

Bamboo features the outstanding biologic characteristics of keeping rhizoming, shooting, and selective cutting every year once it is planted successfully, which makes it can be sustainable utilized without destroying ecological environment. This is a special disadvantage all woody plants lack. But compared with wood, bamboo displays a few disadvantages such as smaller diameter, hollow stem with thinner wall, and larger taper, which bring many problems and difficulties for bamboo utilization.

In early 1980', the scientists and technologists put forward a new utilization way of firstly breaking bamboo into elementary units and then recomposing them via adhesives to manufacture a series of structural and decorative materials with large size, high strength, and variety of properties that can be shifted accordance with different desire. Therefore, two main kinds of products, e.g. bamboo articles for daily use and bamboo-based panels for industrial use, were gradually formed.

Bamboo articles, which are made of smaller diameter bamboo culms by means of the procedures of sawing, splitting, planing, sanding, sculpturing, weaving, and painting etc. include a variety of products answering the advocate of loving and going back nature keeping in people recently.

Accordance with their elementary units, bamboo-based panels are manufactured via following four processing ways: (1) Bamboo strip processing method, in which a round bamboo culm is broken into strips including soften-flattened and sawn-shaved ones by means of sawing, splitting, planing etc. (2) Bamboo sliver processing method, which is a popular method that a bamboo segment is manufactured into slivers with thickness of 0.8mm to 1.5mm and width of 10mm to 15mm. The slivers are recomposed into mats by weaving each other or into curtains by weaving them with thread or by assembling them at the same direction to make products. (3) Bamboo particle processing method, in which the small diameter bamboo culms or processing residues are first broken into particles or fibers via chipping, shaving, hot grinding etc. and then manufactured into bamboo particleboard or fiberboard. But the applying fields of the products must be exploited further. (4) Composite processing method, this is a scientific and rational way by recomposing some of above three elementary units or other materials such as wood, paper, cloth, metal, and plastic etc. This favors to utilize the integral properties of bamboo and other materials and is one of most important development direction in material science.

It is our mission to let people in bamboo production nations understand the bamboo industrial utilization and promote the development of bamboo processing industry via the publication of this book.



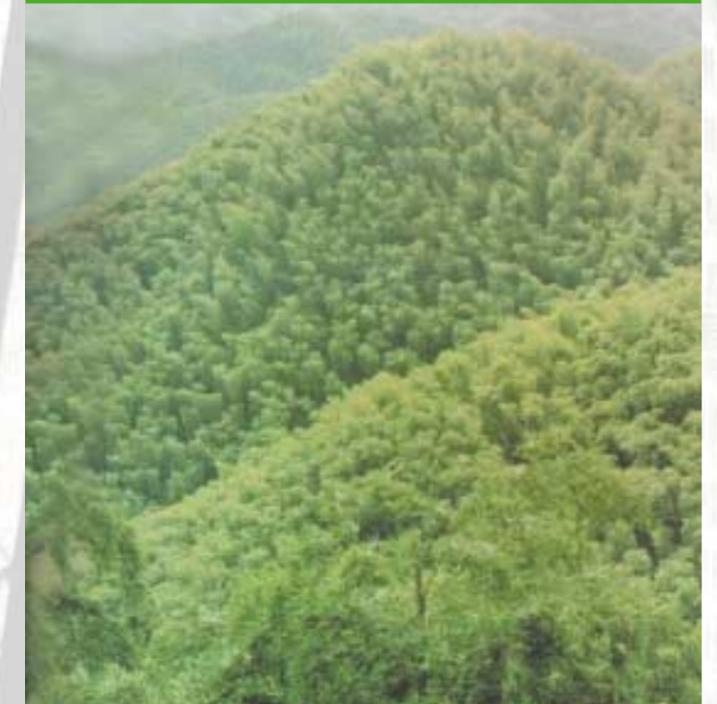
INTERNATIONAL NETWORK FOR BAMBOO AND RATTAN

Industrial Utilization On Bamboo

INBAR

INDUSTRIAL UTILIZATION ON BAMBOO

*Zhang Qisheng,
Jiang Shenxue,
and Tang Yongyu*



INTERNATIONAL NETWORK FOR BAMBOO AND RATTAN

ISBN 962-85124-7-1



9 789628 512478



INTERNATIONAL NETWORK FOR BAMBOO AND RATTAN

The International Network for Bamboo and Rattan (INBAR) is an intergovernmental organization established in 1997 by Treaty. As of January 2003, 27 countries (Bangladesh, Benin, Bolivia, Cameroon, Canada, Chile, China, Colombia, Cuba, Ecuador, Ethiopia, Ghana, India, Indonesia, Kenya, Malaysia, Myanmar, Nepal, Peru, The Philippines, Sierra Leone, Sri Lanka, Tanzania, Togo, Uganda, Venezuela, Vietnam) have become INBAR's member countries. INBAR's mission is to improve the well being of producers and users of bamboo and rattan within the context of a sustainable resource base by consolidating, coordinating and supporting strategic as well as adaptive research and development. INBAR program link partners from the technologies that directly improve the well being of people in developing and developed countries.

INBAR publishes an ongoing series of Working Papers, Proceedings and Technical Reports, occasional monographs, reference materials and the INBAR Newsmagazine. It also provides an on-line library featuring relational databases on bamboo and rattan products, organizations, projects, experts and scientific information.

Financial support for INBAR's programs is provided by the Governments of China and the Netherlands, the International Development Research Center (IDRC) of Canada, and the United National International Fund for Agricultural Development (IFAD).

Anyuan Building No. 10, Anhui Beili, Asian Games Village
Chaoyang District, Beijing 100101, People's Republic of China
Tel: +86 (10) 64956961, 64956978, 64956982
Fax: +86 (10) 64956983
E-mail: info@inbar.int
Website: <http://www.inbar.int/>

Mailing Address:
Beijing 100101-80, People's Republic of China

Disclaimer

Copyright © 2002 INBAR

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior written permission of the publisher.

No responsibility is assumed for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in the material herein.

Printed & published by : Colour Max Publishers Limited.

ISBN : 962-85124-20XXXXXXXXXX

INDUSTRIAL UTILIZATION ON BAMBOO



Zhang Qisheng, Jiang Shenxue, and Tang Yongyu

2001.8.5

P R E F A C E

Bamboo grows fast and matures early. The output of bamboo plantation is great and the use of bamboo stem is wide. Once successfully planted, bamboo plants keep on rhizoming, shooting and maturing every year. The annual selective cutting and sustainable utilization can be implemented without damaging ecological environment. The world is facing rapid decrease of forest resources and suffering serious deterioration of ecological environment. Therefore the development and exploitation of bamboo resource is of considerable importance.

The morphology, structure and chemical components of bamboo differ from those of timber. Consequently, the methods, technology and equipment for timber processing can not be applied indiscriminately in bamboo utilization. This is one of the direct reasons why bamboo is utilized only for manual weaving, simple ware making for hundreds of years.

China is one of the main bamboo-producing countries of the world, possessing bamboo plants of more than four hundred species of forty genera. The total area of bamboo resource is 4,210,000 ha, with annual production exceeds eight million ton, analogous to eight million cubic meters of wood. The rational exploitation of bamboo resource is of great value to the development of China's economy and the protection of ecological environment. In recent twenty years both China and foreign countries paid attention to the industrial use of bamboo, developed plybamboo, laminated bamboo, plybamboo of curtains, bamboo composite board, bamboo chipboard and various bamboo wares of daily use. These products are widely used in vehicle making, building industry, furniture making, interior decoration and packaging.

In order to promote the development of technology for industrial use, International Network for Bamboo and Rattan subsidizes for the compilation and publication of *The Industrial Use of Bamboo*. The chief editor of this is Zhang Qisheng, academician of Chinese Academy of Engineering, professor at Nanjing Forestry University, co-chief editors are Tang Yongyu, professor at Hangzhou Bamboo Centre of State Forestry Bureau, Jiang Shenxue, associate professor at Nanjing Forestry University. Zhu Shilin, researcher at Chinese Academy of Forestry translated the text into English. This book is composed of three parts. The 1st chapter of part one is written by Yin Sici, professor at Nanjing Forestry University, the 2nd, 3rd chapters of part one and 1st and 2nd chapters of part two are by Professor Zhang Qisheng. The 3rd, 4th and 5th chapters of part two are written by Associate Professor Jiang Shenxue, the 6th chapter is by Associate Professor Zhu Yixin. The 1st, 2nd and 3rd chapters of part three are written by Professor Tang Yongyu. The 4th chapter of part three is written by Professor Tang Yongyu in cooperation with Xu Huadang, engineer of Chengzhou Bamboo Weaving Factory. The whole book is planned and revised by Professor Zhang Qisheng.

This book, as the authors' understanding of related problems is limited, cannot in the nature of things be free from error. We would be grateful for comments and suggestions from readers.

Authors
2001.08.05

C O N T E N T S

PART I. A brief account of bamboo	1
Chapter I. Structure and properties of bamboo material	1
Section 1. Bamboo Resources	1
Section 2. The structure of bamboo material	5
Section 3. Bamboo properties	19
Chapter II Specific features and classification of bamboo-based panels	26
Section 1. Specific features of bamboo based panels	26
Section 2. The classification of bamboo based panels	29
Chapter III Structure and physico-mechanical properties of bamboo-based anels	35
Section 1. Structure of bamboo-based panels	35
Section 2. Physico-mechanical properties of bamboo-based panels	38
PART II. Manufacturing technology of bamboo-based panels and their uses	43
Chapter I. Plybamboo	43
Section 1. The collection of raw material	43
Section 2. The processing of bamboo fragments	48
Section 3. The adhesive coating of veneers and their further processing	58
Section 4: The uses of plybamboo	67
Chapter II Combined bamboo and bamboo flooring	76
Section 1. The structure of combined bamboo and bamboo flooring	76
Section 2. The processing technology of combined bamboo and bamboo flooring	78
Section 3. Main factors influencing the quality of products	84
Section 4: Bamboo flooring: paving and maintenance	88
Chapter III. Plybamboo of slivers	90
Section 1. Woven-mat plybamboo	90
Section 2. Curtain plybamboo and mat- curtain plybamboo	94
Section 3. Glued sliver plybamboo	98
Chapter IV Bamboo chipboard and bamboo chip composite board	101
Section 1. Bamboo chipboard	101
Section 2: Bamboo chip composite board	105
Section 3. Bamboo chip composite board overlaid with resin-impregnated paper	107
Chapter V. Bamboo-wood sandwich composites	109
Section 1. General survey	109
Section 2: Sandwich composites overlaid with resin-impregnated paper for concrete-form	110
Section 3. Bamboo-wood sandwich composites for container floor	113
Section 4. Bamboo-wood composite panel	117

Chapter VI. Technological design for factories of bamboo-based panels	121
Section 1. Principles and procedure of technological design	121
Section 2. The technological design of plybamboo product line with an annual output of 4000 m ²	128
Section 3. The technological design of bamboo-flooring production line with an annual output 100,000 m ²	134
Section 4. The design of plybamboo production line with an annual output 3000 m ³ for making concrete form	140
Section 5. The design of bamboo chipboard production line with an annual output 10000 m ³	144
 PART III. Bamboo articles for daily uses, bamboo carbon	 151
 Chapter 1. Bamboo mats	 151
Section 1. Mats of fine threads	151
Section 2. Domino mats	155
 Chapter 2. Bamboo chopsticks	 158
 Chapter 3. Bamboo slips	 161
 Chapter 4. Bamboo furniture	 163
Section 1. Techniques and tools for making traditional bamboo furniture	163
Section 2. Tenon and mortise joint	172
Section 3. Facial plate of bamboo furniture	178
Section 4. Decorative pattern on framework of bamboo furniture	182
Section 5. The making process of traditional bamboo furniture	185
 Chapter 5. Bamboo charcoal and bamboo active carbon	 197

PART I. A brief account of bamboo

Chapter I. Structure and properties of bamboo material

Bamboo material can be obtained easily in all stages of human culture development. It is always utilized actively by the techniques of the time. But it is a quite complicated biological material. With the progress of science and technology, the utilization of bamboo is diversified continuously, and it becomes one of engineering-structural material. In order to utilize bamboo effectively under modern scientific and technological conditions it is necessary to study its structure and properties.

The purpose of scientific research is to probe the unknown. Some of the research results may not of direct and practical value in production, but the deep knowledge of the objective world will bring about active material effects finally.

Section 1. Bamboo Resources

1. The status of bamboo plants in taxonomy

The specific features of plants are stabilized living and self-supporting.

There are two phyla in plant kingdom: angiosperm and gymnosperm. Flowering is one of the specific features of angiosperm. There are ovules in the ovaries of flowers, which develop into seeds after pollination and insemination, while ovaries develop into fruits. The seeds are enclosed in fruits. Such plants are called angiosperms or flowering plants.

The sexual reproduction process of gymnosperm is greatly similar to that of angiosperm. Their seeds are formed in the same way of pollination and insemination. But their reproductive organs and propagating process differ evidently from those of angiosperms. Instead of flowers of angiosperms, spores are formed in the propagating process of gymnosperms. For example, on the newly emerging branches of pines reproduction organs – megaspores and microspores are formed. Microspores are formed on the base part of branches, and develop into pollens. Megaspores are formed on the top of new branches with ovules, which turn into cones after pollination. The seeds are not enclosed within an ovary.

Angiosperms are divided into monocotyledon and bicotyledon.

The embryo of monocotyledon has only one cotyledon, vascular bundles in stems are arranged radially, with primary tissue, without cambium and secondary tissue. The leaf veins are parallel or curve. The main root is not developed, the root system is fibrous in general.

The embryo of bicotyledon has two cotyledons, the vascular bundles are arranged on the cross section of stem in circle form, with cambium and secondary tissue. The leaf veins are netted as a rule, the main root is developed.

Bamboo plants are divided into the subfamily of Bambusoideae, family of Gramineae, order of Graminales, class of Monocotyledons, subphylum of Angiosperms and phylum of Spermayophyta.

Both Bambusoideae and Gramisoideae are under the family of Gramineae. The differences are as follows: Plants of Bambusoideae are woody and perennial, the stem and haulm lignify intensively, the petioles of leaves are short, there are joints between the leaves and sheaths, consequently, the leaves fall easily. Members of Graminsioideae are herbs, the leaves are connected to sheaths directly without petioles, they hardly fall from sheaths.

2. The distribution of bamboo plants

There are more than 1200 species of 50 genera of Bambusoideae in the world, mainly distributed in tropical and subtropical areas. China is one of the centers of bamboo growth, possessing about 400 species of 50 genera, the area of bamboo growth exceeds 4.21 million ha.

There are few indigenous bamboo species in North America, no naturally distributed bamboo plants in Europe. In recent years bamboo plants are introduced into these continents.

3. Bamboo morphology

A. Rhizome

The underground part and tubers of bamboo compose its rhizome system. The rhizome has nodes and inter-node parts. There are small, degenerated scale-like leaves on nodes, axillary buds and adventitious roots on leaf auxils. The axillary buds can grow into shoots or bamboo culms.

Some scholars consider the rhizome as the main stem of bamboo and the culm as branch. Bamboo culms scattered over brush land are connected with one or some underground stems. But in the eyes of bamboo material researchers bamboo culm is the main object of study

Facts are most important: bamboo culm is growing on the rhizome. But from the viewpoint of bamboo utilization bamboo culm is regarded as its main stem in this book.

B. Stem

In the industrial utilization of bamboo, particularly for making bamboo-based panels, stems of large-scale bamboo species are selected. The stem consists of three parts: stem, stem base and stem petiole.

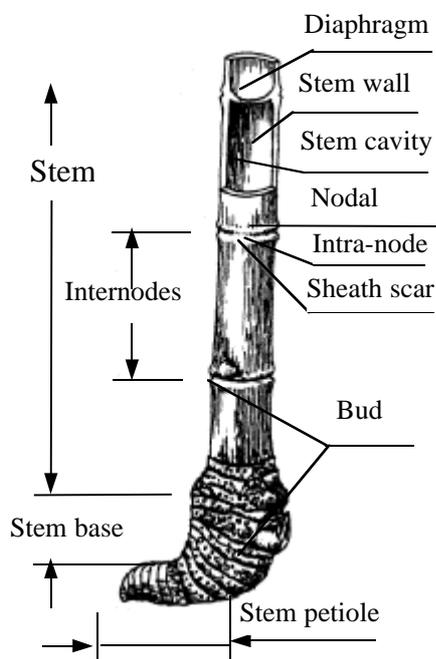


Fig. 1.1 Three parts of bamboo stem

Stem is the over ground part of bamboo, it is straight and cylinder-formed with nodes, and the parts between nodes are called inter-nodes. Every node has two closely positioned rings, the lower one is called sheath ring, a scar formed after the falling of sheath. The upper one is called stem ring, a scar formed after the growth-cease of inter-node tissue. The part between

the rings is the node itself. There is a wooden partition between two neighboring inter-nodes, which strengthens the stem. The length of inter-nodes, the number and form of nodes depend on the species of bamboo. The inter-nodes are hollow inside, which form bamboo cavities. The thickness of stem wall varies greatly in accordance with different bamboo species. Sometimes there are solid bamboo stems. The cross section of bamboo stem is circular (to some extent oval), triangular or nearly square.

Stem base is the lower part of stem, it extends into soil to connect with root system. Stem base consists of numerous short sections, the diameter is quite significant, adventitious roots grow densely on the sections^[1]. On the stem bases of some bamboo species there are up to ten alternate buds, which grow into shoots and then bamboo stems; on those of some other species the buds are fewer, they can grow into rhizome.

Stem petiole is the lowest part of stem, consists of tens of short sections, the diameter of sections decreases with the depth of petiole. Stem petiole is solid in general, with degenerated leaves, without buds.

Table 1-1. The characteristics of three parts of bamboo stem

Position Features	Stem	Stem base	Stem petiole
	Above ground	Underground	Underground
Morphological features	Straight	Curve	Horizontal circular cone
Existence of buds and their development	Buds on upper parts develop into branches those on lower parts fall.	Buds develop into shoots and stem, or into rhizome.	Without buds.
Cross section	Hollow in general, stem of some species is solid.	—	Solid in general, stem petiole of some species is hollow.
Rooting	—	Dense adventitious roots.	Without roots

C. Morphological features of rhizome

There are three types of rhizome from the viewpoint of morphology (Fig. 1-2).

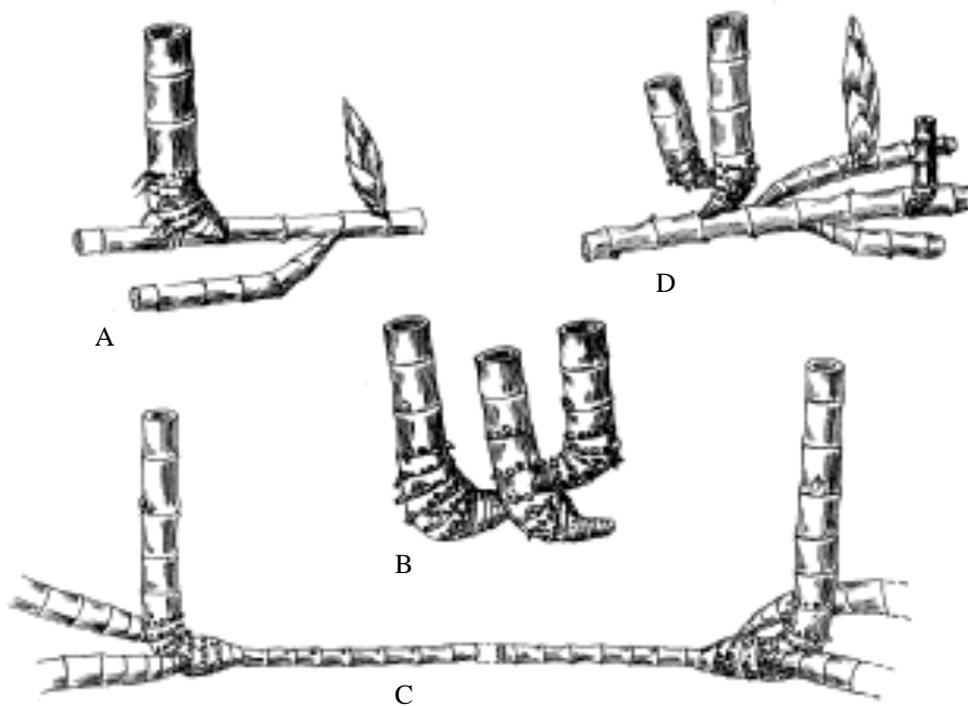
(1) Monopodial type: axillary buds on stem base develop into rhizome. Rhizome is thin, extending horizontally for long distance underground. Rhizome consists of nodes and inter-nodes. Degenerated leaves and roots grow on nodes. There is one bud on every node. Some of the buds grow into new rhizome in soil, some into shoots, turn out of soil and develop into bamboo stems. Bamboo stems of such species grow in scattered state, forming scattered bamboo brush.

(2) Sympodial type: axillary buds on stem base develop into shoots directly and turn out of soil, then grow into new bamboo stems. In the next year axillary buds on stem base of new stems develop into new shoots and grow into new bamboo stems again, thus the propagation cycle is repeated and an underground rhizome system of mother bamboo and new stems formed. Such underground rhizome system cannot extend for long distance. But the length of stem petioles is different, some of them are short, new stems from these petioles grow closely. This is a sub-type of sympodial-tufted brush.

Petioles of some species are longer, forming false rhizomes, which extend for a certain distance (50 ~ 100 cm). New bamboo stems grow in this way are scattered. This is a sub-type of sympodial-scattered brush.

(3) Mixpodial type: axillary buds on stem base of mother bamboo develop into root rhizome, which extends in soil horizontally, the axillary buds on rhizome nodes develop into new stems in scattered state, meanwhile axillary buds on new stem base develop into shoots and form dense bamboo brush. Such underground rhizomes incorporating the features of both monopodial and sympodial types are of mixpodial type, or mixed brush.

Underground rhizome is the main indicator for taxonomic identification of species of Bambusoideae. This means the type of rhizome of every bamboo species is fixed, it determines the distribution of bamboo stems above ground.



A.monopodial. B. sympodial tufted. C. sympodial scattered. D. mixpodial.

Fig.1-2. Types of underground rhizome

4. Bamboo propagation

Flowering and fruit bearing are the common features of seed plants. The flowering cycle of bamboo plants is irregular, from 30 to 40 years or more. As a rule, the flowering phenomena of bamboo plants of one and the same species are concentrated in a short period of time. If a bamboo brush flowers, all the plants of the same species located even at a distance of hundreds of kilometers away will follow closely in several years, no matter of different ages. Most of the bamboo plants flowers only once in their lifetime. They die after flowering and fruit bearing, thus the brushes decline and fall. The underground rhizomes of bamboo are very vigorous in asexual propagation. The introduction and rejuvenation of bamboo are carried out by means of nutrient medium.

Flowering is a natural phenomenon if the lifetime of bamboo plants. Sexual propagation makes plants more vital and more adaptable to environments. But as knowledge of flowering and fruit bearing is insufficient, such a phenomenon can not be used successfully.

The germination percentage of bamboo seeds rightly after harvesting is rather high. The seedlings are vigorous and their survival rate is also high. Chinese experts have had successful experiences to raise seedlings of *Phyllostachys pubescens*. Indian scholar Aietrich Brandis reported that some Indian bamboo species had been introduced successfully to Tanzania by means of seeds in 1900. All these facts are inspiration to professionals engaged in bamboo cultivation and utilization.

Section 2. The structure of bamboo material

1. The growth of bamboo plants

The structure of bamboo material depends closely to the age of plants.

Bamboo growth can be divided into three phases: underground shoot growing, stem forming and stem maturing. There are three types of underground rhizomes, therefore the underground shoot growth differs slightly in connection with the type of rhizome. But the growth and development of second and third phases are similar.

A. Underground shoot growing

The strong axillary buds of underground part of bamboo plants develop into shoot buds under proper humidity. After continuous cell division and differentiation of apex meristem the number of nodes of whole shoot (i.e. whole stem) is fixed underground, it will never increase in second and third phases of growth.

The apex meristem is the primary source of plant growth. The cells derived from it are capable of bifurcating. The apex meristems active only in the period of height growth, while those of needle-leaved and broad-leaved trees active in longer period of time.

The growing and maturing process of cells derived from apex meristems is of primary growth. At the beginning of this process the derived cells are still capable of bifurcating, but, meanwhile, they are differentiating. This makes them different from apex meristems. Bamboo plants are capable of primary growth. The primary meristems derived from apex meristems are called intercalary meristems. In the period of height growth of young bamboo stems vigorous intercalary meristems are distributed on all the inter-nodes of stem. The intercalary meristems and their primary growth differ greatly from those of needle-leaved and broad-leaved trees (table 1-2).

B. Stem forming – height growth of young bamboo

Bamboo grows most rapidly in plant kingdom. It reaches the height of mature bamboo of 15 ~ 30 or 40 meters within 40 ~ 120 days.

The height growth of bamboo shoots and bamboo stems is realized by the growth of inter-nodes by intercalary meristems distributed in them. The sum of growth in length of all inter-nodes is the total height growth of bamboo stem.

The period of time from the coming up of shoot to the end of height growth depends on the bamboo species. The growth increment of *Phyllostachys pubescens* in China is significant, for early shoots the period lasts about 60 days, for later shoots 40 ~50 days.

In the inter-nodes near apex of young shoot the cells divide evenly. In inter-nodes in the middle the cell division of upper part is weaker than that in lower part. Such a tendency becomes more evident from apex to base. In 1 ~ 4 inter-nodes near base cell division is very weak in lower part, and in upper part the division almost stopped.

Table 1-2. Difference of primary growth between bamboo and trees

Material Items	Main stems of bamboo plants	Trunks of needle-leaved and broad-leaved trees
Location of primary bifurcating tissues	Whole inter-nodes are formed from intercalary meristems (primary bifurcating tissues) at the beginning. In the process of height growth intercalary meristems are distributed separately in all the inter-nodes of stem.	Located only near the apex of trunk, limited in the area before secondary growth.
Active time of primary meristems	All the intercalary meristems in inter-nodes are capable of bifurcating until the end of height growth.	The location of primary meristems near apex raises with the height growth of trunk until the secondary growth tissues form on apex.

Cell division in nodes is weaker than that in inter-nodes, this shows the aging process of tissues in this part is quicker than that over or under nodes.

The growth of all inter-nodes does not begin simultaneously. It begins from the inter-nodes near base at first. The speed of growth is also different in inter-nodes. The speed is “slow – quick -slow” from base to apex. At the end of height growth the inter-nodes near the middle are longer than near the apex and base.

In the process of height growth the diameter of stem and the thickness of stem wall also increase, but in comparison with the height growth, they are quite insignificant.

During the peak-hours of growing, the height growth reaches 1 meter in one day and night. The height growth can be completed in a short period of time (40 ~ 50 days). This because the intercalary meristems are widely distributed in all the inter-nodes, and cells divide in all inter-nodes fully and actively.

The division and differentiation of cells take place in intercalary meristems simultaneously. As a matter of fact, intercalary meristems and differentiated cells still continue their division, producing new cells separately, thus promoting the growth of inter-nodes.

Cell division occurs from the upper part of inter-nodes at first, extending downward, this is the enlargement of different cells. The length of fiber increases significantly, from some microns to 2 ~ 3 mm, about a hundred-fold increase.

Along with the enlargement of cells the cell wall becomes thicker. At the same time lignification is the most important step to the improvement of bamboo material. The content of lignin increases continuously in bamboo material.

Consequently, both the structure and quality of bamboo material change in the period of height growth.

C. Stem maturing – a process of bamboo maturity

After the completion of height growth, the height, thickness and volume of bamboo stems do not change evidently. But the tissues of young bamboo stems are tender, with high moisture content. The basic density of young *Phyllostachys pubescens* is only 40% of that of matured ones. This means the rest 60% of density must be obtained in further maturing process. This is of vital importance to the quality of bamboo material. In processing and utilizing of bamboo material close attention should be paid to this problem.

The maturity process can be divided into three phases: improving, stabilizing and declining. In improving phase cell wall thickens and basic density increases, moisture content decreases and physical and mechanical properties increase. In the second phase the quality of bamboo stem reaches the peak and becomes stable. The quality of stem material in the third phase is thought to have a declining tendency.

Stem quality depends on the age and species of bamboo plants. The life of *Phyllostachys pubescens* is longer, stems of 8 years are still in improving phase, those of 6 ~ 8 years in stable phase and 9 ~ 10 years in declining phase.

Table 1-3 shows the differences between bamboo and timber, which is the summary of bamboo growth.

Table 1-3. Differences between bamboo and timber

Material Items	Bamboo	Timber
Height growth	<ol style="list-style-type: none"> 1. Height growth completes within 2 ~ 4 months. 2. It is mainly by intercalary meristems. 3. Height growth begins and ends in different inter-nodes not simultaneously, but whole growth process is realized by intercalary meristems. 	<ol style="list-style-type: none"> 1. Height growth lasts in all lifetime of tree, the speed of growth declines with aging. 2. Height growth is realized by primary meristem on apex. 3. Height growth does not take place on secondary growth tissue.
Diameter growth	<ol style="list-style-type: none"> 1. In the process of height growth of “shoot – young bamboo”, the diameter of stem and the thickness of stem wall increase slightly. 2. After the completion of height growth the diameter does not increase. 	<ol style="list-style-type: none"> 1. The growth of diameter is realized by cambium. 2. Diameter growth lasts in all lifetime of tree.

2. Concepts of composition of bamboo material

A. Composition and structure

The composition and structure of bamboo material are different in meaning. Composition means the matters of which bamboo material is composed, this is studied from the viewpoint of chemistry. The structure of bamboo material is observed under microscopes of different magnifying power. This is studied from the viewpoint of physics.

B. Structure observed by different means.

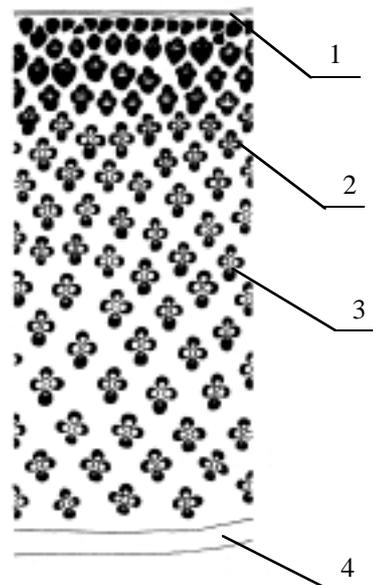
The structure of bamboo material is the morphology observed by different means. Structural characteristics observed by naked eye or by means of magnifying glass are called macrostructure – morphology of tissues composing the material. Structural characteristics observed with the aid of optical microscope up to 1600-fold are called microstructure – morphology of cells composing the material. Structural characteristics observed by means of x ray and electron microscope are called super-microstructure.

It is possible to study the lignification process of stem using bamboo slices with the agent coloring lignin. Microscopes can be used with ordinary light, ultraviolet light or polarizing light, they are applied for different research purposes. Microscope with ultraviolet light can be applied to study the level of lignification with the help of special coloring agent. Microscope with polarizing light can be applied to study the structure of cell wall.

The structure observed under microscopes of 6.5-, 8- and 12-fold showed morphological features of vascular bundles of different bamboo species, which caused regular results of comparatively higher academic value. All the research results gained by means of microscopes of different magnifying power perform their own specific functions, therefore all the results should be studied comprehensively.

