TRAINING MANUAL FOR

VALUE-ADDITION - BAMBOO TECHNOLOGIES

A Training Programme for
Bamboo Artisans and Master Craftsmen
under
Bamboo Technical Support Group of ICFRE
(BTSG-ICFRE)

Institute of Wood Science and Technology
(Indian Council of Forestry Research and Education)
P.O. Malleswaram, BENGALURU - 560 003

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Training Manual

on

VALUE-ADDITION - BAMBOO TECHNOLOGIES

for

Bamboo Artisans and Master Craftsmen

under BTSG-ICFRE

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Date: 21th January, 2020
Place: Bengaluru

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काष्ठ विज्ञान एव प्रौद्योगिकी संस्थान
INSTITUTE OF WOOD SCIENCE AND TECHNOLOGY
(भारतीय वानिकी अनुसंधान एवं शिक्षा परिषद)
(Indian Council of Forestry Research and Education)
(पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय, भारत सरकार की एक स्वायत्त निकाय)
(An Autonomous Body of Ministry of Environment, Forest and Climate Change, Govt. of India)
डाक घर मल्लेश्वरम / P.O. Malleswaram, बेंगलुरु / Bengaluru – 560 003

PREFACE

Bamboos have played a vital role in the life of mankind and are very important from ecological, commercial and socio-economic points of view. Our country is the second richest bamboo genetic resources after China. In India, bamboo forest constitutes about 13% of the total forest area. There are about 90 genera and 1250 species of bamboo in the world. In India bamboos were represented by 23 genera and 136 species. Bamboo has become intrinsic part of life for people especially those from north-eastern region. There are more than ten thousand documented uses of bamboo which is widely used in paper, textile, construction, architecture, incense stick, handicrafts, food and medicine. Bamboo is a potential energy source and by tapping the bamboo for ethanol and bamboo charcoal can reduce the dependency on fossil fuel.

Bamboo sector is growing tremendously and has great potential to provide employment to millions of rural populace. By imparting skills to the youth, encouraging setting up of small scale bamboo based industries providing self-employment and empowering women of the rural area one can contribute to socio-economic upliftment of rural population. As bamboo has higher carbon dioxide sequestration potential, the cultivation of bamboo on marginal waste land and setting up of more and more bamboo product based industries will help in reducing level of greenhouse gases in the atmosphere.

The Bamboo Technical Support Group (BTSG) of the new National Bamboo Mission (NBM) by Ministry of Environment Forests & Climate Change, Government of India being implemented through Indian Council of Forestry Research and Education (ICFRE), Dehradun. This programme has aim of producing skilled human resource to generate employment opportunity by harnessing available bio resources of the country and integrating bamboo based initiatives with skill development. Institute of Wood Science and Technology (IWST), Bengaluru, has done considerable research work on bamboo in the field of diversity analysis, propagation and value addition such as bamboo preservation, bamboo-plastic composite, thermal modification of bamboo etc. and in transferring of technology to stakeholders through various training cum demonstration programmes. Institute is organizing 6-days long training programme on '**Value-addition-Bamboo Technologies**' during 27 January to 1 February, 2020 for the benefit of bamboo artisans, master craftsmen etc. from the states of Karnataka, Andhra Pradesh and Telangana. I wish a great success to the proposed BTSG training programme and hope it will help many unemployed youths to find their ways in life.

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CONTENTS

Distribution of bamboo, their properties and utilization potential for value-added utilization

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INTRODUCTION

Bamboo is one of the oldest building materials used by mankind. It has been traditionally in use in construction, housing, scaffolding, fence post, tent pole, ladders, bridges, bullock cart and agricultural implements. Being a valuable natural resource, it has variety of application in furniture, flooring, many-kind of handicraft articles, pulp and paper, boats, musical instruments, charcoal, plywood and particleboard manufacture etc. Additional uses of bamboo are skyscraper scaffolding, slide rules, fuels, chemical extractives from various parts of the plant have been used for hair and skin ointment, medicine for asthma, eye wash. Bamboos are also used in aquatic environment for the structures such as aqua-culture farm, fencing, poles and fishing nets. As untreated bamboo culms are susceptible to wood boring organisms, it needs preservative treatment. Bamboo is also becoming increasingly popular in the horticultural industry as a houseplant. The rural poor are the principal users of bamboo using more material than the pulp and paper industries. Bamboos are used for manufacture of large number of value added goods, cottage industry depend on for its raw material requirement and a large number of forest dwellers depend on them for their livelihood. Other than the above, because of its faster growth easy propagation and soil binding properties, bamboo is an ideal choice for afforestation, soil conservation and social forestry programmes.

Bamboo is a vernacular term used for members of subfamily Bambusoideae of family Poaceae, the grasses. Bamboos assume special significance, particularly due to following reasons: bamboo is the fastest growing amongst the woody species, attaining harvestable maturity in less than five years; plantation technology for large scale cultivation of bamboo is known. While standard practices have been developed with culm cuttings, tissue culture is gaining acceptance; as a material, mature bamboo ranks potentially higher than juvenile wood having less variability in structure and more properties favourable for making reconstituted panel products; despite its vigorous and invasive growth habit, it is "environmentally friendly" in comparison to many alien species being grown in the country. Fig.1 shows bamboo resources in the country.

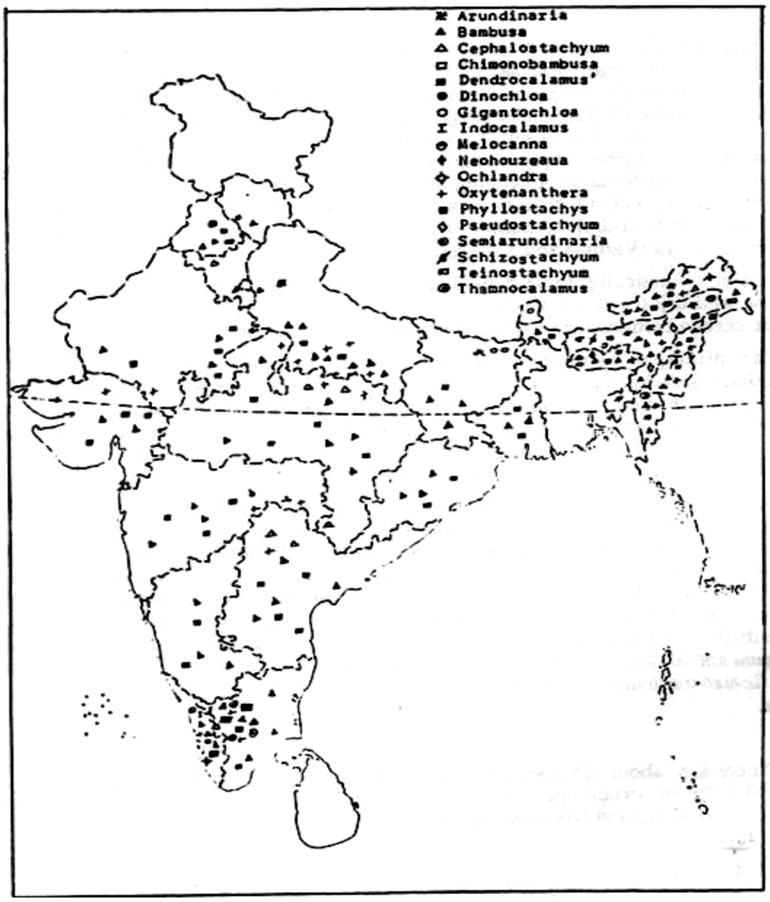

Fig.1: Bamboo resources in the country

A thorough understanding of the relations between structures, properties, behaviour in processing and product qualities is necessary for promoting the utilization of bamboo in different forms – solid, split or reconstituted. About 14 million hectare of the earth surface is covered by bamboo forests with 80% in Asia. They are fairly well represented in all the countries except in Europe. There are about 65 genera of which 14 are endemic to the Asian region. Total number of species is around 900. Bamboos have been traditionally used in construction since time immemorial. It is also one of the most versatile material in forest products utilization and used as a raw material in large scale for pulp and paper. Bamboos are extensively planted in national afforestation programmes to meet industrial and rural requirements. In view of the multifarious uses, research was carried out to generate scientific data on the morphology, leaf epidermal studies for identification, anatomy and fibre morphology, strength properties, engineered uses, pulp sheet properties and utility products. Different parameters for structural, construction, thatching, walling, roofing handicrafts, and novelty items and for pulp and paper as selection criteria, the species are available and used throughout the country. Almost all of the 75 genera and 1250 species of bamboo are woody and fast growing. They range from the size of grass to giants of 40 meter in height and 30 cm in diameter. Bamboos grow at the sea level in tropics to an altitude of 4000 meters in temperate region. They are distributed largely in the tropics, although they are found naturally in all subtropical and temperate zones except in Europe. Bamboos are most abundant in seasonal monsoon forest and prefer distributed habitats, in which they often become weedy. Bamboo is a cultural feature of South-east Asia. No country in the South East Asian region is without an indigenous bamboo flora. Major bamboo growing regions/states are depicted in Table 1.

In India, bamboos form rich belts of vegetation in the well-drained parts of the monsoon region at the foot of the Himalayas and also down in peninsular India and along the Western Ghats or Sahayadri ranges. World's largest reserves of bamboos exist in India, which is represented by 136 species. There are over 136 species of bamboos growing in India. But only few of them are only of economic importance from viability and utilization point of view. The current harvesting of bamboo exceeds 3.2 million tons (5 million cum) a year, 50% of which is utilized for handicraft/structural uses. Additional resource of bamboo may be generated by adopting scientifically advanced practices like improving storage and preservative treatment is about 1.1 million cum which emphasizes the adaptation of advanced techniques of bamboo processing. Requirement of timber (and bamboo) for solid wood and reconstituted wood products was estimated to be 25.72 million cum in India. Out of this, estimated demand for bamboos is about 2.5 million cum. In view of huge gap between production and consumption of timber in India (of the order of 20 million cum), bamboos may be viewed as filling this gap up to some extent.

Table 1: Major bamboo growing regions / states

Regions / States	Area (%)	Gross share
North East	28.0	66
Madhya Pradesh	20.3	12
Maharashtra	9.9	5
Orissa	8.7	7
Andhra Pradesh	7.4	2
Karnataka	5.5	3
Other States	20.2	5

Bamboo consumption in India, estimated on actual production of 2.56 million ton has increased in recent years. Bamboo is in short supply in almost all the states except in Assam and Maharashtra. Projection of requirement of bamboo/Ochlandra reeds as a raw material for the paper, paperboard and newsprint is more than 6.70 million tones. Among different bamboos, *Dendrocalamus strictus, B. arundinaceae* are widely used. Table 2 lists some of the economically important bamboo species in India. Important genera of bamboos are *Arundinaria, Bambusa, Cephalostrachyum, Dendrocalamus, Gigantochloa, Melocanna, Ochlandra, Phyllostachis* and *Thysostachus*. Most of these are indigenous to India. Among the many genera which have potential for various uses**,** *Bambusa bambos* and *Dendrocalamus strictus* which are abundantly available in India in general and South India in particular are chosen from the point of various product developments.

Table 2: Economically important bamboo species in India

S.No.	Name of Species	S.No.	Name of Species
1	*Bambusa bambos*	10	*D. hamiltonii*
2	*B. nutans*	11	*D. stocksii*
3	*B. pallida*	12	*D. strictus*
4	*B. polymorpha*	13	*D. asper*
5	*B. tulda*	14	*Guadua angustifolia*
6	*B. vulgaris*	15	*Meloconna baccifera*
7	*B. balcooa*	16	*Ochlandra travancorica*
8	*Dendrocalamus brandisii*	17	*Schizostachym dullooa*
9	*D. giganteus*	18	*Phyllostachys bambusoides*

Bamboo is a very important non-timber resource that benefits the life of people in a myriad ways. These versatile grasses have the capacity to produce maximum biomass per unit area and time compared to many other forest plants. Bamboo provides food, raw material, shelter, fodder and even medicines in many parts of the world and has been said to be put to 4000 uses. About half of the world's population is estimated to be associated with Bamboo in over US$ 7 billion trade and uses. In Asia, there are billions of people who depend on it for part or whole of their income. For example, in India, it is estimated that there are 2 million traditional bamboo artisans. Their livelihood depends entirely on the harvesting, processing and selling of bamboo and its products. The importance of bamboo, especially to rural communities in the countryside of bamboo growing countries can hardly be over stressed. It plays a vital role in their daily life in numerous ways in as fodder, food, medicine, as material for house construction, agricultural tools and implements, tool handles, fencing, fishing traps and rods etc. It generates large scale rural employment, right from the management, harvesting, collection, transport, storage processing and utilisation.

Bamboo as alternative!

Due to the non-availability of the timber from the natural forests and non-suitability of many plantation timbers, difficulty has been experienced by the Institute to recommend species required for different usage from the Indian standards. The scarcity of solid wood for especially opens new vistas and offers scope and throws challenge to find potentiality of bamboo either in round form or laminates. The suitability of bamboo culms in round form and as layered laminates as an alternative because of inherent culm property and also substitute of timber are likely candidates for exploration. Bamboo an equally strong material as wood is known as poor man's timber. With the increasing gaps in timber demand and supply, a renewed interest has been generated to exploit and utilize this material. Use of solid bamboos has been insisted specially for furniture in place of solid wood as there is shortage of timber and bamboo species are available. Government of India policy is to encourage the utilization of more and more bamboo in place of solid wood. Its plethora of essential uses has led to the use of expressions such as "bamboo culture", "green gold", "poor man's timber", "bamboo-friend of the people" and "the cradle to coffin species". Bamboo substitutes timber in many respects. The alarming rate of shrinkage of tropical forests call for restriction on tree felling apart from environmental considerations thereby increasing interest in plantations of fast growth species; harvesting them at short rotations and utilizing juvenile woods as building materials. In view of diminishing supply of timber from natural forests, a lot of interest has been generated on the improved uses of bamboo. With the advancement of science and technology, new methods are needed for processing of bamboo to make it more durable and more usable in the modern world.

Bamboos are extensively used in round and split form for variety of applications like housing, scaffolding, bridges, ladders, agricultural implements, tool handles, sticks, fences, baskets, sports goods and many other uses besides paper making. Bamboo laminates and other reconstituted bamboo products have also been manufactured and being used for different applications. A lot of research work has been carried out on evaluation of physical, mechanical and chemical properties of different bamboo species and their correlations with anatomical properties. The natural durability of bamboo is very low (varying from 1 to 36 months depending on species) because of its fast and severe bio-deterioration due to stain fungi, rotting fungi and insects. This also depends upon the species and climate conditions. Split bamboos are destroyed more rapidly than round bamboo. Simple and cheap methods of bamboo preservation have also been reported in the literature. The Institute of Wood science and Technology, Bangalore has been involved in the bamboo utilization and improvement work for quality culms for the past 30 years. Institute has also been conducting regular trainings to bamboo artisans for scientific utilization of bamboo. The Institute has a well-equipped laboratory to carryout basic and applied work related to evaluation of properties and processing. Apart from these, the Institute also has basic workshop to work on solid wood, and bamboos.

Important Characteristics of Bamboo

Bamboo, the poor man’s timber is a strong, versatile and renewable woody material having multifarious uses both in rural and urban sector. It has been an integral part of India’s’ cultural, social and economic traditions. Millions of people depend on it for their livelihood and for household and functional uses. It is the nature’s most valuable gift to mankind especially to rural people. Because of easy workability and low costs, bamboo has been useful to the general mass. The culm growth is faster and matures within 3 to 4 years. The unique properties of bamboo such as its strength, straightness, smoothness, durability, easy to cut and split, easy to carry have made it useful to the villagers in almost every need of life. One of the important characteristics of bamboo is its fibrous structure. The fibers are longer compared to wood fibers. The strength properties are better than many timber species. The circular and hollow cross-section of bamboo gives it a high strength-weight ratio. Bamboo is elastic in comparison to wood. The cross partition walls at each node make the bamboo are strong and hard to bend or break at joints. It has a smooth and clean surface. It can be easily cut into required size and split-up into strips with house hold tools. Bamboo culms can be easily stored and transported. Ordinary methods of seasoning and treatment such as submerging in water can increase its durability.

Growth conditions (locality) may apparently effect the composition and structure of the tissue and therefore may have some influence on the overall physical and strength properties of bamboo. There are some variations between genera and also species, partly related to the types of vascular bundles present. The basic differences in the anatomical make-up must affect a number of properties like density, strength, bending behavior, splitting and shrinkage. Table 3 shows a comparison of strength parameters among different materials. Main characteristics of bamboo are listed below:

- Availability in different sizes
- Straightness of the culm
- Lightness of the material
- Good physical and mechanical properties:
    - Avg. density & low shrinkage
    - Good flexural properties
    - High tensile strength
    - Very good weight to strength ratio
    - Pressure tolerance (>3600 kg/cm^2)
- Easy to handle with simple tools
- Renewable raw material
- Bamboo is well suited to replace wood in several applications

Table 3: Comparison of strength parameters among different materials

Property (kN/cm²)	Wood	Bamboo	Steel
Elastic modulus	1100-1500	1800-2200	21000
Bending strength	7-12	8 - 28	14
Compressive strength	4-6	6- 9	14
Tensile strength	9-12	15-38	16
Shearing strength	1-2	2-3	9

Anatomy (Microstructure) of Bamboo

Outer layer of culm is about 0.25 mm thick, contains silica to protect plant, but not good for tools as silica blunts the sharp edges within a short time. Dark spots are fibers together with vessels which concentrate near outside. The fibres act as reinforcement, similar to steel bars in reinforced concrete structure. Bamboo is an excellent example of structural design of Mother Nature. Vessels take care of the transport of liquids during the life of the bamboo. Material between dark spots is called "parenchyma", where fibers are bedded. Approx, a bamboo culm has 40% fibers, 10% vessels and 50% parenchyma. Microstructure of bamboo is depicted in Fig.2. Unlike wood, bamboo does not have any "rays”. Rays are places for food transport and storage, but they also weaken the material. Consequently, bamboo is stronger than wood, especially in shear. Bamboo tissue contains organic and inorganic extractives, deposited within cell walls. Starch grains mainly occur in parenchyma cells in vascular bundles, even fibers may contain starch which makes bamboo susceptible to fungi (blue stain) and insect attack, thus affecting its durability. Table 4 shows specific gravity and certain anatomical parameters of *D. stocksii* bamboo.

