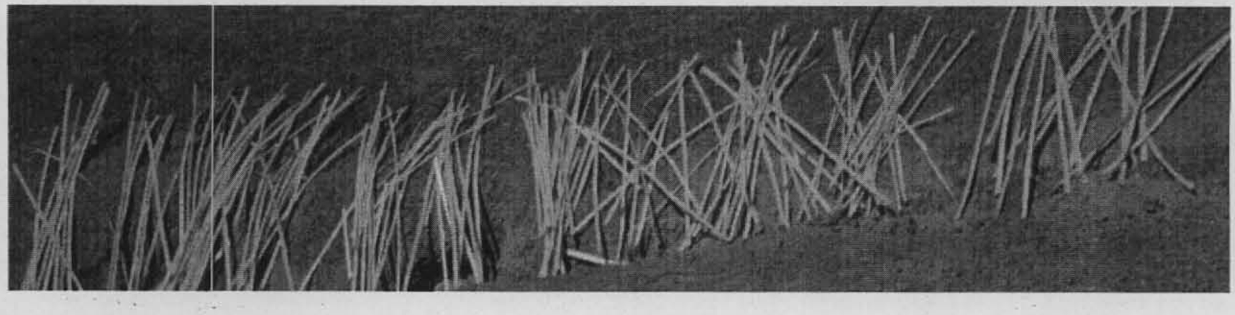
Table 1. Details of the boron impregnation treatment of *Eucalyptus grandis* and *E. tereticornis* wood - size and moisture content of samples, concentration of treatment solution used and treatment schedules employed.

Mean MC%	Size (width, mm x thickness, mm x length, mm)	Concentration of treatment solution (% BAE)	Schedule initial vacuum, min/ pressure, min/ final vacuum, (min)
E. grandis			
Green Wood			
73	50 x 50 x 1800	6	45'/90'/5'
Partially Dry Wood			
54	50 x 50 x 1800	6	60'/120'/5'
32	75 x 25 x 1800	6	30'/30'/5'
32	75 x 50 x 1800	6	15'/45'/5'
32	75 x 50 x 1800	6	30'/30'/5'
32	75 x 25 x 1800	6	15'/15'/5'
32	100 x 25 x 1950	6	15'/15'/5'
32	125 x 25 x 1950	6	15'/15'/5'
28	75 x 25 x 1800	6	15'/45'/5'
E. tereticornis			
Green Wood			
80	150 x 15 x 1050	8	15'/15'/5'
80	*125 x 12.5 x 1050*	*8*	15'/45'/5'
80	150 x 15 x 1050	8	15'/60'/5'
80	150 x 15 x 1050	8	15'/75'/5'
80	150 x 15 x 1050	8	15'/105'/5'
Partially Dry Wood			
40	175 x 17.5 x 1050	4	15'/30'/5'
40	150 x 15 x 1050	8	15'/15'/5'
40	*125 x 12.5 x 1050*	*8*	15'/45'/5'
40	*125 x 12.5 x 1050*	*8*	15'/90'/5'
40	150 x 15 x 1050	8	15'/105'/5'

Bamboo - *Bambusa bambos*

Six samples of 1 m length air dry, partially dry and green round rod *Bambusa bambos* were subjected to VPI treatment employing the schedule 15'/60'/5' using 4% CCB solution. The DSR and penetration of preservative in treated bamboo were determined.

Coloration of bamboo slivers using natural dyes



Details the different natural dyes used in the study are as given in Table 2. Slivers of thickness 1-2 mm and width 15mm were prepared manually by traditional bamboo workers using hand tools, from mature *Bambusa bambos*, the major bamboo species of Kerala. Ten samples of 150 mm length were cut and used for each treatment. Dyeing trials were conducted on slivers in both green and air dried conditions. Efficacy of soaking in 5% aqueous dye solution for 12 hours in room temperature was tested in the preliminary trial. Soaking in boiling solution of the dye with the same concentration for a period of 3 hours was also tested in all the cases and its efficacy was compared with the cold soak method.

The dye solution was prepared by extracting the estimated quantity of the powdered plant part in boiling water for an hour. The resultant solution was filtered and used as the dye solution. The colored bamboo slivers were kept exposed to air for a period of two months in order to stabilize the color and to account for the slight color changes caused by oxidation or light. Then the developed color was assessed in terms of its hue, chroma and lightness value using standard Munsell color charts (Munsell Color Company 1975) and accordingly the color names were given.

Table 2. Details of the natural dyes used for coloring bamboo slivers.