3. Macrostructure of bamboo material

The macrostructure of bamboo material is observed with naked eye or under magnifying glass (see fig. 1-3). There are many dark rhomboid speckles on the cross section of stem wall. They look like strands of tissue in the grain direction on lengthwise surface. These are vascular bundles, which can be picked out with a knife.



1. Bamboo skin. 2. Fundamental tissue. 3. Vascular bundles. 4. Pith
Fig.1-3. Macrostructure of cross section of stem wall

Bamboo stem wall is composed of three parts: bamboo skin, bamboo timber and pith.

Bamboo skin is the outermost part of cross section of stem wall, where no vascular bundles are seen.

Pith is the part of stem wall next to bamboo cavity, it does not contain vascular bundles tool. Bamboo timber is the part between skin and pith. Vascular bundles are observed on its cross section, among vascular bundles are fundamental tissues.

The density of vascular bundles decreases from outer side of stem wall to inner side. The outer part where vascular bundles are dense is call bamboo green, while the inner part where vascular bundles are rare is called bamboo yellow.

4. Cells of bamboo material

A. Cells and tissues

Bamboo material is composed of cells. Cells are its basic morphological units. The depth of bamboo structure research depends on the means applied. The specific structural features of bamboo material and differences between different species are shown on the images observed under microscopes of different magnifying power. Super-microstructure shows more commonness of bamboo material of all species. Every structural image is of unique use in industrial utilization.

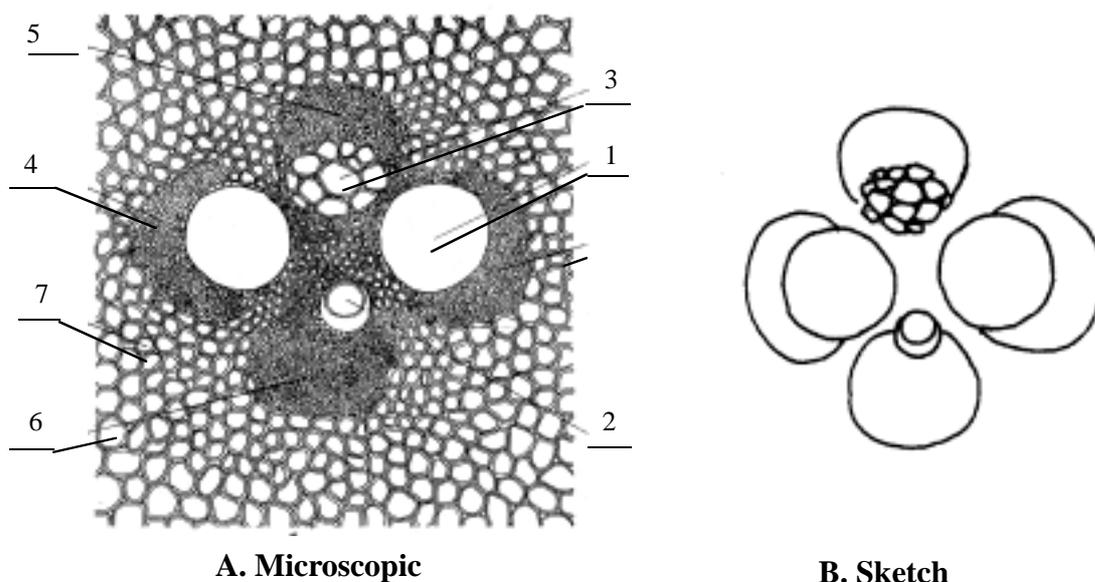
Bamboo is a kind of high-grade raw material in papermaking. Fibers are the cells of bamboo material composition. Cells are basic units in bamboo structure and of great academic value in scientific research.

Bamboo plants demonstrate prominent adaptability to environments, possessing cells of different physiological functions, morphological and structural features. All these cells of similar functions compose bamboo material. Vascular bundles shown in macrostructure are the tissues of structure.

B. Tissues in bamboo structure

It is recommended to observe different tissues under the microscope of lower magnifying power, then move the tissues to be studied further to the center of image and raise the magnifying power. Therefore, it is of great importance to study the different kinds of cells and their positions in bamboo stem wall.

The tissues of bamboo stem include surface system (epidermis, subcutis, cortex), fundamental system (fundamental tissues, pith rings, piths) and vascular system. The surface system is bamboo skin, located in outermost part, pith rings and piths located in innermost part. They form the outer and inner surface layers of stem wall, protecting the fundamental tissues and vascular system closely. Vascular bundles are distributed among the fundamental tissues of stem wall. They look like a plum flower of four petals (Fig. 1-4).



1. Vessel of post-xylem. 2. Vessel of proto-xylem. 3. Primary phloem. 4. Side fiber cap. 5. Outer fiber cap.
6. Inner fiber cap. 7. Parenchyma cell of fundamental tissue.

Fig.1-4. Cross section of vascular bundles

The most evident specific features of vascular bundles under microscope are a pair of eye-like cells, which are the post-xylem. Move these cells into horizontal position, and the phloem in the form of mesh can be seen above or under them, and opposite is the proto-xylem. The position of phloem is in outer side of stem wall and proto-xylem in inner side.

Around vascular bundles are fiber sheaths, on the outer side are outer fiber caps, to the side of pith cavity are inner fiber caps, on the other two sides are side fiber caps. The above-mentioned situation is the position of vascular bundles of stem wall in scattered bamboo brush. The structure of vascular bundles of tufted bamboo is different from that of scattered bamboo. Vascular bundles of tufted bamboo are composed of central vascular bundles and fiber bundles (Fig. 1-5).

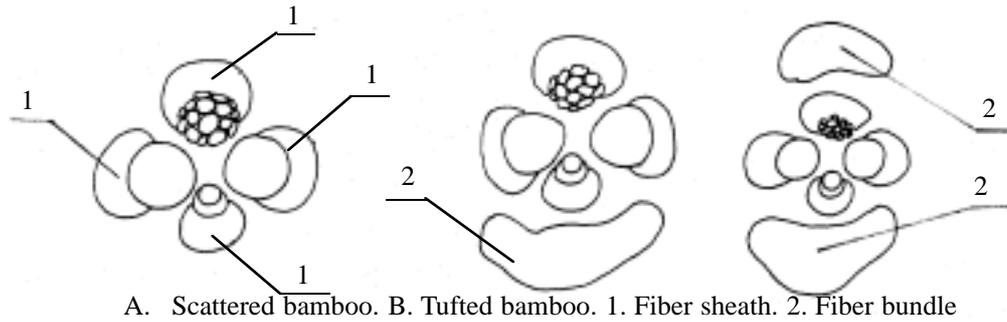


Fig.1-5. Fiber bundles and fiber sheaths in vascular bundles of bamboo stem wall

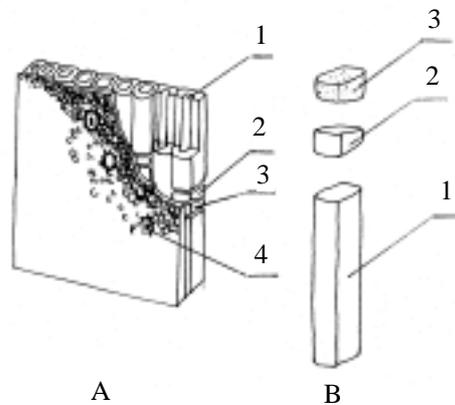
The phloem texture in vascular bundles of bamboo material is analogous to the bark of needle-leaved and broad-leaved trees. The proto-xylem and post-xylem in vascular bundles of bamboo are analogous to xylem of needle-leaved and broad-leaved trees. Therefore the structure of vascular bundles of bamboo is analogous to trees. But there is no cambium in vascular bundle of bamboo, consequently, no diameter growth after the completion of height growth. Besides there are no crosswise ray tissues in bamboo material..

C. Cell structure of bamboo

The structure of bamboo cells is as follows:

(1) Surface system:

a. Epidermis: Epidermis is the cells of outmost layer, composed of oblong cells, phellem cells, silice cells and stomatal organs (Fig.1-6).



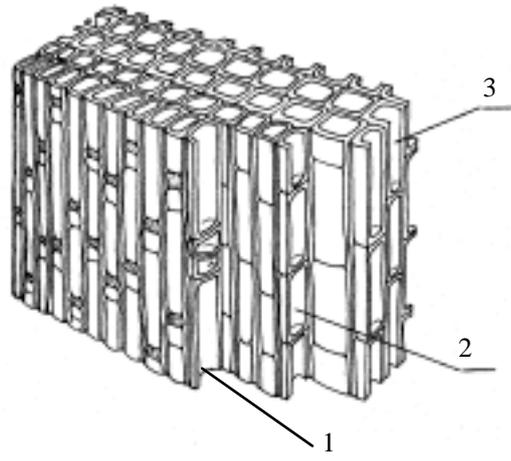
A. Hologram B. Cell morphology
B. 1. Oblong cell. 2. Silice cell. 3. Phellem cell. 4. Stomatal organ.

Fig. 1-6. Epidermis of bamboo

b. Oblong cells occupy most of the surface area, arranged in parallel order along the grain. Phellem cell and silice cell are smaller, they are always positioned in pairs, inserting into the area of oblong cells. Phellem cells are ladder-shaped (hexahedron), with thinner end located outer-ward. Silice cells are triangular (hexahedron or pentahedron), with apex inner-ward. The cross section of epidermis cells are square or rectangular formed, they are arranged closely without gap. The outer wall is always thickened. Many pores are distributed on epidermis as stomas.

b. Subcutis: Subcutis cells are columnar, distributed closely to epidermis, arranged in lengthwise order. Their cross section is square or rectangular. Cell wall is quite thick. Subcutis of most species is formed of cells of one layer, some of them of two layers (Fig. 1-7).

c. Cortex: Cells of cortex are columnar, distributed closely to subcutis, arranged in lengthwise order. The cross section of cortex cell is oval or rectangular, larger than subcutis cell. Cortes cells of some of the bamboo species are not evidently different from subcutiss cells (Fig. 1-7).

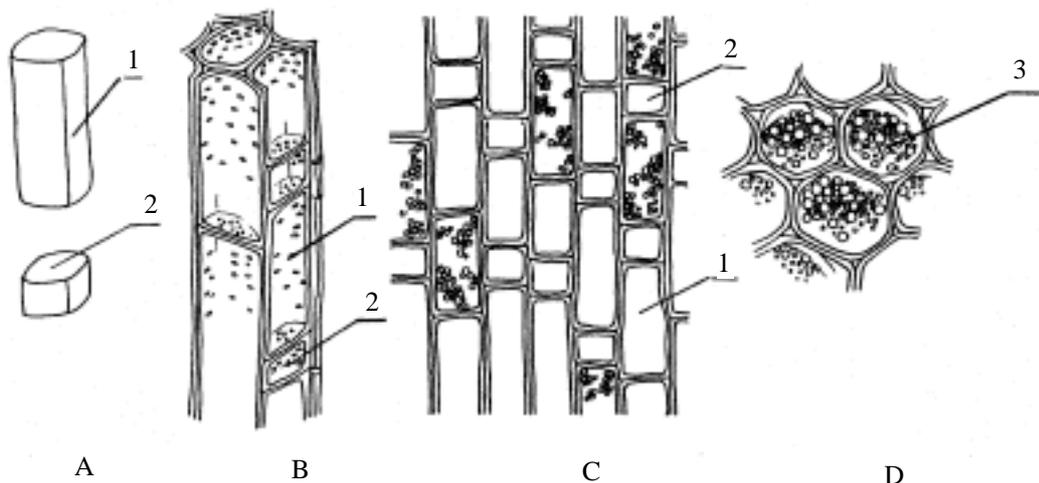


1.Epidermis. 2. Subcutis. 3. Cortex.

Fig. 1-7. Surface system of bamboo stem.

(2) Fundamental system

a. Fundamental tissue: Fundamental tissue is parenchyma, mainly distributed within vascular system as stuffing material. These are the fundamental part of bamboo material and are called fundamental tissue (Fig. 1-8).



A. Morphology of parenchyma cells of fundamental tissue
 B. Parenchyma cells of fundamental tissue tied vertically
 C. Parenchyma cells in the vertical section of fundamental tissue
 D. Cross section of fundamental tissue
 1. Oblong cell. 2. Short cell. 3. Starch grain

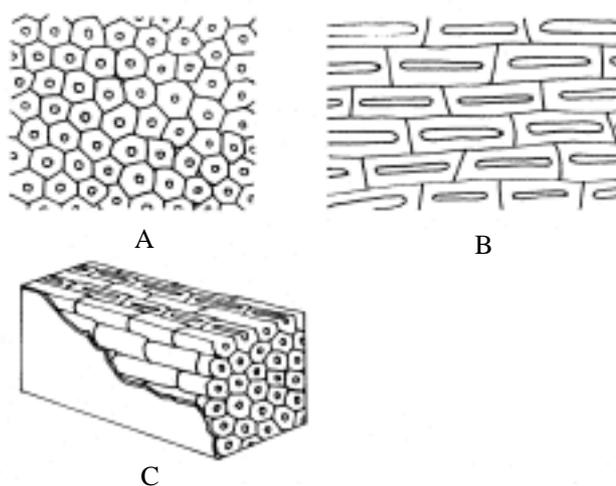
Fig. 1-8. Parenchyma cells of fundamental tissue of bamboo stem

Most of the cells are larger, with thinner wall. The cross section is similar to circular, with evident gap. Pores on lengthwise wall are more than crosswise wall. On the vertical section cells can be divided into oblong ones and rectangular (approach to square) ones. Most of the cells are oblong, short ones are distributed among them.

The wall of oblong cell is multi-layered, lignified at the beginning of shoot growth. The lignin content of wall is high, with tumor layer attached. The wall of short cell is thin, the cytoplasm is dense and the nucleus is distinct. Short cell does not lignify even the whole stem is matured. The physiological functions of these two types of cells are not thoroughly learned at present. The parenchyma cell wall of broad-leaved trees is of pure cellulose without tumor layer. Perhaps lignification process is the precondition of the development of tumor layer.

The starch content of oblong parenchyma cells in bamboo stem of 1 ~ 2 years of age is abundant. But in those of bamboo stem younger than one year there is hardly any starch, and there is no starch in those of older bamboo stem. Short cells also contain no starch, even if their wall thickened.

b. Pith ring: Pith ring is distributed on the outside of bamboo membrane around pith cavity. The morphological features of its cells differ from those of fundamental tissue. They are short-columnar, arranged like bricks in inner wall of a chimney (Fig. 1-9). The cell wall thickens with aging. Sometimes the cell develops into stone cell.



A. Morphology of pith ring cells observed on vertical section. B. Morphology of pith ring cells observed on tangential section. C. Microscopic stereoscopic morphology of pith ring cells.

Fig.1-9. Pith ring of bamboo stem.

Stone cells are formed of parenchyma cells. They differ from neighboring cells by larger nucleus at the beginning. They grow very fast and branch into gaps among nearing cells. All the surface parts of wall grow rapidly at the same time. When stone cells get matured, the secondary wall deposits and thickens then. The forming of stone cell is mainly realized by secondary wall. The thickening process of wall shows unique features and creates morphology differing from neighboring parenchyma tissue.

a. Pith: Pith is formed of larger parenchyma cells. The pith structure declines and leaves a hollow space, which is the pith cavity of bamboo stem. The pith turns into a semitransparent membrane, attaching to the inner wall of bamboo stem. There are also solid bamboo stems with pith.

(3) Vascular system

The vascular system is mainly composed of xylem and phloem. The former transmits water and inorganic salts upwardly, the latter transmits the products of photosynthesis downwardly.

The xylem in vascular bundles of bamboo stem is composed of proto-xylem and post-xylem. The proto-xylem formed earlier and post-xylem later. Most of the post-xylem matures after the completion of height growth of stem, while the proto-xylem matures during the height growth. Consequently, post-xylem is less affected by neighboring tissue elongation. Although there are some differences between these two types of cells, they form an intermediate state of transition, and it is difficult to draw a line of demarcation. Part of proto-xylem is hurt by tissue elongation around. Post-xylem functions normally in the maturing process of stem after height growth.

Primary phloem and primary xylem are located opposite to each other, the former is in outer side and the latter is in inner side. Phloem can be divided into proto- and post-phloem. Proto-phloem matures when all the parts of stem are growing in length, its cells are strained, stop functioning and fade away at last. Therefore, in bamboo documents phloem is not mentioned as proto- or post-. Actually it is post-phloem, which functions in whole period of stem growth.

On the outer side of bamboo vascular bundles is primary phloem, and on inner side is primary xylem.

a. Primary xylem: Primary xylem contains proto- and post-xylem, forming a V. The specific cells of xylem are vessels.

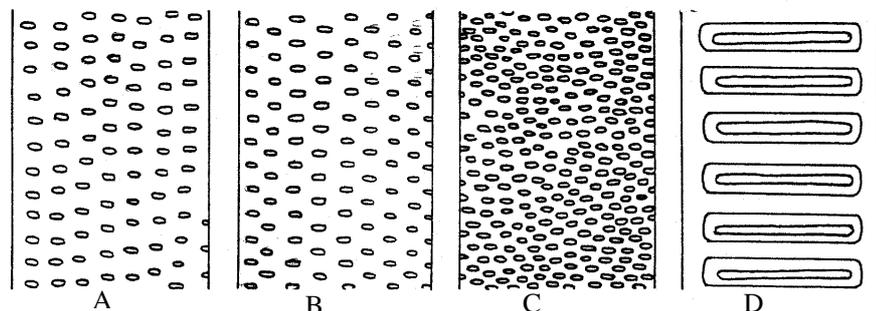
Vessel is a tubular conductive structure, consisting of axial cells that are attached end to end and connected by perforations. The cells composing vessel are vessel elements. Bamboo is similar to timber, with such vessels. On the cross section of timber, vessels are shown in the form of pore. There are no pores on the cross section of macroscopic structure of bamboo, because they are covered by fundamental tissues.

Proto-xylem is located on the base of V shape, containing annular vessels and spiral vessels. The diameter of annular vessel is smaller. The annuluses with thickened ring are distributed on vessel. The diameter of spiral vessel is larger, with thickened part in spiral shape (Fig. 1-10). The vessels of proto-xylem often break due to the rapid growth of stem, most of the undamaged ones are annular (Fig. 1-10).



A. Spiral vessel. B. Annular vessel. C. Elongation of annular vessel.
Fig.1-10. Vessel types in primary xylem and the elongation of annular vessel

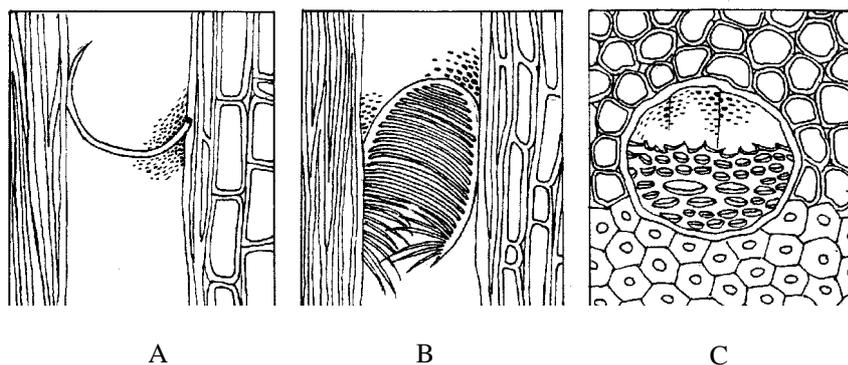
Both the fingers of V are a great vessel of post-xylem each respectively. The whole vessel wall is thickened. The vessels are of different types: pitted vessel, the pits are arranged in pairs or alternately; scalariform vessel with scalariform thickenings; reticulate vessel with reticulate thickenings, the “meshes” are not thickened (Fig. 1-11).



A. Pits arranged in pairs. B. Pit arranged alternately. C. Reticulate. D. Scalariform.

Fig.1-11. Perforation patterns on vessel walls of post-xylem

Annular vessels and spiral vessels show the morphological features of primary xylem not thickened. Scalariform vessels and reticulate vessels of post-xylem are entirely thickened. The vessels of post-xylem are mono-perforated in general, with a plain or slope bordered pit, vessels of some few species are scalariform perforated or reticulate perforated. (Fig.1-12).



A. Mono-perforation. B. Scalariform perforation. C. Reticulate perforation.

Fig.1-12. Perforation patterns of vessels in vascular bundles

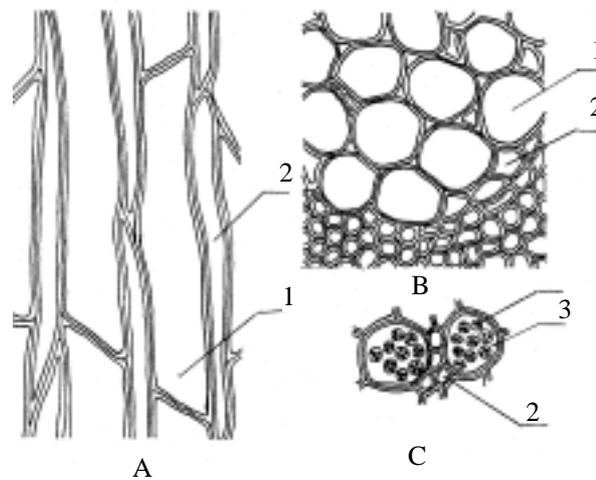
On the curving knots of vascular bundles there is the perforation of some new types. Around the vessels are parenchyma tissues and thick wall tissues.

b. Primary phloem: Primary phloem is located on the outer side of xylem, with sieve tubes and companion cells as characteristic components. Sieve tube is formed from a series of cells joined end to end vertically, every cell is called a sieve element. On the top or near the top are sieve plates with many sieve pores.

There are some or more than ten sieve tubes in phloem.

In sieve tubes of bamboo stem starch grains have never been observed, even if in later phase. Sieve tube functions through the whole period of bamboo stem growth, differing from those of broad-leaved trees. The changes happened in aging process are of particular significance. Sometimes sieve tubes are blocked up and companion cell wall thickened, as a result, both of them stop functioning.

Sieve tube elements are always accompanied closely by one or some oblong thin-walled cells, i.e. companion cells. They are of cytoplasm structure in all the lifetime. Companion cells and sieve tubes are closely interdependent in respect of physiology (Fig. 1-13).

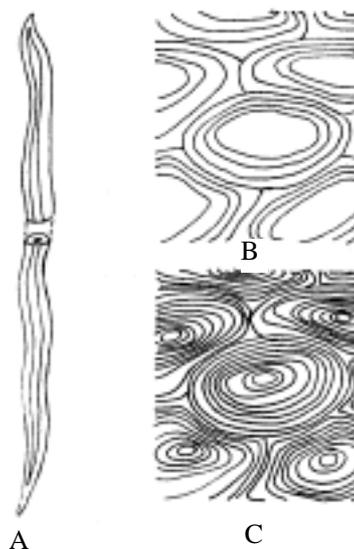


A. Vertical section of phloem. B.C. Cross section of phloem
Fig.1-13. Sieve tube and companion cell of phloem
 1, Sieve tube. 2. Companion cell. 3. Sieve plate. 4. Sieve area

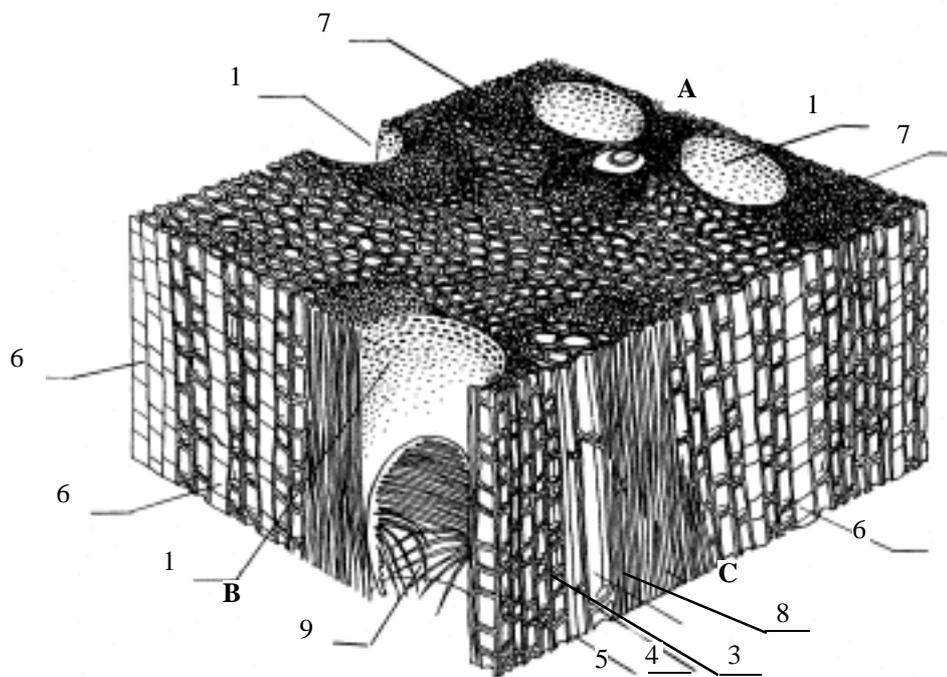
c. Parenchyma cell. All the primary xylem and primary phloem are surrounded by lignified parenchyma cells, except the outer side, covered by fiber.

Parenchyma cells of vascular bundles are smaller in comparison with those of fundamental tissues, and there are more pits on parenchyma cell wall.

d. Fiber: Fibers are specific cells of bamboo stem structure. They are elongated, with both ends pointed. Their walls thicken with aging, with a few small round pits. The average length is 1.5 ~ 4.5 mm, the ratio of length to width is high. This means bamboo is a kind of proper material for papermaking (Fig. 1-14).



A.Fiber morphology. B. Fiber, one year of age (thinner wall of less layers)
 C. Fiber, several years of age (thicker wall of more layers)
Fig.1-14. Fibers in vascular bundles



A. Cross section. B. Plain section. C. Vertical section.

1. Post-xylem vessel. 2. Proto-xylem vessel. 3. Sieve tube. 4. Sieve plate. 5. Companion cell. 6. Parenchyma of fundamental tissue. 7. Fiber sheath. 8. Fiber. 9. Perforation of vessel ends. 10. Pits on side wall of vessel.

Fig. 1-15. Stereoscopic cutaway view of vascular bundles of bamboo stem

5. Cell wall of bamboo material

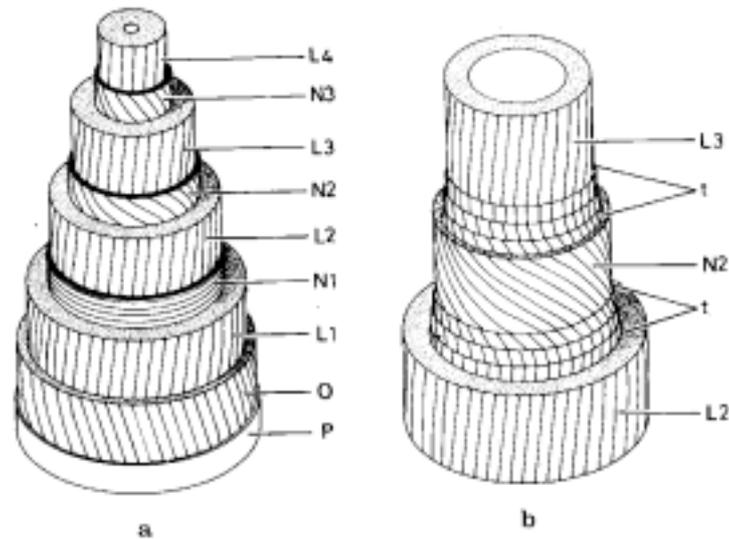
As a kind of engineering structural material, the strength of bamboo depends mainly on the mass of its cell wall, indicated by basic density. Some other physical features are connected with the structure of cell wall. The structure of bamboo cell wall is discussed below.

A. Model configuration of cell wall of bamboo fiber

Wai N. N. and other scientists discovered (1985)^[1]: bamboo fiber was suitable for pulping, the fiber wall layers could be separated in beating process, and the fiber walls expanded outwardly. All these properties are different from those of wood fiber. The structure of cell wall of bamboo fiber was described clearly in detail: *Bambusa polymorpha* Munro of 3 years of age was observed under transmission electron microscope. The cell wall was composed of thick and thin layers arranged alternately, but the number of layers in fiber strand and fiber sheath was different. The cell wall of strand fiber was composed of 3 ~ 4 thick layers, between them were thin layers. The cell wall of sheath fiber had only 1 ~ 2 thin layers. Sheath fiber lignified in higher degree than strand fiber, and thin layers lignified in higher degree than thick layers.

Fig. 1-16 shows a thin outer layer of secondary wall of strand and sheath fibers. Its microfibril join the axis at angles less than 30°, about 20° in general. In the model configuration of bamboo fiber the outmost layer is marked with 0, inside the outermost layer thick and thin layers are arranged alternately, concentrically. The innermost part of secondary wall is a thick layer.

^[1] Wai N.N., H. Nanko & K. Murakami: A morphological study on the behavior of bamboo pulp fibers in the beating process. Wood Science and Technology. 1985 (3): 211-212



a. Wall structure of strand fiber. b. The change of microfibril direction from L_2 to L_3 .
 N_2 – thin layer. t – an intermediate layer between thick and thin layers. P – primary wall.
 O – outermost layer of secondary wall. ($L_1 - L_4$) – thick layers. ($N_1 - N_3$) – thin layers.
Fig. 1-16. Model configuration of secondary wall of fiber of *Bambusa polymorpha*

The direction of microfibril of thick layers is almost the same as that of axis. The microfibril angle is $3 \sim 10^\circ$. Thick layers are not of the same thickness, they are marked not with thickness, but microfibril angle. In Fig. 1-16 thick layers are marked with L_1, L_2, L_3, \dots , the microfibril angle in a thick layer is nearly the same. Parameswaren and Liese reported (1976)^[2]: the microfibril angle of outer thick layer was less than that of inner thick layer. But such a phenomena hasn't been observed in the structure of *Bambusa polymorpha* Munro. The microfibril of O layer and L_1 layer are in opposite direction. The microfibril angle thinner layer is $30 \sim 90^\circ$, in most cases is $30 \sim 45^\circ$. Its direction is opposite to the neighboring thick layers. Parameswaren and Liese reported^[2]: the direction of microfibril angle in thin layer approaches horizontal.

There is an intermediate layer on both sides of the thin layer respectively. In fig. 1-16, N indicates thin layer, t indicates intermediate layer. The direction of microfibril in intermediate layer changes abruptly.

The number of layers in secondary structure of sheath fiber and strand fiber is different, but the fundamental structure is the same. The most important difference between the direction of microfibril of outermost layer of wood and bamboo is as follows. Bamboo microfibril is vertical, wood microfibril is horizontal and spiral.

B. The variations in wall fiber of bamboo

Murphy R. J. and Alvin K. L. observed the layers of cell wall of *Phyllostachys viridiglaudcescens* under polarizing microscope through double reflection^[1].

The research found that the number of layers in cell wall of *Phyllostachys viridiglaudcescens* depended mainly on their location in vascular bundles, along with the location of vascular bundles in bamboo stem wall and stem age.