Table 4: Anatomical properties of *D. stocksii*

Property	Values
Specific gravity	0.55-0.85
Fibre length (mm)	3.3-3.5
Fibre diameter (µm)	16.6-18.5
Lumen diameter (µm)	5.7-6.5
Wall thickness (µm)	11.0-12.6
Vascular bundles/sq.cm	247-316

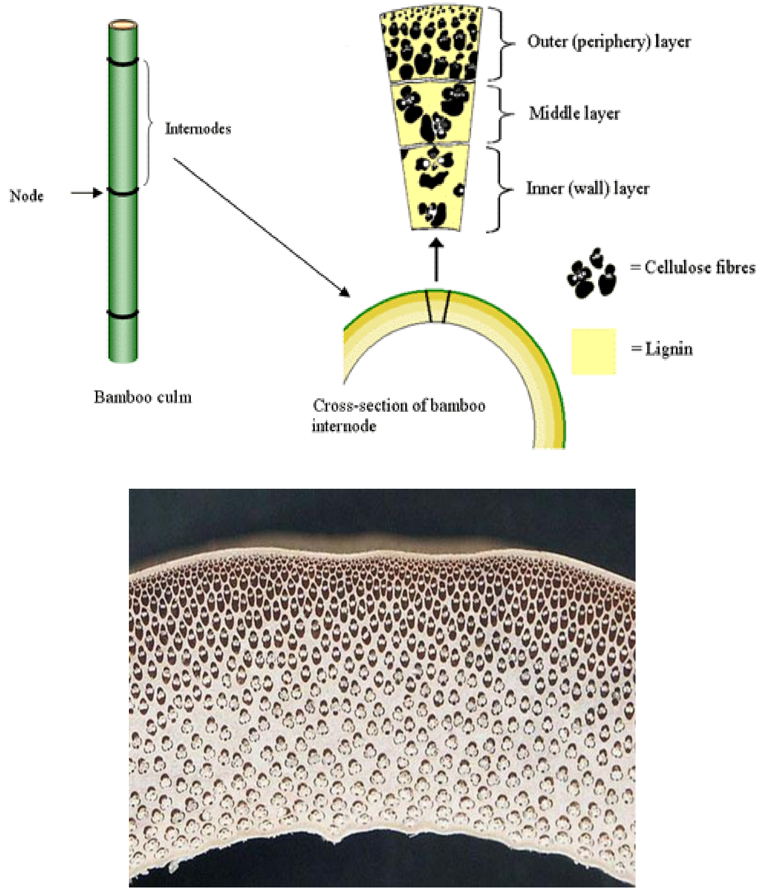

Fig.2: Microstructure of bamboo

Physical and mechanical properties:

Moisture Content (MC):

Specimen to be taken from tested samples of mechanical properties near the place of failure. Matured culms should be seasoned to 12-15% moisture content before use.

Density:

Density is computed by mass per unit volume and generally ranges 600-900 kg/m^3. Density varies with site quality, species, position in culm, moisture, etc. Heavier bamboos have greater densities. Denser material results in better properties desired in most applications.

Shrinkage/swelling:

Shrinkage or swelling in bamboo occurs due to loss or gain or moisture/water. Bamboo exhibits little dimensional change compared to other commonly used woods (2.5x more stable).

Mechanical Properties:

Bamboo possesses different mechanical properties such as static bending strength (MOR) and stiffness (MOE), compression parallel to grain, tension parallel to grain, shear parallel to grain etc. For most of bamboos, the range of MOR values is 700 - 1200 kg/cm^2 while MOE lies in the range of 120 - 200 x10^3 kg/cm^2. Based on strength properties, bamboos are classified in different groups. Table 5 shows the classification of bamboo.

Table 5: Classification of Bamboo

(for structural purposes, strength values in green condition)

Type of Class	MOR (N/mm^2)	MOE (x10^3 N/mm^2)	MCS (N/mm^2)
Group A	>70	> 9	> 35
Group B	50 - 70	6 - 9	30 - 35
Group C	30 - 50	3 - 6	25 - 25

Comparing efficiency of bamboo and timber with same cross-section area: bamboo is hollow tube, while timber has a massive structure giving bamboo better structural efficiency. In terms of specific stiffness (MOE/density): Bamboo > Steel > Concrete >Timber. In terms of specific strength (MOR/density): Steel > Bamboo >Timber > Concrete.

Value-added Utilization:

The bamboo is in its size, lightness and strength an extreme product of nature. It is stable and because of its cavities an extreme light and elastic building material. The reinforcement by diaphragms and its physical conditions cause its enormous superiority compared to other building materials. Bamboo has a very efficient natural structural design; because of the hollowness and the fibers in longitudinal direction, less material mass is needed than in case of materials with a massive section, e.g., timber. In terms of load-bearing mass, as with all tubular elements, bamboo functions as an I-shaped cross-section, in each direction it is loaded, whereas other cross-sections are most efficient in one or two directions. Due to the favorable mechanical properties, the high flexibility, the fast growing rate, the low weight and the low purchasing costs, bamboo is one of the most important building materials with many opportunities. It can be used in many applications; from very traditional handicraft (e.g., baskets) to products that are completely industrialized (e.g., parquet and panels). Some bamboo species can very well be used in supporting structures as the very high bamboo scaffolds against Eastern skyscrapers demonstrate. Especially for the less wealthy population in tropical areas, bamboo plays a very important role in daily lives (shelter, employment, income, fuel, etc.). Recently, bamboo has also found more applications in the industrial applications as well as in temporary structures. Besides being an essential component of cottage and rural industry, bamboo is also found to be used in some specialized novel uses such bamboo timber, bamboo based-laminates; bamboo laminated flooring tiles, reinforcement in cement concrete etc.

- Pulp and paper
- Fuel (charcoal)
- Furniture and Handicrafts (baskets, jewelry, pens, bicycles etc.)
- Construction (homes, bridges scaffolding, reinforced, fences, concrete, boats).
- Musical Instruments
- Traditional medicines
- Food (shoots, wine)
- Fodder

As described above, bamboo can be used for many different purposes. Often only some species are suitable or preferred for certain uses, whereas other species are neglected or even disregarded. It is generally known that restrictions in processing and utilization are often related to unsuitable properties. Therefore a thorough understanding of the relations between structures, properties, behavior in processing and product qualities is necessary for promoting the utilization of bamboo. Fortunately, bamboo is much simpler constructed than wood and the differences among the about 700 species appear relatively small. The lignifying cell construction of the bamboo texture and its technical conditions are very similar to the original texture of wood. Whereas wood has got a hard centre and becomes weaker towards the outer parts, the bamboo is in its outer parts hard and in its inner parts weak, what causes a much more stable construction. Comparing the different results of investigation of the strength properties of bamboo, there is a big fluctuation of the results, although they all tested the same species of bamboo. Nevertheless, a detailed analysis of the relations between structure and properties does hardly exist so far. The fibers contribute 60-70% by weight of the total culm tissue. Some bamboo species have shorter fibers and the fibre length shows considerable variations within a culm. Since, fiber length influences density and strength properties, detailed studies appear to be worthwhile. The occurrence and distribution of thick- and thin- walled fibers affect processing qualities and certain other properties, detailed studies with technological superior and inferior bamboo species will be very useful.

Processing of bamboo:

Air seasoning of split or half round bamboo does not pose much problem but care has to be taken to prevent fungal and insect attack during seasoning. Bamboo with poor initial condition on account of decay, borer hole etc. generally suffer more drying degrades. Green bamboo may contain 50-150% of moisture. As in the case of wood, seasoning of bamboo is necessary before its efficient utilisation. Air seasoning of split or half round bamboo does not pose much problem but care has to be taken to prevent fungal and insect attack during seasoning. Fungal and insect attack can be controlled by rapid drying in open sun as usually adopted for several handicraft items like baskets, mats, chicks, etc. Seasoning of round bamboo presents considerable problem. A study on seasoning behaviour of bamboo indicated that immature bamboo gets invariably deformed in cross section and thick walled immature bamboo generally collapse. Thick mature bamboo tends to crack on surface with the crack originating at the nodes and at decayed points. Moderately thick immature and thin and moderately mature bamboo season with much less degrade. Bamboo with poor initial condition on account of decay, borer hole, etc. generally suffers more drying degrades. The round bamboos should be kept in vertically standing position for air drying.

Bamboo composites

Bamboo products are finding increasing uses in various applications such as flooring, veneer, handicrafts, decorative boards, sports equipment and other building materials. Bamboo as raw material is used for pulp, paper and panel board industries. Bamboos are used in many traditional applications such as fencing, water pipes, fishing rods, umbrella handles, musical instruments and decorative handicrafts. But, presently the focus is on bamboos as structural materials. The suitability of bamboos for structural products is demonstrated by its mechanical and physical properties. Bamboo composites are normally used for structural products rather than the raw bamboos. This is because of possible variability of properties along the longitudinal and radial directions as well as physical dimensions of the products required. For load carrying structural composite products, mechanical properties such as tensile strength, compressive strength, shear strength, flexural strength and bending elasticity modulus are important. For flooring tiles and veneers, through-the-thickness compressive strength, hardness, abrasion resistance and slip resistance are important. For structural assemblies, nail withdrawal strength is important. Table 6 lists some important Indian Standards (IS) related to bamboo.

Table 6: Important Indian Standards (IS) related to bamboo

BIS Code No.	**Title of IS Standard**
IS 6874:2008	Method of Tests for Bamboo
IS 8242:1976	Method of Tests for Split Bamboo
IS 1902:1993	Code of Practice for Preservation of Bamboo and Cane for non-structural purposes
IS 9096:1979	Code of Practice for Preservation of Bamboo and Cane for Structural purposes
IS 14588:1999	Specification for Bamboo Mat Veneer Composite for General Purposes
IS 13958:1994	Specification for Bamboo Mat Board for General Purposes
IS 8295:1976	Specification for Bamboo Chicks ; Part 1 Fine, Part 2 Coarse
IS 7344:1974	Specification for Bamboo Tent Pole
IS 15476: 2004	Specification for Bamboo Mat Corrugated Sheets

Bamboos resource distribution in India and it's importance

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INTRODUCTION

Bamboos belong to the natural group Poaceae under the subfamily Bambusoideae. They are mainly distributed in the tropical and subtropical regions of the world. Although, bamboos are known as 'tree grass', certain bambusoid characters set them off from other grasses. A well-developed rhizome system, woody culms bearing the branch complements, petioles of the leaf-blade, the culm-sheaths covering the new shoots and buds, presence of lodicules, flowering and seeding behaviour are some of the most important morphological characters that make this group distinct from other grasses. Taxonomically, bamboo is considered as one of the most difficult group of plants owing to the non-availability of flowers and fruits. Most of the bamboo species flower only once in their lifetime at irregular intervals and often die, soon after. The life span varies from 7-120 years. The flowering is unpredictable and seeds are not available always.

Bamboos form a part of biological diversity intermingled with life, tradition and culture of indigenous people from time immemorial. Ancient Chinese started to use bamboos 7000 years ago. It is known from '**Vedas**' as a source of fire (5000 years ago); '**Ancient Medicinal Text**' as surgical equipment; '**Arthasastra of Kaudilya**' as a source of income (300 B.C.). Oldest Publications "**Colloquies on the Simples and Drugs of India**" published (Garcia da Orta, 1568) indicates 'Tabasheer' a medicine (Oxalate crystal/ liquid present in certain bamboos). The first published document in which bamboos have been included is the ***Hortus Malabaricus*** – by van Rheede 1675.

Bamboo Distribution

The *Bambusoideae* appears to be one of the most successful and diverse subfamilies of grasses. They have strong adaptability and are distributed widely from near the equator zone to boreal zone. They occupy habitats from sea level to high mountains, up to an altitude of 3300-4000 m. Most of the bamboo species need warm and humid climate and are distributed over plain and hilly area in tropical and subtropical monsoon zone between the Tropic of Capricorn and the Tropic of Cancer. The geographical distribution of bamboos is governed largely by the conditions of rainfall, temperature, altitude and soil. Most of the bamboos require a temperature from 80C to 360C, and a minimum annual rainfall of 1000 mm and high atmospheric humidity.

World distribution

The true bamboos (Poaceae, subfamily Bambusoideae), with approximately 1,810 described species in 128 genera are classified into two major groups recognized as tribes. The woody bamboos (Bambuseae) with ca. 1,600 species are distributed worldwide, while the herbaceous bamboos (Olyreae) with ca. 210 species are restricted largely to the American continent. They appear in the natural vegetation of many parts of the tropical, subtropical and mild temperate regions of the world. They are abundant in the southern and south-eastern regions of Asia, from India through China and Japan to Korea. Bamboos are also growing in Africa, Australia and in Madagascar. In the Western hemisphere bamboos extend from eastern United States to Chile and Argentina. South America is rich in bamboos.

Three major bamboo growing geographical regions are recognized in the world:

1. Asia-Pacific (42°S-51°N): Major bamboo growing countries in these regions are China, India, Myanmar, Thailand, Cambodia, Japan, etc.
2. American (47°S-40°N): It extends across south and north Americas, Mexico, Guatemala, Honduras, Columbia, Venezuela, the Amazon valley in Brazil are the main centres of bamboo distribution in this region.
3. African (22° S-16° N): The southern Mozambique and eastern Sudan from south to north. The main places are Senegal, Guinea, Liberia, Ivory Coast, Nigeria, Congo, Zaire and Madagascar Island.

Distribution of bamboos in India

The tropical moist deciduous forests, the deciduous and semi-evergreen regions of the north-eastern part show maximum diversity of bamboos. They thrive best and form rich belts of vegetation in the well-drained parts of monsoon forests at the foot of the Himalayas and in the peninsular region. Bamboos also form secondary breaks and they also occur as pure patches. *Bambusa bambos, Ochlandra travancorica* and *Melocanna baccifera* are some of the species, which form bamboo breaks. The main bamboo-growing regions in India are the north-eastern region and the Western Ghats. In India the diversity of bamboos is mainly confined to the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, West Bengal in the north east; some regions of Madhya Pradesh, Utter Pradesh, Bihar, Orissa in central region; Andhra Pradesh, Kerala, Karnataka and Tamil Nadu in the Peninsular region. Andaman and Nicobar Islands also have a promising diversity.

Major parts of the Western Ghats receive both southwest and northeast monsoons. Tropical moist evergreen, semi-evergreen and moist deciduous forests are the important forest types of the Western Ghats region. Bamboos are most abundant in the semi-evergreen and moist deciduous forests. They are also rich as part of riparian flora, found along the river and streamside. Based on the forest types dominant 5 species of bamboos indifferent forests have been recognised (Table-1)

Table 1. Distribution of Bamboo in different Forest types

S.No.	Forest Type No.	Forest type/Sub type	Dominant Species
1.	1/E2	Wet Bamboo Brakes	*Ochlandra* sp. *Bambusa* sp.
2	2/E2	Wet Bamboo Brakes	*Ochlandra* sp. *Bambusa* sp.
3	3/E2	Moist Bamboo Brakes	*Bambusa bambos,* *Schizostachyum* Kurzii
4	3/2S1	Dry Bamboo Brakes	*Dendrocalamus strictus*
5	5/E9	Dry Bamboo Brakes	*Dendrocalamus strictus.*
6	8/E1	Reed Brakes	*Ochlandra* sp.
7.	12/DS1	Montane Bamboo Brakes	*Sinarundinaria sp/Yushania*

Bamboo diversity

As per the classification based on **Geographical** occurrence bamboos are grouped as:

Old world bamboos: The bamboos of Asia pacific region and Africa are generally considered as old world bamboos.

New world bamboos: The bamboos of south and north Americas, Mexico, Guatemala, Honduras, Columbia, Venezuela, the Amazon valley in Brazil

As per the classification based on **morphological** appearance the bamboos are categorized into **Woody bamboos and herbaceous bamboos** (only three species so far known from India).

Resource in India

Bamboo resources of the country based on the report of the Forest Survey of India, pure bamboo is found maximum in Mizoram (226 Km sq) followed by Arunachal Pradesh (217 Km sq), M(192 Km sq) and Nagaland (101 Km sq). Dense bamboo is found in Arunachal Pradesh. Arunachal Pradesh having more than 75 species (50% of total bamboo diversity in India).
Four fifths of the growing stock of bamboo in India comprises of three species:

Dendrocalamus strictus (53%), *Bambusa bambos* (15%) and *Melocanna baccifera* (15%).

Species suitable for commercial products in different application segments are *Dendrocalamus asper* (for shoot and timber), *Dendrocalamus hamiltonii* (for shoot), *Dendrocalamus stocksii* (for crafts, structural and household applications) and *Bambusa balcooa, Bambusa tulda, Bambusa nutans*, *Bambusa bambos, Dendrocalamus strictus* (for wood substitutes).

In India, 148 species of bamboos under 29 genera are found growing. As per the recent compilation, there are 106 species belonging to 29 genera that are native bamboos and 42 species are cultivated. The tropical moist deciduous forests of the north and south, deciduous and semi-evergreen regions of the north-eastern part show maximum diversity of bamboos. They are most abundant in the northeastern states, western and also in Eastern Ghats. North-eastern hill regions possess largest species diversity. Bamboos also form secondary brakes and then, they occur in pure patches. *Bambusa bambos*, *Ochlandra travancorica*, *Melocanna baccifera and Schizostachyum* sp. are some species, which form bamboo brakes. In India the diversity of bamboos is mainly confined to the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, West Bengal in the north east; Uttarakhand, Regions of Bihar, Madhya Pradesh, Orissa, Uttar Pradesh in central region; Andhra Pradesh, Goa, Kerala, Karnataka, Maharashtra and Tamil Nadu in the Southern region.

THE HIMALAYAN SUBTRIBES AND GENERA

Bambusinae Agardh

1. *Bambusa* Schreber
2. *Dendrocalamus* Nees

Melocanninae Reichenbach

3. *Melocanna* Trinius
4. *Cephalostachyum* Munro
5. *Teinostachyum* Munro
6. *Pseudostachyum* Munro

Arundinariinae Bentham

7. *Arundinaria* Michaux
8. *Thamnocalamus* Munro
9. *Borinda* Stapleton
10. *Yushania* Keng f.
11. *Drepanostachyum* Keng f.
12. *Himalayacalamus* Keng f.
13. *Ampelocalamus* Chen, Wen, & Sheng **Racemobambosinae** Stapleton
14. *Neomicrocalamus* Keng f. **Shibataeinae** (Nakai) Soderstrom & Ellis
15. *Chimonobambusa* Makino

74 species under 17 genera are endemic to India

I. Southern Peninsular India including Western Ghats **21 species under 7 genera**

II. Andamans and Nicobar Islands **- 6 species under 4 genera**

III. Himalayas and North East India **- 27 species under 5 genera**

DISTRIBUTION OF BAMBOOS IN INDIA

ANDHRA PRADESH

Bambusa bambos and *Dendrocalamus strictus* are found growing in many places of Andhra Pradesh. *Dendrocalamus strictus* is the dominant species in the dry areas of Adilabad, Khammam, Vishakhapatnam, West and East Godavari, Karnool and Prakasam districts. Recently one new species and two new varieties have been located from Rajahmundry.