Dye source Plant name	Common name & Local name	Plant part used as dye	Type of Dye present
Acacia catechu	Cutch, karingali	Heartwood powder	Condensed tannins (Catechin)
Bixa orellana	Annatto, kuppamanjal,	Green seed pulp	Carotenoid dyes (Bixin)
Caesalpinia sappan	Pathimugham, chappangam	Heartwood powder	Brazilin
Camellia thea	Tea, theila,	Tea powder	Ployphenolic tannins
Curcuma longa	Turmeric, manjal	Turmeric powder	Curcuminoid dyes (Curcumin)
Lawsonia alba	Henna, mylanchi	Leaves (green)	Alpha naphthaquinones (Lawsone)
Pterocarpus santalinus	Red sandal, rakthachandanam	Heartwood powder	Santalin
Terminalia chebula	Myrobalan, kadukka	Dry fruit pod	Tannins (Pyrogallol type)

Two percent aqueous solutions of copper sulphate, potassium dichromate and ferrous sulphate were used as standard mordents in cases where appreciable coloration is not obtained by simple dyeing. Mordenting was done after dyeing when necessary. Soaking the dyed samples in the mordant solution for 12 hours in room temperature as well as boiling treatment for an hour was tested. The treated samples were washed in water; air dried under shade and the color development was assessed.

The selection of the concentration of the dye and mordant solutions and duration of the cold and boiling soak treatments are arbitrary, for convenience, and are not based on any earlier works.

RESULTS AND DISCUSSION

Eucalyptus grandis

Non pressure treatments

Table 3 illustrates the results of the non-pressure treatment trials conducted on green *Eucalyptus grandis* wood. For indoor use, dry salt retention (DSR) should be at least 5.0 kg/m^3, as per the recommendation of Indian Standards (BIS 2001). Between the two non-pressure methods (diffusion and hot and cold), there is no significant difference in DSR. Even with the use of a highly concentrated solution (20% BAE), both the methods could not achieve the required DSR of 5 kg/m^3. This preliminary study on non-pressure methods for the treatment of *E. grandis* wood points to the need for pressure treatment.

Table 3. Dry salt retention (DSR) of boron chemicals achieved by diffusion and hot and cold process, using 20% BAE solution.

Process	Mean DSR (kg/m^3)	Range	CV (%)	Av. BAE%
Diffusion	4.0	3.3 - 4.7	10.5	0.83
Hot & Cold	4.2	3.0 - 6.3	23.4	0.87

(n = 10; Mean Basic Density = 484 kg/m^3; age 15 years; Mean moisture content = 90%)

Vacuum-pressure impregnation (VPI) treatment

The green wood (MC 73%) subjected to boron impregnation treatment under the schedule 45'/90'/5' was having a mean density of 520 kg/m^3. The slightly higher density could be due to the higher age (30 years) of the material. Required DSR (5 kg/m^3, as per Indian Standard) (BIS 2001) was achieved in this schedule (Table 4). VPI treatment of partially dry material (MC 54%) from a lower aged material (15 years) with a mean density of 477 kg/m^3 achieved a higher mean DSR (7.2 kg/m^3), which indicates the favourable effect of getting an increased DSR at lower moisture content. Again when the moisture was reduced to 32%, a still higher DSR was achieved, irrespective of the fact that a short duration schedule, 15'/15'/5', was employed for the impregnation. The efficacy of the short duration schedule was reported earlier for easy treat perishable species like rubber wood (Gnanaharan and Dhamodaran1993). The slightly higher DSR achieved may be due to the lower moisture content (32%) as well as the lower thickness (25 mm) of the material. The retention, in terms of average BAE%, satisfies the requirements of New Zealand (McQuire 1962), British (BCL 1972) and Australian (Anonymous 1980) standards for perishable timbers susceptible to *Lyctus* beetle attack. The penetration of boron in the treated timber was also found satisfactory as per the Indian Standard 2753 (BIS 1991).

Table 5 reveals the efficacy of employing different treatment schedules on the achievement of desired DSR level, while employing a 6% BAE treatment solution for the impregnation treatment of *E. grandis* wood. There was increase in DSR (from 7.5 to 8.5 kg/m^3) as the duration of the pressure phase of the treatment was increased (from 15 to 45 minutes) when treating wood of 25 mm thickness. However, even the application of the optimum short duration schedule developed for rubber wood (15'/15'15') (Gnanaharan and Dhamodaran 1993) achieved higher DSR than the desired range of 5.0 kg/m^3 (as per the Indian Standards) for the 25 mm thick partially dry material. In the case of wood of 50 mm thickness with high moisture content (73%), longer treatment schedule (45'/90'/5') resulted in the achievement of the required DSR. As wood is not normally segregated by thickness or moisture content levels in the commercial treatment operations, one should go for a treatment schedule which will ensure the minimum requirement of DSR even for wood of higher thickness and moisture content.