Based on the observation of layers of cell wall under polarizing microscope they can be divided into four types:

^[2] Parameswaren N & Liese W.: On the structure of bamboo fiber. Wood Science and Technology 1976 (3) 231-246

^[1] Murphy R. J. & Alvin K. L.: Variation in fiber wall structure in bamboo. IAWA. 1992 (4) 403-410

I. There are no discernible layers, even if a thin polarized light layer near cell cavity is observed.

II. There is 1 ~ 3 polarized light layers in half of the wall thickness area.

III. There is a polarized light part containing 6 layers with well-distributed gaps.

IV. There are many polarized light layers with well-distributed gaps. On lengthwise section the top of these cells is in horizon

Fig. 1-17 demonstrates the variation in bright layers of fiber cell wall of vascular bundles under polarizing microscope. The cell wall of fiber near vascular bundle elements or near fundamental tissue of fiber sheath has most layers. This means that along with understanding the model configuration of cell wall of bamboo fiber, it is necessary to understand that the cell wall structure varies greatly. This is a topic to be researched further. It is of practical value to study this problem in connection with physicochemical properties.

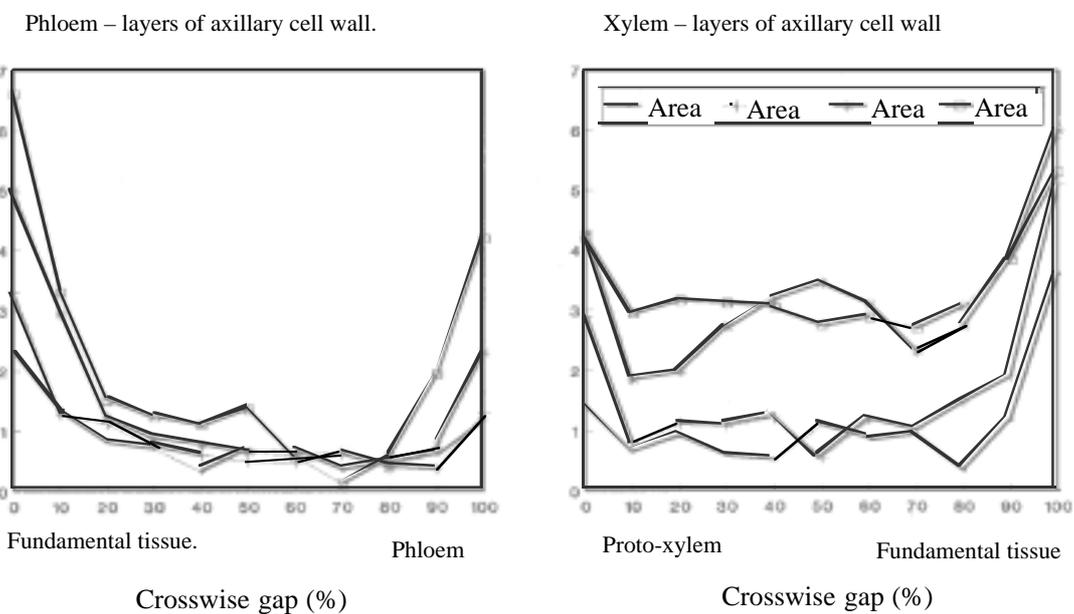


Fig. 1-17. Variation in radial fiber cell wall of vascular bundle under polarizing

Section 3. Bamboo properties

1. Chemical composition

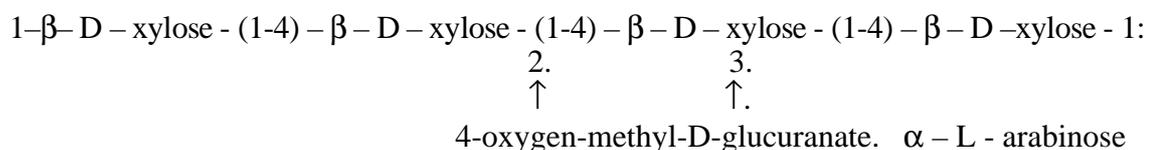
Chemical composition and structure demonstrate the properties of bamboo. The research of chemical composition is of great importance.

A. Organic components

The organic components of bamboo are similar to those of wood, mainly are cellulose ($\pm 55\%$), lignin ($\pm 25\%$) and hemi-cellulose (pentosan $\pm 20\%$)

(1) Hemicellulose: Hemicellulose consists of pentosan mostly, the amount of hexosan is very little.

More than 90% of hemicellulose is xylan, the experiment shows: bamboo xylan is D-glucuronate arabinoxylan, containing 4-oxygen-methyl-D-glucuronate, L-arabinose, and D-xylose. Their molecule ratio is: 1.0 : 1.0~1.3 : 24~25, as follows:



The composition of arabinoxylan of bamboo is different from that of needled- and broad-leaved trees. The polymerized molecules of bamboo are more than that of trees.

The pentose content of bamboo is 19 ~ 23%, approaching to that of broad-leaved trees, much higher than that of needled-leaved trees (10 ~ 15 %). This means it is acceptable to extract uronic acid in the process of pulping and hydrolysis.

(2) Lignin: Bamboo is a kind of typical herbaceous lignin, composed of paradinum, guaiacyl and mauve in the ratio of 10 : 68 : 22. This means the bamboo lignin is similar to broad-leaved lignin qualitatively, not quantitatively.

The specific features of bamboo lignin lie in the existence of dehydrogenated polymerides and 5 ~ 10% of acrylic ester. The lignin content of bamboo of 1 year of age is in the range of 20 ~ 25%, approaching to broad-leaved wood and some grass (such as wheat straw), slightly less than needle-leaved. Less lignin content means less consumption of chemicals in pulping process and easier pulping process.

B. Variation in organic components of different part of bamboo stem.

Table 1-4. Organic components of *Phyllostachys pubescens* (%)

Components	4 years of age		6 years of age	
	Bamboo green	Bamboo yellow	Bamboo green	Bamboo yellow
Cellulose	45.62	27.41	43.68	34.79
Lignin	32.37	28.08	30.33	26.75
Hemicellulose, pentosan	22.02	21.90	22.94	21.53

Table 1-4 shows the organic components of *Phyllostachys pubescens* in Changning, Sichuan. They depend on the location of sample in stem.

Table 1-5 shows the chemical components of *Phyllostachys pubescens* shoot and mature stem in Japan, and *Phyllostachys pubescens* in Lin'an, Zhejiang. The analysis of Japan samples shows: the content of ash, hot water extracts, sodium hydroxide extracts and alcohol-benzene extracts in bamboo stem is higher than that in shoot; the content of pentosan in stem is less than that in shoot. The analysis of Lin'an samples shows: the variation in chemical components of different parts in stem is insignificant, which does not influence industrial

Table 1-5. Chemical components of *Phyllostachys pubescens* (%)⁽¹⁾

origin and position		ash	hot water extracts	sodium hydroxid extracts	alcohol-benzene extracts	cellulose	pentosan	lignin	
Japan	shoot	apex	1.61	16.16	45.44	4.72	31.60 ⁽³⁾	25.10	2.25
		mid	0.88	14.73	32.86	2.33	38.48	36.20	7.80
		base	0.70	15.78	34.17	3.00	35.44	31.62	6.21
	mature stem	1.31	19.96	32.19	4.63	49.12	27.70	26.06	
Lin'an, Zhejiang ⁽²⁾	top	1.22	7.00	25.26	5.99	41.22 ⁽⁴⁾	31.84	24.73	
	mid	1.20	8.43	27.62	7.35	42.35	30.81	24.49	
	base	1.10	9.25	28.75	7.39	42.89	82.84	23.97	

Notes: (1) The analysis methods are different in China and Japan, the results can not be compared. (2) Top – on the 2/3 of stem height, mid – half of stem height, base – 1.2 m from ground surface. (3) In the original paper: α cellulose. (4) In the original paper: cellulose.

C. The difference of chemical components in samples of different age.

(1) Sprout phase: Table 1-5 demonstrates: the content of ash, hot water extracts, sodium hydroxide (1%) extracts and alcohol-benzene extracts decreases with aging of shoot, while the content of cellulose and pentosan increases.

(2) Height growth phase: Itoh (1990)^[1] studied the crosswise and lengthwise lignification process of *Phyllostachys heterocycla* in a whole growth season from sprout to height growth of stem. A sample was selected every 2 ~ 4 weeks to represent 30 bamboo stems. The samples for observation under optical microscope were taken from the 2nd, 10th, 20th, 30th, 40th, 50th, 60th inter-nodes. Crosswise sections 50 micron (μ) in thickness were colored with Wiesner agent.

By means of observation under microscope, the whole lignification process of bamboo was researched:

a. The lignification of an inter-node starts from upper part downwardly.

b. The lignification process begins from outer part toward inner part. c. The axial lignification process formed by epidermal cells, fibers and parenchyma cells starts from base inter-nodes toward higher inter-nodes.

d. The lignification of epidermal cells and fibers is prior to that of parenchyma cells of stone cells and fundamental tissue.

e. The lignification of fiber starts at the beginning of height growth of stem, it lasts through the whole period of height growth, but the parenchyma cells on the upper part do not lignify in this period.

f. The massive lignification of parenchyma cells happens after the sprouting of new axillary buds and leafing, it reaches the peak when all the new leaves spread.

^[1] Itoh T. Lignification of Bamboo (*Phyllostachys heterocycla* Mitf) during its Growth. *Holzforschung* 1990 (3) 191-200

Table 1-6. Lignin content of bamboo in period of height growth and stem maturing

Sampling date	Ordinary number of inter-node	Lignin content (%)	Stem age (years)	Ordinary number of inter-node	Lignin Content (%)
Stem height 1160 mm, sampled from base to 22 nd internodes before buds sprouting. 19 th May	10	19.0	2	10	25.5
	20	15.2		20	25.1
	30	17.8		30	25.6
Stem height 1490 mm, new branches begin extending. Height growth completed. 11 th June	10	20.7	3	10	26.4
	20	22.3		20	25.1
	10	22.5		30	25.7
New branches extended, new leaves spread. 7 th July	20	26.3	6	10	25.6
	30	27.2		20	25.0
	30	27.3		30	26.1
			8	10	26.1
				20	25.3
				30	24.0
			10	10	24.9
				20	24.3
				30	24.0
			12	10	25.4
				20	24.2
				30	23.6
			14	10	23.2
				20	24.8
				30	24.9

g. The lignification process of all cells completes in one growing season.

Itoh also conducted chemical analysis in the previous study. The samples and lignin content are listed in table 1-6, and shown in fig. 1-18.

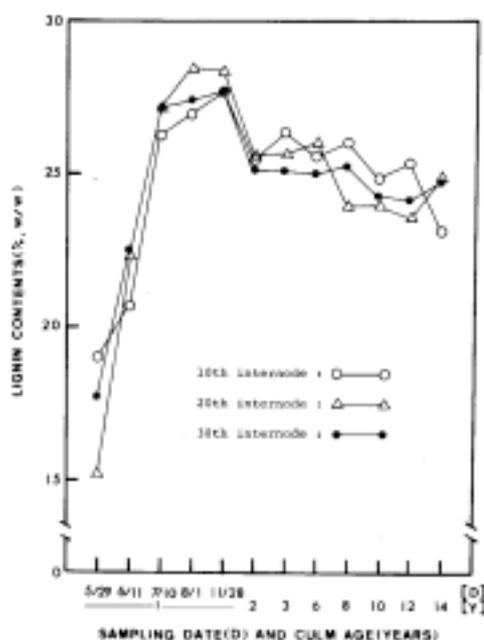


Fig. 1-18 Lignin contents of stem in different stages of development and aging

It can be seen from Fig.1-18 that the lignin content increases significantly during the first growing season, from 2nd to 14th year it remains almost at the same level.

It is clear from the above mentioned research that the lignification of parenchyma cells of fundamental tissues lasts continuously through the first year. The

Table 1-7. Chemical components of bamboo of different species and ages (%)

Species	Item Age	Water	Ash	Hot water Extra cts	Cold water Extra cts	Sodiu m hydr- oxide extrac ts	Alcoh ol- benze ne Extra cts	Ligni n	Pento san	Cellul ose	α cellul ose
Ph.pubescens	Half year	9.00	1.77	5.41	3.26	27.34	1.60	26.36	22.19	76.62	61.97
	1 year	9.79	1.13	8.13	6.31	29.34	3.67	34.77	22.97	72.07	59.82
	3 year	8.55	0.69	7.10	5.11	26.91	3.88	26.20	22.11	75.09	60.55
	7 year	8.51	0.52	7.14	5.17	26.83	4.78	26.75	22.01	74.98	59.09
B.textilis	Half year	9.09	2.39	6.64	8.03	32.27	4.59	18.67	22.22	77.71	51.96
	1 year	10.58	2.08	6.30	7.55	30.57	3.72	19.39	20.83	79.39	50.40
	3 year	10.33	1.58	6.81	8.75	28.01	5.43	23.81	18.87	73.37	45.50
B.chungii	Half year	9.21	2.73	8.10	9.70	35.17	4.16	17.58	23.91	79.00	47.63
	1 year	10.33	2.10	8.07	9.46	29.97	4.35	21.41	18.72	73.72	47.76
	3 year	10.26	1.50	6.34	9.21	30.57	3.98	22.70	18.88	71.70	43.65
B.pervariabilis	Half year	8.38	2.16	4.93	6.35	27.71	2.14	20.92	21.47	79.41	52.63
	1 year	11.66	2.29	7.64	7.71	29.99	2.15	21.43	20.26	73.34	48.15
	3 year	11.04	2.65	9.51	9.25	30.63	6.42	22.02	19.22	69.14	45.33
B.sinosipinosa	Half year	9.17	2.69	7.29	8.23	29.98	4.23	19.90	21.81	78.29	52.58
	1 year	11.49	1.92	8.08	9.91	30.25	5.49	20.51	20.27	71.16	49.45
	3 year	11.13	1.84	9.07	9.27	26.92	5.88	24.17	19.72	72.77	17.10
Ph.heteroclada	1 year	8.38	1.24	13.27	9.60	30.89	5.38	22.42	20.43	71.98	58.15
	3 year	10.87	1.27	9.68	15.94	34.84	9.11	22.72	21.83	59.92	38.96
Ph.nigra	Half year	10.31	1.98	6.72	8.30	31.83	4.12	28.49	22.21	70.77	45.38
	1 year	7.70	1.81	10.69	8.53	33.24	5.29	23.90	22.08	73.61	58.85
	3 year	11.61	1.71	6.50	8.36	33.65	5.58	25.00	22.30	68.64	13.79
Ph.Bambusoides	Half year	10.69	2.22	4.62	5.93	27.30	1.81	24.51	22.69	76.41	48.92
	1 year	9.44	1.25	10.49	8.97	29.93	7.34	23.39	22.46	72.65	56.74
	3 year	9.90	0.98	6.11	7.32	31.33	5.86	25.15	22.65	66.39	12.02
Ph.Meyeri	Half year	10.70	1.68	3.60	5.315	27.27	1.81	23.58	24.95	78.17	49.97
	1 year	8.29	1.29	10.70	8.91	34.28	7.04	23.62	22.35	72.84	57.88
	3 year	9.33	1.85	8.81	12.71	35.32	7.52	23.35	22.49	62.40	39.95
Ph.praecox	Half year	10.64	3.24	6.72	8.57	33.36	2.25	26.74	21.98	72.83	42.23
	1 year	8.19	1.93	11.21	7.38	32.84	3.80	21.68	22.21	73.85	56.03
	3 year	11.29	2.26	7.18	9.09	23.26	5.64	25.65	22.39	65.77	40.81

lignin content does not increase after that. It even decreases from 2nd to 14th year slightly. The lignin content is indicated by the percentage of dry weight of bamboo material. This proves that the lignification progress continuous in the period of height growth.

(3) Stem maturing phase: Table 1-7 demonstrates the research results of Chen Youdi and others (1985)^[1] about the chemical components of ten bamboo species in connection with different ages. For the purpose of research four samples were taken from important species, such as *Phyllostachys pubescens*, *Bambusa textilis*, *Bambusa pervariabilis* and *Bambusa chungii*. One was from strong stem, two from middle and one from weak stem. From every stem, take a section 1 meter in length, positioned 1 meter above ground surface, another section positioned in mid stem and third section in top part, all are 2 meter in length. These three sections are made into a complete sample. From small species such as *Phyllostachys nigra* five stems for sample are taken, one strong stem, three middle stems and one weak stem. With all branches removed, the whole stems are used for analysis. Thus table 1-7 demonstrates the average results of comprehensive analysis of whole bamboo stems. The research proves that

the growth of bamboo is concentrated in the first several months after sprouting. After half a year's growth, the variation in chemical components is insignificant, only the lignification and hornification of stem deepens slightly. A tendency is evident, cellulose, α cellulose and ash content decreases a little, while the content of lignin and alcohol-benzene extracts remain the same or increase a little.

In stem maturing phase the thickening process of cell wall is accompanied by the accumulation of fundamental tissue matters. The lignification and thickening take place simultaneously. Lignin, cellulose and hemicellulose accumulate respectively, but their weight ratios to each other remain the same or vary little. Organic components from table 1-7 show that bamboo material for processing and utilization should not be taken from older stems. The cutting age of bamboo plants should be decided from the viewpoint of groove regeneration and bamboo mass quantity. The organic composition of bamboo is similar to that of wood. This is not an accidental phenomena, this is the result of evolution of perennial plants.

The rot-fastness matter in bamboo extracts is few, the natural durability of bamboo material does not improves with aging. There are few theoretical studies in this respect. Table 1-7 indicates that ash content of bamboo stem decreases with aging. From inorganic elements, the content of silicon is comparatively high. Silicon content in nodes is higher, in bamboo green is less, in bamboo yellow is very little.

Chemical composition of flowering bamboo stem and no flowering stem is almost the same. Flowering is a phenomenon of physiological process, which does not affect the chemical composition of stem. But the moisture content of stem decreases after flowering to the extent that is favorable for the breeding of fungi, and bamboo material rots quickly.

2. Physical properties of bamboo material

A. Moisture content

The moisture content of growing bamboo is rather high, it depends on different seasons and species. The average moisture content of *Phyllostachys pubescens* at the cutting age is approximately 80%.

The equilibrium moisture content of bamboo material after air seasoning changes in connection with atmosphere temperature and humidity. The equilibrium moisture content of *Phyllostachys pubescens* in Beijing area is 15.7%.

B. Density

The basic density of bamboo material (whole stem weight/green bamboo volume^[1]) is in the range of 0.40 ~ 0.8 (0.9)g/cm³. This is mainly depends on the density of vascular bundles and their composition. As a rule, the density of bamboo stem increases from inner to outer part, and from lower to upper part. The density of inner layers of stem wall increases with the growth of stem and thinning of wall, while the outer layers only change slightly. The density of nodes is higher than that of inter-nodes.

C. Dry shrinkage

Dry shrinkage of bamboo is resulted from water evaporation in the drying process after cutting. The dry shrinkage varies in different directions. From air seasoning to full drying, when the moisture content decreases 1%, the average shrinkage rate of *Phyllostachys pubescens* is as follows: lengthwise – 0.024%, tangential – 0.1822%, radial – 0.1890% (on node parts – 0.2726%, on inter node parts – 0.1521%). It is clear that the lengthwise shrinkage is much less than crosswise shrinkage, the tangential shrinkage is similar to radial shrinkage.

[1] Volume of bamboo material with maximum water absorbing can be applied as green bamboo volume, but there may be some difference between them.

The shrinkage rate of inner and outer part on one and the same height is different. The lengthwise shrinkage of bamboo green is insignificant and can be neglected, but its crosswise shrinkage is most great. The lengthwise shrinkage of bamboo yellow is larger than that of bamboo green, but the absolute value is not great, its crosswise shrinkage is less than that of bamboo green evidently.

Liese reported that bamboo material shrinks as it begins to be dried. This is different from timber. When moisture content decreases to certain extent, dry shrinkage almost stops. But when drying process continues, dry shrinkage restarts again. Such a phenomenon should be researched further.

3. Mechanical properties

A. Mechanical characteristics of bamboo material

Bamboo, similar to wood, is a kind of heterogeneous and anisotropic material. Therefore its physico-mechanical properties are extremely unstable, in certain respects it is more unstable than wood. The complexity is:

(1) Due to the uneven distribution of vascular bundles the density, dry shrinkage and strength changed in connection with different height and position. In general, the distribution of vascular bundles outer part of stem wall is more closely than in inner part. thus the strength of outer part are higher. The density of stem wall increases from lower part to upper part, consequently, the strength also improves in the same direction.

(2) The variation in moisture content causes the changed of density, dry shrinkage and strength. It is said that the compression strength of *Ph. pubescens* with moisture content 30% is 90% of the compression strength of material with moisture content 155. Others reported the difference was twice more.

(3) Physico-mechanical properties of node part and inter-node part are different. For example, the pull resistance of node part is less than that of inter-node part.

(4) Physico-mechanical properties change with aging of bamboo stem. Generally speaking, material of bamboo under 2 is soft, without proper strength; bamboo material of 4 to 6 years is tough, with high mechanical strength; material of bamboo over 7 becomes brittle, with decreased strength.

(5) Physico-mechanical properties of bamboo material in all three directions are also different. For example, the cleavage strength parallel to grain is the lowest.

All the complex features must be taken into consideration for the utilization of bamboo material.

Table 1-8 demonstrates the data about mechanical features of *Phyllostachys pubescens* in Zhejiang and Sichuan. It indicates that the pull resistance parallel to grain of about 10%. The density of bamboo is only 1/6~1/8 of steel density, but its compression strength parallel to grain is 1/5~1/4 of steel, and the shearing strength parallel to grain is 1/2 of steel (A3). Therefore bamboo is a material of high strength and low weight.

Table 1-8 Mechanical properties of *Ph. pubescens*

Mechanical properties	Unit	Sichuan origin	Zhejiang origin
Tensile strength parallel to grain	kg/cm ³	2118	1805
Compression strength parallel to grain	kg/cm ³	510	711
Bending strength parallel to grain	kg/cm ³	1348	1544
Shearing strength parallel to grain	kg/cm ³	149	153

B. Recent development of research into bamboo mechanical properties

Bamboo material is of hollow cylinder form, with uneven distribution of cell wall matter. All the existing data about mechanical properties are obtained from samples of stem wall. In order to measure mechanical properties and their changes, Ye Mingquan from Taiwan, China undertook new research (1995)^[1] and reported the tensile strength of vascular bundles parallel to grain in inner, middle and outer units of stem wall, which provided reliable basis for studying bamboo mechanical properties further.

The testing material, methodology and research results are as follows:

Species of be tested: *Phyllostachys pubescens*. Origin: Taiwan, China, elevation 1200 m. age; 4~5 years. The location of samples on stem is higher than 1.83m (6 feet). Five pieces of testing material were taken successively from one stem; every piece was processed into 10 small pieces 30.5 cm in length parallel to grain. The small pieces of stem wall were cut into 3 units: inner, middle and outer units. Vascular bundles 7~9 cm were picked out with a knife.

The thickness of samples was 0.3 cm.

Twenty vascular bundle samples from inner, middle and outer units were taken respectively, to be conditioned under 65% of relative humidity and 23°C of temperature. The testing force was 50 kg, and loading speed was 1 mm/min.

The number of vascular bundles, their total area and research results are shown in table 1-9.

Table 1-9. Tensile strength parallel to grain of *Ph. pubescens*

Test items	Stem wall		
	Outer unit	Middle unit	Inner unit
Tensile strength of vascular bundles (kg/cm ²)	8936±2043	8450±3090	10682±3195
Tensile strength of unit material (kg/cm ²)	2088±331	1352±261	1217±240
Quantity of vascular bundles (number/mm ²)	5.41±0.66	2.69±0.35	1.97±0.30
Percentage of vascular bundle (%)	65	44	28

Research conclusion:

(1) There are no evident differences between tensile strength parallel to grain of vascular bundles in inner, middle and outer units of stem wall.

(2) The tensile strength of middle unit is about equal to that of inner unit. The tensile strength of outer unit is higher than the average strength of middle and inner unit by 62%. The tensile strength of vascular bundles is much higher than that of unit material, consequently, the percentage of vascular bundle area can be applied to evaluate the strength.

(3) The number of vascular bundles per square millimeter in outer, middle and inner units on cross section is 5.41, 2.69 and 1.29. The number of outer unit is twice the middle and 2.75 times of the inner unit. This causes the difference in tensile strength among them.

(4) The practical tensile strength of outer, middle and inner units of stem wall is lower than the theoretical strength by calculating vascular bundle area. The lowering extent of outer unit is larger than that of inner unit. The average tensile strength of unit material is 1552 kg/cm², only 16% of that of vascular bundles. The tensile strength of outer, middle and inner units of bamboo stem wall can be evaluated in the following way: Percentage of vascular bundle area % x 96862 kg/cm² x 0.33 (outer), x0.32 (middle), x0.45 (inner).

^[1] Ye Minquan; Evaluation of tensile strength of vascular bundles of *Phyllostachys pubescens* China Forestry Science 1995 (1) 129~137

Chapter II Specific features and classification of bamboo-based panels

Section 1. Specific features of bamboo-based panels

1. Specific features of bamboo material

Bamboo is natural organic matter like wood, both of them are heterogeneous and anisotropic material. But there are significant differences in morphology, structure and chemical composition between them, demonstrating specific physico-mechanical properties. In comparison with wood, bamboo has enough strength, great toughness and high rigidity, and it can be processed easily. For this reason, bamboo material is widely utilized. These are strong points generally speaking, but they may turn into shortcomings from certain other angle. Therefore it is necessary to understand them thoroughly for successful utilization of bamboo resources. The specific features of bamboo material are shown below.

A. Easy processing

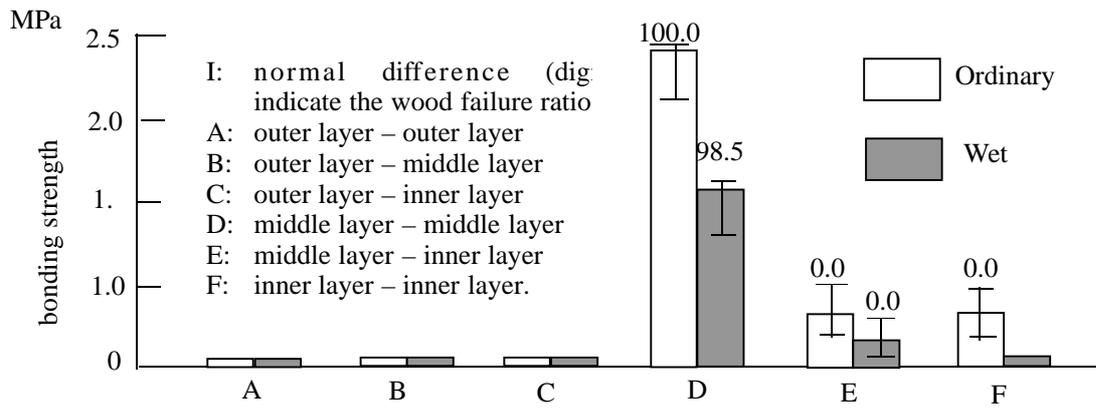
Bamboo material has straight grain. It can be cleaved into thin splits (several micron in thickness) easily with simple instruments. The splits can be used to weave handicrafts of different patterns, furniture, agricultural tools and articles of daily use. Fresh bamboo stems can also be made into curved articles of unique shapes through baking. Bamboo material is of light color, it can be bleached and colored easily. Raw bamboo can also be used directly in building industry, fishing and other fields.

B. Small diameter, hollow and taper

The diameter of bamboo is smaller than wood. The diameter of big trees reaches 1 ~ 2 meters, the thinner ones – tens of centimeters. The diameter of thinner bamboo stems is only 1 ~ 2 centimeters. The most important bamboo species in China is *Phyllostachys pubescens*, which has a very wide distribution and high economic value, with a diameter of 7 ~ 12 cm. The diameter of some big sympodial bamboo species in tropical areas reaches 20 ~ 30 cm. Wood is solid, while bamboo stem is hollow, with a thin wall. The diameter and wall-thickness of bamboo decrease from base to top. The maximum thickness of stem wall of base part reaches 15 ~ 20 mm, the minimum is only 2~ 3 mm.

C. Uneven structure

The outer part (bamboo green) of stem wall is of compact texture, its surface is smooth and bright, covered with a wax layer of poor affinity for water and adhesives. The properties of middle part of stem wall are between bamboo green and bamboo yellow. It is the main part of bamboo utilization. The difference in structure of these three parts causes evident differences in density, moisture content, shrinkage coefficient, strength and adhesion. Such specific features lead to negative influences on processing and utilization of bamboo. As for wood, although there are some tree species with comparatively evident difference between heartwood and sapwood, but no differences in physico-mechanical properties and adhesion observed. Fig. 1-19 demonstrates the relationship of bonding capacity of bamboo samples to their location on stem. It can be seen that the bonding capacity of bamboo green and bamboo yellow for phenol-formaldehyde resin equal to zero, while the capacity of middle part is good. The bonding capacity of bamboo green, bamboo yellow and middle part for urea-formaldehyde resin is similar to phenol-formaldehyde resin.



Adhesive: phenol-formaldehyde resin..
Fig.1-19. Bonding capacity of bamboo samples to their location on stem

D. Evident anisotropic features

Both bamboo and wood are anisotropic. The vascular bundles of bamboo are arranged in parallel tidy order, the grain is even, without crosswise connection. Therefore, the lengthwise strength of bamboo material is high, while the crosswise is low. This is the reason why bamboo can be split easily. The ratio of lengthwise cleavage strength to crosswise strength of ordinary wood is 20 : 1, that of bamboo reaches 30 : 1. The differences in physico-mechanical properties, chemical components in all directions bring many unstable factors to bamboo processing and utilization.

E. Liable to insect damage, rottenness and mildew

In comparison with wood, bamboo contains more nutrients for insects and microbes (fungi). These organic matters are protein (1.5 ~ 6.0%), carbohydrate ($\pm 2\%$), starch (2.0 ~ 6.0%), fat and wax (2.0 ~ 4.0). Under the conditions of proper temperature and humidity bamboo is apt to be attacked by insects and fungi. Main insect pests are bamboo beetle, termite and bamboo wasp. The most serious damage is by bamboo beetle, rottenness and mildew are by fungi. Mildew is apt to take place under high humidity and high temperature with poor ventilation. Many tests showed that the durability (resistance to aging) of untreated is lower.

F. Great transport expenses and difficult storage

Bamboo stems are hollow, they are bulky, but the practical volume is small, which affects the loading capacity of vehicles. The long distance of transport is extremely unprofitable. Bamboo material is liable to insect damage, rottenness, mildew and drying check, it can not be stored outdoors for long. The cutting season is strictly limited for bamboo regeneration, March and April are the period when cutting is prohibited. Consequently, it is difficult to guarantee reliable raw material supply for industrial production.

As a result of above-mentioned specific features of bamboo, all the high efficient methods and equipment of woodworking industry can not be applied to bamboo-processing directly. For example, bamboo boards of proper thickness can not be produced by means of sawing, bamboo strips can not be produced by peeling or slicing. For many years raw bamboo is used directly or through simple processing in agriculture, fishery and house construction in primitive manner, or for weaving traditional handicrafts. It is not processed in many ways and used in various fields of engineering as wood.

1. Specific features of bamboo based panels

Inspired by the achievements in woodworking industry, professionals have started the research in manufacturing bamboo-based panels since 1960s. With the deepened understanding of specific features of bamboo material and the bonding capacity of bamboo green, middle part and bamboo yellow, professionals developed several sorts of bamboo-based panels. Comparing with wood-based panels, these new products demonstrate the following specific features:

- A. Great dimensions, small deformation and stable size.
- B. High strength, enough rigidity and high wear resistance
- C. The structure and dimensions can be regulated in accordance with the requirements of consumers, the strength and rigidity can also be regulated.
- D. Some insect resistance and rot resistance
- E. Improved properties of raw bamboo in different directions
- F. The surface of products can be decorated in various ways to meet varied requirements.