GOA

Bambusa and *Dendrocalamus* are found growing in many places of Goa. *Bambusa bambos, Dendrocalamus stocksii* are the main species that are commonly seen.

KARNATAKA

Fifty per cent of the bamboo population belongs to the species *Bambusa bambos*. *Dendrocalamus strictus* contributes 40 per cent. One species each of *Bambusa* and *Dendrocalamus,* three species of *Ochlandra,* two species of *Oxytenanthera,* one species of *Schizostachyum* are found growing in Karnataka. The major bamboo growing areas in Karnataka are Mysore, Coorg, South Canara, Shimoga, Chikmagalur, Bhadravati, Begur, Baba Budangiri range and Agumbe.

KERALA

The major bamboo-growing areas include the forests of Thiruvananthapuram, Kollam, Pathanamthitta, Idukki, Ernakulum, Malappuram, Waynad and Palakkad districts. However, some of the species like *Bambusa balcooa*, *Bambusa nutans*, *Bambusa pallida, Bambusa polymorpha, Bambusa tulda*, *Bambusa vulgaris 'green', Bambusa vulgaris 'striata', Bambusa membranaceus, Dendrocalamus giganteus, Dendrocalamus brandisii* and *Thyrsostachys oliveri* are cultivated for its various commercial purposes.

MAHARASHTRA

The main genera found in Maharashtra are *Bambusa, Dendrocalamus, Gigantochloa* and *Melocanna*. Three species of *Bambusa*, six species of *Dendrocalamus,* One species of *Gigantochloa,* and one species of *Melocanna* are found growing generally in top of the ridges, hilly areas and banks of streams.

TAMIL NADU

Bamboos are distributed in the hills and mountains of Kannyakumari, Thirunelvelly, Courttalam, Madurai, Coimbatore, Nilgiris, Salem and North Arcot districts. *Bambusa bambos* and *Dendrocalamus strictus* are very common. Three species of *Ochlandra*, one species of *Oxytenanthera,* two species of *Arundinaria* and one species of *Schyzostachyum* are also reported.

ASSAM

From Assam 24 species among which, 14 species belong to the genera *Bambusa*, three species of *Dendrocalamus,* three species of *Dinochloa,* two species of *Gigantochloa,* one species of *Melocanna,* one species of *Phyllostachys* and four species of *Schizostachyum* is known to occur (State Forest Research Institute, Itanagar- 'Survey of Bamboo in North East India').

UTTARAKHAND

Bamboos occurs throughout the State, the most significant concentrations are in the Lansdowne and Kalagarh Forest Divisions. In the foothills, in the Siwalik Hills, and in adjacent plains. The dominant species are *Dendrocalamus strictus. Bambusa bambos* and *Bambusa nutans. Dendrocalamus hamiltonii* is cultivated on private lands, especially on lower slopes and valleys. The dominant group of species is locally known as ringaal, typically thin, reedy, shrubby, thornless and clump forming. The flowering cycle is 30 years. The culms are used for weaving mats and baskets and leaves are used for fodder. Ringaal grows on steep mountain slopes, within temperate zones, at an elevation of 1800-2400m in the Garhwal and Kumaon Hills. It is distributed over 66,000 hectare at elevations between 1800-2500 metres.

The most common species found in Uttarakhand are:

• ***Drepanostachyum falcatum*** (syn. *Arundinaria falcata*), locally known as Ghad ringaal.

• ***Himalayacalamus falconeri*** (syn. *Thamnocalamus falconeri*), locally known as Deo ringaal.

• ***Thamnocalamus spathiflorus,*** (syn.*Thamnocalamus aristatus*), locally known as Thaam ringaal.

• ***Thamnocalamus jaunsarensis*** (syn. *Chimnobambusa jaunsarensis*), locally known as Jamura ringaal.

JHARKHAND

The State of Jharkhand comprises of the Chota Nagpur and Santhal Pargana regions. These forests are primarily in the districts of Medininagar (Palamau), Latehar, Lohardaga, Gumla, Dhanbad and Giridih. Most of the bamboo from the State goes to meet the needs of pulp and paper industries. According to a survey report of the State Forest Department, 75% of bamboo is used for pulp and paper, 23% for household and constructional needs, and 2% for bamboo based cottage industries.

GUJARAT

Bamboo occurs as an under-storey is a natural component of the forests. There are 22 reported species of bamboos reported from the State; the dominant species are *Bambusa bambos* (Katas or Thorny bamboo) and *Dendrocalamus strictus* (Manvel or Solid bamboo*). Dendrocalamus strictus* is economically the most important. It is found in the dry deciduous forests over a large part of the State. *Bambusa bambos* is found in mixed moist deciduous forests as well as in the moist dry deciduous forest of the State. Bamboo bearing forests exist all along the southern, eastern and northern borders of the State and in the hilly portions of Junagadh & Porbandar districts. Of the 25 districts in Gujarat, bamboo forests are located in 13 districts. However, the major concentration of bamboos is in the southern districts of Valsad, Dangs, Surat and Narmada. Within these districts is 4,177 sq km of bamboo forests, about two-thirds of the bamboo bearing areas of Gujarat. The Girnar and Barda are the only forests in the Saurastra region, which have got bamboos.

ORISSA

The bamboo species available in Orissa can be broadly classified in to four different categories:

1. **Occurring naturally in the forests**

   Dendrocalamus strictus (Salia), *Bambusa bambos* (Daba).

2. **Cultivated by villagers in their homestead land** *Bamusa vulgaris*

   (Sundarkani), *Bambusa nutans* (Badia)

3. **Found in small numbers in specific locations either in forests or in village land**

Schizostachyum pergracile (Dangi), *Gigantochloa rostrata* (Pani bans), *Thyrsostachys oliveri* (Nala bans), *B. tulda* (Taleda)

1. **Occurring as very few individuals**

Bambusa striata, *Bambusa wamin*, *Dendrocalamus giganteus*, *Thyrsostachys regia*.

TRIPURA

So far 21 species are reported from the whole state covering an area of 2397 km^2 (all strata) and the resource is in a highly degraded condition.

MEGHALAYA

So far 52 species of bamboos belonging to 10 genera are reported from Meghalaya. Assam has 27 species common with Meghalaya. Of all the 10 indigenous genera 8 are represented in Assam. Arunachal Pradesh has 21 representatives of 9 genera. Twenty one species under 5 genera of Meghalaya are also found in West Bengal. Manipur and Nagaland have 18 species each and Sikkim has 17 species common with Meghalaya. Sixteen species occurring in Meghalaya are found in Mizoram, whereas only 10 species are reported from Tripura. Important species of bamboos known from south India is given in Table 2.

Table 2: Important species of bamboos known from south India

Subtribe	Genus	Species
Arundinariinae	*Arundinaria* Michaux	1. *A. densifolia,* 2. *A. walkeriana* 3. *A. wightiana,* 4. *A. floribunda*
Bambusinae	*Bambusa* Schreber	5. *B. bambos*
	Dendrocalamus Nees	6. *D. stocksii,* 7. *D. strictus*
	Oxytenanthera Munro	8. *O. bourdillonii,* 9. *O. monadelpha*
	Munrochloa Muktesh et al	10. *M. ritchiei*
Melocanninae	*Ochlandra* Thwaites	11. *O. beddomei,* 12. *O. ebracteata* 13. *O. kadambaranii,* 14. *O. keralensis* 15. *O. scriptoria,* 16. *O. setigera* 17. *O. spirostylis* 18. *O. talboti* 19. *O. travancorica* 20. *O. wightii*
	Teinostachyum Munro	21. *T. wightii*

Some of the rare, endangered and threatened bamboos of Western Ghats are given in (Plate-I, 1-3).

PLATE- I-1 RET Species of Bamboos of Western Ghats

Ochlandra ebracteata *Raiza. & Chatter.*

Arundinaria walkeriana Munro

Ochlandra beddomei Gamble

Ochlandra keralensis Muktesh *et.al.*

Ochlandra spirostylis Muktesh *et. al*

Oxytenanthera bourdillonii Gamble

Munrochloa ritchiei **M. Kumar & M. Remesh**

PLATE-II-1 Bamboos of Southern India

Arundinaria densifolia Munro

Arundinaria walkeriana Munro

Arundinaria wightiana Nees

Arundinaria floribunda Thawaites

PLATE-II—2 Bamboos of Southern India

Bambusa bambos (L.) Voss

Dendrocalamus stocksii (Munro) M.Kumar, Remesh & Unnikrishanan

Dendrocalamus strictus (Roxb.) Nees

Munrochloa ritchiei M. Kumar & M. Remesh

PLATE-II-3 Bamboos of Southern India

Oxytenanthera bourdillonii **Gamble**

Oxytenanthera monadelpha **(Thwaites) Alston**

PLATE-II-4 Bamboos of Southern India

Ochlandra spirostylis Muktesh, Seetha & Stephan

Ochlandra talboti Brandis

Ochlandra scriptoria (Dennst)Fisch.

Ochlandra setigera Gamble

PLATE-II-5 Bamboos of Southern India

Ochlandra travancorica Benth.

Ochlandra wightii (Munro) Fischer

Teinostachyum wightii Bedd.

Insect pest problems of bamboos and their management

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Introduction

Bamboos are one of the fastest growing perennial grasses belong to family Poaceae (Graminae) of sub-family Bambusoideae. There are more than 1,250 species under 75 genera of bamboo are reported found in worldwide, which are unevenly distributed in the various parts of the humid tropical, sub-tropical and temperate regions of the earth (Subramaniam, 1998). India is very rich in bamboo diversity. There are 124 indigenous and exotic species under 23 genera, found naturally, under cultivation or both (Naithani, 1993). Bamboo generally forms the understory in the natural forests. It is found to grown practically in the tropical, sub-tropical and temperate region where the annual rainfall ranges between 1,200 mm to 4,000 mm and the temperature varies between 16oC and 38oC. The most suitable conditions for the occurrence of bamboo are found between 770-1,080 meter above sea level. However, two thirds of the growing stock of bamboo in the country is available in the north-eastern states with supports about 50% of the total genetic resources of bamboo being tropical moist region. This natural resource plays a major role in the livelihood of rural people and in rural industry. Bamboos are good soil binders owing to their peculiar clump formation and fibrous root system and hence also play an important role in soil and water conservation. *Bambusa bamboos,Bambusa nutans, Bambusa tulda, Bambusa balcooa, Dendrocalamus brandisii, D. giganteus, D. hamiltonii, D. stocksii, D. asper, D. strictus, Guadua angustifolia* are some of the commercially important bamboo species planted in most parts of India. These bamboo species are sometimes susceptible to insect pest attack particularly the sap sucking pests and defoliators causing serious damage to the nurseries and plantations (Mathew and Varma, 1988; Singh and Bhandari, 1988; Tewari, 1988).

Some of the earliest records of pests of Bamboo species in this region relates to Beeson (1941) and Browne (1968). More than 800 insect species on bamboo have been recorded from Asian countries (Wang et al., 1998). Viswanath et al. (2013) reported the pests of Aphids and Mealy bugs on *D. brandisii* in Karnataka. Remadevi and Revathi (2012) reported the incidence of outbreak of bamboo mired bug, *Mecistoscelis* sp. for the first time at Koppa, Chickmangalur district of Karnataka during 2009 and 2010. The leaf rollers *Pyrausta coclesalis* and *Algedonia bambucivora* (Pyralidae: Lepidoptera) were reported on *B.nutans* (Senthilkumar, 2008). 50 post harvest pest species of Cerambycidae, Bostrychidae and Lyctidae reported on bamboo (Singh and Bhandhari 1988). Of these Bostrychidae are the most prevalent. Nearly 16 species of Bostrychids are reported to attack post-harvest and finished bamboo products. The finished products made out of bamboos are also prone to attack by insect borers (Mathew and Nair, 1988). Thakur and Bhandari (1997) reported from a study carried out by Forest Research Institute (FRI), Dehradun in Jaffrabad Forest Deport, that nearly 40 percent of stored bamboo was damaged severely by borer attack which resulted to almost a loss of 40 million rupees to the forest department. Similar reports from the storage yards and on finished products made out of bamboos have also been reported from Kerala (Puduvil, 2008). Raja Muthukrishnan *et al.* (2009) enlisted 65 species of insects occurring on bamboos under storage. The common beetles which attacks the stored bamboos are *Dinoderus brevis* Horn., *D. ocellaris* Steph. and *D. minutus* Fab. (Coleoptera: Bostrychidae)- *ghoon* borers (Beeson, 1941; Sen Sarma, 1977). Insects that cause damage to felled culms and finished products are probably the most common and serious pests for the Asian bamboo industry (Wang *et al*.1998). The damage usually results in the loss of materials in a period of 8-10 months (Thapa *et al*., 1992). The details of some of the major pest problems in green bamboo in nurseries and plantations as well as the stored bamboos and their possible management strategies to control the pest are furnished in this article.

Nursery and plantation pests

Sap feeders

1. ***Ceratovacuna silvestrii*** Takahashi belongs to the Order: Homoptera Family: Aphididae, commonly called as woolly aphid, are yellow to reddish brown or almost black in life, with numerous white wax tufts over dorsum and sides of body. This aphid make gregarious colonies on young leaves and tender shoots of bamboo resulting into pale yellowing and thick fungal coating of leaves and shoots. The aphids suck the sap of the leaves and tender shoots in the nurseries and in young plantations. Severe infestation due to this pest is during the month of December to March in *Bambusa balcooa*, *B. nutans* and *B.tulda*. A giant ladybird beetle, *Anisolemnia dilatata* (F.), which exclusively feed on woolly aphid of bamboos, has been recorded as important natural enemies of this aphid.

It is difficult to control these aphids with chemicals due to heavy waxy coating and also this method is not economically feasible. Hence, as an alternative, it is imperative to use giant lady beetle *Anisolemnia dilatata* for natural control of woolly aphid.

2. ***Myzus obtusirostris*** David,Narayanan & Rajesh belongs to the Order: Homoptera Family: Aphididae are shiny black in colour with dark appendages. This aphid makes gregarious colonies on young leaves, foliage and tender shoots of *Bambusa pallida* and *B.tulda* which results in pale yellowing of foliage and shoots. The aphids suck the sap of the leaves and tender shoots in nurseries and young plantations. Releasing of *Menochilus sexmaculatus*, an effective predatory ladybird beetle in the field keeps the pest population suppressed.

3. ***Astegopteryx*** sp. belongs to the Order: Homoptera Family: Aphididae, are small aphids with well-developed frontal horns and segmentally arranged wax glands, forming large colonies on the leaves. Aphids are yellow with variable dark green dorsal markings and white wax, especially on margins. Both adults and nymphs suck the sap of the leaves and tender shoots in the nurseries and in young plantations of *Bambusa nutans*, *B.pallida* and *B.tulda*

Foliar spraying with Tobacco leaf extract control the pest

4. ***Palmicultor lumpurensis*** (Takahashi) belongs to the Order: Hemiptera Family: Pseudococcidae. Adult and immature stages of this mealy bug are grayish-pink to red in color. Individuals lack lateral wax filaments and are covered with a fine white mealy wax. Mealy bugs are found beneath culm sheaths of bamboos. The mealy bugs suck the sap of the leaves and tender shoots in nurseries and young plantations. The severely attacked *Bambusa nutans* and *B. tulda* show wilting and gradual die-back symptoms. Releasing of *Menochilus sexmaculatus*, an effective predatory ladybird beetle in the field keeps the pest population suppressed. Clipping off severely affected branches and spraying Neem oil (2.5%) control the pest population.

5. ***Antonina*** sp. belongs to the Order: Hemiptera Family: Pseudococcidae**,** are elongate oval shaped. Antenna 2 or 3 segmented. Many ants tend mealy bugs and use the collected honeydew as a sugar source. The bamboo node mealy bug *Antonia* sp. are sap feeders. The mealy bugs suck the sap of the tender shoots in the nurseries and in young plantations of *Bambusa nutans* and *B.tulda*. The severely attacked nursery plants show wilting and gradual die-back symptoms.
Clipping off severely affected branches and spraying Neem oil 2.5% control the pest. Spraying with Rogor @ 0.05 to 0.075% water emulsion can also control the pest.

Leaf feeders

1. ***Crocidophora*** sp. belongs to the Order: Lepidoptera Family: Pyraustidae**.** Larvae feed individually inside leaf cases from May to September. There are five larval instars. The fully grown larvae pupate in thin, silk cocoons. Pupation period is 10-14 days. The larva rolls up green leaves with silken thread and feeds on the inner leaves of *Bambusa balcooa, B. nutans, B. pallida* and *B. tulda.* Foliar spraying with the entomopathogenic fungus, *Beauveria bassiana* at a concentration of 7.8 x 1010 or 108 control the pest. Foliar spraying with biopesticide, *Acorus calamus* rhizome powder extract and Neem Seed Kernel Extract (NSKE) 5% control the pest. Spaying of Dichlorvous 76 WSC (2ml/litre of water) on leaves effectively control the pest.

2. ***Psara licarsisalis*** Wlk. belongs to the Order: Lepidoptera Family: Pyraustidae. The adult female moth lays eggs in groups mostly on leaves. It is fairly uniform light brown in color with some small black dots scattered about the wings. Fully developed larvae are 20-25 mm long. The larvae mature in about 2 weeks, feeding at night and remaining inactive in webbing tunnels during the day. The complete life cycle takes about 16-18 days, and there are continuous generations throughout the year. The larva rolls up green leaves with silken thread and feeds on the inner leaves of *Bambusa balcooa, B. nutans, B. pallida* ans *B. tulda*.

Foliar spraying with an entomopathogenic fungus, *Beauveria bassiana* at a concentration of 7.8 x 1010 or 108 control the pest. Spraying with biopesticide, *Acorus calamus* rhizome powder extract and NSKE 5% control the pest.

3. ***Pyrausta coclesalis*** Walker belongs to the Order: Lepidoptera Family: Pyraustidae. This is the most common and destructive pest among the leaf rollers. The adult moth is 8-13 mm long and yellowish brown in colour. The light green larvae feed in groups or individually. The larvae tie the leaves together as leaf cases and feed on the upper tissues of the leaves. The fully grown larvae pupate in cocoon made between the rolled leaves. The larvae tie the leaves together as leaf cases and feed on the upper tissues of the leaves of *Bambusa balcooa*, *B.nutans, B. pallida* and *B. tulda.* Foliar spraying with an entomopathogenic fungus, *Beauveria bassiana* at a concentration of 7.8 x 1010 or 108 control the pest. Spraying with biopesticide, *Adhatoda vasica* leaf extract control the pest.