Table 4. Dry salt retention of boron compounds achieved by vacuum-pressure impregnation (VPI) process, using 6% BAE solution, in green and partially dried *E. grandis* wood.

Schedule	Size (mm x mm x mm)	Mean MC%	Mean Wood Density (kg/m^3)	Age	Mean DSR (kg/m^3)	Range	CV (%)	Av. BAE%
45'/90'/5'	50 x 50 x 1800	73	520	30	5.1	3.6-8.0	33.1	0.98
60'/120'/5'	50 x 50 x 1800	54	477	15	7.2	4.1-11.6	39.3	1.51
15'/15'/5'	75 x 25 x 1800	32	452	15	7.7	7.0-8.5	7.0	1.70
15'/15'/5'	100 x 25 x 1950	32	452	15	7.0	6.5 – 7.6	6.6	1.55
15'/15'/5'	125 x 25 x 1950	32	452	15	7.1	5.7 – 8.5	17.9	1.57

(n = 6)

Up to a thickness of 50 mm (the ordinary thickness range required for common end use products), in order to achieve a dry salt retention of 5 kg/m^3 boron compounds, neither the moisture content of wood nor the treatment schedules is found to pose any problem in the pressure treatment of *E. grandis* wood. Use of the short duration schedule, 15'/15'/5' is suggested for partially dry wood of 25 mm thickness (Table 5). Depending on the thickness of wood and moisture content appropriate schedule need to be employed for achieving the desired DSR level.

All the treatment samples had moisture content above fibre saturation point. As the study was not designed to look into the effect of varying moisture content, as far as the effect of moisture content is concerned, no clear indication could be obtained. The result of DSR for 50 mm thick wood is confounded by the effect of moisture content and treatment schedule. In the pressure treatment for the same moisture content (32%) and for the same treatment schedules (15'/45'/5' and 30'/30'/5'), DSR decreased with increase in thickness. However, both the thicknesses achieved more than the required DSR.

Table 5. Efficacy of employing different treatment schedules on the boron impregnation treatment of *Eucalyptus grandis* wood using 6% BAE solution.

Sl. No	Size (mm x mm x mm)	Schedule	DSR (Kg/m^3) Mean	Range	Coefficient of Variation (%)	Average retention in terms of BAE%	MC (%)	Density (Kg/m^3)
1	75 x 25 x 1800	15'/15'/5'	7.7*	7.0-8.5	7.0	1.70	32.0	452
1	75 x 25 x 1800	15'/45'/5'	8.5	5.8-9.9	17.2	1.89	32.0	450
2	75 x 50 x 1800	15'/45'/5'	6.1	3.7-7.7	23.2	1.35	32.0	455
3	75 x 25 x 1800	30'/30'/5'	8.5	4.6-15.4	48.0	1.90	32.0	452
4	75 x 50 x 1800	30'/30'/5'	6.1	3.4-9.3	38.2	1.34	32.0	452
5	50 x 50 x 1800	45'/90'/5'	5.1	3.6-8.0	33.1	0.99	73.0	520
6	50 x 50 x 1800	60'/120'/5'	7.2	4.1-11.6	39.3	1.50	54.0	477

* - Extracted from Table 1

The study did not look into the effect of concentration of treatment solution on DSR, even though it is known to affect DSR positively. As *E. grandis* is difficult to treat in comparison to rubber wood, depending on the thickness of wood and moisture content either we should increase the concentration of the treatment solution or go for longer treatment schedule.

E. tereticornis

Effect of age/wood density

Wood density of *Eucalyptus tereticornis* was found to vary within and between age groups. Wood density ranged from 550-850 kg/m^3 with a pooled mean value of 700 kg/m^3 for the test samples from 15-year-old trees and 760 kg/m^3 for the samples from 30-year-old trees.

Surprisingly, when air dry *Eucalyptus tereticornis* wood samples of dimension 25 x 25 x 500 mm were subjected to a preliminary trial on VPI treatment using a 4% copper - chrome boric (CCB) formulation employing a long duration schedule, 15'/60'/5', very high DSR values were achieved, as shown in Table 6. This indicated the treatability of the species.

Table 6. Vacuum - pressure impregnation treatment of air dry *Eucalyptus tereticornis* wood using 4% CCB solution employing a schedule 15'/60'5'.