Section 2. The classification of bamboo based panels

Bamboo based panels are made from raw bamboo through a series of mechanical and chemical processing. They are manufactured under proper temperature and pressure, with the aid of adhesives and bonding capacity of bamboo material.

The thickness of bamboo based panels is 2 ~ 40 mm in general, their dimensions can be decided by the specifications of manufacturing equipment, or by the requirements of users. There are many sorts of bamboo based panels, more twenty from them are of efficient use and in scale production. They can be classified as follows.

1. Classification in the respect of manufacturing technology

A. Products made of bamboo strips

Cut bamboo stem into plain fragments of certain thickness, make plybamboo of three or more layers. The strips are made in the ways of pressing-flattening and planing (Fig. 1-20).



a. Pressed and flattened.



b. Planed.

Fig.1-20. Bamboo strips made in different ways

(1) Plybamboo (pressed and flattened)

Soften bamboo fragments under high temperature, press and flatten them into strips 60 ~ 120 mm in thickness. Assemble them in lengthwise and crosswise direction alternately, and make into plybamboo by means of hot pressing, using phenol formaldehyde resin as resin. Plybamboo is excellent engineering material of great dimensions, high strength, small deformation and stable form. The thickness of bamboo veneer is 4 ~ 9 mm. Most of the products are of 3 or 5 layers, therefore the adhesive consumption is rather low, about 40 kg per cubic meter. The density is 0.8 ~ 0.85 g/cm³, similar to hard deciduous wood. The lengthwise MOR// ≥ 90 Mpa, the crosswise MOP_⊥ ≥ 40 Mpa. They are suitable for making bottom board of trucks and buses.

The technology of pressing-flattening under high temperature is simple, and the utilization ratio is high, but there are cracks after flattening on the surface. Such products can not be applied for decoration purpose.

(2) Laminated bamboo board (planed)

Cut bamboo stems into square edged strips of even thickness and width, applying 2 parallel saw blades fixed on one and same axis and planer. The work efficiency and utilization ratio of this method is low. But there are no cracks on the surface of such strips. All these strips are arranged in one and the same direction during assembling, and then pressed bi-directionally. The strips are bleached or carbonized before pressing. The products are multi-

layered, of great dimension. The surface of laminated bamboo board is fine-grained. They can be used for furniture making and inner decoration like laminated veneer wood or high-grade wood.

(3) Laminated bamboo flooring (planed)

Arrange strips of same thickness and same width in one direction or in crosswise and lengthwise order alternately during assembling. The dimensions of final products are 9 ~ 18 mm in thickness, 90 ~ 150 mm in width and less than 1800 mm in length.

The technological standards of laminated bamboo production are very strict. The products are of fine quality and good appearance. The manufacturing process is complicated and difficult. The raw material for making laminated bamboo must be of high quality (great diameter and freshness). This is a new product with higher added value developed in recent years.

B. Products made of bamboo strips

Bamboo material can be split into lengthwise strips 0.5 ~ 30 mm in thickness, 10~ 20 mm in width. These strips can be woven into bamboo mats or bamboo curtains (Fig. 1-21).

(1) Mat plybamboo

Weave slivers 0.8 ~ 1.2 mm in thickness into mats. Assemble and press after drying and gluing.

The products are of two to five layers. Most of them are thin board. Common mat plybamboo are made of thick coarse mats. Thin boards are mainly used as packaging material and covering material of railway wagons. Thick boards are used as concrete forms and bottom boards of trucks.



a
a. Bamboo mat.



b
b. Bamboo curtain

Fig.1-21. Forms of sliver weaving

The splitting and weaving operations can be done in rural households without complicated equipment. In this way the scattered Ph. Pubescens of small diameter and stems of miscellaneous species can be exploited successfully, therefore the source of raw material is unlimited.

It is feasible to build factories producing mat plybamboos in economically less developed areas, where bamboo resources are of small diameter.

(2) Curtain plybamboo

In order to simplify weaving process, strips are arranged in parallel order, connected with strings to make them into curtains. After gluing and drying, curtains are to be assembled and pressed into curtain plybamboo. If surface curtain is made fine strips accurately, the products

after sanding can be of high grade. The thickness of strips can be regulated according to the requirements of final products. Plybamboo can be diversified by means of adjusting thickness and width of strips, assemble patterns and processing ways for various uses.

(3) Laminated bamboo of strips

Strips are glued and dried, then assembled and pressed into laminated bamboo of strips. The strips are soaked in phenol formaldehyde resin and arranged in parallel order. Most of the products are thick, used as structural material.

As all the strips are soaked, and the unit pressure is high, the density of final product exceeds 1.0. The strips are arranged in parallel order, the lengthwise strength is high, MOR// \geq 100 Mpa, but the crosswise strength is low.

Plybamboo of strips is mainly used for making bottom boards of trucks, buses and railway wagons. The strips can be produced in rural households separately. There are no specific requirements concerning the diameter of bamboo stems.

(4) Mat-curtain plybamboo

For making mat-curtain plybamboo soaked mats are used as surface layers, glued curtains as inner layers. They are arranged in lengthwise and crosswise order alternately, then pressed under high pressure. It is possible to cover the surface mats with paper soaked in melamine resin or phenol formaldehyde resin in case of need. This product is mainly used to make concrete forms. The curtains and mats used for making mat-curtain plybamboo are woven and dried in scattered peasant households. These curtains and mats are purchased by factory workers and transported to the factory. These semi-finished articles are dried, soaked, assembled, pressed and edged in factory. The equipment for producing mat-curtain plybamboo is quite simple, while the products are durable, suitable for making concrete forms.

C. Products made of bamboo chips

Bamboo chipboard

For the sake of improving utilization ratio of bamboo resources the stems of small diameter and of less known species, stem tops and all bamboo processing residue are used to make bamboo chipboard. The manufacturing process is designed following the technology of wood particleboard — rolling, cutting, chipping, re-drying, gluing, spreading and hot-pressing.

The supply of raw material for making bamboo chipboard is abundant. All small bamboo stems of less known species and residue of bamboo cutting on groove land can be used for production. The utilization ratio of raw material for chipboard production is high, From 1.3 ton of raw material 1 m³ of chipboard can be produced. The technology and equipment for bamboo chipboard production are similar to those of wood particleboard. It is recommended to develop bamboo chipboard for improving the utilization ratio of raw material and the economic performance of enterprise. Fig. 1-22 shows the form of bamboo chip.



Fig.1-22. Bamboo chips

Bamboo chipboard manufactured with phenol formaldehyde resin is of comparatively high strength and MOE, low expansion rate of water absorbing. In case of need the products can be strengthened by adding bamboo curtain or bamboo mat to the surface. Such products have broad prospect.

D. Products of composite materials

In order to improve product quality and decrease production cost, some of the above mentioned bamboo processing residue, strips, boards, particles and fibers, and metal, texture, plastics and soaked paper are selected to make composite boards. As bamboo and wood are cheap and easy to be processed, most of composite boards are made of bamboo, wood and soaked paper at present. Both bamboo and wood have their strong points and shortcomings in processing and utilization. Wood is of larger diameter, it is cheaper than bamboo, and its processing efficiency is high. But the strength and rigidity of fast growing wood are lower than bamboo. Bamboo stem is hollow and of smaller diameter, its price is high and processing efficiency is low. The strength and rigidity of bamboo are higher than wood in general. Its surface quality is also better. The surface material of structural board bears the main load, while the load on intermediate material is smaller. Therefore for both structural and ornamental boards the surface materials are key factors deciding the quality of products. The production technology of bamboo-wood composite board combined the specific features of plybamboo and plywood. The production efficiency of composite board is higher than plybamboo, and the production cost is lower. The physico-mechanical properties of composite board are better than plywood. To develop bamboo-wood composite board is a rational way to the successful exploitation of bamboo resources. Main products of composite boards are as follows:

(1) Bamboo-wood sandwich composites:

Prepare a list of paper soaked in phenol formaldehyde resin, a bamboo mat and two bamboo curtains as front and rear surface layers, several wood strips as inner layers. Assemble and press them into bamboo-wood sandwich composites 28 mm in thickness. The production cost is lower and production process is simpler. The products are of excellent wear-ability, great strength and high rigidity, with less internal stress. These products are suitable for making bottom board of containers, the density is less than 0.85, MOR \geq 80 Mpa, MOE \geq 10000 Mpa. The traditional bottom boards of containers are made of tropical timber apitong (*Dipterocarpus*). They are of 17 ~ 19 layers of rotary-cut veneer, with phenol formaldehyde resin, 28 mm in thickness. The crosswise and lengthwise strength and modulus of elasticity are high. This is the wood product of highest grade. Bamboo-wood sandwich composites can be made in one step, or make the base plate of wood veneer at first, then assemble is with soaked paper, bamboo mat and bamboo curtain to undergo secondary hot pressing.

(2) Laminated bamboo-wood sandwich composite

This is a kind of thick board, made of curtain plybamboo as surface layers and several sawn boards 10 ~ 12 mm in thickness as inner layers. The products possess high strength and wear-ability as bamboo, and enough nail holding power as timber. As the thicker wood boards are selected to substitute for thinner rotary-cut strips, the production cost is much lower. The products can be used to make bottom boards of railway wagons. In the production process first step is to make curtain plybamboo and sand the surfaces. Then assemble with wood boards for secondary hot pressing.

(3) Bamboo-wood composite flooring

This is a new type of bamboo-wood flooring with outward appearance of bamboo and properties of wood. It is composed of thin bamboo pieces as front and rear surface layers, wood boards 8 ~ 15 mm in thickness as inner layers. In comparison with pure bamboo flooring, the manufacturing process is simplified and production cost lowered.

(4) Strengthened bamboo chipboard

In order to improve the strength of bamboo chipboard insert a bamboo curtain into chipboard as reinforcing bar, or add one bamboo mat or one to two bamboo curtains as surface layers, then perform secondary hot pressing.

(5) Overlaid bamboo chipboard

In order to improve the smooth finish and decrease the water absorption of bamboo chipboard to be used as concrete form, it is recommended to cover the board with one or two pieces of paper soaked in phenol formaldehyde resin or melamine resin. This operation can be done simultaneously with chipboard assembling before hot pressing, or cover the chipboard and carry out secondary hot pressing.

(6) Overlaid plybamboo

Select sanded and processed plybamboo or curtain plybamboo as inner layer, a wood veneer and 1 ~ 2 pieces of soaked-paper as surface layers, then assemble and press. The surface of products is covered with a hard adhesive layer, bright and smooth. The overlaid plybamboo is widely used as concrete forms on construction sites of great bridges and highways.

2 Classification in the respect of product structure

A. Plybamboo products

(1) Mat plybamboo

(2) Plybamboo

(3) Curtain plybamboo

B. Laminated products: laminated bamboo of strips

C. Chipboard products: bamboo chipboard

D. Composite board products

(1) Bamboo-wood sandwich composites

(2) Laminated bamboo-wood

(3) Bamboo-wood composite flooring

(4) Strengthened bamboo chipboard

(5) Overlaid bamboo chipboard

(6) Overlaid plybamboo

3. Classification in the respect of uses

A. Plybamboo used in vehicle making

(1) Bottom board of trucks and buses (plybamboo, laminated bamboo strips)

(2) Bottom board of railway wagons (laminated bamboo slivers)

(3) Side board and ceiling board of railway wagons (mat plybamboo)

(4) Bottom board of railway flatcar (bamboo-wood composite board)

B. Plybamboo used in making concrete form

(1) Plybamboo concrete form (mat- curtain plybamboo)

(2) Bamboo chipboard of concrete form

(3) Dendified bamboo chipboard of concrete form

(4) Overlaid plybamboo of concrete form

(5) Overlaid bamboo chipboard of concrete form

C. Plybamboo used in boats (curtain plybamboo)

D. Bamboo flooring

(1) Laminated bamboo of flooring

(2) Bamboo-wood composite board of flooring

E. Plybamboo used for making furniture and other articles, for decoration (laminated bamboo)

Chapter III Structure and physico-mechanical properties of bamboo-based panels

Section 1. Structure of bamboo-based panels

1. Structure form

From the viewpoint of production technology and product quality the structure of bamboo based panels can be divided into two types:

A. Single-layered structure

(1) Homogeneous structure

On cross section of such panels no evident layers are observed. The size and density of component units (such as bamboo chips) are even and identical. The arrangement of fibers is not oriented. Therefore the physico-mechanical properties on every part and every direction are basically similar to each other. Bamboo chipboard is one of such products.

(2) Graduated structure

On cross section of such panels no evident layers are observed and the distribution of component units is uneven. But a phenomenon of regular and gradual change can be seen on the section. This is an intermediate type between single-layered and multi-layered structures. Graduated bamboo chipboard is one of such products.

(3) Oriented structure

On cross section of such panels no evident layers are observed. The size and density of component units are even and identical. The fibers are arranged almost in one and the same direction. Consequently, the strength on one direction is extremely high. Such products, as oriented structural boards, are suitable for bearing unidirectional load.

B. Multi-layered structure

On the cross section of such panels evident layers are observed. In respect of direction of fiber arrangement of layers the products are of two types.

(1) Oriented structure

The fibers of one unit (bamboo strips, bamboo mats) are arranged in one and the same direction. Furthermore, fibers of all adjacent units are also arranged in one and the same direction. Laminated bamboo strip board is one of such products. The strength in one direction of such products is high. But the differences in strength, dry shrinkage and wet expansion in two directions are great. Thus the quality of products as a whole is not ideal. Such products are used in cases where unidirectional load is high. For example, apply laminated bamboo strip board to substitute for wood board in truck bottom of steel-wood structure.

(2) Non-oriented structure

The fibers of component units (bamboo strips, bamboo curtains, bamboo mats) in one layer are arranged in one and the same direction. But fiber directions of adjacent units are perpendicular to each other. Plybamboo, curtain plybamboo, plybamboo of woven layers and various bamboo composite boards are of this type. Panels of this structure improved mechanical properties of raw bamboo, the strengths of lengthwise and crosswise directions are similar, dry shrinkage and wet expansion are small, the quality of products as a whole is better.

2. The principles of structure

The principles of structure design of bamboo-based panels are similar to those of wood-based panels. The main purpose is to overcome the natural shortcomings of raw bamboo, make the panels of great dimensions without deformation and cracks. In structure design the following principles are important.

(1) Principle of symmetry

This principle means that the counter layers on both sides of central plane must be of same species, same thickness and number, same fiber direction, moisture content and processing technology (Fig.1-23). Layers on one side of central plane can be of same material, thickness and processing technology, or different. But the counter layers on two sides must of same features.

In the process of storage and transport the component units of bamboo-based panels shrink or expand with the changes of temperature and humidity, which lead to deformation. But as all the units are glued into a whole, they can not change their form freely and cause inner stress. The inner stress is calculated in accordance with the following formula:

$$\delta = E \cdot \varepsilon$$

where δ - stress (Mpa), E – MOE of material (Mpa) (connected with species, processing technology, moisture content and other factors) ε – strain (connected with material and fiber direction) $\varepsilon = \Delta l / l$. l – original length of material, Δl – deformation of material (elongated or shortened).

It is clear from the above-mentioned formula, if the structure of bamboo-based panel is in line with the principle of symmetry, the inner stress occurred in one side of central plane equals to that in opposite side. The entire structure of panel is stable, without any deformation.

Principle of symmetry is a basic principle of structure design. In order to design products of good structure, work out rational technology and make products of high quality it is necessary to abide by this principle.

(2) Principle of odd number layers

The principle of odd number layers must be followed in structure design. As the fiber directions of adjacent layers must be perpendicular to each other and counter layers symmetrical, the layers must be of odd number. In bamboo-based panel of odd layers, the central plane of central layer coincides with the central plane of the panel. When the panel is being crooked and distorted, the maximum shearing stress is distributed on the central plane of central layer (Fig.1-23) and the panel is in a stable state. But if the panel is made of layers of even number, the maximum shearing strength is distributed on the adhesive film between two adjacent layers, which may lead to cracks. But in case when the product must have high unidirectional strength and the distortion on certain direction is limited, it is possible to design a symmetrical structure of even number layers (4, 6 or 8 layers). When the panel of even number layers is being crooked, the maximum shearing stress is distributed on the adhesive film of central plane, but as most of the panels are made with phenol formaldehyde resin, it is possible to produce panels of high bonding quality and weather resistance.

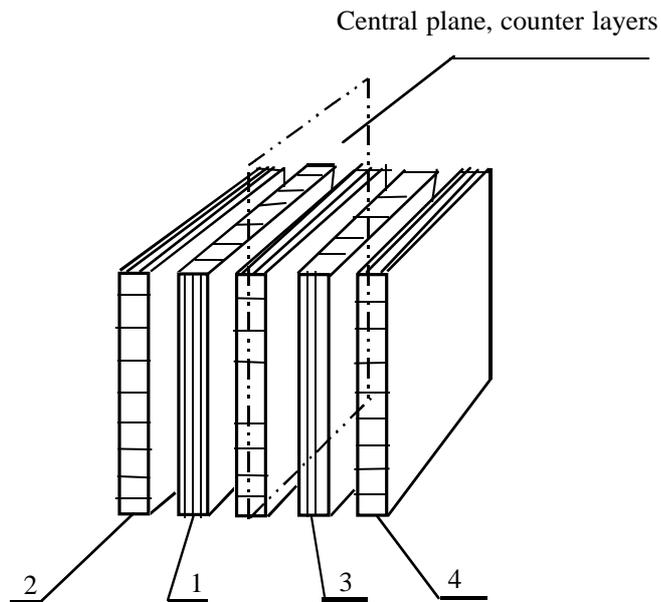


Fig.1-23. Central plane and counter layers of 5-layered plybamboo (1 countering 3, and 2 countering 4)

(3) Principle of proper layer thickness

The component units (bamboo strips, bamboo curtains, bamboo mats or other units) of multi-layered bamboo-based panels can be of same thickness or of different thickness, but the thickness of counter units on opposite sides of central plane must be of the same thickness strictly. When the thickness of panel is unchanged, the more layers of less thickness lead to higher quality, but the production cost and consumption of adhesive are also higher. If decrease the number of layers and increase their thickness, the quality of products will be affected, but the production cost also lowered. Therefore, the number of layers and their thickness must be determined carefully, considering the standards of final products.

Section 2. Physico-mechanical properties of bamboo-based panels

Bamboo-based panels are developed in recent years. They are not popular at present. It is necessary to learn their physico-mechanical properties for their rational utilization and broadening the field of utilization. These properties are connected with many factors, such as bamboo species, bamboo age, adhesives, production technology and product structure.

1. Mechanical properties

A. Moisture content

In the production process semi-finished articles are to be dried. Moisture is added during glue coating (impregnating), but a great deal of moisture is released after hot pressing. Therefore the moisture content of final products is kept at a low level. Proper moisture content guarantees good physico-mechanical properties and stable dimensions. Moisture content depends on the type of adhesive and technological conditions. It is measured by sampling after storage for a certain period of time under room temperature. The absolute moisture content is calculated according to the following formula:

$$H = \frac{M_H - M_o}{M_o} \times 100\%$$

where: H – absolute moisture content of sample (%);

M_H – weight of sample at sampling (g)

M_o – absolute dry weight of sample

As a rule, the moisture content of bamboo-based panels of phenol formaldehyde resin must be less than 10%, those of urea formaldehyde resin less than 12%.

B. Density

Density is the weight of unit volume. The density of bamboo-based panels depends on the density of bamboo material, the type of adhesive applied, hot pressing conditions and other factors. As bamboo material has comparatively high density, the density of bamboo-based panel is slightly higher than wood-based panel of same type. Generally speaking, higher pressure and higher temperature during pressing lead to higher density and strength of products, but the higher density increases the pressure loss and reduces the utilization ratio of raw material. As a rule, the density of panel correlates positively with its strength, but it should be taken into consideration that the higher density causes higher production cost, greater weight and expansion rate. As a kind of engineering structural material to be used as bottom board of vehicles, bamboo-based panels should have great strength, high rigidity and small density, which reduce the dead weight and loading capacity of vehicles. The density of bamboo-based panels can be calculated according to the following formula:

$$\gamma = \frac{w}{v}$$

where: γ - density of sample (g/m^3)

w – weight of sample at sampling

v – volume of sample at sampling

C. Water absorption

Water absorption is the amount of water absorbed by bamboo-based panels after soaking in water for a certain period of time. The water absorption of bamboo-based panels is connected with the water absorption of bamboo material itself, and their processing technology. As a result of gluing, hot pressing and plastic deformation, the water absorbing capacity of component unit of bamboo-based panels is affected. Therefore the water absorption is lower than that of raw bamboo material. Water absorption is calculated according to the following formula:

$$\Delta W = \frac{G_2 - G_1}{G_1} \times 100\%$$

where: ΔW – moisture content of sample (%)

G_1 – weight of sample before absorbing (g)

G_2 – weight of sample after absorbing (g)

Many tests indicated: the water absorption of bamboo-based panels after soaking in cold water for 24 hours is $\pm 20\%$, it does not exceed 45% after 72 hours of soaking.

D. Dry shrinkage, expansion coefficient

Bamboo-based panels expand after absorbing water and shrink when water is discharged. The dry shrinkage and expansion coefficient can be calculated according to the following formula:

$$H = \frac{h_2 - h_1}{h_1} \times 100\%$$

where: H – dry shrinkage (or expansion coefficient) of sample (%)

h_1 – length of sample before absorbing (or drying) (cm)

h_2 – length of sample after absorbing (or drying) (cm)

Many tests showed: dry shrinkage and expansion coefficient differentiated greatly in connection with different adhesives and structures. The dry shrinkage and expansion coefficients of bamboo-based panels, in which the fiber direction of adjacent layers were perpendicular to each other, are restricted by each other. Consequently, both the lengthwise and crosswise shrinkage and expansion of panels are reduced. For example, a piece of 5-layered plybamboo 22 mm in thickness, soaked in cold water for 24 hours, the expansion coefficient is 0.015% in length, 0.017% in width and 0.202% in thickness. A piece of laminated bamboo strip board, 1.0 mm in thickness, all the strips have been soaked in adhesive and pressed under high temperature and high pressure, also soaked for 24 hours, the expansion coefficient is 0.015% in length, 0.181% in width and 0.127% in thickness. The expansion coefficients in length of these two pieces are the same, but those in width differ greatly. This is because all the strips of latter are arranged in one and the same direction, the crosswise expansion has not been restricted. The expansion coefficient of the former is greater, because the strips of former are thicker (4 ~ 6 mm), and they were only overlaid with adhesive, while the strips of latter are thinner, and they have been soaked in adhesive. Plybamboo is widely used in auto industry to make bottom boards, and in building industry to make concrete forms. The dimension requirements are very strict. It is of great importance to study the patterns of shrinkage and expansion of products.

E. Specific heat, thermal conductivity

The structures of bamboo and wood are similar. But both of them have their own special features. The heat properties of bamboo-based panels differ from wood-based panels of same type. In general, as the density of bamboo is higher than ordinary wood, the specific heat and thermal conductivity are also higher than wood-based panels of same type (table 1-10).

2. Mechanical properties

Bamboo-based panels are mainly used as material of engineering structure mechanical, properties are important index of their quality (table 1-2). Main mechanical properties are shown below.

Table 1-10 Specific heat and thermal conductivity of plybamboo

Products	Specific heat (kc/kg • °C)	Thermal conductivity (kc/m•h •°C)
Plybamboo	0.423	0.162
Plybamboo covered with wood veneer	0.333	0.152
Ply-wood	0.327	0.095

A. Modulus of rupture (MOR): Capacity of material bearing bending stress. MOR of bamboo is quite high, of most species the MOR exceeds 150 Mpa. The MOR of bamboo-based panels is much higher than wood-based panels of same structure, same thickness and density. MOR is calculated according to the following formula:

$$MOR = \frac{3PL}{2bh^2}$$

where: MOR – modulus of rupture of sample (Mpa)
P – destructive load of sample (N)
L – length of base (mm)
b – width of sample (mm)
H – thickness of sample (mm)

B. Modulus of elasticity (MOE): Modulus of elasticity shows the capacity of deformation resistance of material. Due to its good structural quality, bamboo material has MOE only 11000 Mpa, similar to ordinary wood of intermediate hardness. The MOE of bamboo-based panels is also similar to wood-based panels of same structure, same density and same thickness. MOE is calculated according to the following formula:

$$MOE = \frac{1}{4} \cdot \frac{\Delta PL^3}{\Delta fbh^3}$$

where: MOE – modulus of elasticity of material (Mpa)
L – length of base (mm)
B – width of sample (mm)
H – thickness of sample (mm)
 $\Delta P/\Delta f$ – slope of curve, showing load-deformation of sample

C. Bond strength: Bond strength is the efficiency of bonding of plybamboo. Bamboo green and bamboo yellow do not have wetting capacity for ordinary phenol formaldehyde resin and urea formaldehyde resin. Therefore they can not be glued. After removing bamboo green and bamboo yellow, the inner part of bamboo stem wall has wetting capacity for many kinds of adhesives. The bond strength is similar to wood, it is expressed by the shearing stress on glued face:

$$\pi = \frac{P}{A \times B}$$

where: π – bond strength of sample (Mpa)
P – maximum destructive load of sample (N)
A – width of shearing face of sample (mm)
B – length of shearing face of sample (mm)

D. Shock resistance: Shock resistance is the energy born by surface of sample when it is broken under the shock. It is also called impact-bending strength. Bamboo material is of high toughness, it can crooked or deformed easily, the shock resistance of bamboo-based panels is higher than wood-based panels of same structure. Shock resistance is calculated according to the following formula:

$$T = \frac{A}{b \cdot h}$$

where: T – shock resistance (J/cm²)
A – energy born by sample (J)
b – width of sample (cm)
h – height of sample (cm)

Table 1-11. Main mechanical properties of bamboo-based panels

Mechanical property		MOR Lengthwise Mpa	MOE Lengthwise Mpa	Bond strength Mpa	Sh resistance Lengthwise J/m ³
Products					
Plybamboo	15 mm 3-layered	113	10584	3.68	8.7
	22 mm 5-layered	126.1	98.96	3.50	9.1
Overlaid high- strength plybamboo of concrete form	12 mm 3-layered	≥ 98	≥ 9000	≥ 2.5	—
	18 mm 5-layered	≥ 98	≥ 8000	≥ 2.5	—
Laminated bamboo strip board		≥ 110	≥ 8000	—	≥ 10
Curtain plybamboo		121.2	11200	—	13.6
Bamboo chipboard (12 mm)		43.3	4580	—	—
Mat plybamboo (5-layered, 5 mm)		93.5	—	—	—
Overlaid chipboard of oriented structure (17 mm)		Lengthwise 98.7 Crosswise 62.5	Lengthwise 8500 Crosswise 6980	—	—
Bamboo-pine composite board of container bottom (28 mm)		Lengthwise 98.7 Crosswise 62.5	Lengthwise > 10000 Crosswise > 3000	2.04	Lengthwise 8.8 Crosswise 2.6
Overlaid bamboo chipboard (12 mm)		53.84	7087	—	—

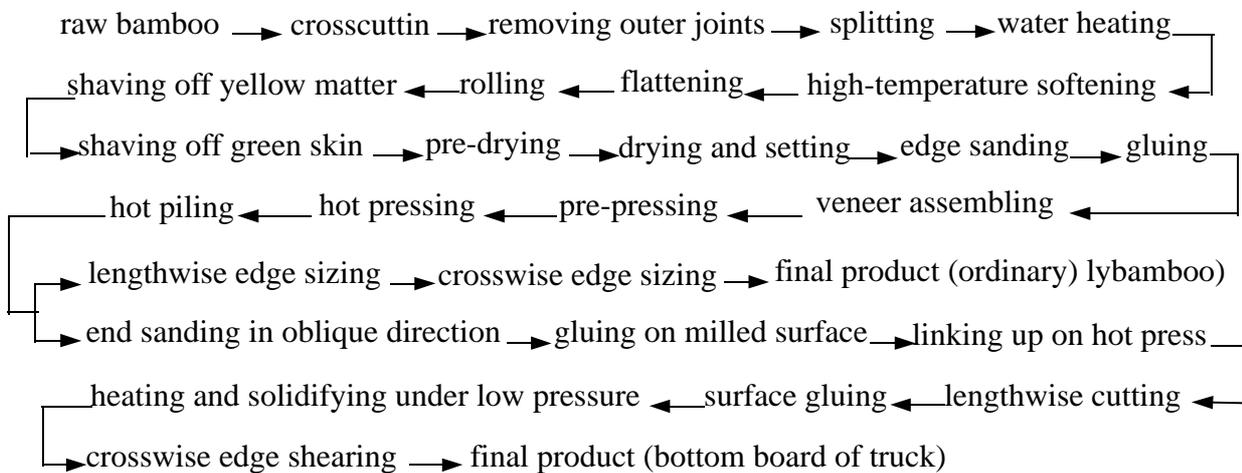
PART II. Manufacturing technology of bamboo-based panels and their uses

Chapter I. Plybamboo

Section 1. The collection of raw material

Plybamboo is a special category in the wide variety of bamboo-based panels. The main feature of its manufacturing technology is “high-temperature-softening and flattening”. Softened at high temperature and flattened, bamboo material is processed by a scientific-proved, simplified and continuous method, with the thickness and width being unchanged. As a result, bamboo veneers of maximum thickness and width are acquired. Consequently, plybamboo of high strength, high rigidity and high wear-ability, which can be used for engineering construction is produced. The manufacturing process is less laborious and consumes fewer adhesive.

The technological process for the production of plybamboo is as follows:



1, Requirements in collecting raw material

Due to the application of “softening and flattening” technology the yellow and green matter on the inner and outer surface of raw bamboo is to be shaved off. Consequently, the thickness of raw material will be affected. As the minimum thickness of material to be shaved on planer is 3 cm, it is desirable to select bamboo culm of comparatively larger diameter, thereby a higher productivity and veneer-rate can be achieved in this way. For the production of plybamboo it is better to choose the culm of *Phyllostachys heterocycla* (Carr.) Mitford, *Phyllostachys bambusoides*, *Dendrocalamus latiflorus* Munro and *Dendrocalamus giganteus* Munro, with a diameter on the breast height of 9 cm or more.

The change of physical quality of bamboo culm in connection with its growth is divided into three phases: strengthening, stable and weakening. For example, the physical quality of *Phyllostachys heterocycla* is in strengthening phase when it is 1 – 4 or 5 years old. In this phase the density increases rapidly, the water content decreases and physical strength improves. At the age of 5 or 6 years, it enters the phase of stable quality, the density and physical strength are on the highest level. The weakening phase begins at the age of 9 or 10 years, when the growth declines gradually, the density and physical strength decrease.

The time of bamboo cutting for plybamboo production should be fixed at the age favorable for both the acquiring of qualified material and the cultivation of bamboo grove. In *Phyllostachys heterocycla* grove of different ages the bamboo to be cut should be at the age

of 6 or 7 years, bamboo under 5 years should be retained and those exceed 10 years are not suitable for making plybamboo.