4. ***Sylepta derogata*** Fb. the cotton leaf roller belongs to the Order: Lepidoptera Family: Pyraustidae is polyphagous and attacks agricultural crops and forest plants apart from several bamboo species. The moth is pale yellow in colour. The eggs are laid on the lower surface of the leaves after hatching larvae make leaf cases by rolled leaves. The mature larva, 2.3 to 2.5 cm long, has smooth body of transparent grayish or greenish colour and a brown head. Larval period is 13-17 days. Pupation is in the soil or litter. The larvae rolls up portions of the leaf in cylindrical shapes fastened with silk threads and feeds on the portions of the leaf outside of plants *Bambusa nutans* and *B.tulda.* Spraying with biopesticide, *Adhatoda vasica* leaf extract control the pest. Spaying of Dichlorvous 76 WSC (2ml/litre of water) on leaves can effectively control the pest.

5. *Parasa* sp. belongs to the Order: Lepidoptera Family: Limacodidae**.** Adult moths are green in colour and 23-30mm in size has green colour head, thorax and forewings and brown colour abdomen and hind wings. Fully developed larvae are 24-34 mm long. There are six larval instars. Larvae feed in groups on leaf surface and consume all leaf tissues of *B.balcooa* and *B. tulda.*

Spraying with *Acorus calamus* rhizome extract (biopesticide) control the pest. Foliar spraying with an entomopathogenic fungus *Beauveria bassiana* at a concentration of 7.8 x 1010 or 108 control the pest population. Spaying of Dichlorvous 76 WSC (2ml/litre of water) on leaves can effectively control the pest.

6. ***Dasychira*** sp. belongs to the Order: Lepidoptera Family: Lymantriidae. Adult moth has pale hind wings. Forewings are irregularly patterned with various shades of brown. It lays masses of yellow eggs. Fully grown larva is about 4 cm long with reddish head. The body is grayish or pale yellowish, spotted and striped with red and tufts of whitish hairs. The larvae feeds the tender as well the matured leaves of *Bambusa nutans* and *B.tulda*

Spraying with biopesticide, *Acorus calamus* rhizome extract and NSKE (5%) will control the pest population.

7. ***Discophora sondaica*** (Boisduval) (Common duffer) belongs to the Order: Lepidoptera Family: Nymphalidae**.** Upper side of male dark brown. Female has an upper side of purplish brown. Fore wing with three transverse series of white spots. Full-fed larva 2 inches long, colour black mottled with grey. The larvae feeds the tender as well the matured leaves of *Bambusa pallida* and *B.tulda* Spraying with biopesticide, *Acorus calamus* rhizome and NSKE 5% will control the pest. Spraying of Dichlorvous 76 WSC (2ml/litre of water) on leaves can effectively control the pest.

8. ***Pteroma*** sp. belongs to the Order: Lepidoptera Family: Psychidae. Larva inhabits in portable smooth bags constructed out of silk and plant materials. The larva feeds the tender leaves of *Bambusa nutans* and *B.tulda.*

Hand picking of bags and destruction can reduce the pest population. Foliar spray with NSKE (5%) control the pest.

Shoot/culm borers

1. ***Oligia vulgaris*** Butler belongs to the Order: Lepidoptera Family: Noctuidae the adults of this shoot borer are mid-sized moths, ranging from 11 to 20 mm in length and varying in colour from light to dark brown. There is one generation per year. Larvae are light purple or pale brownish purple in colour. The fully developed larvae drop on the ground and pupate in cocoons formed with soil and leaf litter just below the ground surface. Larva mine into the shoots of *Bambusa pallid, Bambusa balcooa* and *B.tulda*, feed inside and make tunnels running in different directions. Damaged shoots can be identified by the feeding holes on sheaths and the debris or bored tissue on the outer surface of the shoots. Adult moths are active at night with strong phototaxis. Hand collection and destruction of affected shoots reduce the damage. Entomopathogenic fungus, *Beauveria bassiana* is very effective in controlling the pest. Mass culturing of the fungus on agricultural products like maize flour, rice bran or vegetable waste (media) and spraying of aqueous solution of the fungal spores at a conc. of 3.6 x 1010 or 108 (150 gms of medium containing fungal spores dissolved in 10 litres of water) on the feeding areas on the shoot and applied over the bore holes kill the larvae effectively. Spray with 0.05% Dimethoate or 0.07% Dicholrvos control the pest if occurring at very high levels.

2. ***Pareuplexia*** sp. belongs to the Order: Lepidoptera Family: Noctuidae**.** The brown eggs are laid on new culms and the small larvae eat their way into the culm cavity through a hole in the softest region of the internode towards the base. Once inside they eat extensively into the walls of the culm, progressing upwards to where the tissues are softest, leaving a small circular hole in each nodal diaphragm and long grooves on the walls which may show through to the outside as streaks or slits. In severe cases the top of the culm dies and may fall off. The white larvae with brown head capsules can reach 5 cm in length and many larvae have been found in a single culm of *Bambusa balcooa* and *B.nutans*. Cutting out infested culms and removing dead culm tops would quickly

control this insect. Simpler measures such as blocking the entrance hole (which is usually at a convenient height 0.5-2m above the ground) may be effective in reducing numbers appreciably. 0.07 % Dicholrvos spray can control if occurring at very high levels.

Root feeders

1. *Holotrichia* sp. white grubs belong to the Order: Coleoptera Family: Scarabaeidae, the “C” shaped grubs with orange head of the beetle Holotrichia sp. are usually found in the soil. Adult is a brown beetle. Grubs feed on fine rootlets and then girdle the main root of Bambusa balcooa, B.pallida and B.tulda. The seedlings damaged by grubs dries up. Applying 200 gm of neem seed pellets per bad at the time of transplanting can give satisfactory control of grubs.The grubs and adults can be collected and killed. Collection of adults with light traps after rains and destroy. Chlorpyriphos 0.03% treated soils can be used to fill poly bags. Root trainers along with the seedlings can also be dipped in 0.03% Chlorpyriphos solution

2. *Microtermes* sp. the termites belong to the Order: Isoptera Family: Termitidae. Soldiers: Head capsule and labrum of the soldiers are pale yellow to yellow, mandibles pale brown proximally, brownish distally; pronotum and body whitish. Head sparsely and pronotum, legs and body moderately hairy. In nurseries, termite damage the seedlings and cuttings of different bamboo species. Sometimes, it cause total loss of planting material. Termites hollow out or de-bark the root system. If good cultural practices are maintained, incidence of termites can be reduced to some extend. Proper disposal of waste and litter should be carried out regularly. Partially decomposed manure, dried leaves and leaf litter accumulating in the vicinity should be avoided. 0.03% chlorpyriphos treated soils can be used to fill poly bags. Root trainers along with the seedlings/ cuttings can also be dipped in 0.03% chlorpyriphos solution.

Post Harvest pests of Bamboo

1. *Dinoderus* spp. the important shot hole borer belongs to the Order: Coleoptera Family: Bostrychidae. Three different species of Dinoderus responsible for causing major damage to bamboos during storage viz., *Dinoderus brevis*, *D. minutes* and *D. ocellaris*. They cause immense damage when the bamboos are in the process of drying. Presence of starch, soluble carbohydrates and proteins in the bamboo increases its susceptibility to borer attack. The beetles bore in to the cut bamboo through spots where external rind has been damaged. Adults gain entry in to the culm through the cut end. They also bore in to the exposed transverse sections of the cut ends and into internal walls of the bamboos. They construct tunnels either vertically or horizontally and reduce the bamboo to mere dust. The beetles make horizontal tunnels in which the eggs are deposited. Adults and larvae feed inside the felled culms. Life cycle takes about two months for completion. These shot hole borers also attack the bamboo even after it has been made in to furniture, mats and other finished products.

2. *Lyctus africanus* Lesne belong to the Order: Coleoptera and Family: Bostrichidae. The beetle is flattened, light brown to almost black coloured beetle. It attacks *Bambusa bambos* and *D. strictus* throughout the year. The female beetle lays 30-50 eggs in the open pores or in the cut end of bamboos. The grubs after hatching starts feeding the wooden tissues, converting it to a very fine powder which remains closely packed in the tunnel. The life cycle of this insect depending upon the availability of food and moisture within the wood, varies from one to three years. Management of Bostrichidae beetles: Botanical treatment of 4 and 6% extracts of leaf and bark of *Cleistanthus collinus* can be effective against these borers. Phosphine fumigation of 1.0mg/L can be effective in controlling these pests. The heating of culms using fire, boiling water or exposure to direct sunlight in hot summers, can kill borers including the eggs, larvae, pupae and adults.

3. *Chlorophorus annularis* Fabricius belong to the Order: Coleoptera and Family: Cerambycidae commonly called as Tiger longicorn beetle. The beetle is 8-15 mm long, yellow with a dark brown or black pattern of curved and rounded spots on the elytra and pronotum. The finished products are also being attacked by this beetle. It has normally one generation in a year. Larvae overwinter in tunnels in the culm. The primary hosts are Bambusa spp. and Dendrocalamus spp. culms. Treating the infected culm with the pyrethroids – cypermethrin and permithrin can control this pest attack.

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SAP SUCKERS

Sap sucking pest *Antonina* Sp.

Mealy bug attack on the seedling of *b.pallida*

Palmicultor lumpurensis

Aphid *Astegopteryx* sp. on *B.tulda*

***Bamboo* Leaf hopper *Aphrophora* sp.**

Aphid *Myzus* sp. *B. pallida*

DEFOLIATORS

Crocidophora Sp.

Psara licarsisalis

Parasa Sp.

Discophora sondaica

Hexacentrus unicolor

Shoot/culm borers and root feeders

Larva *Pareuplexia* sp. attack on bamboo

Termite attack on roots

Bamboo damaged by *Dinoderus minutus*

Methods of bamboo harvesting

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1. Introduction

As the harvesting of bamboo culms from their natural habitats i.e., forest area or a plantation is very laborious and time consuming, efficient management system requires for sustainable harvesting of bamboos. Bamboo sustainability integration is regarded as a mean of enhancing culm production and the life cycle of clumps, which largely depends on how efficiently the culms are selected during harvesting and how the extracted culm are processed into diverse products. Efficient management of bamboo clumps involves the systematic harvesting of mature culms from a group of clumps without affecting the environment of other culms, and this enhances continuous sustenance of production of culms. When this procedure is followed carefully on the plantations, it tends to increase the annual yield (Farrelly 1984). In this paper, felling rules, felling cycle and methods of bamboo harvesting are discussed in details.

2. Felling age and cycle of bamboo harvesting

The new culms are produced generally located along the periphery of the clump. As young culms (<3 year old) are not strong and durable, they have little demand and highly susceptible to pest and diseases. Hence, old culms (> 3 years old) are harvested and < 3 year old culms left in the clump. There is a practice to leave an equal number older culms and 1- year old culms in the clump. A three or four year felling cycle appears to be the most suitable in India (Tewari 1992) with 3-4 years rotation. However, one year old culms are harvested for pulp and paper mills. A three -or four- year and 10-12 year felling cycle are adopted in Punjab and Odisha with selective felling and clear felling, respectively and a 4-year felling cycle is followed in rest of states of India.

3. Time of culm harvest

The best time to harvest bamboo is during the dry season. The very best time is when the new shoots are almost at their maximum height and are just beginning to develop branches and leaves at the top. At this time, the older culms have the least starch. The forest dwelling people especially tribal harvest bamboo according to the moon cycle. At the new moon, the energy of the plant is in the roots, so there will be less sugar in the culms; therefore less to attract the borers. Scientific evidence shows that this is not as important as the time of year. Combine both ideas for the best results (http://permacultureguidebook.org/). However, harvesting of bamboo culms on the plantation depends on the type of species that have been cultivated, since some species can be harvested after four years and others not until after six years. Harvesting from a clump of bamboo that has been scientifically managed through proper pruning, thinning, and fertilising does enhance annual harvesting of culms through proper management programs. A well-thinned clump from the early stages of planting gives a quality yield of culms, since spacing in a clump enhances efficiency in the harvesting of selected culms. The implementation of proper supervision of harvesting culms promotes regeneration of young shoots of culms based on which a constant supply of raw bamboo culms for industrial purposes is sustained. The cutting off of the mature culms also helps in maintaining the vitality of the plant and also ensures germination and regeneration of new shoots.

When harvesting mature culms, it is advisable to harvest culms which are older than three years, and only about 70–80% should be harvested, leaving about 20–30% of the mature culms to protect the young seedlings in the group of clumps. The reason for this practice is to ensure the young culms do not fall over as a result of high winds or storms, and this does help the growth. Culms that are in the age range of one–two years should be cared for during the harvesting of matured culms, along with a few of the three-year-old culms that are vigorous. This process would help the culms left in the clump to mature and also to regenerate young culms along with the already developed ones, after which, they may also be harvested.

However, sustenance of the culms in a clump is required for continuous harvesting, so therefore the implementation of an appropriate cutting of culms needs to be strategically implemented for quality bamboo plants. Bamboo sustainability integration is regarded as a mean of enhancing culm production and the life cycle of clumps, which largely depends on how efficiently the culms are selected during harvesting and how the extracted culm are processed into diverse products.

4. Method of bamboo harvesting

There are two kinds of bamboo harvesting methods viz., clear felling and selective felling are adopted in homestead and bamboo plantations.

a). Clear felling system

In this system, all culms are clear felled in one stroke at end of the felling cycle period. Now-days the farmers usually prefer this method to fell the culms which grow at the periphery of the clumps as this is easy and quick to cut.

Advantages

It is simple and cost-effective method of harvesting. It is not requires skilled man power for felling and extraction.

Disadvantages

The culms harvested are young (9-18 month sold), not mature enough for utilization works. Regular felling in the periphery of clump develops a dense mass of dead rhizomes that prevent the growth of rhizomes from spreading outwards and the new culms production gets reduced. Thus at the clump center, culms are packed tightly together with many coppice shoots and often twisted in congested condition, this frequently seen especially in village bamboo groves. Additionally when culms are not harvested for several years, it also created congestion and clumps gradually become susceptible to diseases. In such case to maintain the proper clump growth and shape, clear felling of culms has been found good for clump health. The clear felling harvesting results in slow recovery and low above-ground biomass production and the clumps take 10-15 years to produce normal size culms after clear felling.

After care of clear felled clump

- Too old rhizomes with stumps, usually from the center should be dug out from the clump.
- Add and mound loose soil mixed with organic manure at clump base.
- Mulch and if possible, do watering in dry climate and also up to 3 years of clear felling.
- Buds on the stumps nodes activate and produce many thin tender shoots/branches resulting in vigorous leafy and bushy growth in the clump. Small tender shoots needs protection from cattle and weak shoots may be trimmed. In the 2nd year, lightly thin out the poor shoots, make space for new shoot emergence.
- Protect and manage these shoots from browsing, weed and vine suppression and fire.

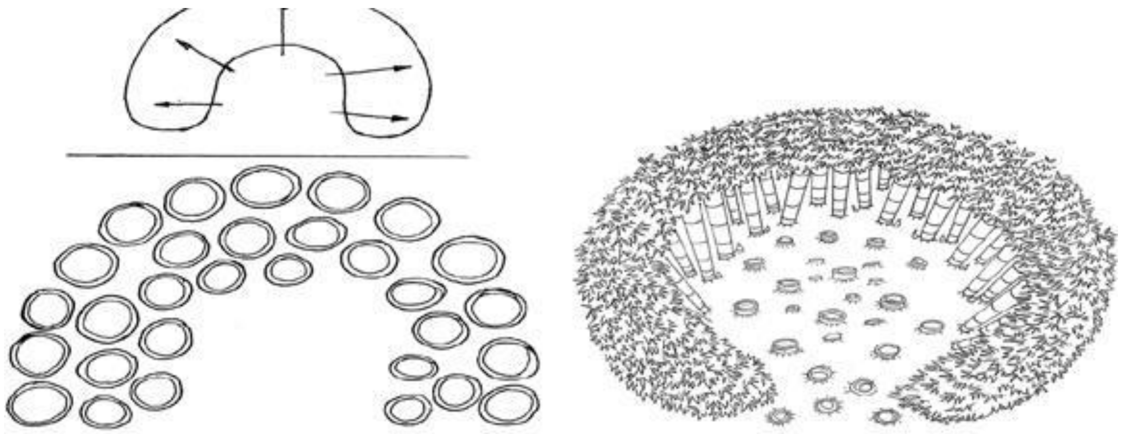
b). Selection felling system

For maintaining sustainable growth, young bamboos are not harvested from the clump. There should not be any felling a least for 3 years so that culms in the clump attain maturity. Therefore, in the homestead, at least 4 clumps need to planted, from which equal number of culms will be harvested with 3 year felling cycle. Once extracted, the culms are trimmed to full length. Cutting length of the felled bamboo depends on the types of use. Usually the bamboos are cut into suitable lengths for ease transportations depending up on mode of transport.

On the basis of above said-principles, there are two kinds of harvesting methods viz., horse-shoe and tunnel methods are adopted in the selection felling.

(i). Horse-shoe felling method

In this felling method, a 60-100 cm wide path has to be made inside the clump so that one can enter into the central part of the clump to start felling and dragging out the mature culms. As the path will be made from periphery towards the centre, it is likely that a few numbers of young culms may have to be cut. So one must make path from side of a clump where minimum numbers of young culms are scarified. Most of mature culms from the central part of the clump have to be cut. The e un-harvested mature culms should left scattered throughout the clump to provide mechanical support to young immature culms against the strong wind and storms.



Horse-shoe felling method (source: www.premacultureguidebook.org)

(ii). Tunnel felling method

In this felling method , there are two openings are made, one opposite to other, forming a tunnel in the clump (Banik, 1992; 2000) through which harvested older culms from the clump center dragged out.

(iii). Points need to be keep in mind while adapting selection felling system

- Number of harvested culms should not exceed the number of emerged last year culms. For example a clump has 20 culms, out of which 4 and 6 culms emerged in 1993 and 1994 respectively. This, the clump has 6 one -year old culms and 5 three -year old culms and older culms in the felling year in 1995. To keep the clump productive and healthy, older culms are felled.

- Before entering into clump, branches, if any, on the lower nodes need trimming thoroughly to facilitate harvesting operation. Cut culms in a slating manner just above the lower most nodes to minimise the wastage and rain water will not stagnate in cut end. Branches and twigs from the harvested culms have to be cleared and trimmed out.
- Dead and rotten stumps of felled culms usually found at clump centre should be dug out as sanitary cleaning and used as fuel. After that soil, sand and organic manure mix added to the clump base.
- No felling operation should be done during the culm emergence period. Harvest culms from September/October to march/April. Sharp cutting tools/ chain saw may be sued to avoid splitting of cut end.
- Felling during the year of flowering is not desirable to enable the regenerating seedlings to get establish on the ground culm should be harvested only after seed collection.
- Both over- and under - exploitation of bamboos cause degeneration of clumps.

c). Practices of bamboo harvesting in NE India

The existing felling and transportation practices of bamboos in NE- India and eastern part of sub-continents are unique and interesting one. There are two kinds of common harvesting methods are followed in NE India viz., Mohal system and Permit system.