Sample No.	DSR (kg/m^3)	MC (%)	Density (kg/m^3)
ET1	13.0	15.6	615.4
ET2	18.7	13.2	612.9
ET3	16.8	15.0	615.4
ET4	15.3	15.4	611.8
ET5	16.9	16.2	578.1
Mean	**16.1**	15.1	606.7
CV%	13.2	7.5	2.6

Size of samples: 25x25x500 mm

The effect of age/wood density on the treatability of partially dried (MC 40%) *Eucalyptus tereticornis* wood (17.5 mm thick) is investigated employing 4% BAE solution of boric acid and borax and the results achieved is reported in Table 7. A mean DSR of 5.3 kg/m^3 was achieved for the material of lower age or density. When the wood density increased due to age, the corresponding DSR achieved was lower (4.1 kg/m^3). As reported by Malan (1993), it was found here also that wood density has an adverse effect on preservative pick up in *E. tereticornis*.

Table 7. Effect of age/ wood density on the dry salt retention (DSR) of boron preservative in treating partially dried (MC 40%) *Eucalyptus tereticornis* wood with 4% BAE solution.

Sl. No	Age (Years)	Mean Density (kg/m^3)	Treatment Schedule	DSR (kg/m^3) Mean	CV (%)	Range	Mean BAE%
1	15	700	15'/30'/5'	5.3	8.1	4.7-5.7	0.78
2	30	760	15'/30'/5'	4.1	68.8	1.2-8.7	0.54

(Size of samples = 175 mm x 17.5 mm x 1050 mm; n =6)

Effect of treatment schedule on DSR

The DSR values achieved in treating partially dry (MC 40%) wood with 8% BAE solution of boric acid and borax under different schedules are given in Table 8. Unlike in rubber wood, an easily treatable species (Dhamodaran and Gnanaharan 1994), short duration schedule

(15'/15'/5') was not capable of achieving the required DSR even by using 8% BAE solution. Longer pressure periods yielded better absorption of preservative. Out of the various schedules employed, the shortest schedule, 15'/45'/5' is found the optimum one for treating partially dry *E. tereticornis* wood.

Table 8. Effect of treatment schedule on the dry salt retention (DSR) of boron preservative in treating partially dried (MC 40%) *Eucalyptus tereticornis* wood (15-year- old) with 8% BAE solution.

Sl. No	Treatment Schedule	DSR (kg/m^3)				n
		Mean	CV (%)	Range	Av. BAE%	
1	15'/15'/5'	4.1	44.4	2.3 - 7.9	0.61	**15**
2	15'45'/5'	13.2	32.9	6.5 - 19.9	1.88	**10**
3	**15'/90'/5'**	**13.3**	**22.6**	**9.6 - 18.9**	**1.90**	**10**
4	**15'/105'/5'**	**15.1**	**36.8**	**8.5 - 22.6**	**2.18**	**5**

(Size of samples = 125 mm x 12.5 mm x 1050 mm; Mean density = 700 kg/m^3)

The results of different schedules in treating green wood (MC 80%) are shown in Table 9. Longer schedules, 15'/60'/5', 15'/75'/5' and 15'/105'/5', yielded DSR values higher than the desired minimum level of 5 kg/m^3 and 15'/60'/5' is found ideal for boron impregnation treatment of *E. tereticornis* wood in green condition.

Evaluation of the data from Table 6, 8 and 9 leads to the conclusion that the optimum effective common schedule for pressure treating E. tereticornis wood at any moisture condition could be 15'/60'/5'.

Table 9. Effect of treatment schedule on the dry salt retention (DSR) in the boron impregnation treatment of green (MC 80%) *Eucalyptus tereticornis* wood (15-year-old) with 8% BAE solution.

Sl. No	Treatment Schedule	DSR (kg/m^3)			Mean BAE%
		Mean	CV (%)	Range	
1	*15'/15'/5'*	*3.7*	*38.4*	*1.7-6.4*	*0.55*
2	15'/45'/5'	4.6	36.3	2.9-9.0	0.67
3	15'/60'/5'	6.4	37.1	3.1-10.9	0.94
4	15'/75'/5'	8.2	41.4	3.3-15.9	1.22
5	15'/105'/5'	16.9	21.2	10.5-22.4	2.5

(Size of samples = 150mm x 15mm x 1050mm)
(Mean density = 670 kg/m^3; n = 15)

Effect of moisture content (MC) of wood on DSR

The effect of moisture content on DSR can be seen by comparing Tables 8 and 9. It can be seen that moisture content has an adverse effect on the treatability; however, it is clear that *E. tereticornis* wood can be effectively pressure-treated even in green condition by employing long pressure duration schedules.

Effect of concentration of treatment solution on DSR

Even though the use of a 4% BAE solution was found satisfactory for low-density samples at partially dry condition, it was not sufficient to achieve the required DSR in denser samples

(Table 7). Use of an 8% BAE solution for the treatment of partially dry wood in long duration schedules yielded much higher DSR values than what is required (Table 8). Hence, for the treatment of partially dry wood, the concentration of treatment solution can be still lowered from 8% BAE. For the treatment of green wood, however, use of 8% BAE solution with the schedule 15'/60'/5' is recommended for ensuring DSR value just higher than the threshold level.