The surface color of bamboo culm changes in connection with its growth, In general, the surface of young bamboo culm is green, that of middle-aged is yellow-green and the matured one is yellow or bronze. The age of bamboo can be judged according to the color of culm surface. For example, the culm of one year is dark green, with brown “eyelash” on the sheath rings and white powder under the sheath rings. The culm of 2-3 year is green, the brown eyelash is sparse or all fallen off, the powder under sheath rings becomes dark gray. The culm of 4-5 years is yellow green with a hoary wax cover. The culm of 6-7 years is green yellow, the hoary wax cover is getting thicker, the powder under sheath rings becomes gray black. The culm of 8-9 year is green yellow with bronze color, the hoary wax cover begins drop. The culm of 9-10 years and more is of bronze color, most of the hoary wax cover dropped, often with cicatrix. The color of bamboo culm changes under the influences of surrounding environment to a great extent. The culms of different bamboo species show their color stamps. The correct judgement of age can be achieved by experience gathered from close observation and regular comparison.

The season of cutting affects directly the growth of bamboo grove and the quality of acquired bamboo material. The metabolism of bamboo in its growth period is vigorous. The cutting of bamboo leads to rich wound secretion. As the secretion is very nutritious, its accumulation in bamboo grove will cause the breeding of bacteria and ferment, which results in the rot of bamboo, decrease of shoot harvest and its size. The activity of bamboo cutting in its growing season damages the stands and new shoots, it has negative effects on the regeneration of bamboo grove. Therefore it is necessary to avoid the cutting in growth season.

2. The stockpile of material for plybamboo production

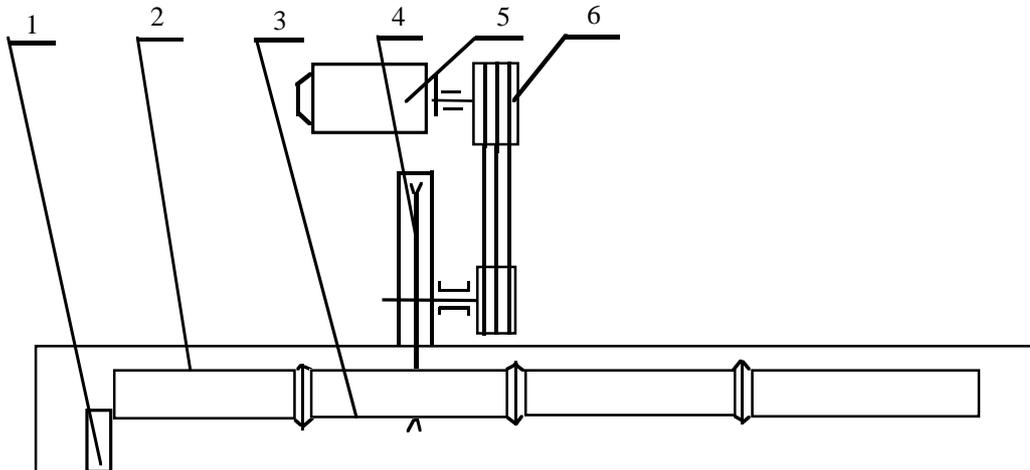
The plybamboo is produced all the year round, while the cutting of bamboo can be carried out only in certain season of the year. In order to ensure the balanced production of plybamboo, the mills should keep a stockpile of raw material for 3-4 months. Bamboo material is cracked easily under the sun. It contains much soluble saccharide, starch, protein and fat, which breed the insect pest and fungus pest. In the process of stocking great attention should be paid to the prevention of pests. In order to prevent the insect and fungus pests effectively, it is desirable to soak the bamboo culm in water. But as bamboo culms are hollow, they can not be put fully in water. In addition, the quantity of bamboo material is enormous, ordinary mills can hardly prepare such a great water pool to preserve them. Therefore, this method of water stocking is not practical in production.

With the enlargement of production scale of all the mills the amount of stockpile is also increasing. In the process of stocking great attention should be paid to the following problems: (1) To level and roll the stocking ground, to arrange drainage on it, to cover the ground with cement if possible. (2) To arrange truck roads and unloading field for the effective motion of trucks and unloading of raw bamboo. (3) To establish parallel foundation ridges of armor concrete, the space between two adjacent ridges is 2 meters. Raw bamboo can be piled up over the ridges. In this way the raw bamboo does not come into contact with the ground surface for keeping efficient ventilation. (4) To set up poles of armor cement on the ground for helping the piling operation and ensuring certain height of piles without collapse. The poles must be of enough strength, 2.0-2.5 meters high, the space between piles should be 1.5-2.0 meters. (5) To set up awnings to shelter the sun if possible, otherwise to cover the bamboo piles with straw mats. (6) To indicate the date of stacking for every pile to follow the principle “first come, first used” and decrease the stack time.

3. The crosscutting, joint-removing and splitting

A. Crosscutting

The raw material for plybamboo production is transported to mills in the form of raw bamboo. It is crosscut according to the size of products. The equipment for cutting is shown in fig. 2-1. The purpose of crosscutting operation is to divide the raw bamboo into sections of certain length in accordance with the size of final products, to utilize the raw material rationally and economically, taking into consideration its crookedness and obliqueness.



1. Retaining block. 2. Working table. 3. Raw bamboo. 4. Saw. 5. Electro-motor. 6. Belt pulley.

Fig 2-1: Cutting machine

The crosscutting operation should be carried out in the following order:

- (1) To cut off the end of raw bamboo with the traces of hacking.
- (2) To start the cutting operation from the root part.

(3) The thickness of culm wall is quite big under the height of 1.5 meters. It decreases rapidly in this part. From two meters and higher, the thickness decreases slowly and gradually. The diameter of culm changes also in this manner. For the rational use of raw material it is reasonable to cut the first one into a short section to be used as an inner layer. The second and third ones can be long sections to be used as surface layers. The fourth and further sections should be short again, to be used as inner layer.

(4) During the cross-cutting of bamboo culm with great crookedness, it is better to make more short sections for inner layers. To remove the significantly crooked part and try the best to get the straight sections or those with little crookedness.

(5) The bamboo sections must have proper margin of processing. Too much margin increases the consumption of raw material and subsidiary material, and the production cost, and decreases the utilization ratio of raw material. Too little margin makes the processing difficult and causes more inferior and defective products. The rational margin in length and width is 50 – 60 cm.

In mountainous areas where the transport is not convenient, it is also reasonable to cut the bamboo culm into proper sections according to the above-mentioned rules and transport them to the mill.

B. Removing outer joints

The surface of bamboo culm is green, smooth and bright between the joints. The formation of sheath and the change of vascular bundle direction cause the collar flange around the joints. The raised part must be removed for the successful flattening, rolling and cutting.

For removing the outer joints the removing machine is used (Fig.2-2). The outer joints are removed one by one with the milling cutter fixed on the outside board

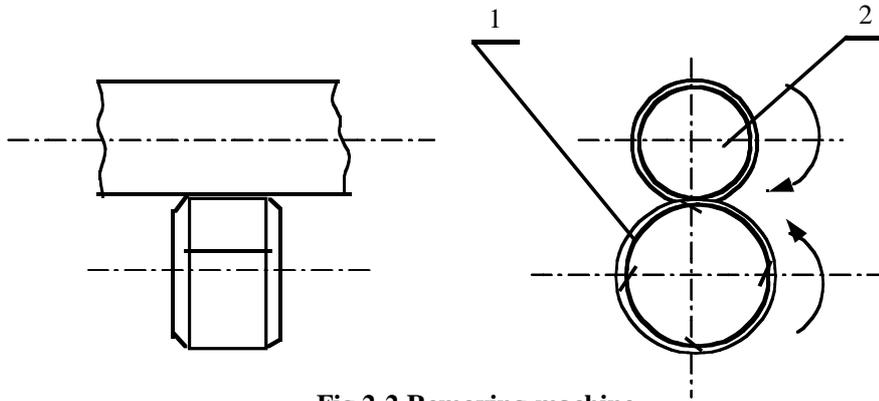
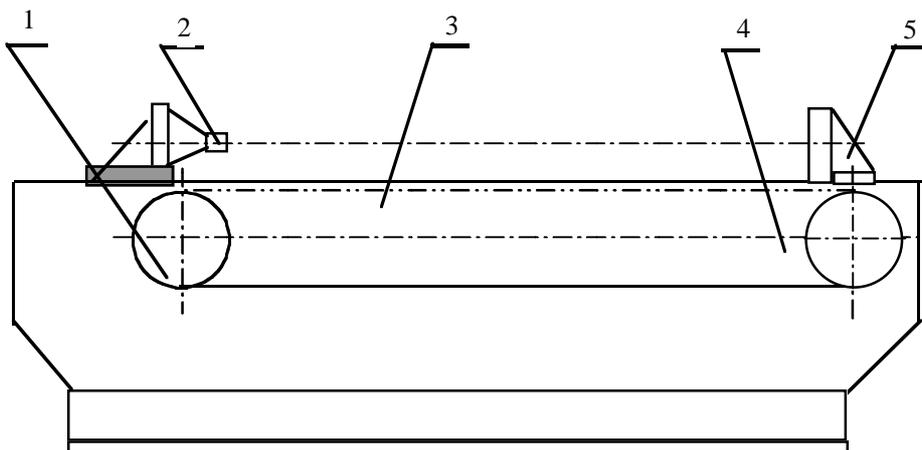


Fig.2-2 Removing machine

C. Splitting bamboo sections

In order to produce bamboo veneer the bamboo sections must be split into two or three fragments. Bamboo sections are split with a splitting machine. (Fig.2-3). The vascular bundles of culm wall are collocated in parallel order and the linkage between them is loose. The splitting operation is easy and laborsaving. The knives of splitting machine are fixed on the knife-carrying disc, bamboo sections are driven with a moving block and split into two or three fragments. Two knives fixed on knife-carrying disc opposite to each other or three knives fixed on disc, forming obtuse angles of 120° can split a bamboo section into two or three fragments. Increase the number of knives, the number of fragments can also be increased.



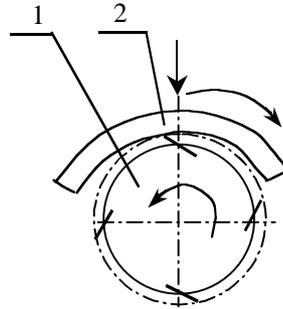
1. Chain wheel. 2. Splitting knife. 3. Chain. 4. Driving chain wheel. 5. Driving block.

Fig. 2-3. Splitting machine

In the splitting operation the center of bamboo section must be in alignment with the center of knife-carrying disc. In this way fragments of comparatively uniform size can be made.

D. Removing inner joints

The raising part of inner flange still remains on fragments after splitting. The thickness of raising part is about 50-60 mm, at least 20-30 mm. To achieve satisfactory flattening effect, the inner joints must be removed. They are removed by means of an inner joints removing machine (Fig. 2-4).



1.Milling cutter. 2.Bamboo fragment.

Fig. 2-4. Inner node removing machine.

The milling cutter of removing machine revolves at a high speed. On both ends of the cutter axis there are two pressing spacers, which control the depth of milling-cutting. Press inner joints of fragment closely to the milling cutter, the satisfactory effects of removing can be achieved.

Section 2. The processing of bamboo fragments

1. The softening of bamboo fragments

A. The aim of softening

In the process of flattening semicircular bamboo fragments, its outer surface is under pressing stress, while the inner surface is under pulling stress. These stresses can be calculated with the following formula:

$$\delta = \frac{E \cdot S}{2\gamma}$$

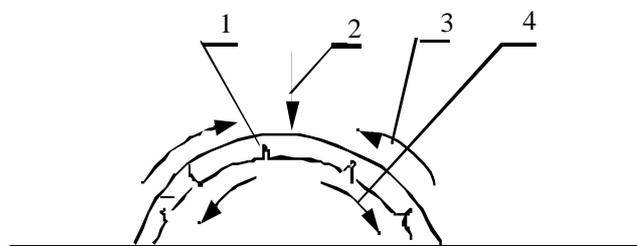
δ – pressing stress on outer surface or pulling stress on inner surface of bamboo fragment during flattening (MPa)

E – crosswise modulus of elasticity of fragment. $E = 1.0 \times 10^4$ (MPa)

S – thickness of bamboo culm wall (cm)

γ – curvature radius of bamboo fragment (cm)

The diameter of bamboo is comparatively small, while its curvature is quite big (Fig. 2-5).



1. Bamboo fragment. 2. Pressing directions during flattening.
3. Direction of pressing stress on outer surface. 4. Direction of pulling stress on inner surface

Fig.2-5: Stresses on surfaces of bamboo fragment during flattening

Therefore, in the process of flattening the pressing stress on the outer surface and the pulling stress on the inner surface are rather significant. The calculation shows: To flatten a bamboo semicircular fragment of 1 cm thick with the diameter of 10 cm under normal temperature, the pressing and pulling stresses on outer and inner surfaces are 1.05×10^3 MPa. The allowable stress of crosswise-linked vascular bundles is about 0.68 MPa. The pulling stress in the process of flattening exceeds the crosswise linking capacity of bamboo material, i.e. allowable stress. Generally speaking, the capacity of bamboo material for bearing pressing stress is comparatively high, consequently, there will not be any defects on the outer surface of bamboo fragment after flattening. But its capacity for bearing pulling stress is low, so the cracks on the inner surface after flattening are inevitable. It can be seen from the above mentioned formula that the stresses in flattening are directly proportional to modulus of elasticity E and thickness of bamboo culm wall S , and inversely proportional to the diameter of bamboo culm. For the flattening of certain bamboo fragment, S and γ can not be changed. While the value of E , relating to its temperature, water content and surface conditions, can be changed by human efforts. Accordingly, to minimize the value of E is an effective way for the decreasing of pulling stress, thereby reducing the depth and width of cracks on the inner surface of flattened fragments. To raise the temperature and to increase the water content are efficient measures for lowering E . This process is called the softening of bamboo fragments.

B. The method of softening

To raise the plasticity of bamboo material is an effective way to change its mechanical properties and its value of E . The following methods can be applied for this purpose at present: (1) Treatment with chemicals. (2) Increase the water content of bamboo material. (3) Raise the temperature of bamboo material. (4) Change the surface structure and conditions.

To soak bamboo material in limewash, caustic soda, sodium sulfite, ammonia and other alkalinity solutions, its chemical structure can be changed and certain softening effects can be achieved. But due to the use of chemicals the interior structure of bamboo will be destroyed and its mechanical strength damaged. Besides, after such a treatment the bamboo material turns black and yellow. As a result, the quality of final products – plybamboo is affected. In addition, the disposal of liquid waste from chemical treatment brings about many technical and economic difficulties.

Tests prove: bamboo fragments whose green and yellow matter had been shaved off and the fragments with green and yellow matter not shaved off were flattened under the same hot treatment conditions. The depth and width of cracks on the former are less than those on the latter. If cut oblique short grooves 1 mm deep on the surface of bamboo fragment before the hot treatment and flattening, the grooves link the parallel cracks and prevent them run through the whole fragment. Both the two methods improve the flattening effects and the quality of products. But as the design and manufacture of green-shaving, yellow-shaving and grooving machines are quite complicated and difficult, it is unpractical to change the surface conditions for flattening in plybamboo production.

Under present technical conditions, to raise the water content and temperature of bamboo fragment are the most effective measures for increasing the plasticity of bamboo fragment and reducing its elasticity modulus. As a result, the pulling stress in the process of flattening will be decreased.

(1) Raise the water content: Water content of bamboo fragment relates to its age, cutting season, its position on the bamboo culm, its storage time and way of storing. It takes a quite long period of time from cutting in hilly areas, purchasing and transporting, to the storage in mill yard. The water content of bamboo material at mill yard is different, and it is too small in general. For increasing the elasticity of bamboo material and decreasing its value of E , it is necessary to raise its water content. For this purpose bamboo material can be soaked in cold water. But as the raise of temperature also increases its plasticity, to soak it in warm water 70-80°C for two to three hours is recommendable. By means of the interchange of water and heat, both the water content and initial temperature are raised. This process is called “water heating”. Table 2-1 shows the comparison of water contents of bamboo material before and after water heating.

(2) Raise the temperature: Both the bamboo and wood are natural grown organisms. But the cellulose content of bamboo is higher than that of ordinary wood. On the other hand, the content of hemi-cellulose and lignin of bamboo is lower than that of ordinary wood. Tests demonstrated: hemi-cellulose shows certain plasticity under 80°C, and lignin 100°C. While cellulose needs 130 ~ 150°C to show such a plasticity. Accordingly, the plasticity of bamboo material can not be improved by means of water boiling under normal pressure. The temperature of bamboo material must be raised to 140 ~ 150°C to achieve a better plasticity. This is the great difference between plybamboo and plywood production. The processing under high temperature is called high temperature softening.

Table 2-1. The water content of bamboo soaked in water of 70 ~ 80°C for 2 hours

Age (years)	2 - 3	4 - 5	6 - 7	4 - 5	4 - 5
Height form Ground surface	0.6 - 2.5	0.6 - 2.5	0.6 - 2.5	2.5 - 4.4	4.4 - 6.3
Water content Before soaking	65.80	46.60	42.80	39.0	36.0
Water content after soaking	79.20	76.90	78.10	57.20	54.70

Note: the bamboo had been stored in room for 1 month before soaking

C. Softening equipment and technology

The softening process is carried out in two phases. Phase 1 is water heating, to raise the water content and initial temperature of bamboo fragments. Phase 2 is high temperature softening, to raise the temperature to 140 ~ 150°C.

(1) Water heating:

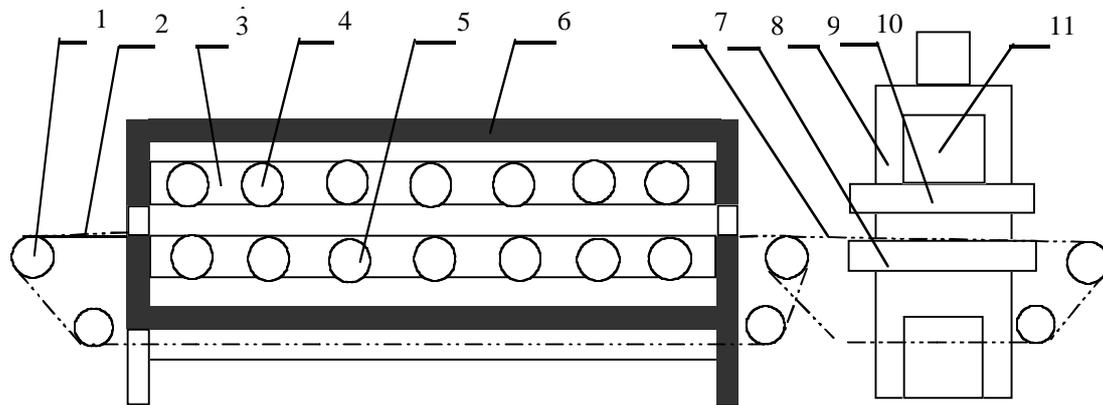
To sort bamboo fragments into groups of different length and thickness, put them in hanging cages. Lay down in water 70 ~ 80°C for 2 ~ 3 hours. The heating water must overflow bamboo fragments. Water must be replenished regularly due to its evaporation, and the water surface kept over bamboo fragments. The heating pool should be put in order once a week: to drain off water waste, clear away mud and rubbish. The water heating process raises the water content and temperature of bamboo fragments, and extracts many kinds of organic matter as well. This is favorable for strengthening the anti-insect and antiseptic capacity of bamboo material and plybamboo.

The heating pool is of armor cement structure. As the temperature of heating is comparatively low, the waste gas released from drying-boarding machine and hot press can be used for heating. In order to prevent that the temperature raises too slow, it is recommendable to arrange fresh steam pipe for supplementary heating. Around the heating pool must set up protective fence to avoid personal injury.

(2) High temperature softening:

The temperature of water heating under normal pressure can not exceed 100°C. Extremely high pressure is needed for raising temperature to 150°C. It is very difficult to keep such a high pressure technically. Besides, the temperature drops down quickly in further operation when the pressure is loosened. In addition, the safety of operation can hardly guaranteed. Therefore the high pressure heating is not feasible. The method of media heating is quite convenient to raise the temperature of bamboo fragments to 150°C. To heat the paraffin wax to 160 ~ 170°C and put water-heated bamboo fragments in paraffin wax trough. To heat them for 2 ~ 3 min and the temperature of fragments achieves 150°C. But in this way the paraffin wax evaporates easily, and bamboo fragments also absorb some paraffin wax. It consumes some 50 ~ 60 kg of paraffin wax to produce 1 m² of plybamboo. Furthermore, the evaporated wax gas causes air pollution. Consequently, wax media method is not acceptable from both the environmental and economic viewpoints. Another method is to establish resistance wire or far infrared pipe in the heating chamber. The temperature in heating chamber increases to 180 ~ 200°C when it is electrified, and bamboo fragments can be heated in this chamber. But the vast consumption of electricity increases the production cost significantly. In addition, the resistance wire and far infrared pipe can be damaged easily, the maintenance cost is also high, and the production will be interrupted when the resistance wire and far infrared pipe are being maintained. So such a method is not an ideal way too.

After numerous tests and practice, a high effective softening machine with a chain conveyor (Fig. 2-6) is created for the plybamboo production at present. This machine consists of two parts: a furnace and a softening machine with a chain conveyor. The wastes resulted from bamboo cutting such as shavings and flakes are transported to furnace with a wind feeder. They burn in suspended state. The high temperature gas (about 270°C), filtered and mixed with air, enters the heating radiator pipe in the form of S. By means of upper and lower heating pipes the air in softening machine is heated to 180 ~ 200°C. Four conveyor chains run through softening machine and connected with the flattening machine. The chains start moving every 25 ~ 30 sec. Water-heated fragments, sorted into groups of different length and thickness, are conveyed into softening machine. The softened fragments enter the flattening machine. The operation cycle of flattening machine lasts 25 ~ 30 sec. The pressing board runs down, closes, presses and returns to initial state. The chamber of softening machine is separated from outside atmosphere with two wind curtains of surplus energy, one of the curtain is arranged on the entrance and the other is on the exit of the chamber. These curtains prevent the leak of heat and steam, reduce the loss of energy and support a space of high temperature and high humidity in the chamber. All these factors prevent the decline of water in the process of bamboo heating, which may influence the effect of flattening operation.



1. Chain wheel. 2. Conveyor chain. 3. Softening furnace. 4. Upper heating pipe. 5. Lower heating pipe. 6. Insulating layer. 7. Chain of flattening machine. 8. Bottom board of flattening machine. 9. Flattening machine. 10. Pressing board of flattening machine. 11. Plunger.

Fig.2-6: High effective softening machine

2. The flattening and rolling of bamboo fragments

The process of flattening and rolling is to turn the water-heated and high-temperature-softened semicircular bamboo fragment into flat bamboo veneer under pressure. After this operation there will be several cracks on the inner surface of bamboo veneer, but the veneer will not split into pieces due to these cracks. It can be processed further for plybamboo production.

A. The way of flattening:

Bamboo fragments can be flattened with three methods.

(1) Simple flattening under pressure.

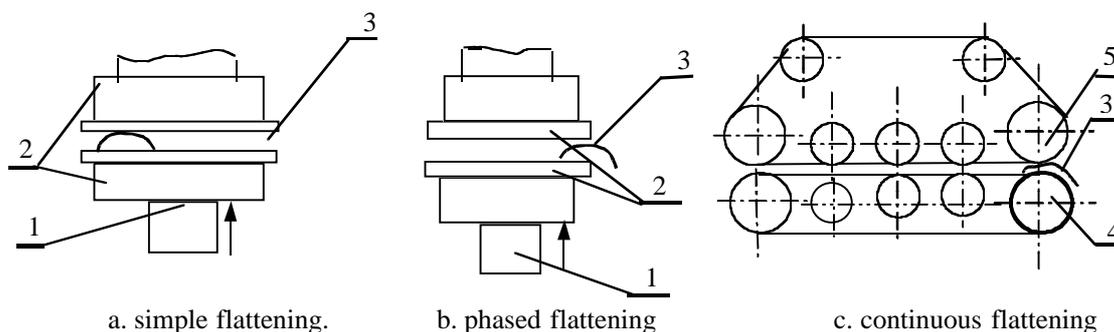
To put the semicircular bamboo fragments into mono-tier or multi-tier flattening machine, flatten them under pressure once for all. The equipment and technology used for simple flattening are comparatively simple, but the stress during flattening is significant, the cracks are deep and the quality of veneer is lower.

(2) Phased flattening under pressure.

The principle of this way is to divide the semicircular arc of bamboo fragments into several phases and flatten them under pressure phase by phase.

(3) Continuous flattening under pressure.

Bamboo fragments move in the direction of tangent of arc and are pressed simultaneously. This method can be used for continuous production and for improving productivity. When applying methods (2) and (3), the stress on bamboo fragments are smaller, cracks are not deep, thus the flattening effect is good. But as bamboo fragment are of different size, curvature and form, it is difficult to design and manufacture a continuous flattening machine. In phased flattening machine the load of pressing board is not well-distributed, its productivity is low and does not meet the requirement of mass production. At present the simple flattening machine is applied in plybamboo production. Fig. 2-7 shows the methods of flattening.



1.Plunger. 2. Lower pressing board. 3. Bamboo fragment.
4. Driving roll of lower conveyor. 5. Driving and pressing roll of upper conveyor.

Fig. 2-7. The methods of flattening

B. Technology of flattening.

Two methods are applied in production at present.

(1) Pressing-flattening and keeping pressure

Put the water-heated and high-temperature softened bamboo fragments into multi-tier (4 ~ 5) flattening machine, press them for once, release the pressure, remove the pressing board and release the water and let the flattened veneers shrink. Press the flattened veneers after shrinkage and keep the pressure for 1 ~ 2 min. These flattened veneers can be delivered into further processing. The water content and temperature of bamboo fragments are the key factors influencing the flattening effect. In general, water content can be kept in range of 60 ~ 80% after 2 ~ 3 hours of water heating. When bamboo fragments have been heated in high-temperature softening machine (chamber) of 180 ~ 200°C for 3 ~ 5 min, and “grease spots” appear on their green matter, the temperature of fragments reaches some 150°C, a suitable temperature for flattening.

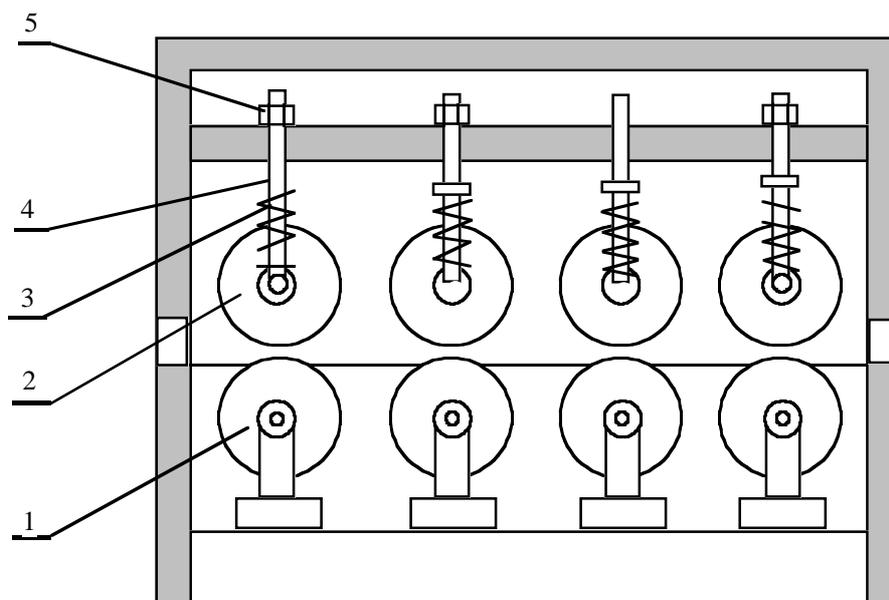
The time needed for high temperature softening is influenced by the air temperature in the softening machine (chamber), besides, it is also influenced by the thickness of bamboo fragment itself. The main shortcomings of this method is:

a. As bamboo culm is in conical form, the thickness of culm wall is uneven. The two hot pressing boards perform a kind of rigid pressure. Bamboo fragments can not be flattened fully, and the green and yellow matter can not be shaved off fully too. This will affect the quality of gluing and exterior features of plybamboo. If make efforts to remove all the green and yellow matter, too much outer part will be lost, and the utilization ratio of raw material and the mechanical strength of products will be affected.

b. To increase the production capacity of flattening machine, multi-tier machine is applied. As the pressure directs upward, it is impossible to make the production continuous.

c. To achieve better flattening effect, the pressing boards must be heated to 150°C, which leads to great consumption of energy. Besides, due to the frequent movement of pressing boards, the joints of steam pipe are often damaged. As a result of above-mentioned shortcomings, it is necessary to improve this method.

(2) Flattening and rolling Load the softened bamboo fragments into flattening machine. Press them once and unload them without keeping the pressure. Both the upper and lower steel boards are not heated with steam. The flattening machine is of mono-tier structure. Its upper board functions as a pressing board. Such a machine is suitable for continuous production. The pressed bamboo fragments enter the rolling machine right after unloading from flattening machine. Rolling machine consists of four pairs of upper and lower rollers. Bamboo fragments move thorough rollers, being rolled and flattened four times. Bamboo fragments contact with rollers lineally, and the lineal pressure is high. So bamboo fragments are pressed evenly. The flattening effect is much higher than that of the previous method. The amount of green and yellow matter shaving is decreased and the quality of flattened fragments improved. As the upper and lower boards are not to be heated with steam, the energy consumption is reduced. Another distinguishing feature of this method is its suitability for continuous production. Fig. 2-8 shows the structure of flattening-rolling machine.

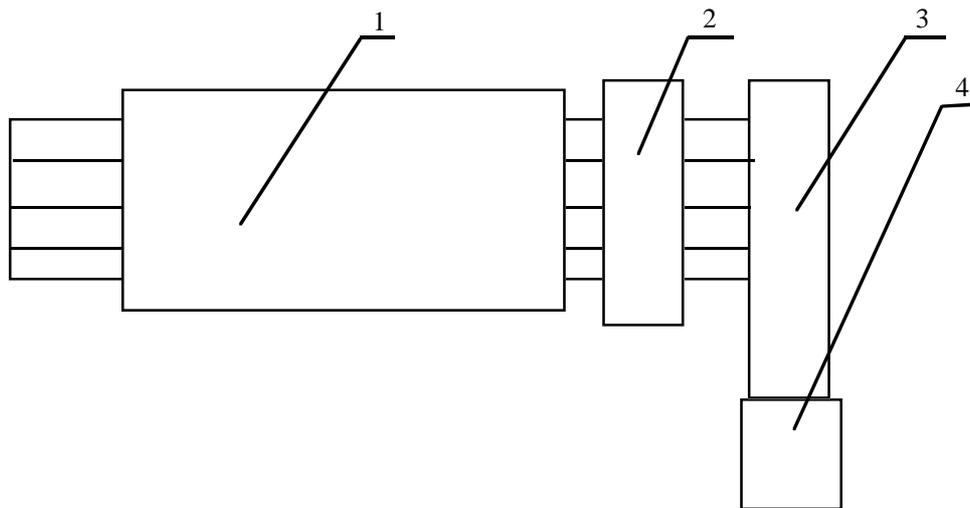


1.Lower roller. 2.Adjustable upper roller. 3. Pressing spring.
4. Adjusting screw nut of spring. 5. Screw nut adjusting the clearance between rollers.

Fig. 2-8. Bamboo rolling-forming machine

C. “Softening-flattening-rolling” production line.

As a result of applying “flattening and rolling” technology, the “high temperature softening, flattening and rolling” continuous production can be realized. Fig. 2-9 shows the process of continuous production. The process is as follows: water-heated bamboo fragments are loaded on feeding chains respectively according to their size.