(i). **Mohal system**

In Mohal system, 3- 4 year felling cycle with definite intensity of felling is followed. The felling is done in number of steps and transportation is mostly through water courses where as in permit system, shoulder load transportation is followed. The Mohal systme is the main system of selling in natrual forests in Mizoram. Harvesting rights are sold to Mohaldars (contractors) and they have rights to remove any quantity of bamboo from the specified forest.

(ii). Permit system

Bamboos mostly sold through permits sysrtem. Permits are issued, specifying quantity, area and time limit, by the local officers.

(iii). Season and harvesting age of bamboo in NE India

In general, bamboos are not allowed to harvest for 3 -months from June to mid -September in most of forests of NW India since these 3-months are peak shoot emerging period. Bamboos are not durable, if harvest in March -May (summer). The local people used to cut bamboo during November to March (dry winter season). Generally bamboos are worked on a 3-4 year felling cycle and felling rules restrict cutting of less than 2 year old culms and allow retaining a few old culms scattered manner in the clump. Felling is purely done manually with sharp knife. Only mature culms (>3 years) are harvested. The local people can identify the maturity of culms based on sound that is produced while beating bamboo using the back side of knife. Further, mauture culms have smooth surface with light yellowish color and absence of culm sheath. There is belief that if bamboos are felled in the 1st day of new moon, harvested bamboos will be more durable and resistant to pests and diseases.

5. General rules for bamboo harvesting

The following points/rules are followed during harvesting of bamboo:

- Bamboo culms selected in the harvesting process must be older than six years, if that is the first harvest since its cultivation, while for subsequent harvesting of selective culms from the clump require leaving an allowance
- On each culm ranging 0.15-1.3 m above the ground, or immediately after the first node above from the base. Cutting the culm to the given dimension and at the required point helps prevent stagnant water from accumulating in the internode as this could lead to insects breeding in them, as well as culms rotting.
- Harvesting of mature culms from a class of clumps is more appropriate done in the dry season of the year as compared to rainy season. It has been observed that starch content of culms reduces in the dry seasons, and, by this period, the culm is resistant to attacks by wood borers.
- Harvesting of culms from clumps needs to be carefully observed during the exercise in order not to cut the juvenal culms, as they might be fragile and the slightest touch of a sharp tool edge may easily destroy them.
- Matured and healthy culms (3-5 years) must be selected for harvesting.
- Culm harvesting should start from the central portion of the clumps since most of the matured culms are located in the inner sections.
- Harvesting of the culms must be performed with very sharp tools, and the harvesting tools should be disinfected using bleach as this can prevent any bacterial-risk infection to both the harvested and un-harvested culms.
- Harvesting of quality and matured culms should not be above the juvenal culms in the group of clumps, as they need protection from the matured culms to shield them from a storm or the wind, so they do not collapse.

- Harvesting from a group of clumps requires leaving a sizeable number of culms in the groups of clumps for their sustenance. However, in an outbreak of disease in a clump, total cutting of culms is suggested to limit spreading to other clumps.
- Harvesting of matured culms is recommended during the dry season of the year unless control of congestion from the clumps is necessary.
- Harvesting of culms from the class of clumps with the aim of preventing congestion and also maintaining high accessibility to culms in clumps should be executed with the technique of forming a C-shaped opening. This technique must make room at the periphery for the emergence of new shoots, resulting in the growth of multiples of culms.
- Harvested culms should be immersed in reservoirs filled with water or in rivers to aid leaching of starches and sugar from the culms. The leaching process provides resistance to insects and fungal attack on the culms, as these pests primarily feed on culm nutrients for survival. Storage of harvested culms in a river or tank can require take days or weeks for their preservation.
- When there are no rivers or reservoirs of water at the site to treat them, they can be hauled to a flat-surface area where they can be air dried to aid in the reduction of biodegradation of the culms.
- Wall horizontally at an angle of 60% to allow for adequate ventilation to dry the culms.
- The branches and leaves produced from the culms as waste material should be used as a mulching material on the remaining group of clumps, as it may serve as organic manure after its decay and hence enrich the soil.

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Preservative treatment of bamboo for value addition

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INTRODUCTION

Bamboos are tall arborscent grasses belonging to Bambuseae, a tribe of Graminae. They are primarily tropical in origin thriving well in forests where they attain their maximum development and dwindle under shrubs in temperate regions and take the form of grasses at high altitudes. Almost all continents except Europe have indigenous bamboo species. Bamboo are, however, more abundant in the tropics, with over 75 Genera and 1250 species, ranging from small grasses to gaint of over 40M in height and 0.3 in diameter (Tewari, 1993). On a conservative estimate, it constitutes about 12.8% of the total area under forests is under bamboo in India. The annual production of bamboo in India is about 4.6 million tonnes rank second only to China in bamboo production (Palthick, 1989), over 136 species in 30 genera occur in India (Suri and Chauhan, 1984). Bamboo is densely distributed in Arunachal Pradesh, Assam, Manipur, Meghalaya, Tripura, West Bengal, Andhra Pradesh, Madhya Pradesh, Maharashtra, the Western Ghats and Andaman and Nicobar Islands. The more important genera of bamboos in India are *Arudinaia, Bamboosa Cephalostachyuim, Dendracolamus, Gigantochloa, Gudecia, Melcanna, ochlandicphyllostachis and Thyrostachy*. Bamboo provides food, raw materials, shelter, fodder and even medicines in many parts of the world (Liese 1985) and has been said to put to 4000 uses. About half of the world’spopulation is estimated to be associated with bamboo in over US $7 billion trades and uses (Anon, 1997).

In Asia, there are billions of people who depend on it for part or whole of their income. In India, it is estimated that there are 2 million traditional bamboo artisans and their livelihood depends entirely on the harvesting, processing, and selling bamboo and its products (Belcher, 1996). The importance of bamboo, especially to rural communities in the countryside of bamboo growing countries can hardly be over stressed, it plays a vital role in their daily life in numerous ways as fodder, food, medicines as material for house constructions, agricultural tools and implements, tool handles, fencing fishing traps and rods etc., It generates large scale rural employment right from the management, harvesting, collection transport, storage processing and utilization. For instance, in India, based on current production and uses of bamboo, it is estimated that a total of 432 million workdays are generated from bamboo operations. Bamboo is a versatile material that has been used for construction of houses and huts since long and occupies an important place in the economy of rural areas (Dobrial et al., 2002). Being a fast growing and short maturity period species is used as scaffolding, bridges, shelters, towers and for simple and modern engineered structures. Its wider use as a substitute for wood is supported by the increasing scarcity and expense of timber in several bamboo producing countries. Its wider acceptances however are often hindered due to problems with biological degradation of the raw material, construction components as well as finished products.

Most of the structures using untreated bamboo last only a few years resulting in colossal looses of material and labour since the natural durability of bamboo is very low and varies between 1 and 36 months (Durability class III) depending on the species and climatic condition (Liese, 1980). 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. Preservative treatments increase the service life of bamboo and avoid frequent replacement of the structures and in turn conserve the forest produce. Protection of this versatile material, especially in areas where longer service life is desired, can result in immense social and economical benefits.

Prophylactic treatment

Bamboo are susceptible to rapid attack like insects including termite and fungi unless they are quickly seasoned and utilized in the pulp industry or given comprehensive treatment for other purposes. Storage of bamboos in forests/mills results in considerable losses due to biodegradation as stated above. Studies by Kumar et al. (1985) have shown that sodium pentachlorophenate and a mixture of borax-boric acid were quite effective in controlling losses of bamboos during storage in paper mills. (Purushotham, 1963) has also suggested that when bamboo stock for paper mills has to be kept for long period, bamboo may be chipped immediately after extraction and give a prophylactic dip with suitable preservative solution. Alternatively, layers of bamboo stocks may be sprayed with preservative solutions. Also bamboos can be taken in suitable bundles (25 or 50) and dipped in solutions for 5-6 minutes. The most successful and effective method found to control bamboo ghoon borers is by spraying 1% Lindane or 3% Boric acid Borax mixture (1:2) (Mathur 1964) the dipping of the bamboo culms to varying period in chemical solution of the above compound has also been found more effective than spraying. Such a treated and stacked bamboo can be expected to resist attack for about a year or two.

Preservative Treatment of bamboo

Traditional or non-chemicals treatments: Traditional or non- chemicals methods are being widely used by villagers and artisans in several countries for many centuries and the skill is passed on from generation to generation. Typical traditional methods include: smoking, white washing and water storage or pounding.

Smoking: smoking is carried out in chamber. Where continuous supply of smoke and heat is given for 15, 30 and 45 days, which destroy starch in bamboo thus making them immune to insect attack and also blackens the culms.

White washing and storage in water

Bamboo culms are often painted with slaked lime, which prolongs their life by delaying/reducing moisture absorption.

- Storage in water:

Freshly cut bamboo is stored either in running water or in water pools for 3-4 weeks to leach out starch. This process prevents bamboo from insect attack.

Treatment of bamboo can be generally divided into two categories

1. Treatment of dry bamboos and
2. Treatment of green bamboos

Treatment of dry bamboo:

Brushing

Articles made of round and split bamboo which are not expected to give a long service life or used in location where biological deterioration is not serious through brush application with the oil type (Coal tar creosote) water soluble type (Copper Chrome Arsenic, Copper Chrome Boric; Boric acid and Borax) and organic solvent type of preservatives Copper/Zinc Naphthanate, Copper/Zinc abiatate etc). Successive coatings can be given.

Dipping Method

However, if the bamboos are used in the open and in the contact with the ground and if they are round, a hot dipping method (2 hours) or open tank method (4-6 hours) or pressure (1 hour) can be used.

TREATMENT	Absorption kg/m3 (creosote: Fuel oil 50:50)	Expected service Life (years)
1. Hot dipping	16-32	2-5
2. Open tank dipping	48-96	10-15
3. Pressure process	48-128	10-20

Better result can be obtained if the septa in the bamboo are bored through using a hot auger. Since bamboo split during drying, large quantities of preservative can be locked at in-between the internodes during the open tank and pressure treatments. The method however has some limitations. The trapped preservatives is difficult to be removed immediately increases the cost of treatment, besides non-uniform service, results in case of split bamboos, satisfactory treatment can be given by pressure and open tank process, which give a service life (in the open and in contact with the ground) of 20 to 25 years. In this case, more uniform service life can be expected than in case of round bamboos so treated.

Pressure Treatment:

When the treated material needs put in the most hazardous places, maximum absorption of the preservative is desired, for this purpose, the Full cell- process or Vacuum pressure impregnation method is followed. In this method an initial vacuum is created. Preservative is introduced into the cylinder. Pressure up to 3 to 12.5Kg/cm2 will be applied. Depending on the species and the time period the bamboo needs to survive; the treatment schedule needs to be calculated. After the required time period the preservative is withdrawn and a final vacuum for a short period is applied. Then the bamboo is removed from the treatment cylinder after the dripping of the preservatives is stopped. Then the bamboo is kept for fixation period of 3-4 weeks. After that the treated bamboo can be put into use.

Vacuum Pressure Impregnation method

Treatment of green bamboos

It is not easy to treat bamboos conventionally as they are refractory to treatment. They resist the entry of preservatives; it is because of the structure of bamboo. Bamboo is divided into nodes and internodes. The tissue is made of parenchyma cells and vascular bundles. The latter consists of vessels, thick walled fibres and sieve tube. The water movement takes place through vessel). Bamboos have no radial elements like rays in wood. Outside and inside membranes are covered by hard cuticles, which offer considerable resistance to absorption of water particularly when dry even after the application of pressure. The node and internodes anatomical features explain the refractory nature bamboo (Ding and Liese, 1995). This has made to explore other methods to conventional pressure treatment.

Bamboo culm is resistant to lateral penetration of preservatives because of its hard skin, but has a very high longitudinal permeability in living bamboo. This is because of sap flow activity. This property is taken advantage of to achieve an axial liquid exchange. This technique is commonly referred to as sap displacement technique and is specially suited for treating green bamboos. In this method sap is replaced slowly by preservative solution in the vessels, which offers continuous flow. There are different types and methods in treating green Bamboos, which are briefly described under following heads

Diffusion process:

This is the best and simplest process for the treatment of green, round or spit bamboo wherein the materials (3 to 4 years old) is submerged in preservative solution sufficiently to obtain adequate absorption in quantity and depth. In fact, this method could be universally specified for the treatment of bamboos for all purpose because of requiring little equipment and technical knowledge. However, details of schedules of treatment such as, type of preservatives, concentration in water solution and period of immersion in the solution are required to be worked out well in advanced. However, this process takes a long time because of 5 to 6 weeks' immersion in the preservative particularly if the bamboos are needed for ground contact. Punching the internode partition walls is helpful for obtaining better and quicker treatment.

 

Sap-Displacement Method:

IWST has developed a simple technology to treat green (freshly cut) bamboo and Timber of small girth which are pole type, based on displacement of sap with water borne preservative, called **Sap displacement method.** Containers like oil drums, plastic drums, and porcelain or cement tanks to hold preservative and wood materials, waterborne preservatives like CCA, CCB and ACC (6 to 8%) small plastic rope to tie the poles, safety equipments like gloves, boots etc. Freshly cut debarked poles in the varying diameter and (round/ spilt) bamboo are made to stand on their butt end submerged to a height of 30-40cm in a suitable container containing preservative solution. The preservative pass through the cells and replaces sap of the poles/bamboo by wick action. After 24-48 hrs, poles/posts are reversed with the top ends submerged in the solution. After 24-48hrs the treated material can be removed and should be allowed to dry in shade for 2-3weeks for the fixation of preservative chemicals and after that they can be used.

Green Bamboo immersed in preservative solution

Modified Boucherie process:

In this process poles/bamboo will be treated within 4-6hrs. In this process also the sap is displaced with waterborne preservatives but the treatment is expedited by pushing the sap out of the pole by applying little pressure with the help of a cycle pump or leg pump and replacing with preservative. It consists of a storage tank of 30-50litres capacity where preservation solution is stored. At the bottom of the container a main pipe is attached. The main pipe is attached with a divisible pipe with stopcocks and rubber tubes of different girth where poles are attached. To secure leak-proof between rubber tubes and poles suitable metallic clamps are used. The top of the container is provided with a nozzle through which a tube of the pump is attached to create a pressure of 1-2kg/cm2 and a Pr gauge to measure the Pr. Freshly cut poles/bamboo branches with bark and leaves intact are attached to a rubber outlet by their butt ends connected to the storage tank containing preservative solution. An air pressure of 1to2 kg/m2 is applied on the surface of the preservative in the storage tank with the help of cycle or leg pump. The preservative displaces the sap which is then forced out at the other end. We can see the colour of the solution from colourless to orange the colour of the preservative. Treatment of Poles/Bamboo completes within 4-6hrs. We can treat 4-6 poles at a time. Cost is same as Sap displacement method.

Boucherie equipment

Boucherie process

Dripping of preservative

After the treatment, bamboos must be stored in a rack under the roof to avoid direct sunlight and rain for atleast two weeks. The bamboo must be stored in shades. The rack must support bamboo in horizontal not in vertical position. If bamboo dries in vertical position the preservative solution may leak out. During these periods of slow drying process, the preservative will diffuse from sap to the surrounding tissue of the bamboo and multiple salts like CCA and CCB get fixed.

Green bamboos cut fresh in the farm can be treated by sap displacement within 6 to 15 hours, from the time felling. If there is delay between felling and treatment the latter can be taken up by keeping felled green bamboos soaked in fresh water tank, steam, channel or trough for a period ranging from 1 to 2 days.

Bamboo treated in green condition were found effective against attack of fungi and wood boring insects like Dinoderus or lyctus. These insects cause severe damage in untreated bamboo which eat the nutritious materials inside the bamboo and weaken the bamboo structures.

Advantages of treating bamboos in green conditions

- Treatment is very simple requiring very little equipment and technical knowledge.
- Treatment can be done at the felling site itself so transporting the materials from the felling site to the treatment site is avoided.
- Seasoning the material before the treatment is totally avoided as the treatment are done in green condition.
- The treatment technique can easily be taught to the villagers and the illiterate people as it does not involve any technical knowhow. They should know only to handle the chemicals.
- Simple sap displacement method, sap displacement of bamboo carryout by conventional and modified Boucherie process are best suited for the protection and preservation of bamboo, involve very little investment and therefore highly recommended for rural application.

Performance of treated Bamboos

Treated bamboos have indicated varied durability. CCA (Copper-Chrome-Arsenic) treated bamboos in exposed conditions show sign of decay after 15 years. Treated bamboo used for reinforcement in mud had also the same life span with damage upto the height of 50 cm from the ground level. The damage was attributed to moisture ingress from the ground. The performance in particularly exposed and under covered conditions was much better and practically no damage to CCA treated bamboo, used as exterior cladding in low cost huts and as roofing support for thatched huts was noticed even after 33 years. At the forest research institute, Dehra Dun two species namely, Bambusapolymorpha andDendrocalamusStrictus treated with CCA, Acid Copper Chrome (ACC), Copper Chrome Boric (CCB) and Creosote:fuel (50:50) were installed in 1985 and till recently the bamboo treated with creosote preservative have been found superior to other preservatives.

Preservative of Bamboo Handicrafts

Bamboo and bamboo handicrafts are susceptible to many deteriorates due to mould and insect attack and causing thereby incalculable loss to the bamboo handicraft industries, it is therefore desirable that the bamboo needs preservative treatments.

Boric acid and borax preservatives which are not injurious to human beings and does not impiar the health, so this is the only preservative which may be safely used for these handicrafts items in which edible are directly stored. Five percent aqueous solution of the mixture is used (2.5:2.5) 2% solution of sodium pentachlorophenate (NaPCP) is also effective against insects. 2% aqueous solution may be applied on the finished product about three times at an interval of 24 hours

Economic aspects of bamboo preservation by sap displacement:

If untreated, no-durable bamboo is used, the decay is inevitable calling for loss or early replacement of material, sometimes with heavy labour changes. Failure of a piece of bamboo in a building through decay or insect attack may involve expensesenormously greater than the actual cost of the piece of bamboo itself. There are also indirect costs involved such as in the case of replacement of bridge bamboo where there will be traffic diversion and hence transportation costs, etc. therefore the use of untreated bamboo gives rise to maintenance problems and high annual costs. A comparison of the annual charges presents the true cost of bamboo construction. This cost represents the amount necessary to provide for renewal. Comparing only the initial cost of treated and untreated material is misleading. It is also important to take into consideration, it useful life. It is a mistake to determine annual charge on the basis of excessive life, if relocation or revision is needed sooner, as is often the case with the temporary structures. The annual cost of a structure is the amount of money that will have to be provided annually to replace the structure at the end of its useful life, and thus provide for perpetual service. This annual cost can be computed by the compound interest formula:

$$A = P \frac{R(1+r)n}{(1+r)n-1}$$

Where A=annual charge

P=total investment cost

r=rate of interest expressed in decimals (0.15 for 15%)

n=number of years’ service

Bamboo is a low cost material and has therefore found extensive use in low cost products. Additional treatment costs have therefore to fit in the overall economics of these products. Additional treatment costs have therefore to fit in the overall economics of these products keeping in view their marketing potential. Since costs of material and labour vary from country to country, exact analysis of treatment costs is rather difficult. In a house made completely of a bamboo, it is estimated that untreated bamboo posts last about 2 years, walls 5 years, ceiling 10 years and roof8 years. Average life of an untreated bamboo house thus may be considered not more than 7 years. Treated bamboo posts may lost about 15 years and treated woven mats for walls about 20 years treatment may involve an additional cost of about 20% to 13% respectively. But this will help in increase in service life of bamboo and its products by 3 to 5 times. This means the cost of bamboo can be decreased to one third to one fifth of original costs through treatment and the benefits are obvious.