Penetration of preservative in the treated wood

The treated samples that had the desired level of DSR were tested for the penetration of boron by colour reaction with turmeric extract and salicylic acid. The surface on cross-sections showed uniform red colouration indicating satisfactory result. The presence of boron was detected even in the core; satisfactory as per the Indian Standard 2753 and 401 (BIS 1991, 2001). The successfully CCB treated samples also found passed in the penetration of preservative test.

Mahogany wood

Partially dry (MC 55%) *Swietenia mahogany* wood planks of 25 mm thickness is found getting loaded with adequate quantity of born preservative by using 8% BAE solution while employing the short duration schedule, 15'/15'/5'. DSR greater than the desired range of 5.0-6.5 kg/m^3 is found achieved (Table 10).

Table 10. VPI treatment of partially dry (MC 55%) Mahogany using 8% BAE solution employing the schedule, 15'/15'/5'.

Size (mm x mm x mm)	Mean DSR (kg/m^3)	CV (%)	n
1250 x 25 x150	7.2	46.0	10
800 x 25 x 75	9.5	30.5	8

Density of wood: 550 kg/m^3

Generally, mahogany wood is reported to be extremely difficult to treat (Bhat *et al* 2008). However, the present study revealed that this is not true; at least as far as its pressure treatment potential is concerned.

Acacia mangium

Result of the boron impregnation treatment of green *Acacia mangium* wood using 8% BAE solution, employing the short duration schedule, 15'/15'/5' is given in Table 11. Required DSR is found not achieved, may be due to the high moisture content of the samples and the application of the short duration schedule. Due to paucity of more timber, it was not possible to carry out further work in this line. However, the implication of the result obtained is that for the effective VPI treatment of *Acacia mangium* timber, it is suggested to use at least partially dry timber; use of lengthy schedules and a solution of concentration more than 8% (say around 10% BAE) could yield desired loading of preservative.

Table 11. VPI treatability of green *Acacia mangium* wood using 8% BAE solution, employing the schedule 15'/15'/5'.

Size (mm x mm x mm)	Mean DSR (kg/m^3)	CV (%)	MC (%)	Density (kg/m^3)	n
700 x 150 x 30	3.7	50.0	97.6	536.0	10
1250 x 100 x 25	4.7	42.5	104.0	526.0	7
2100 x 220 x 30	2.3	15.8	105.0	488.5	7

Teak (*Tectona grandis*) juvenile thinning wood

The teak thinning wood was partially dry (MC 45%), having a density of 636 kg/m^3. The overall heart wood content was only around 17%, showing significant quantity of perishable sapwood in the thinning wood. As it was found not practical to segregate the heartwood and sapwood in the teak thinning sawn wood due to its low heartwood content and poor sawn timber recovery that could be yielded by such segregation, all the samples were sawn without removing sapwood and was containing significant quantity of sapwood. The samples for treatment were representing the real situation in the utilization of juvenile teak thinning wood. As shown in Table 12, it was found that required DSR as per Indian Standards (BIS 2001) for perishable timbers could be achieved by the use of an 8% BAE treatment solution employing the short duration economical schedule, 15'/15'/5'. A loading 7.2 kg/m^3 achieved in partially dry timber implies that moisture content of the teak thinning need not become a limiting factor for the efficacy of VPI treatment. Penetration of boron in the treated juvenile teak thinning wood was found uniform and through and through.

This clearly opened up the avenue for value-added utilization of juvenile teak thinning containing sapwood.

Table 12. Boron impregnation treatment of teak wood thinning wood in partially dried condition using 8% BAE solution employing the schedule 15'/15'/5' (sample size: 170 cm x 7 cm x 3 cm)

Property	Mean	CV (%)	Range
DSR (Kg/ m^3)	7.2	17.6	5.0-9.7
Density (Kg/ m^3)	636	4.7	579-690
Moisture content (%)	45.0	11.2	37.4-54.3

(*n* = 9)