1. Furnace continuously feed with bamboo fragments. 2. Flattening machine.
3. Metal slide slope. 4. Rolling machine.

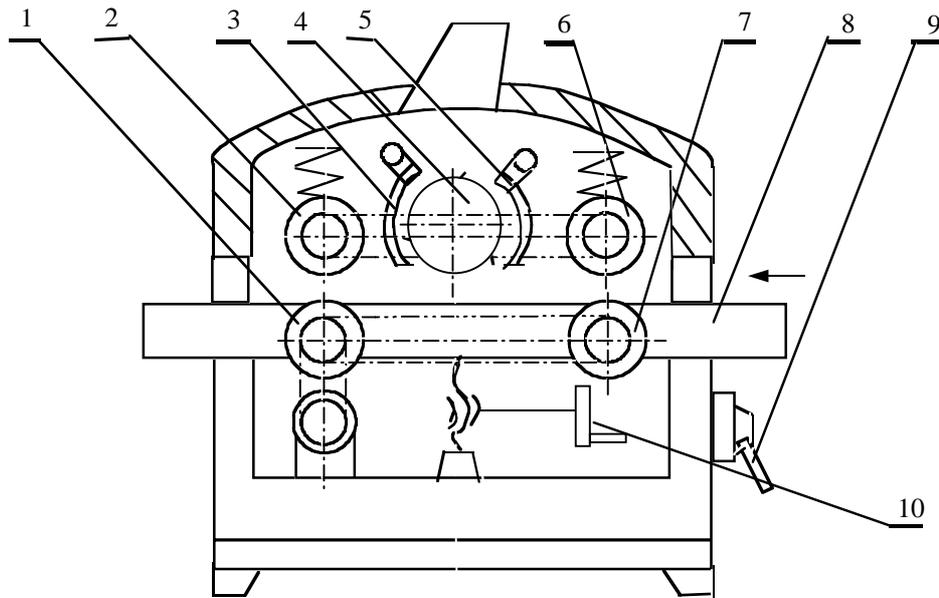
Fig. 2-9. Continuous production line “softening-flattening-rolling”

With the movement of the chains bamboo fragments enter the softening machine to be heated at a high temperature. When the temperature of bamboo fragments reaches the required height, they move to the lower board of flattening machine and the chains stop moving. The upper pressing board moves down to press the fragment. The pressure lasts 3 sec. Then the upper board moves up, the chains start moving. The flat bamboo fragment drop into the lengthwise conveyor, when it come to the entrance of rolling machine, the conveyor stops and the flattened fragment enters the rolling machine to be rolled. The whole cycle takes 25 ~ 30 seconds. When the conveyor stops moving, newly water-heated fragments come to feeding chain without pausing. The continuous production can be realized by repeating such operations. Semicircular bamboo fragments become flat veneers after high-temperature softening and flattening.

3.The shaving and cutting of flat veneers

The green and yellow matter shows little affinity for adhesives. It is impossible to glue together the flat veneers with green and yellow matter. Besides, bamboo culm is of conical form, the thickness of flat veneers is uneven. Longer bamboo veneers show more unevenness. In order to produce well-glued plybamboo of uniform thickness, flattened and rolled veneers must be shaved. The purpose is to shave off thin layers of green and yellow matter of bamboo veneers, and improve their affinity for adhesives. Besides, it is also important to have uniform thickness on the whole length of bamboo veneers, this will improve the gluing effect and reduce the thickness deviation.

The hardness of bamboo material is quite high, about 72.0 MPa, similar to that of oak, a species of hard broadleaf trees. To shave bamboo material under normal temperature is very difficult, the feeding of bamboo material is troublesome, energy consumption is great, the cutting tool can hardly stand up to the wear and tear of such an operation, and the noise is awful. Have been high-temperature-softened, flattened and rolled, the temperature of bamboo fragments is about 70 ~ 80°C, its plasticity is comparatively higher and hardness lower. The surplus heat in bamboo veneers must be utilized, to shave them right after the rolling operation. In this way the consumption of energy and noise can be reduced greatly, and the service life of cutting tool will be longer.



1.Lower roller for front feeding. 2. Upper roller for front feeding. 3,5. pressuring instruments
4.cutter of shaving. 6. Upper roller for back feeding. 7. Lower roller for back feeding. 8.Worktable.
9. Handle for locking. 10. Adjusting handle of working-table.

Fig. 2-10. Press-shaving machine for bamboo material

The shaving operation is implemented on a press-shaving machine. Fig. 2-10 shows a press-shaving machine to be used specially for shaving bamboo material. In comparison with ordinary shaving machines, this machine possesses the following features: **a.** The green and yellow matters of bamboo are stiff and smooth, the friction coefficient is low, the feeding operation will be often interrupted by skids. Therefore the upper and lower rollers are double driven, and there are lengthwise skid grooves carved on feeding rollers. **b.** Due to the significant strength for shaving bamboo material, the radius of cutter axis is enlarged. **c.** Due to the high hardness of bamboo material, the surface of worktable can be damaged and worn quickly. The surface of worktable is hot-treated and/or changeable.

The shaving operation should be started from yellow matter, because the green matter is quite smooth and flat, which can be used as a datum plane for yellow shaving. The green matter can be shaved after yellow shaving. To raise the utilization ratio of bamboo material and to prevent too deep shave the yellow and green shaving operation should be implemented twice respectively. Taking into consideration the rational production and effective management, the thickness standards of bamboo veneer should not be too complicated. The interval can be fixed at 0.5 ~ 1.0 mm in general: 3.5 mm, 4.0 mm, 4.5 mm, 5.0 mm, 5.5 mm, 6.0 mm, 6.5 mm, 7.0 mm, 7.5 mm, 8.0 mm. The residual yellow matter should not be left on the inner surface after shaving, because the inner surface is to be glued, and the residual yellow matter affects the gluing effect. The green matter is to be used as the surface of plybamboo, a little residual green matter left on the outer surface is allowed or not allowed. The residual green matter may influence the effect of paint and dope. Furthermore, it also affects the gluing of plybamboo to other kinds of bamboo material.

4. The drying and processing of bamboo veneer

A. The drying of bamboo veneer

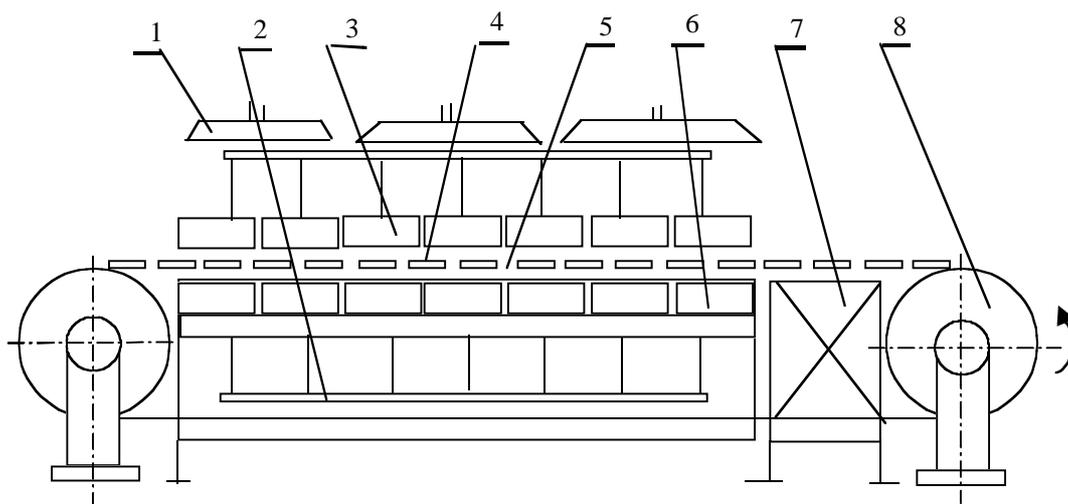
The water content of all kinds of bamboo fragments after water heating becomes even. The moisture of flat veneers after high-temperature softening, flattening and rolling is high, about 35% ~ 50%. Most of the plybamboo are used as bottom of trucks and buses, and concrete forms as well, they must be strongly resistant to water and weather-changes. These

kinds of plybamboo are produced applying water-soluble phenol resin. Plybamboo for inner decoration and packaging can be produced with urea-formaldehyde resin. The water content of bamboo veneer should be less than 8% when phenol resin is used, and it should be less than 12% when using urea-formaldehyde resin. An ideal gluing effect can be achieved with such water contents. Consequently, bamboo veneers after shaving must be dried so that their water content decreased to required standard. In general, bamboo veneers are much thicker than wood veneers, the drying time of bamboo veneers lasts 15 ~ 60 min in ordinary wood dryer. It is necessary to create special technology and equipment for bamboo drying.

(1) Pre-drying: In order to acquire high efficiency of drying special kilns are established. The kilns are provided with heat from a furnace. Burning all bamboo wastes such as flakes, shavings etc heating gas is generated. For reducing investment and increasing productivity a furnace can be designed to provide heating gas for two kilns. The gas generated by furnace functions as a kind of heat media. It is filtered and mixed with air. The mixture (wet air) functions as drying media. The drying media enters the radiating steel pipe of S form in kiln dryers. Driven by a reversible, axial flow ventilator installed on one end of the kiln, the drying mixture moves through the radiator raising the temperature of veneer. There is a steam generator on the top of furnace, which can be used to regulate the flow and humidity of mixture, and, as a result, to guarantee the quality of drying. The process of pre-drying should not be implemented too quickly, which may cause the warp and deformation of veneer. In general, a pre-drying cycle lasts 10 ~ 12 hours. The final humidity should be kept in the range 12% ~ 15%.

(2) Setting-drying: Bamboo veneers are made of semicircular bamboo fragments by means of water heating, high temperature softening and flattening. Due to the numerous cracks happened in the process, the semicircular fragments are turned into flat veneers. But their crosswise elasticity can be recovered under natural conditions. To be dried under natural conditions, the veneer will deformed seriously.

To prevent the deformation caused by the recovering of crosswise elasticity in drying process, it is necessary to apply press-drying equipment. Veneers are heated and dried under proper pressure. The pressure should be relieved intermittently and the veneers shrink freely. Consequently, the crosswise fracture caused by drying can be prevented (Fig. 2-11).



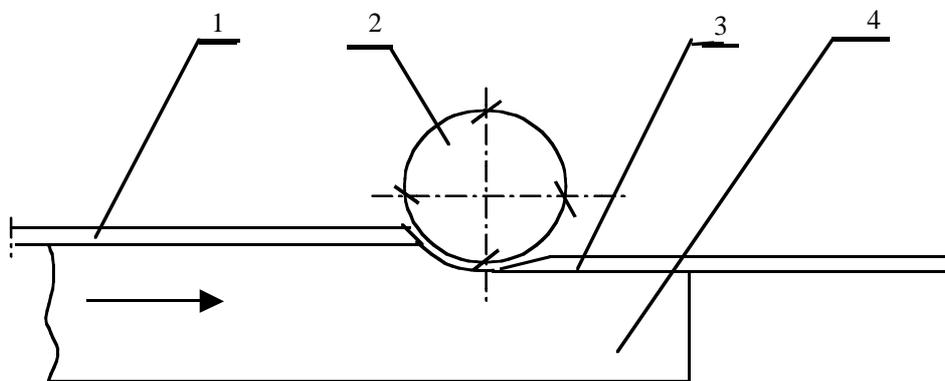
1. Gas release cover. 2. Gas release pipe. 3. Upper pressing board. 4. Veneer 5. Steel belt.
6. Lower pressing board. 7. Worktable. 8. Driving wheel of steel belt

Fig. 2-11. Forming-drying machine

Pre-dried veneers are loaded on steel-belt conveyor, the upper pressing board goes up and the conveyor moves. Veneers come into the space between two hot pressing boards. The conveyor stops moving and the upper board comes down for pressing and heating about 2 ~ 5 min. The upper board goes up after hot pressing and the operation repeats. When the conveyor feeds the machine with veneers, the conveyor on the other end unloads the dried veneers from the machine. In this way the forming-drying operation is carried out. Rolling-spraying dryer is also a kind of equipment for pressing-drying. Tests prove: veneers of thickness under 4 mm can be formed and dried on this machine in one turn without pre-drying. But thicker veneers must undergo two phases: pre-drying and setting-drying.

B. Edge trimming

Because of the cracks happened during splitting operation and the uneven shrinkage in the drying process of veneers, two sides of cross-cut are and uneven. In order to make the joints on plybamboo surface tight these sides are to be trimmed. Trimming operation is carried out on a trimming machine (Fig. 2-12) with manual feeding. But if the sides are crooked, they must be treated several times. Most plybamboo factories are applying such abraders, but its productivity is not high.



1. Front guiding ruler. 2. Trimming cutter. 3. Back guiding ruler. 4. Bamboo veneer.

Fig. 2-12. The structure of trimming machine

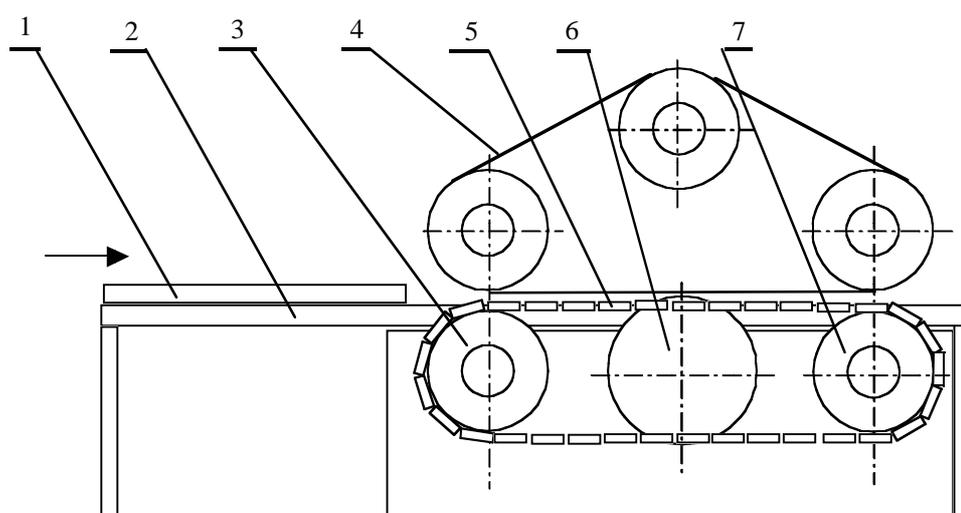
The cross-cut sides can also be processed by an edge trim saw (Fig. 2-13) with track feeding. The sawn sides are smooth and even. The sawing operation can be regulated with a guiding ruler, and the margin of processing can be reduced. Veneers are transported on track under pressure at high speed without the movement off-course. The productivity of circular power saw is high and the sawing quality is good. This is another equipment for side processing, especially suitable for processing short veneers.

Section 3. The adhesive coating of veneers and their further processing

1. Adhesive coating and assembling

A. Adhesives

Adhesives are selected according to the uses of final products. In general, for the plybamboo to be used indoors or as one-off packaging material it is possible to apply urea-formaldehyde resin or some kinds of similar ones. As for the plybamboo to be used as bottoms of trucks and buses, and for making concrete forms, the adhesive should be of high quality, water resistant and resistant to elements. It is better to apply phenol resin or some kinds of similar ones. As a rule, the low-priced, water-soluble and convenient phenol resin is selected. But if the extra high gluing effect is required, it is recommended to use alcohol-soluble phenol resin, or phenol resin modified with resorcin. Phenol is a chemical of wide use in industry, its supply is rather short and price is quite high. In addition, the amount of free hydroxybenzene is more than normal, it pollutes the environment and affects the health of workers. The Nanjing Forestry University in cooperation with Yakeshi Tanin Extract Factory, Inner Mongolia, China applied the tanin extract of larch to replace 40% of phenol in the production of tanin phenol resin (TPF for short). This resin has been tested in plywood production. An aging test of TPF plybamboo has been complemented with reference to US Standard ASTM D1037. It demonstrated that the aging resistant capacity of TPF similar to that of ordinary phenol resin. At present, TPF can be produced in powder, in comparison with liquid, the powder is easier to transport and store. Therefore, this new kind of resin has good prospects.



1.Guiding ruler. 2.Worktable. 3.Roller of track. 4. Feeding belt. 5. Track.
6. Circular saw blade. 7. Driving roller of track.

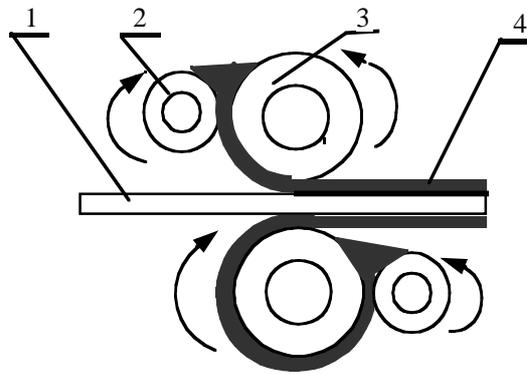
Fig. 2-13. Edge trim saw with track feeding

B. Adhesive coating and assembling of bamboo veneers

(1) Adhesive coating. Bamboo veneers are elementary components of plybamboo.

Bamboo veneers used in plybamboo production are not joined, neither for surface layer, nor for inner layer. The joining technology and equipment used in plywood production are not suitable for plybamboo. The technology should be improved in production in the future.

The thickness of bamboo veneers is about 3.0 ~ 8.0 mm. To guarantee the coating quality and reduce the consumption of adhesive, a four-roller coating machine is used (Fig. 2-14).



1.Veneer. 2. Adhesive pressing roller. 3. Adhesive coating roller. 4. Adhesive layer.

Fig. 2-14. Four-roller gluing machine

The amount of adhesive is regulated with the coating roller. The space between upper and lower rollers can be adjusted according to the thickness of veneers. The amount of adhesive coating is kept in the range of 300 ~ 350 g. (double sides). Two-roller coating machine is of a simpler structure, but its upper roller is pressed closely to the lower roller, in the process of coating, the upper roller vibrates repeatedly, affecting the service life, and the amount of coating is difficult to control. Coating roller is made of an ordinary steel roller with spiral thread, covered with a rubber layer of 85 degrees of hardness. Adhesive-pressing roller is a smooth chromium-plated steel roller of smaller diameter. For the sake of reducing adhesive consumption and improving coating quality, it is recommended to add wheat flour or soybean flour about 1 ~3% as solidifying matter. According to test material, adhesive, added with solidifying matter, forms a film on the surface of bamboo veneer, which reduces the loss of adhesive in the process of pressing-coating, and reduces the brittleness of adhesive layer. Accordingly this is a useful measure, in doing so, close attention should be paid to the homogeneous mixture of the solidifying matter.

(2) Assembling. The assembling operation is to put the coated bamboo veneers as surface layers and inner layer together, forming a set of material for making plybamboo. The thickness of surface layers and inner layer is decided in accordance with the thickness of final product and the compressive coefficient of hot pressing. The principles for determining the thickness of veneers are as follows:

a. The total thickness of assembled veneers should be determined according to the thickness of final product and the compressive coefficient. It can be calculated with the following formula:

$$\Sigma s = \frac{100s_p}{100 - \Delta}$$

Σs : total thickness of veneers assembled (mm).

s_p : thickness of plybamboo (mm).

Δ : compressive coefficient (%).

The compressive coefficient relates to the temperature of hot pressing, the pressure, the species of bamboo and its age during cutting. Under normal conditions, when the temperature of hot pressing is 140 ~ 145°C and the unit pressure is 3.0 ~ 3.5 MPa, the compressive coefficient will be 13.0 ~ 16.0%. In production practice, the thickness of veneers for surface layers and inner layer are determined referring to compressive coefficient. Then assemble some samples to process, check the thickness of product, and determine the thickness of veneers for every layer.

b. The thickness of final product must meet the pre-determined requirement, the thickness of front surface layer and rear surface layer also must meet the requirement. Otherwise the mechanical strength of plybamboo in certain direction may be too high or low, causing unstable structure and other defects.

The lengthwise mechanical strength of plybamboo used as the bottom of trucks and buses must be high. Consequently, the thickness of front surface layer and rear surface layer must be 55 ~ 70% of the total thickness of the assembled veneers. The veneer to be used as inner layer should not be too thick, and not too thin, so as to avoid the insufficient crosswise rigidity and strength, which may cause deformation and warping.

Most of the assembling operations are carried out manually. Attention should be paid to:

a. Sort out the veneers for front surface from those for rear surface. Front surface veneers must be of high quality and harmonious color, without residual green matter or with a little, its cracks must be narrow, its cross-cut edges must be even. While the rear surface veneers of inferior quality is acceptable.

b. The direction of fiber of surface layers must be perpendicular to that of inner layer.

The veneers used as front surface layer and rear surface layer, their green surface must be put outwardly. The veneers used as inner layer, their green surface must be put in one and another direction alternately to avoid the possible deformation.

c. Bamboo veneers are thick and narrow (about 100 mm in average). The amount of adhesive is not significant, its expansion by moisture is also insignificant. The veneers can be put closely without expansion clearance.

d. Veneers used for surface layers and inner layer must be assembled in exact order, all the edges must be even and all the angles must be right. They can be used as datum lines in edge sawing operation.

The assembling of veneers for the production of plybamboo of extra large size is difficult on manual worktable, it is better to use conveyor belt.

2. Pre-pressing and hot pressing-gluing

A. Pre-pressing

In order to guarantee the quality of plybamboo, to reduce the hot pressing time, and to prevent the defects caused by displacement when the assembled veneers are loaded into hot-press, the assembled veneers must be pre-pressed into an integral solid piece. The effect of pre-pressing with phenol resin is good because of its fine initial viscosity. When urea-formaldehyde resin is applied, it is better to add certain amount of polyvinyl alcohol and some soybean flour or wheat flour to improve its initial viscosity and the effect of pre-pressing

The unit pressure of pre-pressing is 0.8 ~ 1.0 MPa. The rigidity and deformation of bamboo veneer is larger than those of wood, the time of pre-pressing should be longer, about 60 ~ 90 min. The effect will be better if the pre-pressing time is longer. As the bamboo veneers are rather thick and the time of hot pressing is comparatively long. The annual production of ordinary factories is only 2,000 m³. It is realizable to prolong the pre-pressing time by means of rational arrangement of production shift teams and groups.

B. Pressing of assembled veneers

(1) Hot pressing and adhering

The process of hot pressing and adhering is to heat and press the pre-pressed assembled veneers, solidify the adhesive, turn the assembled veneers into plybamboo. This is a very complicated process of chemical and physical changes.

The hot pressing and adhering process includes 3 phases:

Phase 1. From loading first set of assembled veneers onto hot pressing board to the full close of pressing boards and achieving pre-determined unit pressure. This is the phase of free heating.

Phase 2. This phase lasts from achieving pre-determined unit pressure to the start of reducing pressure. This is the phase of keeping pressure.

Phase 3. This phase lasts from the start of reducing pressure to the full opening of pressing boards. This is the phase of reducing pressure.

In phase 1 the bottom of veneer set contacts with the lower hot board, veneers begin to shrink to varied degrees before being pressed, and the adhesive begins to solidify to some extent. At the same time, the upper part of veneer set is only heated by hot air, the heating speed is much lower. As the uneven heating between the upper and lower parts of the veneer set, the adhering effect will be affected. When the situation is serious, the veneer set may come unglued, crooked or deformed. For the sake of good adhering quality, it is advisable to make efforts to shorten the phase of free heating. The hot-press of manual feeding should not have more than 10 tiers, the free heating time should not exceed 1 min. If the hot-press is of more than 10 tiers, its loading and unloading must be automated to shorten the phase of free heating.

In phase of pressure keeping the changes in veneer sets are most complicated. There are the change of water and temperature, the change inside bamboo material, and the solidification of adhesive. These changes occur simultaneously or in turn.

The water evaporation in phase 1 is limited due to the partly contact heating and thermal radiation, it is only 1% or so. In phase 2 the temperature of veneer sets goes up regularly as a result of simultaneous heating and pressing. This accelerates the movement of water inside the bamboo material, part of the water turns into steam. As the expansion of steam is more than that of liquid, and the volume of air inside bamboo material expands due to the heating, the steam expands to the peripheral parts of assembled veneers. With the progress of hot pressing, the density of bamboo material is increasing, and the adhesive solidifying, which obstruct the moving of water and steam. Thereupon the steam pressure inside bamboo material goes up rapidly, the temperature of bamboo material also rises gradually. The water in peripheral part evaporates easily, this parts is cooled by surrounding air, hence temperature in this part is kept at 100°C or so in certain period of time. On the contrary, the temperature in the central part approaches to the temperature of hot pressing boards.

With the progress of hot pressing, the temperature goes up, a gradient of temperature is formed. The peripheral part of veneer sets is of lower temperature, its area depends upon the water content of veneer sets, heating temperature and surrounding air. According to related material the lower temperature area of periphery extends 75 ~ 150 mm. The expansion of steam from central part is blocked, which raises the temperature of bamboo material in central part, forming a high temperature area. Great amount of steam and overheated water, which can not turn into steam are accumulated in this area. This is the reason why the water content in central part is much higher than that in the peripheral part.

In the process of hot pressing two kinds of deformation are observed: elastic deformation and plastic deformation. Elastic deformation happens mainly at the beginning of hot pressing. With the progress of hot pressing bamboo material obtains some plasticity, and the plastic deformation begins, thereby the inner structure gets tighter. In the process of hot pressing the force pump often supplements pressing force, because the thickness of veneer sets decreases owing to the plastic deformation, which leads to the loss of unit pressure force.

The compression rate of veneer sets, caused by plastic deformation, depends on the species, age and growing conditions of raw bamboo, and the water content of bamboo material, the pressure, temperature and pressing time. As a rule, high pressure, high temperature and long time of pressing increase the compression rate.

The compression rate can be calculated by the following formula:

$$\Delta = \frac{\sum s - s_p}{\sum s} \cdot 100 \%$$

Σs : thickness of veneer set before hot pressing (the total thickness of all veneers) (mm)

s_p : thickness of veneer set after hot pressing (mm)

Δ : compression rate (%)

Into a space between two pressing boards only one veneer set can be loaded. If load several sets into one space, the sets contacting directly with pressing boards will show higher compression rate than those in the center.

In the process of hot pressing, the adhesive melts at first, then solidifies, then turns into a kind of non-soluble and non-melting matter. Owing to the high temperature in central part, the adhesive in this part solidifies first, while that in peripheral part does not. Consequently, the time and temperature of hot pressing should be determined according to the situation of the peripheral part.

In phase 3 the pressure is reducing, the steam in veneer sets spreads outward and the overheated water turns into steam rapidly. This causes the unbalance of pressure outside and inside the veneer sets. The quicker the reducing, the higher the unbalance. Serious unbalance leads to the peeling of veneer sets. More peeling happens in sets of more veneers. Therefore, the reducing process must be slow, keeping the pressure inside and outside the veneer sets in a basically balanced state and discharging the water inside the veneer sets gradually with the reducing of pressure. To prevent the peeling of veneer sets, the reducing process is carried out in three stages.

Stage 1: Reduce the work pressure to “balance pressure”. The “balance pressure” means the outside pressure which is similar to the inside steam pressure. The value of “balance pressure” relates to the temperature and unit pressure of hot pressing. As a rule, when applying phenol resin in plybamboo production, the value of “balance pressure” is about 0.3 ~0.4 MPa. In this stage the balance between outside pressure and inside steam pressure is kept, the steam and overheated water inside the veneer sets are basically in a static state, they will not be released greatly. The reducing speed can be comparatively high. In general, for 3-veneered sets this stage can be finished in 10 ~ 15 sec.

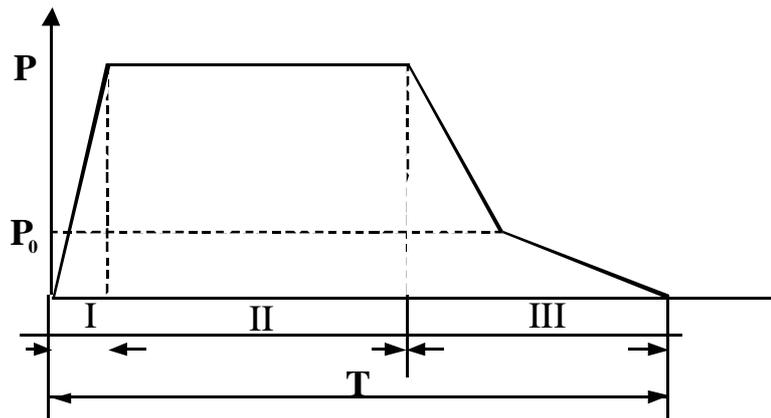
Stage 2: Reduce “balance pressure” to zero. As the outside pressure is being reduced in this stage, the difference between outside and inside pressure is formed.

Along with the great deal of existing steam, the overheated water also turns into steam. If the pressure is reduced too quickly, great amount of steam will escape at high speed, which may break the adhesive layer, causing peelings of veneer sets.

The speed of reducing pressure should be low, complying with the speed of steam release. For 3-veneered sets this process can be finished in 30 ~ 50 sec. If the set consists of more veneers the time must be also longer.

Stage 3: From zero to full open of pressing boards. Open the valve, release the pressure at a maximum speed and open the pressing boards. When the hands of pressure meter point to zero, the lowest veneer set is still pressed by the weight of upper pressing boards. To prevent the peeling of veneer set the lowest board should be opened slowly. The time of this stage depends on the hydraulic pressure system of the machine.

The change of pressure in the whole process of hot pressing is shown in Fig. 2-15.



- I. Free heating stage (min). P- Work pressure (MPa)
- II. Keeping pressure stage (min) P_0 - balance pressure (MPa)
- III. Reducing pressure stage (min). T-time of a pressing cycle (min)

Fig. 2-15. The curve of pressure change in the process of hot pressing

The whole process of hot pressing forms a pressing cycle.

(2) The factors influencing adhesion quality.

The preconditions for a qualified adhesion are:

a. The adhesive must be fit for the bamboo material to be pressed. Along with the correct selection of adhesive and the formula for compounding, it is important to analyze phenol, formaldehyde, caustic soda and other matters in the process of compounding, to measure the solidity and viscosity at the end of pressing. All the physical and chemical indexes of adhesive should meet the technological requirements.

b. The thickness of veneers must be uniform, with minimum error. The surface of veneers must be plane and smooth, the water content of veneers must meet technological requirement. For pressing bamboo veneers with water content higher than 10%, the effect of phenol resin can hardly be satisfied. Proper pressure force, exact temperature and correct pressing time are important factors in solidification of adhesive.

The influence of pressure: For the sake of close contact of bamboo veneer with adhesive, bamboo sets must be pressed properly. For veneers with higher rigidity, the pressure can be higher. But if the pressure is too high, the pressing rate and the consumption of materials will be enlarged, and the utilization ratio of raw material reduced, furthermore, the bamboo material may be damaged and its structure destroyed. Accordingly, the correct calculation of unit pressure is the important factor for guaranteeing high quality of adhesion and high utilization ratio.

Unit pressure is the pressure on unit area in the process of hot pressing. Instrument pressure is the pressure shown on the pressure meter, that is the pressure on unit area of plunger. They can be calculated according to the following formula.

$$P \cdot F = \frac{\pi}{4} \cdot d^2 \cdot n \cdot P_0$$

P : unit pressure (MPa)

d : diameter of plunger

n : number of plungers

F : area of bamboo veneer

P_0 : instrument pressure

Part of the pressure in oil system will be expended on lifting the weight of pressing boards. Calculating unit pressure, it is necessary to define a coefficient of pressure loss K .