Safety precaution in the preparation, handling and application of chemical treatment

1. Wear appropriate protective clothing made of impervious material like plastic gloves, safety boots and helmets. Eye protective goggles are needed while mixing preservative solutions.
2. Do not drink, eat or smoke during or after the application of treatment.
3. Store preservative in correct manner and follow instructions of manufacturer.
4. Spray along the wind direction.
5. Wash hands, feet or take a shower after work. Change work clothes regularly.
6. Place containers out of reach of children. Empty containers can be disposed by burying them underground.
7. Do not allow sludge to accumulate.
8. Do not remove treated bamboo until dripping is stopped.
9. For material treated with water-soluble preservatives like CCA, CCB etc., store the bamboo under cover and use only after drying.
10. Dispose of treating solutions properly. Allow water to evaporate and bury precipitated underground or dispose in dumping ground for chemicals.
11. Do not release CCA preservatives in streams and do not burn treated bamboos as fire wood.
12. Train staffs and displays precautionary materials and gadgets.

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Development of crushed bamboo strand lumber as a wood substitution

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ABSTRACT

Bamboo is a naturally occurring composite material which grows abundantly in most of the tropical countries. Cellulose fibers are aligned along the length of the bamboo providing maximum strength and rigidity in that direction. Studies were carried out to develop a wood substitute using bamboo strands. The Bamboo Strand Lumber (BSL) was developed using crushed *Bambusa bambos* species of bamboo and phenol formaldehyde (1:1.8) and then pressed from two sides. The physical and mechanical properties of BSL were evaluated. From the results, it was found that the BSL meets the required standards and can be used as alternative to various species of timber for different applications like flooring, furniture making, interior decoration, molding and constructional purpose.

INTRODUCTION

Bamboo is a naturally occurring composite material which grows abundantly in most of the tropical countries. India has world’s second highest resources of bamboo. About 136 bamboo species in 36 genera found in India. North east India holds the largest stock and diversity of bamboos. Bamboo has been used widely for household products and extended to industrial applications due to advances in processing technology and increased market demand. In Asian countries, bamboo has been used for building construction, household utilities such as containers, chopsticks, woven mats, fishing poles, cricket boxes, handicrafts, chairs, etc. It has also been widely used in building applications, such as flooring, ceiling, walls, windows, doors, fences, housing roofs, trusses and rafters. it is also used in construction as structural materials for bridges, water transportation Facilities and skyscraper scaffoldings. There are about 35 species now used as raw materials for the pulp and paper industry. Massive plantation of bamboo provides an increasingly important source of raw material for pulp and paper industry.

There are several differences between bamboo and wood. In bamboo, there are no rays or knots, which give bamboo a far more evenly distributed stresses throughout its length. Bamboo has a hollow tube structure , sometimes with thin walls, and consequently it is more difficult to join bamboo than pieces of wood. Bamboo does not contain the same chemical extractives as wood, and therefore it can be glued very well. Bamboo’s diameter, thickness, and internodal length have a macroscopically graded structure while the fiber distribution exhibits a microscopically graded architecture, which lead to favorable properties of bamboo. Cellulose fibers are aligned along the length of the bamboo providing maximum strength and rigidity in that direction. Over the past decade, the demand for wood composites as building material has continuously increased. At the same time, the quantity and quality of wood resources from the forest as a raw material for this application have been going down. Consequently, the search for alternative or substitute materials to wood has come into focus.

In recent years, bamboo has gained greater interest as substitute material of wood because of the global shortage of forest resources. Bamboo strand lumber is developed for the use as structural purpose including beams and columns. It is the latest product of the structural composite lumber family, and its market is still in developing stage. Strength properties make it a highly competitive alternative to traditional lumber and it will become an important forest based product in the future. In the present work, Bamboo Strand Lumber (BSL) was developed using crushed bamboo with special grove designed machine and Phenol Formaldehyde Resin. It’s physical and mechanical properties were studied.

Process and Properties of BSL

For manufacturing of bamboo strand lumber, following raw materials were used.

1). *Bambusa bambos* species of bamboo

2). Phenol Formaldehyde Resin (1:1.8)

For manufacturing BSL, first bamboo length was measured and marking was done on the top middle and bottom portion with four feet one inch length. After marking, following steps were followed:

a. Cross cutting: Cross cutting of bamboo was done to cut the Bamboo culms into desired length on 4’1”.
b. Removal of outer node of bamboo**:** After cross cutting of the bamboo the outer nodes were removed
c. Splitting**:** Splitting was done to split the bamboo culms into desired width of 10 mm to 15 mm.
d. Removal of internal node**:** For getting smooth surface of the bamboo strips, internal node were removed.
e. Skin removal**:** In skin removal process the outer green skin of bamboo is scrapped off. This process gives decontamination and good appearance to strips. Skin removal process is either done by machine or manually. When scraping the skin, apply force evenly along the culm surface in order to ensure a uniform color.
f. Hydrothermal treatment and Preservation**:** Hydrothermal treatment of bamboo strips was done before crushing them. After this treatment the bamboo strips becomes soft and it easy to crush

strips and Fiber would not break during crushing. Hydrothermal treatment can be given by following two methods.

- By Boiling
- By Steam Heating

In this process, boiling method was used. Bamboo strips were kept into a close tank filled with water. The level of water was kept above the level of strips and then the tank water was heated. The advantage of this method is that preservatives can be added in boiling water while in steam heating addition of preservatives during treatment is not feasible. Another good advantage of boiling is that it retains the natural color of strips.

g. Preservation: borax and boric acid wood preservative were added into boiling water. Borax melt’s at 65^0C and it dissolves properly into boiling water. Bamboo strips were cooked for about 45 minutes in borax and boric acid added boiling water. Borax is odorless, colorless, transparent crystals or white granules or powder.

h. Crushing of strips: Crushing was done mechanicaly with the help of specialy degined bamboo groving manchine to disintigrtae the fibres from bamboo. For making bamboo strand lumber, crushing of the strips plays very important role, as with uncrushed strips, more gaps will be developed between strips during pressing. Because of this gap, overall strength of the lumber will decrese. Also, uncrushed strips absorb very less amount of resin which leads to poor bonding in final product. Crushing also lead to mechnaical interlocking or adhesion between bamboo fiber.

i. Drying of Strips**:** The purpose of drying bamboo strips is to reduce its moisture content to a range suitable for gluing which is 6-8%. The crushed strips generally contain more than 30% moisture and strips cannot absorb sufficient amount of resin.

j. Dipping of stri**ps** into Resin**:** Glue was applied on bamboo strands by dipping them into resin. For making BSL, conventional PF resin was used and same amount of water (1:1) was added into resin to reduce its viscocity. 10kg of conventional PF resin was taken and dilluted by adding 10 kg of water into resin. Then strips were dipped into the diluted resin for five minutes.

k. Air drying**:** After Dipping bamboo strips were kept at ambient condition for air drying. The strips kept vertically with support in container for 3 to4 hour to drain out the excess resin.

l. Oven drying**:** Gluing moisture content of the strips was maintained between 10 to 12% before pressing. After air drying, strips were kept in oven until moisture content of strips decreased to 10 to 12%. Temperature of oven was maintained at 50 ± 5^0c to avoid poor bonding of the lumber

Assembling and Hot Pressing:

After strips attained desired moisture content, they were cut into required length. The strips were assembled in such a way that all the strips were in same alignment from both the ends. Then the aligned strips were wrapped with plastic bob film for lamination and tied from both ends firmly with tread. The width of assembled strips was measured and set the same width was set in hot press by adjusting the guider plates. This assembly was loaded into Hydraulic hot press. In this press one hydraulic cylinder was placed at base house which can move up and down. The 25 mm gap between two platens was set by moving up the bottom cylinder. This gap was set after loading the assembly. Thickness of the lumber depends on this gap. Another two hydraulic cylinders were placed in side houses which give side pressure. Bottom cylinder only give the contact pressure to assembly while two side cylinders give side pressure from 10 to 15 kg/cm^2 side pressure. This side pressure is transmitted through guider plates. Assembly was pressed by side pressure. The Hydraulic Hot Press is designed for pressing bamboo strips at high pressure and temperature to give them for making boards. Besides bamboo, the Hydraulic Hot Press Machines can also be customized for pressing of wood and other materials. The pressing parameter is given in Table1.

Table 1: Pressing Parameter

Temperature	145±5ºC
Gauge Pressure	117 kg/cm^2
Specific Pressure	15 kg/cm^2
Time	Thickness + 2 minutes

Trimming:

Trimming was done to give proper size and shape to lumber. It also removes defects present in edges. This process involves cutting of the four edges of the board to obtain a board of required size and perfect squareness.

Sanding:

The process of sanding involves removal of a small extent of the surface layer from a panel by using an abrasive material. Sanding is done for following reasons.

- To produce a panel of required thickness having thickness uniformity within specified limits.
- To produce a clean, smooth surface finish suitable for subsequent polishing, painting or overlaying.
- To clean up splits or remove handling dirt such as dust and finger marks.

Here the lumbers were sanded with wide belt sander. It is a more common typeof sanding machine now in use. These machines come in various combinations of one, two, four and six belts. The wide belt sander has an added roller spaced behind the contact roller and a narrow resilient pad is inserted. This lies below the line of the contact roll pressing the belt down onto the work.

Preparation of Phenol Formaldehyde (1:1.8) Resin: For BSL,, single stage conventional phenol formaldehyde resin with 1:1.8 weight ratios was used. For making 10kg PF resin, the following amount of phenol, formaldehyde, caustic and water was used. Phenol = 3300 gram; Formalin = 5940 gram; Caustic = 264 gram (6% of phenol); Water = 528 gram (Double of caustic). First the caustic solution was prepared by adding 264 gram of caustic in 528 gram of water and this solution was cooled to room temperature. Then, loaded 3300 g of molten phenol into kettle followed by 5940 g formalin. After loading formalin, immediately the condenser was started. Caustic solution was added into the kettle. The temperature inside the kettle was automatically increases because of exothermic reaction. When temperature stopped increasing, burner was started to heat the kettle until temperature inside the kettle reached 60^0c and then the burner was stopped. Because of exothermic reaction temperature inside the kettle automatically increases up to 85^0c. Then the burner was again started to increase the temperature inside the kettle up to 90^0c. This temperature was maintained inside the kettle up to 90 ± 2^0c until precipitate and flow time in B_4 cup reached 14 to 16 seconds. Then the cooling was started and until temperature inside the kettle reached room temperature and the resin was unloaded. The properties of resin are given in Table 2.

Table 2: Properties of resin

SL NO	Particulars	Results
1	Flow time of resin in B4 flow cup (at 90^0c)	14-16 seconds
2	Flow time of resin in B4 flow cup (at room temp.)	20-22 seconds
3	Water tolerance	1:16
4	Practical Solid content	48.23 %
5	Theoretical solid content	57.23%

Testing:

The physical and mechanical properties viz. moisture content, modulus of rupture in bending, modulus of elasticity in bending, compressive strength, screw withdrawal strength in face and edge were conducted as per IS 1734.

Table 3: Properties of Bamboo strand lumber

Sl. No.	**Parameter**	**Results**
1	Moisture content, %	6.20
2	Modulus of Rupture, N/mm^2	34.656
3	Modulus of Elasticity, N/mm^2	7010.8
4	Compressive strength parallel to grain, N/mm^2	38.382

5	Screw withdrawal strength, N a) Edge b) Face	 1245 1985

CONCLUSION

After analysing the physical and mechanical properties of bamboo strand lumber it can be concluded that Bamboo Strand Lumber can be used as building material as a replacement of solid wood. Bamboo strand lumber can be used for flooring, furniture making, interior decoration, molding and constructional purpose.

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Thermal modification of bamboos for improving various properties and value-added applications

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Background

Heat treatment of wood at high temperature is one of the wood modification techniques to improve the dimensional stability and bio-durability of timber (Kamdem *et al* 2002, Niemz and Bekhta 2003). Thermally modified wood material acquires certain novel and unique properties. Thermal treatment of low durability wood has shown improvements not only in the dimensional stability, but resistance to fungal decay of wood and wood products is also enhanced. Thermal modification of wood or any other lignocellulosic material including bamboo may be described as the application of heat to the material at higher temperatures in certain controlled environment in order to bring about a desired improvement in the properties and performance of the material. Important parameters of the heat treatment of woods include temperature control, atmosphere, species and quality in terms of defects before the treatment, thickness and initial moisture content of the material.

Thermally treated lignocellulosic material generally turns towards darker in colour due to modification of certain constituent chemicals present in the structure. At the beginning of the application of this method, the colour change of wood was considered as a negative attribute. However, on the contrary, nowadays it is regarded as one of the main arguments for the application of this technology, because wood species with natural irregularities, like coloured heartwood, turn to aesthetically and technically valuable products when heat treated. The most important property, when compared to untreated material, is that the equilibrium moisture content (EMC), shrinkage and swelling of the heat-treated wood are also reduced. Better dimensional stability in variable climatic conditions is an additional reason for the use of this material for parquet production. To reduce the darkening of heat treated wood, it is proposed to use the inert gases such as nitrogen, helium and carbon dioxide to reduce the oxidation of wood components. Strength properties may slightly be reduced while improving the dimensional stability by the heat treatment. Such products may be well used for applications where dimensional stability is more important parameter with minimum requirement for strength such as flooring, siding, cladding, decking etc.

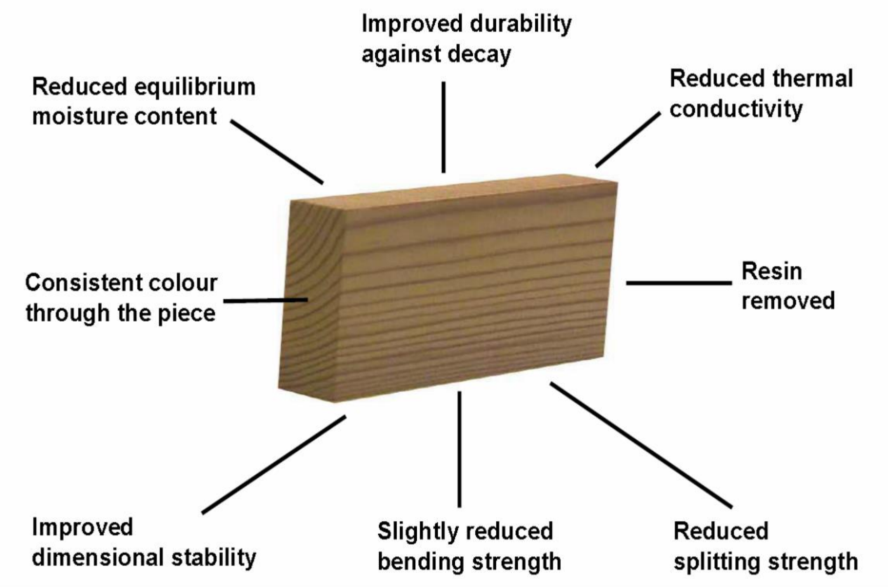

Fig. 1: Wood properties after thermal treatment

Furthermore, heat treated wood can be used to enhance the value-addition of traditionally poor quality woods as a substitute for certain high value tropical species. It provides an economically viable alternative to the darker coloured tropical heartwoods which are generally available at comparatively higher costs. It is especially attractive to use heat treated wood for parquet flooring and similar applications since it is possible to obtain different dark brownish wood colours by varying the process parameters. Due to its good weather resistance, heat treated wood is also suited for certain non-structural outdoor applications such as external cladding, light window frames and garden furniture etc. As a result of the improved dimensional stability, heat-treated wood gives better durability for coatings applied on the surface of the wood products.

Since last few years, IWST has initiated the research work and developed expertise on thermal modification of locally grown wood species for improving their technological properties and providing the value addition towards utilization of these species. Heat treatments of certain plantation grown rubberwood and *Eucalyptus* spp., poplar etc. were carried out successfully using different temperature profiles under different controlled environments. Various physical properties of treated wood specimens were evaluated as per applied standards and compared with the controls. Similarly, various mechanical properties and durability against termite attack in the field conditions and exposure to fungi were carried out. Heat treated wooden planks have shown improved dimensional stability, water resistivity, darker pleasant colour and enhanced durability and were demonstrated for usage as flooring tiles. As thermal modification of above mentioned wood species has shown extremely encouraging results, it is quite useful towards upgrading the certain properties of lower grade wood species. This research work also provides the much required value addition to such species which may be adopted by the interested wood working industry for large scale production.

Fig.2: Heat treated woods and their products (tiles and door)

Bamboo is currently undergoing a transformation from poor man's timber to "green gold". It is a strong, versatile and renewable woody material having multifarious uses both in rural and urban sector. It has been an integral part of India's' cultural, social and economic traditions. Millions of people depend on it for their livelihood and for household and functional uses. Because of easy workability and low costs, bamboo has been an useful material for rural population (Rao *et al*., 2008). The culm growth is faster and matures within 3-4 years. The unique properties of bamboo such as its strength, straightness, smoothness, easy to cut and split, easy to carry have made it useful for almost all facet of life.

One of the important characteristics of bamboo is its fibrous structure. Bamboo fibers are longer compared to wood fibers and strength properties including elasticity are better than many timber species. The circular and mostly hollow cross-section of bamboo gives it a high strength-weight ratio. The cross partition walls at each node make the bamboo strong and hard to bend or break at joints. Ordinary methods of seasoning and treatment such as submerging in water can increase its durability and working performance (Gnanaharan *et al*., 1993). The bamboo is, in its size, lightness and strength, an extreme product of nature. It is stable and because of its cavities an extreme light and elastic building material. Bamboo has a very efficient natural structural design because of medium density, hollowness and orientation of fibers in longitudinal direction. Due to the favorable mechanical properties, the high flexibility, the fast growing rate, lower weight and low purchasing costs, bamboo is one of the most important building materials with many opportunities. It can be used in many applications; from very traditional handicraft (e.g., baskets) to products that are completely industrialized (e.g., parquet and panels). Some bamboo species can very well be used in supporting structures as high bamboo scaffolding. Bamboo also plays a very important role in daily lives for shelter, employment, income, fuel, etc. Recently, bamboo has also found more applications in the industrial applications as well as in temporary structures. Besides being an essential component of cottage and rural industry, bamboo is also found to be used in some specialized novel uses such as bamboo timber, bamboo based-laminates; bamboo laminated flooring tiles, reinforcement in cement concrete etc.