Bamboo - Bambusa bambos

Results of pressure treatment of round rod bamboo in air dry, partially dry and green condition using 4% CCB solution, employing the schedule, 15/60'/5' is given in Table 13. For assuring better and effective penetration, round bamboo samples used for the impregnation treatment were given two small holes drilled near to their nodes, as suggested by Gnanaharan (2000). Mean DSR in the range 6.0 to 8.3 are recorded, depending on moisture content. The results clearly indicated that bamboo can be pressure treated to desired retention levels so as to suit various end uses, as per the recommendations of the Indian Standard 9096 and 1902 (BIS 1972, 1993). Moisture content is found not adversely affecting treatability. The treated round bamboos are half-split and checked for penetration of preservative as per IS 2753 and 401 (BIS 1991, 2001); penetration is found satisfactory (Fig 1). Efficacy of the pressure treatment schedule employed, 15'/60'/5' (an initial vacuum of -85 kPa 15 minutes, followed by the application of a pressure in the tune of 1200 kPa for 60 minutes and a final vacuum of -85 kPa for 5 minutes) is proved beyond doubt for achieving desired retention of the preservative in the treated bamboos. The recommended Indian Standard retention level of 4.8 to 5.2 kg /m^3 CCB is for use of treated bamboo for ceiling, door & door panelling, etc (BIS 1979) is found achievable in any moisture level by employing the schedule developed, using 4% CCB treatment solution. For achieving the higher level retention of 8 kg /m^3 CCB for use in house building components such as trusses, purlins, rafters, poles , walling, , etc under cover (BIS 1979) and for non-structural uses such as for furniture, & basketware; mats, *chicks*, *jafri*, etc exposed to weather (BIS 1993), it is suggested to go for higher concentrated (>4%) treatment solutions.

The finding that bamboo can be pressure treated effectively facilitates the commercial scale treatment of bulk quantity of bamboos in short time, required for housing, furniture, mat and panel products. It also facilitates the promotion of value-added utilization of pressure treated bamboo for industrial uses.

Table 13. VPI treatment of round *Bambusa bambos* samples (with holes made in the nods) of different moisture content levels using 4% CCB solution while employing a schedule 15'/60'5'. *(CV % values are given in parenthesis).*

Mean MC (%)	Mean Density (kg/m^3)	Mean DSR (kg/m^3)	Mean DSR (kg/kg)	Mean DSR (%, wt/wt)
16 (13.0)	750 (9.8)	6.7 (29.7)	0.0064 (12.8)	0.6 (9.6)
35 (14.5)	660 (14.7)	6.0 (19.5)	0.0072 (38.9)	0.7 (42.6)
65 (19.8)	560 (6.7)	8.3 (21.7)	0.0070 (19.0)	0.7 (24.7)

n = 6; Length of samples = 100 cms.

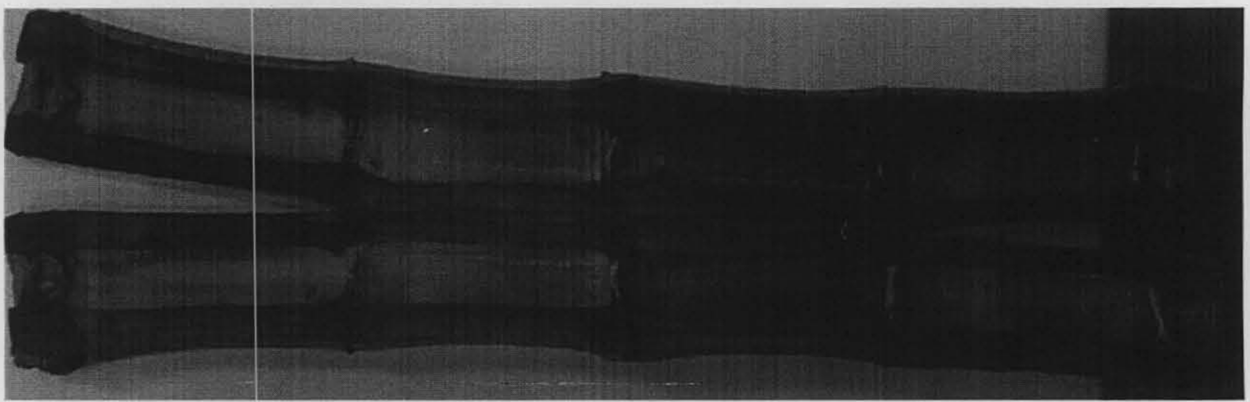


Fig. 1. Photograph showing the successful penetration of preservative in the CCB impregnated bamboo.