In general, $K = 0.90 \sim 0.92$.

$$P = \frac{n\pi d^2}{4F} \cdot P_0 \cdot K$$

Fig. 2-16 and Fig. 2-17 show: When the unit pressure is under 3.0 MPa, the adhering strength changes with the change of pressing force proportionally. When the unit pressure exceeds 3.0 MPa, the adhering strength does not increase obviously with the further increase of pressing force. While the compression rate increases with the increase of unit pressure proportionally in quite a great range. The necessary unit pressure depends on the type of adhesive, surface smoothness and hardness of processed material, and precision of processing. The unit pressure for phenol resin must be a little bit higher than for urea-formaldehyde resin. Higher unit pressure is required for processing material of higher hardness, less smoothness and lower processing precision (great thickness error). The hardness of bamboo material is comparatively high, its surface smoothness is low after pressing-shaving. For guaranteeing a good adhering strength, the unit pressure is fixed within the range 3.0 ~ 3.5 MPa, the compression rate is 13% ~ 16%. With the improvement of processing precision, the unit pressure can be lowered correspondingly.

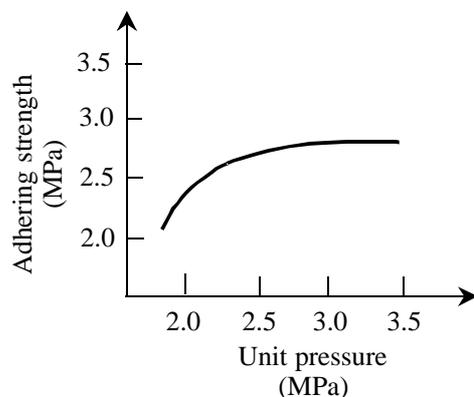


Fig.2-16. Relationship between adhering strength and unit pressure

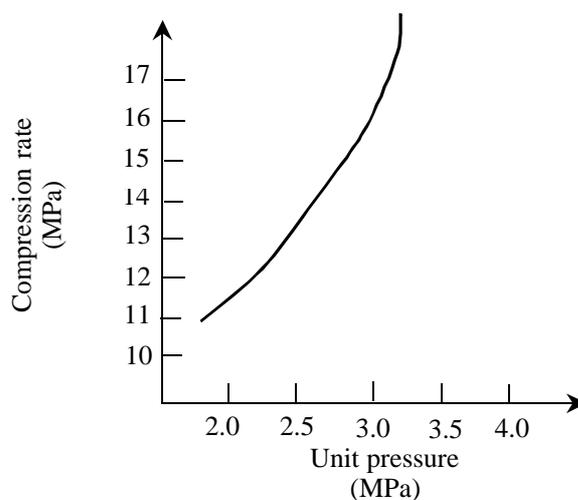


Fig.2-17. Relationship between unit pressure and compression rate

The influence of temperature: In case the processed material contacts fully with the adhesive, temperature is the most important factor causing the solidification of adhesive. Phenol resin and urea-formaldehyde resin must be heated for solidification. The application of acidic hardener (activator) (hydrochloric acid and phosphoric acid for phenol resin, ammonium chloride for urea-formaldehyde resin) promotes the solidification of adhesive under room temperature ($\pm 20^{\circ}\text{C}$). But the addition of hardener (especially strong acidic hardener) affects the adhering strength and water-resistant ability. The more the hardener, the higher the solidification speed and the greater the negative influence. Table 2-2 shows the highest and lowest adhering temperature of phenol resin and urea-formaldehyde resin.

In the process of hot pressing, the high temperature shortens pressure time. But the temperature gradient and inner stress are great, which leads to deformation. With the pressing conditions being unchanged, the higher the temperature, the greater the compression rate and lower the utilization ratio of bamboo material. Therefore it is unacceptable to raise the temperature excessively for shortening pressing time. As a rule, in plybamboo production the reasonable hot pressing temperature for phenol resin is $135 \sim 140^{\circ}\text{C}$, and for urea-formaldehyde resin is $115 \sim 120^{\circ}\text{C}$. For producing thicker plybamboo the temperature must be lowered and the unit pressure raised correspondingly.

The influence to time: Hot pressing time is the time needed for the solidification of all layers of adhesive in the process of hot pressing. Hot pressing time begins when all the pressing boards are close and the assigned pressure reached, it ends when the

Table 2-2: temperature range for phenol and urea-formaldehyde in hot pressing

Adhesive type	Temperature range	
	Lowest temperature ($^{\circ}\text{C}$)	Highest temperature ($^{\circ}\text{C}$)
Phenol resin	125 ~ 130	150 ~ 160
Urea-formaldehyde resin.	100 ~ 105	120 ~ 125

pressure drops. The exothermic reaction occurs when phenol resin and urea-formaldehyde resin solidify. Therefore the veneer set can be unloaded when the 85% of the adhesive layers located far from the hot pressing board is solidified. The hot veneer sets can be piled and the solidification of adhesive continues. In this way the full solidification of adhesive is guaranteed and pressing time shortened. Furthermore, by means of hot piling the inner stress will be eliminated and the deformation and crookedness of veneer sets reduced. If the pressing time is too long, the adhesive solidifies fully, the adhesive layers become brittle, which reduces the strength of plybamboo. If the pressing time is too short, the adhesive has not fully solidified, and the adhering and water consistent capacity are low. Consequently, the pressing time is also an important factor influencing the adhering quality, which should be calculated rationally. Numerous tests show that the proper pressing time is $1.0 \sim 1.1$ min for every 1 mm of veneer set.

Additionally, the processing quality of bamboo veneers strongly influences the adhering quality. Processing quality of bamboo veneer means its residual green and yellow matter, surface smoothness, thickness deviation and water content.

Phenol resin requires that the water content of veneers must be less than 8%. The adhering quality will be affected if it exceeds the limit. On the other hand, if the water content is too low, the surface of veneer will be less active, the adhering quality will be affected too, and the mechanical properties, such as modulus of rupture (MOR) and modulus of elasticity (MOE) of plybamboo will be worse. Therefore, the water content of veneer should be kept in the range of $6 \sim 8\%$.

If the surface of veneers is smooth and its thickness is even, the adhesive consumption and work pressure can be lowered, whereas the rough and uneven veneers lead to contrary results.

The residual green and yellow matter are another important factor influencing the adhering quality. These matter have no affinity for adhesive, consequently, part of the surface covered with green and yellow matter can not adhere to another veneer surface. Hence the area of green and yellow cover must be limited according to the standard.

(3) Defects occurring during hot pressing.

a. Adjacent veneers are disjointed entirely or partly. Adhering quality is poor, the veneers seem adhered, but the adhering strength measured with instrument does not reach the standard. The facts responsible for these defects are: too high water content of veneers or part of veneers is damp; pressure dropped too quick; denaturalization or poor quality of adhesive; insufficient pressing time or low temperature.

b. Peeling of veneer sets, the main reason is too quick drop of pressure.

c. Overlapping and chinks, caused by collision during loading;

d. Surface pollution, grease spots, adhesive stains and other man-made pollution. The reasons are unclean pressing boards and other man-made pollution during assembling.

e. Osmosis of adhesive, this means the adhesive permeates to the surface of plybamboo. In general, bamboo veneers are quite thick, osmosis of adhesive does not occur under normal conditions. But if veneers are too wet, the adhesive will permeate to the surface. This will affect the adhering quality greatly.

3. Edge shearing and sanding

The temperature of veneer sets is quite high when they are just unloaded from hot-press. They must be piled tidily. The purposes of hot piling are as follows: To continue the solidification of adhesive, utilizing surplus heat; to eliminate inner stress and to prevent deformation of products, releasing inner heat gradually. On the top of every pile it is recommended to put two or three pieces of substandard product for avoiding the deformation of ordinary product due to uneven cooling. The proper time of piling and cooling should not be under 24 hours.

The edges of plybamboo must be sawn on lengthwise and crosswise sawing machines of track feeding according to size standard. The edges must be smooth, without evident traces of sawing. The four sides must be sawn at right angles to each other. The tolerances must be kept in limit. Try the best to saw off scorched edges, if they appear.

Due to the great hardness of bamboo material, the saw must be of hard alloy. In general for sawing bamboo material a circular saw 300 mm in diameter, 4 ~ 5 mm in thickness, with 72 ~100 teeth is used. The teeth must be able to saw in both crosswise and lengthwise directions. The hard alloy saw can be sharpened only on special sharpening machine, it is incomparably durable and able to stand wear and tear.

Some of the plybamboo is to be used in truck factories as bottom boards. In order to meet related requirements, plybamboo veneers must be linked up to increase the length. For this purpose there is no need to saw the plybamboo veneers crosswise. They must be linked up first, then processed further in accordance with the size requirements of truck manufacturing.

The sanding of plybamboo improves its surface quality and processing precision. In this way the products can meet different requirements of end users. The sanding operation can be carried out on single-belt or double-belt sanding machines. The amount of sanding must be less than that of plywood.

Section 4: The uses of plybamboo

Bamboo material is of high hardness, high rigidity and high wear-ability. The plybamboo of great size retains these strong points and reduces the shortcomings, such as small diameter, hollow culm, great difference between crosswise and lengthwise strength. It can be sawn, planed, milled, drilled and linked up in further processing. Consequently, this is a comparatively ideal material for engineering structure.

Engineering structure material must meet the following requirements: high mechanical strength, high rigidity, fit for processing and installation or fixation. There are many kinds of materials meet the above mentioned requirements, such as various metal, timber, engineering plastics, cement, sand and stone. All these materials have their own distinguishing features and sphere of utilization. The bottom boards of trucks and buses must be of low weight, high rigidity, proper friction coefficient (to keep cargo and passengers from sliding) and doesn't rust. Additionally, bottom boards of buses must be able to keep heat and insulate from heat. Wood is used to make bottom boards over a long period of time. For making bottom boards, the material must be of high quality and great length. Demand in such wood is quite great, while the supply is short. Some manufacturers tried to apply steel to replace wood, but steel could not be used widely due to its heavy weight, deformation, rust and small friction coefficient. Plastics also have been tested, but it aged quickly and cost more. In building industry concrete forms were made of wood traditionally, wood is easy to process, wood concrete forms are easy to assemble and disassemble. But the surfaces of components made in wood concrete forms are rough, they must be abraded. This influences the progress of building construction, requiring much labor power and material resources, and consuming a great deal of wood. In China efforts were made to use steel concrete forms. But after a long time of practice, it was found that the steel concrete forms were heavy, deforms easily, rusted and difficult to disassemble. In addition, cement components made in steel forms were also rough, need to be abraded. In recent years building industry began to apply plywood for making concrete forms. Smoothness, evenness and tear-ability of plywood can be improved by means of rigidification. Such plywood concrete forms are durable. The surfaces of concrete components from such plywood forms are smooth. Such concrete forms are called "concrete forms of third generation" or "clean water concrete forms" in China.

Both bamboo and wood materials are natural organic matter. Their structure, composition and properties are similar in many aspects. The strength and rigidity of plybamboo are higher than those of ordinary plywood, similar to those of hard broad-leaf wood. Plybamboo has a wide prospect in automobile and building industries.

1. Use of plybamboo in automobile industry

A. Bottom of trucks

For making a middle sized truck (4 ton in loading capacity) 1.28 m³ of wood is needed, while for a light weight truck is 0.699 m³. The wood used on automobile factories must be of high quality, large diameter and length, and the demand is great. Consequently, it is urgent to use plybamboo to replace ordinary wood.

(1) The physico-mechanical properties of plybamboo to be used as bottom boards of trucks. The bottom boards of trucks are serving under very severe conditions: bitter cold, high summer, sun-baking, rainfall and rugged roads. For this reason, the material of bottom boards must of high strength and rigidity, sufficient anti-aging ability and safety coefficient. On the other hand, for the sake of reducing the production costs and dead weight of trucks, it is necessary to determine the thickness and structure of plybamboo scientifically and rationally.

a. Physico-mechanical properties

The main indexes of physico-mechanical properties of plybamboo must be better than or similar to those of the existing bottom boards in use. Tables 2-3, 2-4, 2-5, 2-6 and 2-7 show the main indexes of physico-mechanical properties of plybamboo to be used as bottom boards.

Table 2-3: Density, MOR, adhering strength and impact toughness of plybamboo

Properties Materials		Density G/cm ³	MOR Mpa	Adhering strength MPa	Impact toughness Joule/cm ³
15 mm	3 layers	0.78	113.3	3.68	8.7
	5 layers	0.85	105.5	3.52	9.1
22 mm	5 layers	0.85	126.1	3.50	9.1
Wood of larch 33mm		0.45	82.6		4.44

Notes: the adhering strength of plybamboo was measured when the sample had been boiled in water for 3 hours.

Table 2-4: Anti-aging ability of plybamboo

Properties Process	Adhering strength MPa	MOR Mpa	Test conditions
Before aging	3.68	111.6	USA Standard ASTM D 1037 Acceleration aging trial
After aging	3.03	52.8	
Decline rate (%)	17.7	52.7	

Notes: The sample was 15 mm in thickness, 3-layered, both surfaces were covered with a Protecting layer of phenol resin respectively.

Table 2-5: Acid corrosion resistance of plybamboo

Properties Progress	Plybamboo MOR MPa	Lengthwise Cold-rolled Steel beam	Test conditions
Before acid corrosion	105.2	No corrosion on surface	Soak a sample 22 mm x 20mm x300mm in solution (pH = 4) for 12 h., dry naturally for 10 days, Treat steel beam under same conditions. Observe surfaces before and after test
After acid corrosion	102.8	Serious corrosion on surface	
Decline rate (%)	2.3		

Notes: The sample of plybamboo was 22 mm in thickness, 5 layered structure, and both surfaces were covered with a protecting layer of phenol resin.

Table 2-6: Drying shrinkage of plybamboo

Properties Material	Shrinkage rate (%)			Notes
	Length	Width	Thickness	
Plybamboo	0.016	0.017	0.202	The shrinkage rate is a coefficient measured with the decrease of water content by 1%. The shrinkage in length and width is affected by installation operation. The shrinkage in thickness is natural. If water content decreases by 10%, shrinkage in width of 1000 mm will be 1.7 mm.

Table 2-7: The friction coefficient of plybamboo and other materials

Material Property	Wood	Steel- Wood	Pure steel	Ordinary Plybamboo	Plybamboo covered with stencil phenol resin
Static friction coefficient	0.52	0.31	0.28	0.42	0.47

The above-mentioned tables demonstrate better properties of plybamboo: high adhering strength, aging resistant, acid-corrosion resistant, small drying shrinkage, small difference between lengthwise and crosswise strength, and larger friction coefficient. This means plybamboo has advantages over wood in many aspects. From the viewpoints of science, economy and safety, it is recommended to apply plybamboo as bottom of middle-sized truck (22mm in thickness, 5 or 7 layers) and light weight truck (15mm in thickness, 3 or 5 layers) to replace pine wood of 25mm in thickness.

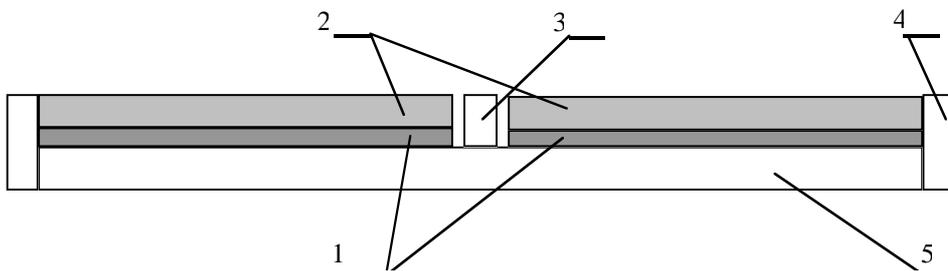


Fig. 2-18: The structure of plybamboo bottom board for middle-sized truck type A

b. Structure

Due to the differences of loading capacity, cargo, overload capacity and technical indexes between middle-sized truck and light weight truck, 3 types of plybamboo bottom board are designed:

(a) Bottom board of middle-sized truck: Type A (Fig. 2-18). The whole bottom board consists of two plybamboo veneers, with a steel beam between them for guaranteeing the necessary rigidity. The plybamboo veneers are fixed on crosswise steel beams of the truck frame with bolts, so as to prevent the possible damages occur when the frame turns round and deforms. For fixing plybamboo board it is much better to use bolts than to use steel nails, the strength can be raised by 6-10%.

(b) Bottom board of middle-sized truck: Type B (Fig. 2-19).

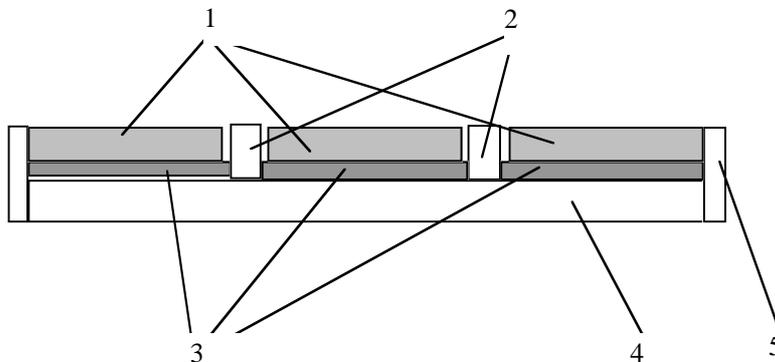
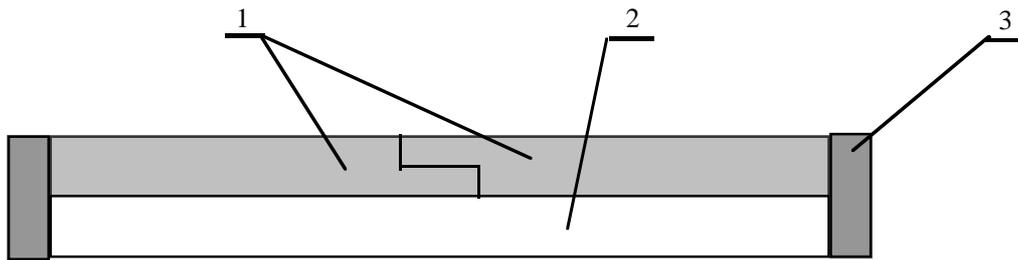


Fig. 2-19: The structure of plybamboo bottom board for middle-sized truck type B

The whole bottom board consists of three plybamboo veneers, with 2 steel beams between them for guaranteeing the necessary rigidity. The plybamboo veneers are fixed on crosswise steel beams of the truck frame with bolts.

(c) Bottom board of light weight truck. (Fig. 2-20).



1. Plybamboo. 2. Crosswise beam. 3. Edge cover.

Fig. 2-20: The structure of plybamboo bottom board for light weight truck

The whole bottom board consists of two plybamboo veneers. There is half ridge on one edge of every piece. These boards are fixed on crosswise beams 2 mm thick, using carburized and quench hardened steel nails, with crosswise and lengthwise fine thread. The gripping power of such nails is 5 times higher than that of ordinary nails.

c. Frame test of plybamboo bottom board

In order to verify the shock resistance, bending resistance and fatigue resistance of plybamboo used as bottom board, automobile factory assembled trucks to be tested on testing ground. They underwent several ten thousand miles of loaded motion test and indoors frame test.

(a) Bending strength test

A certain automobile research institute tested the 5 layered plybamboo in size of 22 mm x 1000 mm x 1200 mm on its crosswise even loading, concentrated loading and bending resistance. The data are shown in table 2-8.

Table 2-8 Bending strength of plybamboo and wood

Bending strength Load		Max. deflection (mm) Max. loading capacity (kN)		Conclusion
		Fixed with 4 bolts M10	Fixed with 10 bolts M10	
Concentrated Load	Plybamboo	44/27.5	42/30	1. Wood board was broken, the loading capacity decreased to 1/4 ~ 1/5. 2. Plybamboo was pulled, the loading capacity decreased to 1/2~1/3. 3. Plybamboo is superior to wood under both the loading conditions. 4. Under concentrated loading the bending strength of plybamboo is twice the strength of wood board.
	Wood	35/7.5	—	
Even load	Plybamboo	51/30	57/30	
	Wood		29/28	

Table 2-9: Torsion fatigue strength of plybamboo and wood

Torsion number Material	Number of torsion when damage occur on frame beam	Check after 500,000 times of torsion	Standard torsion number for high quality products	Test conditions
Plybamboo on light weight truck	When the number of torsion reached 100,000, the frame beam was undamaged, and plybamboo in good order, test stopped.	—	120,000	1. The torsion frequency is 27 times per min. 2. There was a height difference of 312 mm between the right front and left front wheels during the maximum torsion. Axial angle of truck 3.65° 3. . Even load and T sand bag. On the floor of driver's cabin an even load of T sand bag of 52 kg. On the driver's seat an even load of sand bag of 144 kg.
Plybamboo on middle sized truck	130,000	Plybamboo was in good order	120,000	
Steel-wood on middle sized truck	83,000	Welds joining lengthwise steel beam to frame beam cracked	120,000	

(b) Torsion fatigue test: The tests were carried out in Changchun Automobile Research Institute and Nanjing Automobile Manufacturing Research Institute. The results are shown in table 2-9.

(c) Drop-hammer test. The tests were carried out in a certain automobile manufacturing research institute. The results are shown in table 2-10.

Table 2-10: Drop-hammer test of plybamboo board and wood board

Conditions Material	Hammer of 40 kg. Dropped from the height of 1.2 m.	Hammer of 40 kg dropped from the height of 1.5 m.	Conclusion
Plybamboo	Lower surface layer was broken partly, but could be used further.	Lower surface layer was broken through the 1/3 of thickness, but could be used further	The shock resistance of plybamboo board is higher than that of wood board
Wood	Broken entirely	—	

The above-mentioned three tests demonstrated that the bending resistance, torsion resistance and shock resistance of plybamboo are higher than those of wood and steel-wood. This is an ideal material for making bottom board of trucks. Plybamboo for making bottom board can be produced in plybamboo factory according to the required dimension. They can be used as a component on the assembly line of automobile factories. Using plybamboo as bottom board of trucks, it is possible to economize on high quality wood and steel, to reduce the dead weight of trucks and the assembly cost.

B. Bottom board of buses

Since the successful wide use of plybamboo as bottom board of truck, tens of buses factories have begun to substitute plybamboo boards for wood and calcium plastics ones. As these factories produced buses in small batches, there was no standardized structure of plybamboo board. They selected plybamboo of dimensions 915 mm x 2135 mm or 122 mm x 2440 mm, 15 mm in thickness. Plybamboo boards are fixed on frame beams with bolts,

which is convenient to remove and change. In order to prevent the penetration of dust, the joint seams are sealed with glue.

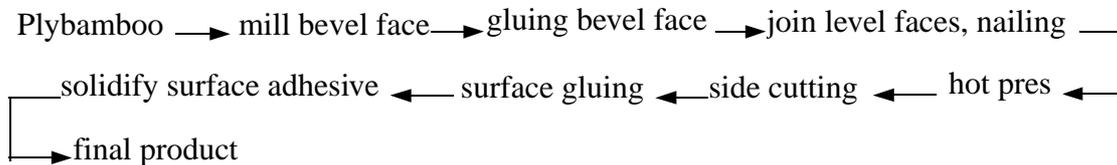
To substitute plybamboo boards for wood or calcium plastics is profitable. It is more durable, convenient to install and clean, chairs can be fixed on bamboo floor steadily. Additionally, the application of plybamboo to make floor of passenger train also passed the test.

C. The processing of plybamboo for making bottom board

The length of plybamboo board used in automobile industry must accord with the length of carriage. Short boards are not acceptable. As the thickness of adjacent boards is not even, the joint seams will be damaged during the loading and unloading of bulk cargo such as sand and coal. Besides, when join several short boards into a long board, the accumulated error will be significant, causing troubles in assembling.

(1) Bevel face gluing and hot pressing joint

This process is:



a. Make a bevel face of the edge to be joined

There are several methods for joining plybamboo veneers: finger joint, tenon joint, bevel face gluing joint. From the viewpoints of related technology and equipment, it is better to select bevel face gluing joint.

The thickness of ordinary plybamboo is 15 mm or 22 mm. The rational bevel rate is 1:5.5. The larger the bevel rate, the higher the adhering strength. But the loss of plybamboo material is also larger. Fig. 2-21 shows the bevel rate of the bevel faces for joining.

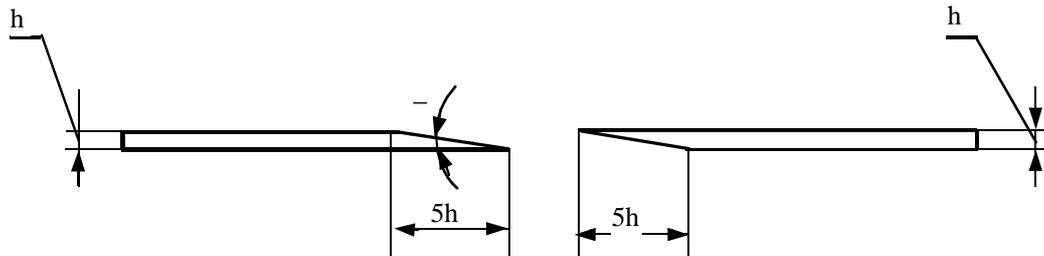


Fig. 2-21: The bevel rate of the edge for gluing joint

The bevel face of the edge of plybamboo is made with a milling machine. The milling machine consists of a s disc saw, an adjustable milling cutter and a worktable. To cut the edge of plybamboo with the disc saw accurately at first, then cut the sawn edge with the milling cutter, making a bevel face. If the thickness of plybamboo board exceeds

30 mm, it is recommended to use two milling cutters to mill the edge in two steps for avoiding the charred edge as a result of great amount of milling.

b. Coat the bevel face with adhesive

Coat the bevel face of boards to be joined with the same kind of adhesive as used in plybamboo production. The coat must be even and not too thin. For moving the joined boards easily, to fix the joints with mails, which must be shorter than the thickness of plybamboo.

Hot pressing

To press the joined boards under the similar conditions as those for plybamboo production, the unit pressure should not exceed that of plybamboo production.

c. Coat the joined board with adhesive and a net

Cut the joined boards in lengthwise and crosswise directions according to the required dimensions. The dimensions of bottom board of trucks or buses must be precise. Positive tolerances are not permitted, negative tolerances must be kept within limits.

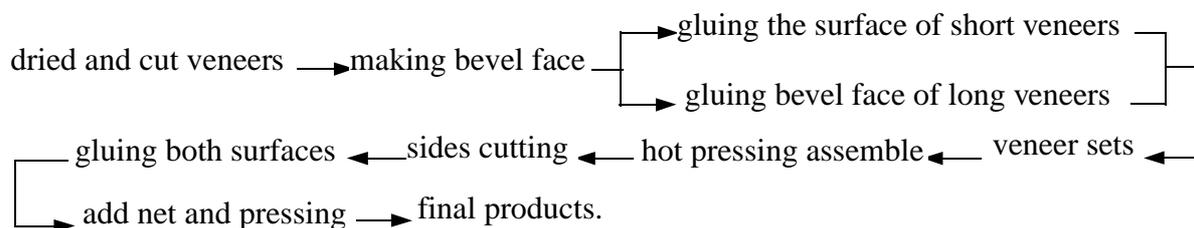
In order to guarantee the corrosion resistance, anti-insect ability, aging resistance and the dimension stability, it is recommended to cover both the surfaces of plybamboo with phenol resin and solidify it under high temperature and high pressure. The solid content of this protecting cover must be kept in the range of 30 ~ 35°C. The viscosity of this cover should be lower than that used for inner layers of plybamboo. To meet the requirements of automobile manufacturer, the phenol resin can be added with some coloring agent.

For improving the friction coefficient of bottom board and preventing the displacement of cargo a metal net can be put on the upper phenol resin cover before hot pressing. In this way the vein of certain depth will be made.

To join plybamboo veneers with bevel face under hot pressure is a widely used method at present. But this method is quite complicated. The twice-hot-pressing of long time affects the quality of products. Affected by the bevel face of joined edges, the mechanical strength of the joint parts is only 70% of the plybamboo itself. For the sake of safety the joint seams of bottom boards must accord with frame beams. Furthermore, unevenness of surface is often found at the joint parts of the bottom board, which can be damaged during unloading of cargo. Therefore it is of great importance to produce plybamboo of large dimensions.

(2) Plybamboo of great dimensions

The diameter and the thickness of culm wall decrease from root part to the top. If cut the culm into sections 4500 mm in length for further processing, the utilization ratio will be lowered. In addition, the maximum processing length of existing equipment for plybamboo production is 2500 mm. For processing bamboo sections 4500 mm in length, it is necessary to increase the dimension of equipment and the area of workshop. This will lead to significant increase of production cost. Evidently, there are technical and economic problems in the production of plybamboo using long bamboo sections. To solve these problems, a new method has been created, its technological process is as follows:



a. Make bevel face.

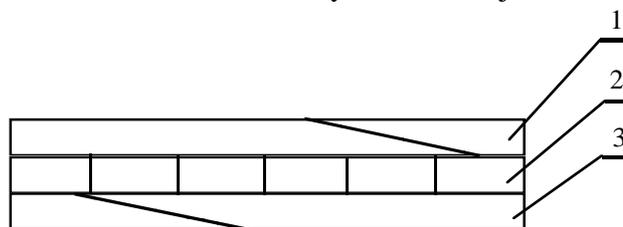
The bevel rate of veneers should be in the range of 1 : 7.5 ~ 10 for improving the adhering strength and preventing the loosening of assembled veneer sets in transport. As veneers are not thick, it is not difficult to realize such great bevel rates. The loss of bamboo material is also not great. The edge of surface veneers and long inner veneers should be turned into bevel face, while that of the short inner veneers should not.

b. Coat the bevel with adhesive

Coat the bevel face of veneers with the same kind of adhesive as used in plybamboo production. The coat should not be too thin.

c. Assemble veneer sets

Veneer sets can be assembled complying with the version shown in Fig. 2-22. The essential requirement is: there could be only one bevel joint on any cross section of the board.



1. Surface layer. 2. Inner layer. 3. Bottom layer.

Fig. 2-22: Assembling scheme of 3-layered plybamboo of great dimensions

d. Hot pressing-adhering

The technology for manufacturing hot-press of great dimensions is mature.

But the veneer set should be assembled on conveyor belt because the assembled sets can not be transported manually, they must be put into feeding machine directly. The feeding machine must be of special structure, it has to load the veneer set together with metal plate onto the pressing boards calmly. Only in this way qualified plybamboo of great dimensions can be produced. The further processing technology is the same as mentioned above.

Table 2-11 shows the comparison of mechanical properties of different veneer sets.

Table 2-11: The comparison of mechanical properties of different veneer sets

Properties Variants	Thickness (mm)	Density (g/cm ³)	Compression (%)	MOR Mpa	MOE MPa
(1)	10.81	0.85	13.8	138.5	13425
(2)	10.08	0.78	14.1	144.6	14953
(3)	10.63	0.67	10.1	121.4	15282

Notes: 1. The surface layer was joined, bottom layer not joined.

2. Both the surface and bottom layers were joined in one and the same direction.

3. The surface and bottom layers were joined in opposite directions.

Table 2-11 demonstrated that the MOR and MOE do not relate to the scheme of assembling: the joining directions of surface layers hardly influence the mechanical properties of products. The mechanical properties of products assembled according to variant (1) are similar to those of those according to (2) and (3). This means the properties of products manufactured in this way is stable.