Variation in growth conditions is expected to influence the technological properties of culms from same as well as from different localities. The structural basis for such variations will be investigated to understand the probable applications and workout expected value addition to these newly introduced bamboo species. In tropical countries such as India, bamboo is abundantly available at reasonable prices; therefore it is used for numerous purposes. However, bamboo (as a lignocellulosic material) is susceptible to fungal, termite and insect attacks and sometimes, it is quite difficult to protect by preservative treatment using hazardous chemicals. Heat treatment is an eco-friendly alternative which may be applied to enhance the dimensional stability and durability of bamboos. The objective of this study is to improve the dimensional stability and durability of bamboos using heat treatment of three bamboo species. Seasoning or drying of bamboo is careful process of bringing down its moisture to level closer to EMC in service. Should be done slowly/controlled schedule (Kiln drying/Vacuum drying), otherwise cracks and splits would develop. Seasoning improves bamboo's resistance to fungi and insect attack and very important and useful before transporting. It limits amount of drying shrinkage in service (dimensional stability) which would affect the joints. Thumb rule: its always better to work with dry bamboo which also possess higher strength values.

Natural durability of bamboo varies from species to species as well as in service application and location of use. Bio-deterioration of bamboo culms is caused by soft rot, white rot and brown rot fungi. Bamboo consists of 50-70% hemicellulose, 30% pentosans and 20-25% lignin. Limited information is available on the natural durability of different newly introduced bamboo species of commercial importance (Kamarudin and Sugiyanto, 2012). Losses due to biological degradation occur even during storage especially when bamboo is not properly protected (Mathew and Nair, 1990). Generally the treatment of bamboo is carried out in either green or dry condition for various end uses. Currently, there is no standard foolproof method for preserving bamboo except impregnating them with toxic chemicals. Some of these chamicals are not only hazardous for mammals but also deleterious for the soil. The presence of considerable quantities of starch in green or dry bamboo makes it more attractive to such organisms, especially fungal stain and borer beetles. Traditional preservation methods have been applied, such as leaching in water and mud, starch removal, baking and smoking, however, traditional method cannot be controlled and excessive heating in smoking or baking can cause severe collapse. No research work on thermal processing of these bamboo species has been reported in open literature. Effect of thermal modification of solid bamboo species on various properties of technological importance including dimensional stability and durability against biological attacks has been investigated. In spite of immense economic importance of these species, not much work has been done on the enhancement of their properties and development of versatile products particularly furniture items. There is a lot of scope for developing industrial processes for heat treatment of these bamboo species of commercial importance for their chemical free preservation.

Bamboo when used for structural applications need to be treated with preservatives to prolong its longevity. Preservatives like CCA and CCB were used commonly until recently. Due to ban on CCA and lesser use of CCB, newer, cheaper and more eco-friendly preservatives are being explored like micronized Copper, Azols. Quats etc. But in new age lifestyle products, use of such hazardous chemicals may adversely affect its consumer acceptance and marketability. Hence, it is desirable to explore other various non chemical methods for preservation of bamboo in lifestyle products like furniture and handicrafts and other utility items where bamboo comes in direct contact with food materials. Thermal modification of wood has shown great potential as an alternative to chemical preservatives in such lifestyle products. Preliminary trials on bamboo have also shown considerable promise. There is also a huge export potential for items like serving trays, bowls, jewellery, home accessories etc. This can directly benefit bamboo based industries. This may also encourage other local entrepreneurs to take up value added products from bamboo and create local employment opportunities.

Heat treatment of bamboos:

Different methods of bamboo treatment have been known for a long time, but in the past there was no economic or environmental urgency to develop novel processing technologies. More recently, there has been growing environmental and legislative pressure on using traditional chemical preservatives and biocides, which are hazardous for health. This has created new opportunities for bamboo treatment/modification. Thermal modification of bamboo is a promising and environmentally friendly (chemical free) technique for treatment. The process has the aim to create and disseminate in Indian market an improved method to produce thermally modified bamboo with enhanced durability and improved properties. The process of thermal modification has been carried out on locally grown different solid and hollow bamboo species widespread in India, but considered economically unattractive. Thermal modification was carried out without adding any hazardous chemicals operating “under vacuum”.

Thermal modification process, a clean and energy efficient technique, uses high temperatures (up to 220°C) for certain duration in a controlled environment to heat and modify the bamboo materials. No chemicals are used in this process. After proper selection of the air-dried culms, defect free sample blocks of each bamboo species will be prepared for different thermal modifications. Samples will be heat treated at 150-200ºC for different durations ranging from 1-6 hours under inert environments and atmospheric pressure for comparison. The presence of air or other oxidative medium can accelerate the degradation process of woody components of bamboos during heat treatment; hence the process is usually carried out in a protective inert medium.

Fig.2: Oven for thermal modification of bamboos

Testing of properties:

For the determination of mechanical properties, the culms will be air-dried to about 12% moisture content. Various physical (moisture content, specific gravity, shrinkage, culm wall thickness, culm diameter and inter-nodal distance), mechanical (static bending – modulus of rupture and modulus of elasticity and compressive strength) and chemical properties of heat treated and untreated bamboos are evaluated according to different national and international standards (Anon, 2008a). The analysis of chemical constituents of the bamboos (cellulose, hemicelluloses, lignin etc.) is also carried out in the untreated control and heat treated bamboos at different temperatures and durations.

Durability Tests (against fungus and termites):

Rot is caused by a fungus. For the fungus to survive the bamboo needs to be relatively wet with at least 20% moisture content, which essentially means the bamboo must be exposed to rain or ground moisture. Certain beetles are attracted to starch in bamboo and lay their eggs inside the culm, after which eggs hatch and larvae eat along the culm and eventually escape leaving small round or oval exit holes (about 1-6mm diameter). Powderpost beetles which leave 1-2mm exit holes, are the most common. Termites also attracted to the starch in bamboo, but unlike beetles, they have enzymes which enable them to break down the cellulose. Because termites live in large colonies they can cause rapid damage to the untreated bamboo.

Decay resistance tests are conducted to study the durability against wood fungi using brown and white rot fungi adopting agar block method as per Indian Standard IS: 4873 (1968). Field-testing of heat treated bamboo against termites is done by assessing the damage of stakes in graveyard condition as per Indian standards IS: 4833(Anon. 1993) and IS: 401(Anon. 2001). For this purpose stakes are implanted in soil with surrounding soil firmly pressed around the stakes to ensure good ground contact with soil. The untreated bamboo states are also installed for comparison. Observations are taken periodically by removing stakes out of the soil and visual assessment for extent of damage according to IS:4873 (Anon 2008b).

Maximum %weight loss due to heat treatment upto 200ºC was found to be in the range of 12-25% depending on bamboo species. Density of heat treated bamboo did not reduce significantly up to 180ºC. Heating temperatures greater than 200ºC were found to be detrimental for density values depending on species. Thermal modification affected hygroscopic behaviour of bamboos and found to reduce EMC (by 50-60%) and water uptake capacity (by 40-60%), while improved dimensional stability (50-55% in wall thickness) was exhibited.

Bamboo stiffness (MOE) was found to be almost unaffected up to 200°C and reduces thereafter with increasing treatment temperatures. Similarly, no significant effect of heat treatments (180-200°C) was observed on compressive strength of bamboo (MCS). However, flexural strength (MOR) of bamboo reduces by 15-20% with increasing heat treatment temperatures (up to 180°C) and found to be correlated with weight loss.

Fig.4: Water repellency test in thermally modified bamboo strips

Advantages of thermal treatment of bamboo:

- Protects against attack by rot, fungus
- Improves the dimensional stability
- Enhances moisture/water resistance
- Provides a warm brownish colour
- Slightly reduction in few mechanical strength.

Clean Energy Solution for Bamboo Treatment

Eco-friendly process of thermal modification involves heating of bamboo at high temperatures under vacuum- a new technological approach to the country. Through this chemical-free process, decay factors may be eliminated along with improvement in dimensional stability and resistance to water/moisture absorption related problems. Thermally-modified bamboo can be used for different lifestyle products including furniture, flooring, handicrafts, panel products etc. Heat treated bamboo has a huge market in country with untapped potential due to slowly banning of toxic preservative treated bamboo for environmental reasons. Technical know-how of this domestically sourced, affordable and eco-friendly technique of processing is available with IWST to produce thermally modified bamboo for different applications.

Fig.3 Thermally modified bamboo round bamboo and strips

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Bamboo lumber

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General Information

India has one of the richest bamboo resources in the World, second only to China in Bamboo production. The annual bamboo production in the country is estimated at 3.23 million tons and according to Forest Survey of India report, in India bamboo grows in 8.96 million hectares of forest area. It is one of the fastest renewable plants with a maturity cycle of 4-5 years thus making it one of the highly attractive natural resources compared to forest hardwoods. Though bamboo has been used for a very long period, it has many defects such as irregular shape, hollow circular section, numerous internodes, low durability and prone to termite/borer attack. However, by using modern bamboo processing technologies, it can be used for various industrial purposes.

Most of mechanical properties of bamboos are either comparable or better than sawn timbers and therefore has huge potential for usage similar to timber in many sectors by its use in technically modified form. It can be a good raw material to replace solid wood for many applications. Development bamboo lumber using bamboo strips is gaining importance as this resembles with wood when used in a particular fashion as in parallel laminates. Bamboo based composites are durable, stable and environmental friendly. These laminates will have superior physical and mechanical properties and are suitable for structural and other specialized applications.

Bamboo can be utilized in form of lumber for which bamboo needs to undergo certain processing to convert into value added applications especially as load bearing components to replace solid wood. Solid hardwood boards have become increasingly expensive whereas bamboo timber can be developed as significantly less expensive product as an alternative to solid timber. To establish the process technology for conversion of bamboo raw material into bamboo timber, first step is to determine technological properties of bamboo raw material. Most of today's bamboo wooden floor board of this kind originates from China and other parts of Asia. MOSO bamboo is the species most commonly used for boards. There are many species of bamboo in India which can be explored to replace MOZO bamboo as bamboo lumbers made from MOZO bamboo are being imported to India to a great extent.

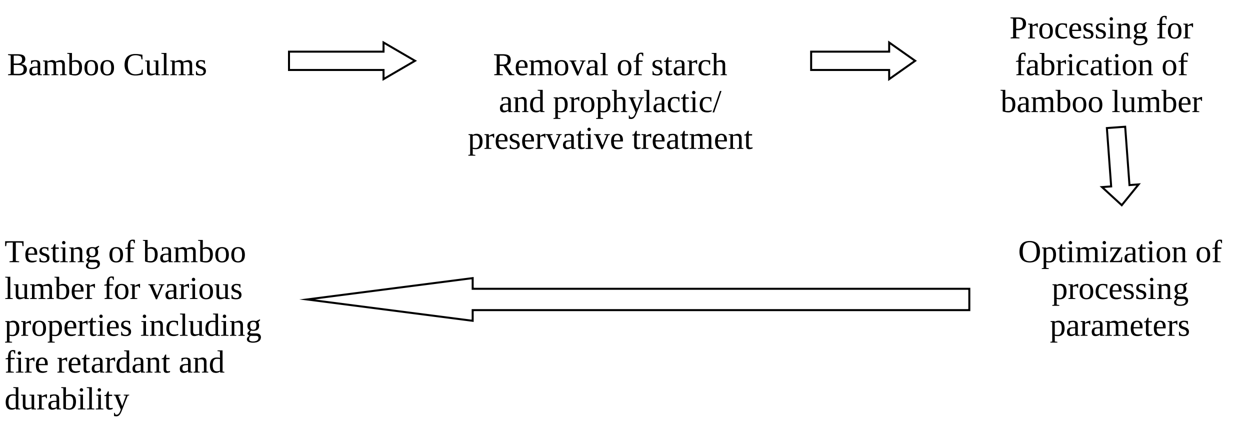
Development of bamboo strip based panel products such as bamboo timber, bamboo lumber, bamboo laminates are gaining importance as these products resemble with wood when used in a particular fashion as in parallel laminates. Bamboo based composites are durable, stable and environmental friendly. Synthetic resin adhesives are used for bonding bamboo strips. These laminates will have superior physical and mechanical properties and suitable for structural and other specialized applications. Moreover, the requirement of resin adhesives is expected to be lower compared to bamboo mat based composites and therefore making the products cost effective which are considered to be ideal for alternates to wood and plywood for several structural and non-structural end use applications.

Methodology for making Bamboo Lumber

Immediately after collecting different bamboo species, starch is removed by dipping the culms in water. Before manufacturing process of bamboo lumber, bamboo culms are cross cut, external knots are removed. After that, the culms need to be split into small strips and all the four sides are generally to be planned. The adhesive is then applied uniformly to bamboo strips. Preservative treatment is also given to avoid biological degradation. Fire retardants can be added during treatment process to impart fire resistance. Lumbers can also be prepared using crushed bamboo strips following the similar procedures. Few experiments need to be carried out on the glue bond made between the bamboos lumber with varying application rates for the glue. After glue spreading, bamboo lumber are prepared and hot pressed at different temperature and pressure.Various processing parameters such as resin uptake, pressure, temperature, preservative and fire retardant loading can be optimized.

All the bamboo lumber boards are then trimmed and cut into various test specimens: 2 x 2 x 30cm for static bending tests [modulus of rupture (MOR) and modulus of elasticity (MOE)], 5 x 5cm for internal bonding (IB) strength tests, 5 x 5 cm for thickness swelling (TS) and water absorption (WA) tests, and 5 x 10 cm for linear expansion (LE) determination. For static bending, the specimens need to be separated into two groups: one group for a load applied to the specimens with a horizontal glue-line and the other for load specimens with a vertical glue line. For dimensional stability, the specimens are submerged horizontally under distilled water for the duration ranging from 2 hr to 24 hr. After submersions, the specimens are suspended to drain to remove the excess water, and the weight and thickness of each specimen are determined immediately. All the tests will be performed on the specimens in accordance with BIS.

Flow Chart for Preparation of Bamboo Lumber



Bio-based thermoplastic composites: new age material

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Bio-based thermoplastic composites are gaining importance day by day as there has been a dramatic increase of interest in using them as filers in organic and inorganic composites because of their bio-degradable, renewable and environmentally friendly nature. Composite materials essentially combine more than one material or substance, most commonly a reinforcing fiber and a matrix resin. Many bio-based fibers have been used as fillers in thermoplastic composites like jute, flax, wheat straw, kenaf, hemp, bamboo, coir, bagasse and so on in addition to wood powder and fibers. Blending of polymers with fillers is a powerful way to produce newer materials with a desirable combination of properties unavailable with a single component. Typical desired properties are improved stiffness, thermal stability, tensile and bending strength, reduced shrinkage of molded parts and reduced wear due to usage and environmental factors.

Several billion pounds of reinforcements and fillers are used to improve the performance of the plastics and to reduce their cost. Most commonly used reinforcements are glass, kevlar, carbon fiber, whereas talc, calcium carbonate, clays, etc are fillers. Manufacturing of glass/carbon fibers is highly energy intensive and hazardous to health. It would be particularly beneficial; both in terms of the environment and also in socio-economic terms, if a significant amount of the fillers were obtained from a renewable agricultural source. Environmental awareness and cost effectiveness today motivates the researchers to study the agro based fiber filled thermoplastic composites. The material can reduce the consumption of plastics significantly. Material cost savings due to the incorporation of the relatively low cost agro-fibers and the higher filling levels coupled with the advantage of being non-abrasive to the mixing and molding equipment, are benefits that are not likely to be ignored by the plastics industry for use in the automotive, building, appliance, and other applications. Plant-based composites may in the future, become materials to replace both, polymer based composites and costly wood because of their attractive specific properties, lower cost, simple processing technologies, reduced environmental impact, and ability to be recycled after use. Taking advantages of fiber cell wall modification chemistry and combining fibers with other materials provide a strategy for producing advanced composite materials that take advantages of both natural fibers and thermoplastic resin. It also provides flexibility to tailor made materials as per end use requirement within the frame of cost availability.

Background:

In the age of composites, combining biological fibers and commercial plastics can bring in transition to safer and more environmentally friendly composites. These materials can be used to make lighter, stronger and more durable products that save resources and energy. Long life and eventual recycling can be engineered into these products. Natural/Bio-fiber composites are now emerging as a realistic alternative to glass fiber reinforced composites. In recent years, use of synthetic polymers has grown tremendously because of the capability to mould these thermoplastics into desired shapes and engineer desired properties into them. However, there are some drawbacks also. These include poor mechanical properties, e.g. impact toughness and stress relaxation behaviour. One of the most effective ways to improve these properties is by addition of reinforcing fibres or particles. For fibrous material there are two classifications: (1) continuous and (2) discontinuous fibres. In this study we had concentrated on discontinuous fiber composite material, classically defined as combination of short (chopped) fibres with a continuous surrounding material. Short fibre filled composites find the best application in moulded products. Most commercially important composites use glass fiber as reinforcement.

Advantages of Using Wood Fibres

Advantages of using wood fibers as a reinforcing element for thermoplastics arise from the fact that they are: light weight, damage tolerant, non-corrosive, and less abrasive to processing equipments. Because of low density of plant fibers, a wood fibre reinforced product will always be thicker than the one reinforced with the same mass of glass fibre. When the product design is stiffness limited (as is frequently the case) rather than failing stress limited, a thicker product could be stiffer and still acceptably strong for the same mass. Overall performance of any fibre reinforced polymer composite depends to a large extent on fibre matrix interface. Wood fibre surfaces are fairly irregular which should in principle enhance the fibre matrix interfacial bond.

Further, high specific strength and modulus, low cost, and availability in most geographic regions make wood fibres even more attractive as fillers. The principal advantage of natural fibre reinforced composites is their ability to absorb tremendous amount of energy during impact fractures. The higher strength is not just due to fibre pull out work and work done in creating new surfaces but also due to complex fracture mode of natural fiber as compared to glass or carbon fibres reinforced composites.

The compact design of biological fibres introduces an element of redundancy which is very desirable from the safety point of view. They rarely fail in brittle manner because the interaction between the sub elements is such as to allow non elastic deformation before fracture. Natural fibres can combine resilience (energy storage) and toughness (energy absorption). Plant fibres are carbon dioxide neutral in their production (they derive carbon from air and not from oil or natural gas) and require only small energy inputs for processing. Plant fibres cause less dermal and respiratory irritation, and are more pleasant to work with than glass fibers.