Coloration of bamboo slivers using natural dyes

Attractive colors were developed by the use of natural dyes. The different colors developed in the treatments (simple dyeing or dyeing followed by mordanting) are given in Table 14. Generally, dyeing in boiling aqueous dye solutions was found more effective than prolonged soaking (12 hours) at room temperature in imparting dark shades to the color developed, and hence suggested. Similar was the result in mordanting too; mordanting in boiling aqueous solution for an hour is suggested. Some dye sources such as *Bixa orellana, Camellia thea, Curcuma longa, Lawsonia alba* and *Pterocarpus santalinus* are found not responsive to mordants, indicating that there is no special advantage in using mordants while dyeing with these dyes. *Lawsonia alba* was found capable to impart a reddish gray color even at ambient temperature. The nature of the mordanting chemical was also found to have a significant role in deciding the color development. Use of mordants resulted drastically contrasting color, as in the case of dyeing bamboo slivers with *Terminalia chebula* offered a brownish yellow color which turned very dark gray in mordanting with ferrous sulphate. This indicates the potential of mordants in order to get different color shades while dyeing bamboo slivers with natural dyes.

Between the green and air dried bamboo slivers, in general, for all the treatments, intensity of the color developed were not found very significantly different, as assessed visually. Hence, bamboo slivers can be dyed conveniently at any moisture levels.

Table 14. Colors developed by the use of different natural dyes and mordants in bamboo slivers

Dye source	With/Without Mordant	Color developed	Hue	Chroma	Lightness value	Color
Acacia catechu	Without mordant	Reddish gray	10R*	1	6	
	Boiling $K_2Cr_2O_7$ solution as mordant	Reddish brown	2.5YR**	4	4	
	Boiling $CuSO_4$ solution as mordant	Dark reddish brown	2.5YR	4	3	
Caesalpinia sappan	Without mordant	Pale red	10R	4	6	
	Boiling $CuSO_4$ solution as mordant	Red	10R	6	4	
	Boiling $K_2Cr_2O_7$ solution as mordant	Dark reddish brown	2.5YR	4	3	
Terminalia chebula	Without mordant	Brownish yellow	10YR	6	6	
	Boiling Fe SO_4 solution as mordant	Very dark gray	2.5Y	0	3	
Bixa orellana	Without mordants No advantage by using mordants	Reddish yellow	7.5YR	8	7	
Camellia thea	Without mordants No advantage by using mordants	Light brown	7.5YR	4	6	
Curcuma longa	Without mordants No advantage by using mordants	Yellow	2.5Y***	8	7	
Lawsonia alba	Without mordants No advantage by using mordants	Reddish gray	5YR	2	5	
Pterocarpus santalinus	Without mordants No advantage by using mordants	Light red	2.5YR	6	6	
Control	Not dyed	White	10YR	2	8	

** R - Red; ** YR - Yellow-Red; *** Y - Yellow*

CONCLUSION

Non-pressure methods of treatment (diffusion and hot and cold processes) are found not effective in achieving required dry salt retention (DSR) (5 kg/m^3) of boron chemicals in *Eucalyptus grandis* wood. *E. grandis* and *E. tereticornis* wood can be effectively pressure treated using diffusible boron compounds in partially dry and green conditions. Depending on the thickness and moisture content of the wood, by choosing the appropriate concentration of the treatment solution (around 6% BAE) and treatment schedule, the required DSR can be ensured in the vacuum pressure impregnation (VPI) treatment of *E. grandis* and *E. tereticornis*. In order to achieve a DSR of 5 kg/m^3 boron compounds, the desired DSR level as per the Indian Standard for perishable timbers for indoor use, it was found that up to a thickness of 50 mm neither the moisture content of wood nor the treatment schedule poses any problem as far as the treatability of *E. grandis* wood is concerned. Increase in wood density or age was found adversely affecting the treatability of *Eucalyptus tereticornis* wood. For the pressure treatment of denser *E. tereticornis* wood as well as material with high moisture content, the concentration of treatment solution should be about 8%. Only long duration treatment schedules were found to yield the desired DSR levels in *E. tereticornis*. The extent of vacuum and pressure suggested for all the VPI treatment of all the species is in the tune of an initial vacuum of 760 mm Hg (- 85 kPa) followed by the application of a pressure of1300 kPa and a final vacuum of 760 mm Hg. For the VPI treatment of *E. grandis* wood of up to 50 mm thickness in green and partially dry condition, the suggested schedule consists of the application of an vacuum for 45 minutes followed by pressure period for 90 minutes and a final vacuum for 5 minutes (denoted by 45'/90'/5'); where as for partially dry wood of up to 25 mm thickness, the short duration schedule 15'/15'/5' is found enough to achieve the required retention level. For the VPI treatment of *E. tereticornis* wood planks of up to 17.5 mm thickness in partially dry or green moisture condition, only long duration schedules such as 15'/45'/5' or 15'/60/'/5' is found to be capable of achieving the required retention level. The penetration of the boron preservative in the successfully pressure-impregnated E. *grandis* and *E. tereticornis* wood was found satisfactory. The long duration schedule. 15'/60'/5' is found effective even for the CCB treatment of air dry *E. tereticornis* wood while employing the VPI method. Further, the study revealed that the general notion that *Eucalyptus grandis* and *E. tereticornis* wood are difficult to treat is not true as far as impregnation treatment is concerned. In general, it was possible to conclude that the selection of appropriate schedule and use of the treatment solution of the right concentration are the factors of supreme importance for effective boron impregnation treatment of *Eucalyptus* wood.