Limitations of using Wood Fibres as reinforcement in thermoplastic composites

Despite of all the advantages mentioned above cellulosic materials are less frequently used in common thermoplastics such as polyethylene, polypropylene, polyvinyl chloride, and polystyrene because of difficulties associated with surface interactions between hydrophilic wood fiber and hydrophobic thermoplastics. Such divergent behaviour results in difficulties in compounding these materials, and poor mechanical properties of the end product. The hydrophilic-hydrophobic boundary between the pulp and the plastic is a very high energy surface, when compared with hydrophilic-hydrophilic and hydrophobic-hydrophobic surface interactions when the two phases separate. Thus, polymer and pulp segregate into pure thermoplastic and pulp clumps. The abundant hydroxyl groups in plant cell wall are strongly attractive to water, and resultant sorption cause anisotropic swelling. If this swelling is restrained mechanically, e.g. by encapsulating the fiber in a water unreactive matrix, the uptake of water cause a swelling stress. If the fiber is exposed to water, swelling stresses can eventually cause failure of any matrix resin that is used to bond fibers together. A survey of literature reveals that adhesion and chemical affinity between cellulose and polymer matrix can be improved by modifying the surface of cellulosic fiber through use of various additives, such as grafting vinyl monomer chain on to fiber backbone or using coupling agents, which can react with both matrix polymer and reinforcing fiber.

To take full advantage of high tensile strength and low weight of these lignocellulosic fibers as a true reinforcing elements in composites, it is necessary to modify natural fibers or plastic matrix to optimize stress transfer, minimize stress concentration and maximize final mechanical properties. The quality of interface is enhanced with the introduction of chemical bonds across the interface or through increased secondary interactions. The surface characteristics of cellulosic fibers are modified by treating the fibers with compatibilizers or coupling agents. After treatment with compatibilizers the surface energy of the fibers is increased to a level much closer to the surface energy of the matrix. Thus, a better wettability and a higher interfacial adhesion can be obtained.

Natural fiber as reinforcements for both thermoplastics and thermosets are one of the fastest growing types of additives in plastics. According to a recent study by Kline & Company, the North American market for wood and agricultural fiber reinforcements was estimated to be in excess of $150 million in 2000 with average annual growth exceeding 20% in automotive applications and 50% in selected construction applications. The primary market force behind these materials will be their low cost. But, natural fiber can offer much more in terms of technical advantages over conventional composites. For example good specific strength, higher stiffness, ease of recycling and a "green" perception, provided the major disadvantages mentioned earlier are addressed.

Novel applications, growth prospects and patenting opportunity have accelerated interest in the wood filled polymer composites. Scientific community, Industrial researchers and universities are working aggressively on developing these hybrid materials and finding new applications for them. Composites of wood flour and PP, PE, or PVC are the buzz in today's business. Dozens of firms are seeking to exploit these materials for manufacturing tough, lightweight window profiles, plastic lumber, and interior auto panels. A very large number of companies worldwide which, till now were in plastic compounding business and even old wood product industries are adding more and more wood filled composites in their product range.

In India, very few companies are producing wood fiber filled thermoplastic composites likes manufacturing of door and window frames, decking, wall cladding etc. Similarly the panels are made from agro-fibre and resin adhesive by compression moulding using a patented technology. The major problem seems to be lack of availability of competitive technologies. Although some research institutes are working in this direction, but a lot more needs to be done, especially with respect to processes conditions and properties.

The Technology

Natural fiber as reinforcements for both thermoplastics and thermo sets are fastest growing types of additives in plastics. Conventionally in India fillers such as clay, calcium carbonate, aluminates, silicates, etc are used to reduce the cost and to improve stiffness of thermoplastics. As on now, natural fibers filled plastics are not commercially popular in India. The technologies used abroad are expensive and often not suited for machineries, production practices and raw-materials available locally. Institute has undertaken a systematic study to improve the interfacial adhesion between natural fibers and matrix materials. At Institute of Wood Science & Technology Bangalore, a co-rotating intermeshing twin screw extrusion system with volumetric feeders and a twin screw side feeder for force feeding of wood fibers into polymer melt was designed for production of wood filled composites (Figure 1). Studies on processes optimization enabled us to constitute screw profiles which produce homogeneous dispersion of fillers with least degradation of matrix resin and wood fibers. By using compatibilizers in the extrusion processes, a chemical compatibility was established in boundary layer.

A novel coupling agent has been developed for wood and other natural fibers filled polypropylene composites. The composites prepared with this coupling agent exhibited much superior mechanical properties when compared to conventional coupling agent like maleated polypropylene. The increase is attributed to superior interfacial adhesion and lower thermal degradation of wood.

Fig. 1 Twin Screw Extruder

Fig. 2. Barrel section of extruder

The system is equipped with two volumetric feeders and a twin screw side feeder. Studies on processes optimization have been completed, and this enabled us to constitute a screw profile for homogeneous dispersion of fillers with least degradation of matrix resin and wood fibers.(Figure 2). Figure 3 shows the schematic diagram of twin screw extruder.

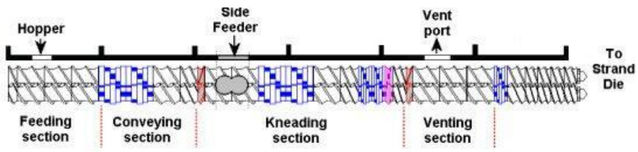


Fig. 3. Screw profile

The study on wood polymer composites has shown that biological fibers and synthetic resins like polypropylene and polyethylene can be combined to make composites that are equally strong, but environmentally friendly. By using a suitable coupling agent it is possible to produce advanced composite materials that take advantages of both natural fibers and synthetic resins. A novel vinyl monomer with isocyanate functional group was synthesized. The maximum grafting yield achieved in this new coupling agent is ~9% as against 1-2% reported for maleated polypropylene. The functional group in this coupling agent gets grafted as single monomer unit without any oligomerization, which further improves its efficiency as coupling agent. Also the isocyanate group of this coupling agent is less reactive to water, this is very important, as side reactions with residual moisture in wood can be avoided. Thus this new coupling agent has proved to be superior than most of the commercially available coupling agents. Mechanism of coupling is indicated in Figure 4.

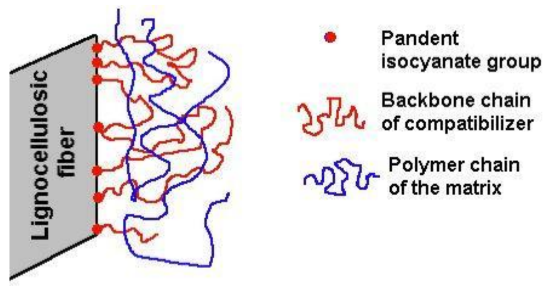


Fig. 4: Mechanism of coupling

Under the study, we have also done complete characterization of the composites. Mechanical properties, chemical ultra-structure, water absorption, thermal behaviour, non destruction evaluation of mechanical properties and damping behaviour of the composite materials have been systematically studied. The study provides complete understanding of the material. In conclusion, the coupling agent synthesized during the study proved to be a much superior coupling agent than those reported in the literature. Addition of wood fibers at all levels leads to significant improvement in stiffness, tensile strength and flexural strength with some loss of impact strength.

The specimen were prepared using Injection Molding Machine (Figure 5)The specimens shown in Figure 6 were used to evaluate the mechanical properties of wood-polymer composites.

Fig. 5. Injection Molding Machine

Fig. 6: Test specimen for evaluation of mechanical properties of WPC

Addition of coupling agent enhances the mechanical, physical properties of the composites.

State of Art Facilities and Expertise

Institute of wood science and technology has very well equipped laboratories with state of art equipments.

Facilities available for work related to the project are as below:

1. A 28 mm co-rotating twin screw extrusion system with segmented screw and segmented barrel attached with twin screw side feeder for force feeding the fillers and two volumetric feeders for metering the feed. The system also has a palletize and a haul-off unit. A new twin screw extruder has been procured which is highly advanced.
2. Haake make torque rheometer for studying the rheology of melt blending of wood and polymers and for small compounding experiments.
3. 60 Ton L&T - Demag make injection moulding machine with mould for ASTM type specimens.
4. 10KN Universal testing machine for evaluating mechanical performance of composites.
5. Instron make pendulum-type impact tester with 1 and 5 J hammers; both Charpy and Izode jigs; notch cutting machine.
6. Laboratory size wood chipper and pulverizer for making wood flour and range of wood processing machineries like sawing, routers" edge bending, wood CNC, etc.

The Institute is having expertise in terms of above equipments and Scientist working in the field. There are five students on different aspects of WPC ranging from developing WPC, Weathering and biological degradation of WPC to Nano-cellulose composites. It was found that *moisture adsorption* was different for different formulations and depended not only on the composition of the impregnates, but also on wood properties. Liquid water uptake was similar regardless of the formulation of the WPC. Wood–polymer composites with novel coupling agent in combination with Jute/ Bamboo displayed enhanced dimensional stabilities. Tangential and volumetric Anti Swelling Efficiency were strongly dependent on the type of treatment and fiber. Dimensional stability and strength properties of the composites can be improved by increasing the polymer content or by addition of coupling agent. (Karmarka et al 2007; Aggarwal et al. 2013; Mohanty et al., 2004; Rahman 2010)

Economics:

Wood plastic composite materials will generally be comparable on price with premium wood products. In the USA, for instance, currently, margins on key WPC products, such as decking, moulding and trims, fencing and windows are attractive as there is little price competition

There is a wide range of factors that need to be taken into account to estimate cost of a WPC manufacturing process. This includes.

- The availability and cost of raw materials (polymer, wood and additives)
- Whether or not to use recycled materials
- Whether to compound in-house or to buy in pre-compounded pellets
- The end use of the product (decking, fencing. door profiles, etc)
- The product performance requirements
- What processing equipment a potential manufacturer currently owns
- The technology / manufacturing background or expertise of the company

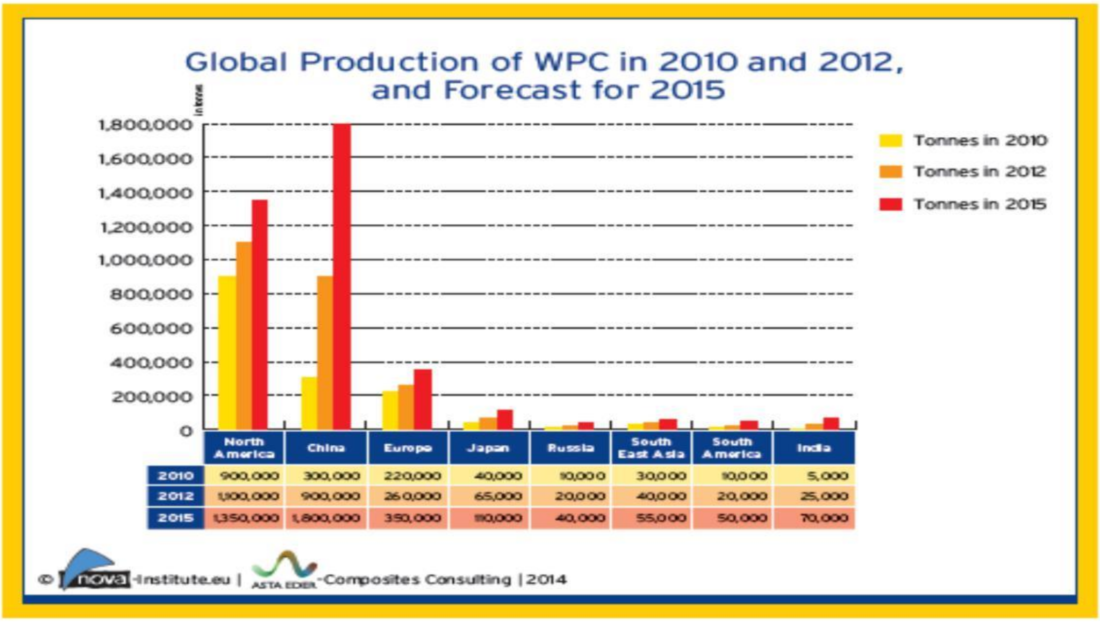
Adding wood fibers to commercial thermoplastics results in significant cost savings and at the same time improved the properties of the composites. Due to cost advantage, plastics can make way into new markets currently occupied by wood and metals like steel and aluminum

Identified End Users

In the age of composites, combining biological fibers and commercial plastics can bring in transition to safer and more environmentally friendly composites. These materials can be used to make lighter, stronger and more durable products that save resources and energy. Long life and eventual recycling can be engineered into these products. Natural/Bio-fiber composites are now emerging as a realistic alternative to glass- reinforced and wood-filled composites. The composites developed have superior mechanical properties (Stiffness, toughness, tensile strength etc.) and could be moulded to any shaped articles or can be calendared into sheets or extruded into complicated profiles. The applications are in the field of moulded products (Furniture components, automobile interior, electrical/electronic appliances etc.) Agencies which can utilize the results of the project are the industries engaged in producing: master batches, moulded product, automobile interiors/panel materials/ dash boards etc, doors and window profiles, decking, toys, storage crates/ brush handles/storage bins, office partitions/railings/floorings, furniture components/garden equipment/benches etc., plastic components for housing electrical and electronic appliances (e.g. T.V. Cabinet).

Market potential

Wood plastic composite materials will generally be comparable on price with premium wood products. In the USA, for instance, currently, margins on key WPC products, such as decking, moulding and trims, fencing and windows are attractive as there is little price competition. The future of wood material industry is no doubt is the WPC. Despite of the fact that, it is a very small market all over the world but is increasing exponentially day by day as the industries considers WPC as one of the most important future technologies.



	Tonnes in 2010	Tonnes in 2012	Number of producers in 2012	Average production per Company	Growth % p.a. 2010 - 2012	Tonnes in 2015	Growth % p.a. 2012 - 2015	Global share in 2015
North America	900 000	1100 000	56	19 643	11	1350 000	7	35%
China	300 000	900 000	422	2 133	73	1800 000	26	47%
Europe	220 000	260 000	62	4 194	9	350 000	10	9%
Japan	40 000	65 000	25	2 600	27	110 000	19	3%
Russia	10 000	20 000	30	667	41	40 000	26	1%
South East Asia	30 000	40 000	45	889	15	55 000	11	1%
South America	10 000	20 000	10	2 000	41	50 000	36	1%
India	5 000	25 000	21	1 190	124	70 000	41	2%
Total	**1515 000**	**2430 000**	**671**	**3 621**	**27**	**3825 000**	**16**	**100%**

Fig. 6 Global trends in WPC production*

[*Source: Global trends in Wood Plastic Composites: 2013. Asta Eder Asta Eder Composites Consulting, Vienna, Austria Michael Carus nova-Institut, Hürth, Germany].

The main reason behind the success of WPC is that the material features a high technical substitution potential. The conventional materials can be replaced in all the important sectors so that wood material market can open up to all the end users. Major production growth rates of WPC can be found in America, Europe and recently in China. Chinese domestic demand for WPC is growing. China’s WPC industry is the second largest in the world after the United States. According to the forecast (Fig. 6) China will reach 33% of the global WPC production in 2015, following the USA, which produces almost half of the total global market share. After China, South East Asia, Russia, South America and India are rapidly emerging WPC markets. It is clear from the above global production of WPC; Indian market has shown 52% growth per year which is the maximum as compared to other developed and fast developing economy. Market report on wood plastic composites can be had from the site: http://www.marketsandmarkets.com. WPC industry is growing rapidly and at present the German WPC market is estimated about 150 USD which is expected to grow to 250 USD million by 2024 (Figure 7). Though the WPC market has developed very well in recent time and the large manufacturer doubled their production rapidly but the smaller manufacturer either have disappeared or suffered loss in business because of lack of funding, staying power and lack of technology. Technical inputs are very much essential in WPC business, which the manufacturer underestimates many a times.

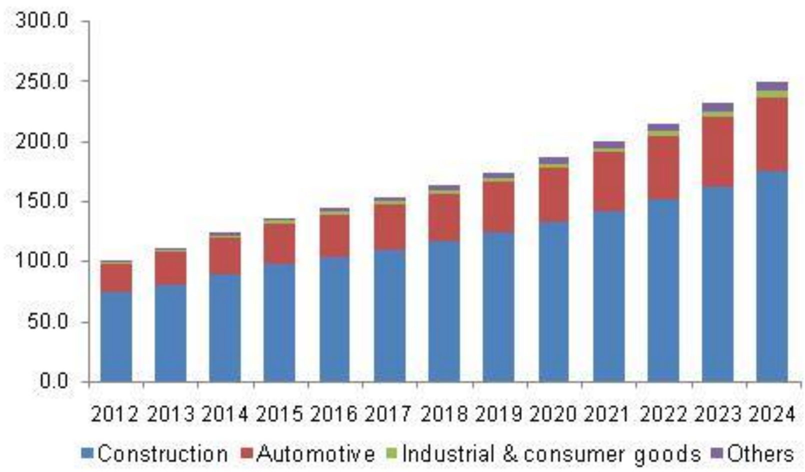


Fig.7. German wood plastic composite market revenue, by application, 2013 – 2024 (USD Million) [Source: Grand View Research, press release, 2016-05-18].

The most important trends for the future are,

- More suppliers, producers, traders; better distribution channels.
- The end customer is fully informed and accepts the product on the market.

- The quality becomes better and the price more attractive
- Further extension of the range of products: in recent years, coffered decking produced by injection moulding, fixing materials, strips, underpayments, etc.
- The door stands open for further building applications. Other manufacturers will make use of this: facades, fence systems etc. However, the bureaucratic obstacles for construction parts such as North America (e.g. bridges of simple residential buildings) are higher in Germany.
- The automotive industry offers potential, but only for big and established manufacturers with top qualities and long-term assured distribution channels.
- The furniture construction sector manages to enter global markets and offers big potential.
- Numerous developments in the consumer goods sector (today: office supplies, advertising materials, outdoor products, urns, flowerpots, but also packing materials and pallets; in the future other mass-produced articles, toys and disposable products).

Technology transfer: Institute has standardized the technology and already in contact with many industries. There is a policy to transfer the technology to interested clients. Institute has established a 'Wood Polymer Composite Research and Training Centre" within its premises and offer three days specialized training course on Wood Polymer Composite. As is clear from facilities and expertise available with the institute, services like testing of WPC for mechanical and physical properties are being provided to the industries.

Deliverables:

From WPC technology, following are the main deliverables:

- A complete technology package for production of wood polymer composite using three agro based fibers extruded product using raw material available in Karnataka will be developed.
- Testing, training, and demonstration to stakeholders.
- Development of eco-friendly material and reduction of usage of plastic.
- Demonstrating concept for new business opportunities for industries.
- Utilization of waste material to eco-friendly and strength material.

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