It was found that teak thinning wood can be pressure treated to desired retention levels. Here also, it was found that the short duration schedule 15'/15'/5' yields to required DSR while using 8% BAE solution for the treatment of partially dry juvenile teak thinning wood.

Mahogany wood is found pressure treatable under the short duration schedule, 15'/15'/5', using 8% BAE solution, achieving desired DSR level. The general notion that mahogany timber is extremely difficult to treat is found not true as far its VPI treatment trials attempted.

It is suggested to treat *Acacia mangium* timber in partially dry condition; use of long duration schedules is recommended.

Bamboo is found pressure treatable to desired retention levels for various end uses as recommended by the Indian Standards. A pressure treatment schedule consisting of the application of an initial vacuum of -85 kPa 15 minutes followed by the application of a pressure in the tune of 1200 kPa for 60 minutes and a final vacuum of -85 kPa for 5 minutes (denoted by 15'/60'/5') is found effective for achieving desired retention of the preservative in the treated bamboos. A minimum concentration of 4% CCB solution is found to yield DSR levels ranging 6.0 to 8.3 kg/m^3, depending on the moisture content of bamboo. Irrespective of the moisture content of bamboo, the newly developed pressure treatment schedule, 15'/60'/5', is found to be capable to achieve the desired DSR levels as recommended by the Indian Standards, provided the appropriate concentration of treatment solution is employed depending on the end use - retention specification requirements.

As far as colouring of bamboo slivers with natural pigments is concerned, seed pulp of *Bixa orellana*, leaf powder of *Camellia thea* (commercial tea powder), rhizome powder of *Curcuma longa* (commercial turmeric powder), leaf pulp of *Lawsonia alba* and heartwood powder of *Pterocarpus santalinus* are found yielding reddish yellow, light brown, yellow, reddish gray and light red colours respectively to bamboo slivers directly on dyeing. There was no special advantage in using metal salts post-treatment (mordanting) as far as the color development is concerned while using these dye sources.

Chemical nature of mordant is also found to have a deciding role in the color development while dyeing bamboo slivers with natural dyes. *Acacia catechu* and *Caesalpinia sappan* heartwood powder yields reddish gray and pale red color respectively on direct dyeing. Use of potassium dichromate or copper sulphate mordants improved the darkness of the shade of the color while using *Acacia catechu*. In the use of *Caesalpinia sappan* dye, copper sulphate post-treatment yielded red color whereas potassium dichromate post-treatment yielded a different color, dark reddish brown, to the dyed bamboo slivers. Certain dyes such as *Terminalia chebula* fruit powder, will offer contrasting color after treatment with metal salts (ferrous sulphate, in this case; very dark gray color).

Dyeing and mordanting at elevated temperatures is found more effective. Dyeing in 5% aqueous boiling dye solution for 3 hours followed by post-treatment with 2% aqueous boiling metallic salt mordants (copper sulphate, potassium dichromate or ferrous sulphate as the case may be) for an hour was found to be effective and can be followed for imparting satisfactory color and shades to bamboo slivers. Between green and air dried slivers, there was not significant difference in color development while dyeing; indicating that moisture content of slivers need not be a limiting factor in color development.

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APPENDIX

Recommended retention levels of preservatives in treated bamboo as per Indian Standard IS 9096: 1979 & IS 1902: 1993

Preservative	DSR (kg/m^3)	Application/End Use
CCB	4.8 - 5.2	Ceiling, door & door panelling
CCB	8.0	Housing, walls, trusses, purlins, rafters, tent poles, etc.. under cover; *Chicks, jafri* & mats exposed to weather; Furniture, & Basketware
CCA	3.2	Ceiling, door & door panelling
CCA	4.0	Housing, walls, trusses, purlins, rafters, tent poles, etc.. under cover
CCA	4.8	*Chicks, jafri* & mats exposed to weather; Furniture exposed to weather; Basketware
CCA	4.8 – 8. 0	Bridges, scaffoldings, ladders, etc.. exposed to weather but not in contact with ground.
CCA	8.0 – 12.0	Posts, poles, fencing, etc.. exposed to weather and in contact with ground
Boric acid & Borax	4.0	House hold use including *chicks*, mars and furniture under cover; Packing of edible material including fresh fruits and vegetables
Boric acid & Borax	5.2	Ceiling, door & door panelling