1. The use of plybamboo in building industry

A. Concrete forms of ordinary plybamboo

Plybamboo possesses higher strength, high rigidity and attrition resistance. To be covered with phenol resin, after pressing and solidifying, this kind of plybamboo can be used to make concrete form. The thickness of plybamboo for making concrete form is: 10 mm, 12 mm, 15 mm, 18 mm. The dimensions are: 1000 mm x 2000 mm, 915 mm x 2135 mm, 1220 mm x 2440 mm. The dimensions can be determined in accordance with the requirements of users.

B. Concrete form of plybamboo covered with wood veneer and paper

On the building sites of bridges, power stations and tunnels cement components are formed and directly used without surface processing. The concrete form for producing such components is called clean water concrete form. Material for clean water concrete form must be of sufficient smoothness, little thickness tolerance, high strength and MOE. In order to meet the above-mentioned requirements, it is recommended to cover plybamboo with wood veneer and paper. The process is: abrade the ordinary plybamboo, adjust its thickness to tolerance limit, cover wood veneer and soaked paper on both surfaces of the plybamboo, put the assembled set into hot-press to press. The properties of such products are:

(1) Thickness tolerance: ± 0.5 mm.

(2) MOR: Thickness ≤ 12 mm. MOR // ≥ 100 MPa

$$\text{MOR}_{\perp} \geq 60 \text{ MPa}$$

Thickness = 18 mm. MOR // ≥ 80 MPa

$$\text{MOR}_{\perp} \geq 48 \text{ MPa}$$

(3) MOE: Thickness ≤ 12 mm. MOE $\perp \geq 9000$ MPa

$$\text{MOE} // \geq 7000 \text{ MPa}$$

Thickness ≥ 15 mm. MOE // ≥ 8000 MPa

$$\text{MOE}_{\perp} \geq 5600 \text{ MPa}$$

(4) Adhering strength: Samples of 75 mm x 75 mm to be boiled in water for 3 hours, the length of opening should not exceed 25 mm. Twenty percent of total samples exceed the limit is permitted.

(5) Thickness expansion: Samples of 75 x 75 mm to be soaked in cold water for 72 hours, the expansion coefficient $< 6\%$.

(6) Attrition resistance: ≤ 0.08 g / 100 revolutions.

(7) Surface conditions: The surface is smooth and even. The rate of unevenness and roughness are less than 0.5 mm.

The strength and rigidity of plybamboo are high, but its appearance looks not so ideal. Therefore, plybamboo is mainly used as structural material. Some kinds of structural material require not only high strength and rigidity, but also good-looking appearance. To meet such requirements, it is better to combine plybamboo with wood, metal or other non-metal material to acquire all their strong points.

Chapter II. Combined bamboo and bamboo flooring

Section 1. The structure of combined bamboo and bamboo flooring

Both combined bamboo and bamboo flooring are formed of bamboo strips of pre-determined width and thickness, and are manufactured by means of hot pressing and adhering. They are utilized to substitute for valuable timber in furniture making, interior decoration and flooring. Combined bamboo is a kind of proper material with stable dimensions, fine grain, excellent structure and high mechanical properties. At present the shortage of valuable timber supply is serious. The price of valuable broadleaf timber is much higher than that of coniferous timber. Consequently, to develop combined bamboo to substitute for valuable timber is profitable.

1. Combined bamboo

The manufacturing process of combined bamboo is as follows: raw bamboo, cross cutting, splitting, rough shaving, water boiling (including bleach, anti-insect, anti-mould and anti-corrosion treatments) or carbonizing, drying, precise shaving, piece selecting, adhesive coating, assembling sets, double-sided hot pressing-adhering, edging and milling. The product (Fig. 2-23) is of great dimensions: 3 ~ 30 mm in thickness, 1200 ~ 2400 mm in length, 500 ~ 1200 mm in width. The structure of combined bamboo is the same as that of combined wood. The usage and properties of combined bamboo are similar to those of combined wood. All the elements of combined bamboo are assembled in one and the same direction. The combined bamboo can be divided into two types: thinner and thicker. The thinner combined bamboo of 3 ~ 8 mm is mainly used for interior decoration and surface ornament of furniture.

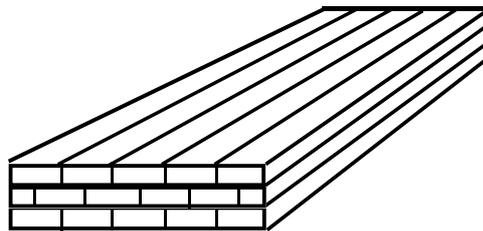


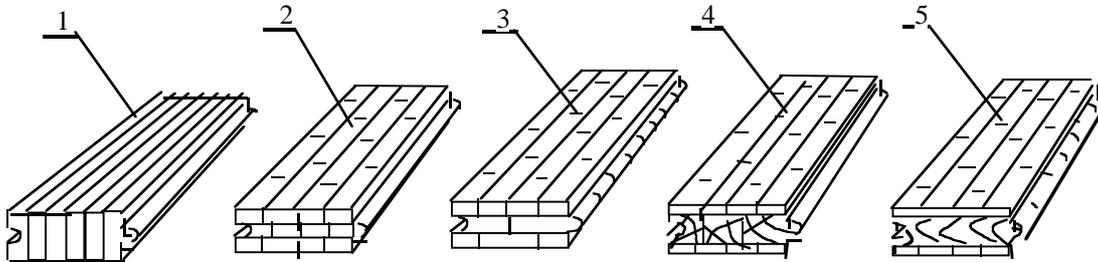
Fig. 2-23: Combined bamboo

The crosswise strength of thinner combined bamboo is poor because of the small thickness of its elements and small area of side adhering between adjacent elements. As a result, thinner combined bamboo can be damaged easily. Furthermore, bamboo elements are not homogeneous, their green and yellow surfaces shrink and expand unequally, which also lead to deformation and damage. The side shaving and sanding operations must be carried out carefully to prevent crosswise breakage. As a kind of material for decoration and ornament, the outward appearance of combined bamboo is very important. In the process of its storing and transporting close attention must be paid to anti mould measure. It is suggested that the products be covered with plastic bags and packaged in boxes.

Thicker combined bamboo can be utilized as both structure material and decoration material. Bamboo pieces of its surface layer must be of high quality, meet the technological requirements in processing. Those of core layer can be somewhat inferior. In the manufacturing process of combined bamboo the double-sided hot pressing-adhering is a key link, which must be complemented with great care.

2. Bamboo flooring, its structure and assortment

The elements used for making floorboard are the same as used for combined bamboo. The assembling and further operations are somewhat different. According to its structure bamboo flooring can be sorted into the following types: radial-cut face (side pressed), chord-cut face (right pressed, lengthwise core layer and crosswise core layer), bamboo-wood combined (right pressed, lengthwise core layer and crosswise core layer). Samples of these types of floorboards are shown in Fig. 2-24.



1.Radial cut face (side pressed); 2.Chord cut face (right pressed, lengthwise core layer); 3.Chord cut face (right pressed, crosswise core layer); 4. bamboo-wood combined (right pressed, lengthwise core layer); 5. bamboo-wood combined (crosswise core layer)

Fig. 2-24: The structure of bamboo floorboards

According to the structure of bamboo culm, the width of a bamboo piece is its chord-cut face, while the thickness is radial-cut face as shown in Fig. 2-25.

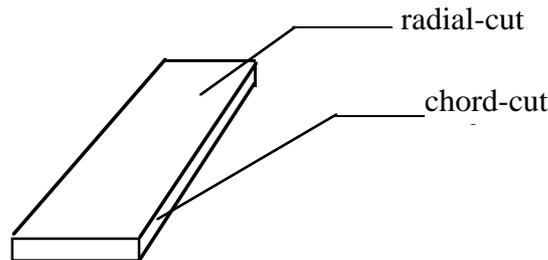


Fig. 2-25: The radial face and chord face of a bamboo piece.

Floorboard of radial-cut surface is made of bamboo elements, their chord-cut faces are coated with adhesive and pressed together, such floorboards are called side pressed boards (see Fig. 2-24.1). Floorboard of chord-cut surface consists of surface layer, core layer and bottom layer. Pieces in one and the same layer are joined with their radial-cut faces, pieces of adjacent layers are connected with their chord-cut faces. Such floorboards are called right pressed boards. The green surface part is of fine and close texture, with good-looking grain. On the contrary, the yellow surface part is of loose texture, with monotonous grain. For the sake of symmetric structure, stable dimensions and fine appearance, the green part of bamboo pieces in surface and bottom layers must be arranged outwardly. There are two kinds of radial-cut surface floorboard, the grain of bamboo pieces for core layer is in the same direction as that of surface and bottom layers (see Fig. 2-24. 2), and the grain of core layer is perpendicular to grain of surface and bottom layers (Fig. 2-24.3). As for bamboo-wood combined floorboard, the surface and bottom layers are made of bamboo pieces 3.0 ~ 3.5 mm, the core layer is sawn wood board of lower density, 10 ~ 12 in thickness. The grain of wood can be arranged in the same direction as that of bamboo (see Fig. 2-24. 5) or perpendicular to that of bamboo. Bamboo-wood combined floorboard possesses nice appearance of bamboo and elasticity of wood. In comparison with pure bamboo flooring, the bamboo-wood combined board has simpler technology, higher productivity and better performance-price ratio.

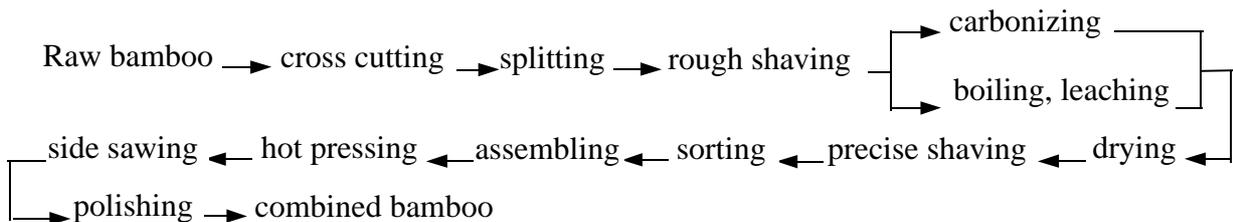
The color of bamboo flooring can be natural or carbonized. Bamboo pieces of natural color board are boiled and bleached, and, as a result, acquired bright gold-white color. Those of carbonized board are carbonized at a high temperature, under high pressure and saturated steam, its color turns into brown.

Section 2. The processing technology of combined bamboo and bamboo flooring

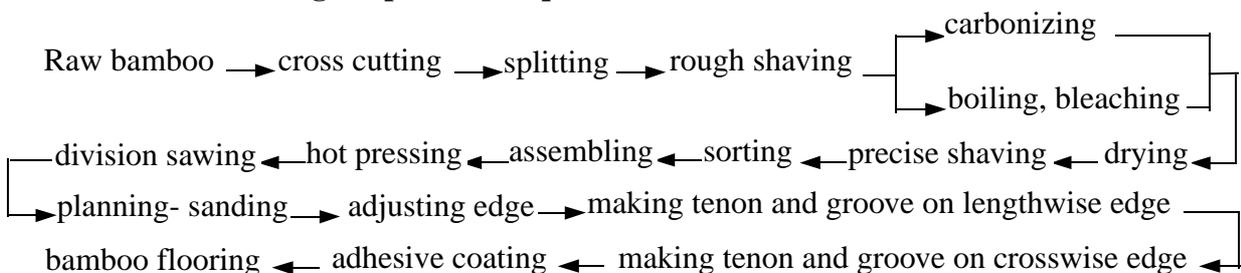
1. Technological process of production

The processing technology of combined bamboo and bamboo flooring differs from that of plybamboo, based on “softening and flattening”. The essential part of this technology is to process bamboo pieces of pre-determined width and thickness with a coaxial double-disc-saw. The processing precision and outward appearance of these products are higher than other kinds of bamboo-based panel. For producing bamboo flooring, there will be some more operations: making ridge-sized tenon and groove, adhesive-coating and further ones.

The technological process of combined bamboo and bamboo flooring are:



2. Technological process: requirements



(1) Cross cutting

Select fresh bamboo of 4 or more years old, cut them into sections of pre-determined length. The diameter of raw bamboo for floorboard production must exceed 10 mm, the culm be straight, the culm wall be thick. It is important to utilize bamboo material properly, to raise utilization ratio and reduce production cost.

a. To cut off the end of raw bamboo with the traces of hacking, forming a new smooth end.

b. To start the cutting operation from the new end, cut sections of pre-determined length.

c. During the cross-cutting of bamboo culm with great crookedness, it is better to cut sections of smaller length. In case of cracks the cracked parts must be cut accurately, without affecting the use of other parts.

d. The bamboo sections must have enough margin of processing. In general, if the length of floorboard is 910 mm, the section length should be 950 mm, if the length of floorboard is 610 mm, the section length should be 650 mm. The rational margin in length is 40 – 50 cm.

e. The culm wall near the top is thinner, therefore this part of bamboo is not fit for making pure bamboo floor. If the wall thickness is less than 7 mm, it can be applied to make chopsticks, toothpicks, bamboo curtains, or to make small bamboo pieces for bamboo-wood combined floorboards.

(2) Lengthwise cutting

Use coaxial double disc-saw to cut bamboo strips of same length and same width. The clearance between disc saws depends on the width of bamboo strips. The wider the strips, the more the cut amount of green and yellow matter, the lower the utilization ratio. But if the strips are too narrow, the loss of sawn dust also increases. Therefore the width of strips must be determined rationally. General speaking, for making radial-cut surface board, the rational width is 25 mm. and for chord-cut surface board is 19 mm. In lengthwise cutting, the small end of culm must be put as the forward end to avoid the width shortage of the last strip.

The process of lengthwise cutting is: move a section of bamboo culm along a rail at proper speed toward two rapidly rotating disc saws, making two chinks through the culm wall. Move the section back to the starting point, turn the section to aim one of the chinks at a disc saw and move the section forward again, cutting another strip. Repeat this cycle to cut the whole section into strips. In the process of lengthwise cutting the strips are linked by inner joints, and not scattered. This is convenient for operation. When the process finished, throw the section to the ground and the strips will be scattered.

(3) Rough shaving (shave four sides evenly)

A strip is a part of the circular wall of bamboo section. For the sake of further processing the green and yellow matter on both faces must be removed and the cross section of the strip must be shaped into rectangular. If the green and yellow matter remain on the faces of strip, the chemicals can hardly permeate into the strip during boiling and bleaching, and the effects of treatments are reduced. In addition, green and yellow matter also affects the efficiency of adhesive.

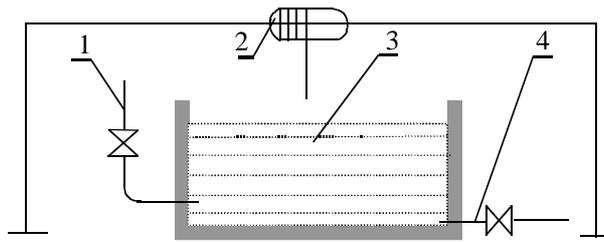
This operation is carried out on a rough shaving machine. First of all, remove the residual inner joints with a knife, then sort the strips into groups of different thickness, as a rule, two or three groups. Adjust the cutting thickness of rough shaving machine according to the dimensions of strip and begin the rough shaving. Pile the shaved strips and bundle them up. Rough shaving means to make the surfaces roughly even, the residual green and yellow matter should not exceed 30%. The shaving amount should not be too large, enough margins in further processing must be guaranteed.

The process of rough shaving is: The feeding wheel moves the strips into the space between two rapidly rotating knives, the knives remove green and yellow matter from the strips and discharge it.

(4) Boiling and bleaching

Bamboo material contains more nutrients than ordinary wood does. These nutrients provide excellent nourishment for insects and fungi. The content of protein in these nutrients is about 1.5 ~ 6.0%, carbohydrate – about 2%, starch – 2.0 ~ 6.0%, fat and wax – 2.0 ~ 4.0%. Stored under ordinary temperature and humidity, the strips will be attacked by insects and/or become mildewed. The insects are bamboo worm, termite and bamboo wasp, the most dangerous from them is bamboo worm. The mould and rottenness are caused by parasitic fungi, which often occur under warm and humid conditions with poor ventilation. The service life of floorboard must be long, but it can be affected by these damages. Therefore, in producing bamboo flooring great attention should be paid to the prevention of insect and mould damages.

There are two prevention methods used in production: boiling-bleaching and carbonization. Boiling-bleaching is an essential part of technology for manufacturing floorboard of natural color. It is to drain all the soluble organic matter from bamboo material and to kill insect ova and fungi by means of boiling with bleacher, insecticide, pesticide and preservatives (see Fig. 2-26). Besides, thanks to the bleacher, different colors of various strips are harmonized.



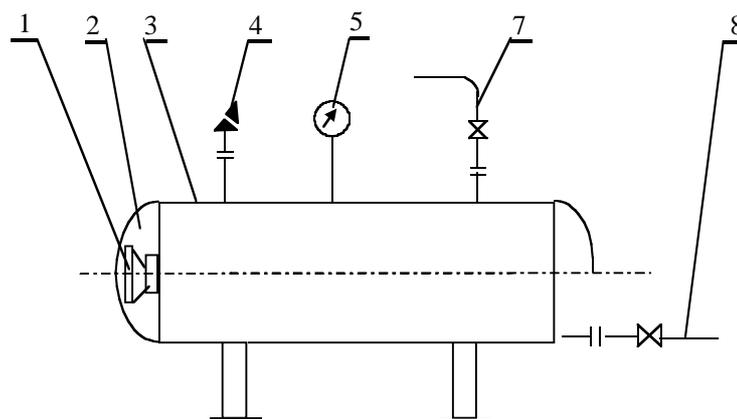
1.Steam pipe. 2. Crane. 3. Boiling pool. 4. Drainage pipe.
Fig. 2-26: Scheme of boiling-bleaching

The practical operation is as follows: Put roughly shaved strips into warm water of 60°C, add hydrogen peroxide (30%), insecticide and preservative, the amount is 5 ~ 8%. To boil the water with steam for 6 ~ 8 hours. Take out the strips after boiling, the water in boiling pool can be used further, but the above-mentioned chemicals must be added with the progress of the boiling operation. As most of the green and yellow matter has been removed, chemicals can permeate into bamboo strips easily. The boiled and bleached strips show higher insect and fungi resistance.

(5) Carbonization

Put bamboo strips under the conditions of high temperature, high humidity and high pressure. Decompose the organic matter, such as carbohydrate, starch and protein, cut off insect and fungi's nourishment, and kill the ova and fungi. The color of carbonized bamboo fiber turns into brown, whereby giving the bamboo flooring a kind of classical flavor. As the soluble organic matter has not been drained from bamboo material during carbonization as it has happened in boiling-bleaching, the specific gravity of carbonized strips is a little higher than that of boiled-bleached ones. Carbonization of bamboo fiber under the conditions of high temperature and high pressure does not affect the strength of the material greatly (reduced a few in general), but the rigidity of surface is a little higher.

The carbonizing operation is to load roughly shaved strips into special carbonizer and fill it with steam to keep proper pressure (see Fig. 2-27). First of all, put bamboo strips into a metal basket, move it along a rail into the furnace and close the draft. Open the steam valve, raise the pressure to about 0.3 MPa and keep it for 70 ~ 90 min. Close the steam valve, release the steam, open the draft and unload bamboo strips.



1.Hand wheel. 2. Draft of furnace. 3. Furnace body.
 4. Pressure meter. 5. Steam filling pipe. 6. Steam releasing pipe
Fig. 2-27: Carbonizer

(6) Drying

The drying of strips is an important link in the production of combined bamboo and bamboo flooring. The effects of drying operation are as follows: 1. Prevent the shrinkage, cracks and deformation of floorboard in its use. 2. Prevent the growth of insects and fungi effectively. 3. Create favorable conditions to improve adhering strength. Therefore, this operation must be carried out carefully and strictly. The water content of bamboo strips for hot pressing must be about 10%. But before hot pressing the dried strips have to undergo several operations, which take a certain period of time, and the strips may absorb some moisture. Accordingly the water content of strips after drying must be about 8%.

The water content of strips after boiling-bleaching and carbonization is about 35 ~ 50%. The fibers of bamboo are arranged tidily, and the strips are of small size. In the process of drying bamboo strips will not be cracked or warped, which are often observed in wood drying. Consequently the technology of bamboo drying is much simpler than that of wood. In general, keep the temperature within the range from 60 ~ 70°C for 72 ~ 84 hours, the water content can be reduced to less than 10%. But the temperature should not exceed 70°C, otherwise strips will be warped and floorboard deformed.

For the rational utilization of processing wastes, all the bamboo wastes can be used as fuel of stove for drying..

(7) Precise shaving (shave four sides accurately)

The dimensions of strips after rough shaving and drying become stable and regular basically. But the width and thickness of strips must meet the requirements so as to make the adjacent strips joined closely and correctly. This will be achieved by means of precise shaving, which is performed on a precise shaving machine. The upper and lower hobs of the shaving machine are used to process the chord-cut faces (the green and yellow faces), while the left and right hobs are to process the radial-cut faces. The correct width and thickness are achieved by adjusting the clearances between upper and lower hobs, and between left and right hobs. Attention must be paid to the following points: 1. Remove all the green and yellow matter, otherwise it may affect adhering strength. 2. Make every part of the surface of strips even, some of them shrink more than others, therefore the clearance between hobs must be adjusted correspondingly. 3. The specification of dimensions should not be complicated, strips must be piled according to their dimensions for assembling. 4. The tolerance must be kept under 0.1 mm.

(8) Assembling and hot pressing

This operation is implemented in accordance with the dimensions of final products.

a. The preparation of adhesive

The adhesive applied for making combined bamboo and bamboo flooring is thermosetting urea-formaldehyde resin. Promoted by catalytic agent, urea is combined with formaldehyde, forming incipient resin. Treated with curing agent, this incipient resin turns into a kind of insoluble and infusible resin. This resin of low production cost possesses comparatively high adhering strength, water tolerance and heat resistance. It is easy to make use of urea-formaldehyde resin without polluting the products. But ordinary urea-formaldehyde resin contains certain amount of free formaldehyde. Numerous scientific tests demonstrated that free formaldehyde is harmful to human body. Consequently, there are rigid restrictions on the release of free formaldehyde both in China and abroad. So it is recommended to select urea-formaldehyde resin with little free formaldehyde.

Urea-formaldehyde resin can be made in the factories of bamboo flooring or be purchased.

Urea-formaldehyde resin must be added with curing agent before hot pressing. Curing agent can be added to emulsion resin directly and mixed evenly. If the curing agent is in powder form, it must be dissolved in water at first, then added to resin and mixed.

b. Adhesive coating

Bamboo strips must be coated with adhesive before hot pressing. For strips of surface and bottom layers the yellow face and both radial-cut faces are to be coated. As for strips of core layer, all the four faces must be coated. The strips can be coated by means of a coating machine or manually. But if apply a coating machine, the radial-cut faces must be coated manually at first, then the chord-cut faces by machine.

c. Assembling

Coated strips are assembled in accordance with the pre-determined dimensions and structure of final products. For producing boards of chord-cut face with lengthwise layer, the strips of adjacent layers must interlock with each other to avoid the crosswise warp showed in Fig. 2-28.



Correct

Incorrect

Fig. 2-28: The arrangement of strips

d. Hot pressing

The assembled sets are moved into hot-press to be pressed right after assembling. The adhesive solidifies rapidly under required temperature and pressure. The process is as follows:

- (a) Raise the temperature of platens to 100 ~ 110°C.
- (b) Arrange assembled sets on platen in proper order.
- (c) Close platens.
- (d) Raise side pressure to eliminate the side chinks (to be observed by naked eyes).
- (e) Bring right pressure once again to make the set straight fully and the adhesion correctly.
- (f) Keep the right and side pressure for about 10 min to make the adhesive solidified completely.
- (g) Release the right and side pressure, unload the pressed sets.
- (h) Abrasive planing-sanding

The thickness of pressed sets is about 1 ~ 1.5 mm larger than that of the final product, because the processing margin should be kept during the precise shaving of strips. The surface of pressed sets is rough and uneven due to insufficient precision of platens and the permeated adhesive. Therefore it is necessary to apply a sawing machine to make the thickness of pressed sets a little larger than that of the final product, then apply a four-side shaving machine and a sanding machine to achieve the required dimensions of final product. The dimensions of combined bamboo are too large to be processed on a press-shaving machine, it is better to apply a sanding machine to adjust the thickness.

The thickness of bamboo flooring is adjusted on a special press-shaving machine. The specific features of the machine are: 1. The surface part of the machine is removable or hot-treated to improve its attrition resistance, because the hardness of bamboo material is high and the processing volume is great. 2. The diameter of cutter axis is larger than usual and the rotate speed is raised properly.

The first step is to shave the surface, removing all the permeated adhesive and residual green matter, eliminating the trace of pressing. The volume of shaving should not be too large. Because the fiber near green surface is fine, close and good-looking, while the fiber located far from green surface is loose and monotonous. The rest of processing margin can be removed by bottom shaving.

(10) Edge adjusting

The dimensions of hot-pressed sets are basically unanimous, but the straightness of their edges is not complete due to the error of pressing. One of the edges must be straightened, and this straightened edge can be used as a basic line to make groove or ridge-sized tenon. The precision of groove and ridge-sized tenon depend directly on the straightness of edge. The edges are straightened on plane machine of manual feeding.

(11) Making groove and ridge-sized tenon

The shape of bamboo flooring is rectangular as traditional ones. In order to fit the floorboards together closely, it is designed to make groove or ridge-sized tenon on four edges of the board. Groove and tenon on lengthwise edges are called side groove and side tenon, those on crosswise edge are called end groove and end tenon.

Side groove and side tenon should be made first, then end groove and end tenon. In this way the precision of flooring can be guaranteed. This operation is carried out on a four-sided shaving machine of high precision. First of all, adjust the four-sided shaving machine to the pre-determined dimensions precisely, load the processed sets into the feeding system of the machine. The upper and lower cutters shave the surface and bottom of the set, the left and right cutters make side groove and side ridge-sized tenon. When the sets are being loaded, their surface must be put downward, and the straightened edge must be arranged close up to the locating block of machine.

The end groove and end ridge-sized tenon are made on double milling machine. The length of processed sets is adjusted by disc saw, the end groove and end tenon can be made by milling cutter.

(12) Sanding

The aim of sanding is to adjust the thickness of floorboard precisely and to make the surface of floorboard even and smooth. The sanding machine for bamboo flooring is of single face. The granularity of grit is less than 100# at first, and more than 120# at last. The thickness of combined bamboo can be adjusted on sanding machine too, but the granularity of grit must be regulated properly.

(13) Painting

Painting is the last link of bamboo flooring manufacturing. The aims of painting are as follows: 1. Improve the surface hardness of product and its service life. The wear resistance of painted bamboo flooring reaches 2500 rpm. The paint coat lasts 15 years under normal conditions without peeling off. 2. Make the surface good-looking, smooth and shiny, convenient for cleaning. 3. Block the floorboard and make it moisture-proof. The pores of bamboo texture are stuffed with the paint before its solidification, the paint forms a firm film after solidification. Therefore, the moisture from air can not permeate into the floorboard, preventing the shrinkage and expansion of floorboard in connection with the change of air humidity, and the growth of insects and fungi. The quality of painting influences the service life of floorboard, this is an important link of processing.

For the painting of bamboo flooring heat reactive resin varnish or light reactive resin varnish are applied. These two varnishes are of different raw materials, the painting methods are also different.

Section 3. Main factors influencing the quality of combined bamboo and bamboo flooring

Combined bamboo and bamboo flooring differ from other kinds of bamboo-based panels. Along with sufficient strength and rigidity, these products must have more stable structure and good-looking appearance. The main factors influencing their qualities are as follows:

1. Raw material

The selection and control of proper raw material is the precondition of successful manufacturing of combined bamboo and bamboo flooring. To select proper raw material, it is necessary to bear in mind four words: age, freshness, straightness and diameter.

Age: This means the raw bamboo must be 4 or more years old. Bamboo material of this age has stable texture, high density, high rigidity, low water content and small shrinkage.

Freshness: Raw material must be fresh. For avoiding mould and withering the time of its storage (from cutting to boiling-bleaching or carbonization) must be as short as possible, especially in spring and summer of high temperature and high humidity. In this period of time bamboo is growing vigorously, its content of water and carbohydrate is high, the time of storage should not exceed 5 days. In autumn and winter bamboo is entering a rest period, the content of water and carbohydrate is reducing, temperature is declining, the air is dry, fungi breed slowly. In these seasons it is better to store more raw material, but the time of storage should not exceed 15 days.

It is desirable to store bamboo strips as much as possible, while raw bamboo must be less. Because boiled-bleached or carbonized strips can be stored longer than 2 months.

Straightness: Bamboo culm must be straight, of small obliquity, high utilization ratio.

Diameter: The diameter of raw bamboo must exceed 100 mm. Greater diameter means higher utilization ratio. If the diameter is great, its culm wall is thick, which is more suitable for making bamboo flooring.

2. Precision of processing

There are three links in the manufacturing process of combined bamboo and bamboo flooring, which influence the cracks between the strips of the surface layer and the precision of joining: precise shaving of strips, making grooves and tenons, sanding of floorboard. The precision of strip dimensions decides the possible chinks between strips and between layers during hot pressing, which influence the strength and appearance of floorboard. The precision of grooves and tenons decides the possible cracks and accuracy of flooring. The precision of sanding decides the evenness of the whole floor. The precision of all the processing operations depends on the quality of equipment applied: precise shaving machine, four-sided shaving machine, double milling machine and sanding machine. At present these machines are made in Taiwan, China, in Germany, Holland, Italy and other countries. In recent years factories in mainland China also developed capability for producing the equipment, particularly the machines for processing strips and pressing machines. The quality of these machines is similar to that of imported ones, while the prices are only 1/3 of the latter. This will promote the development of bamboo industry.

The tolerance of processing is: width of precise shaving: < 0.1 mm. thickness of precise shaving: < 0.1 mm. cracks of flooring < 0.2 mm. unevenness of floor: < 0.2 mm. If the precision of groove and tenon making is not stable, it is recommended to blunt the point of right angles to avoid the possible damages to workers.

3. Stability of dimensions

Keep stable dimensions and prevent deformation is the basic requirement for the production of combined bamboo and bamboo flooring. Main factors influencing the stability of dimensions are the symmetry of board structure, symmetry of fiber of strips, evenness and balance of water content.

(1) Symmetry of board structure

Combined bamboo and bamboo flooring are a special kind of plybamboo. To guarantee the dimensions stable, the structure must be symmetrical. The structure can be of single-layer, double-layer, triple-layer and multi-layer.

Boards of single-layer and double-layer are mainly used for decoration. The structure of single-layer boards is not symmetrical, because the green and yellow surfaces are different. Such boards deform easily. The structure of double-layer board is symmetrical, the central plane of symmetry is on the adhesive film. In the structure of triple-layer board, the core layer serves as the central plane, the surface and bottom layers are symmetrical, forming a balanced body. Triple-layer board can be made of bamboo wholly, or of bamboo with wood. The combined boards have to undergo shaving and sanding operations after hot pressing, which may affect the thickness of the boards. In order to keep their structure symmetric, the operations must be implemented equally on both the surface and bottom layers. The core layer of triple-layer board can be of bamboo or wood, if select cheap wood, the production cost can be reduced.

Multi-layer boards consist of 4 or more layers, the number of layers can be both odd or even. Generally speaking, for a product of determined thickness, more layers means the more stable structure, but the production cost will be higher. If the culm wall is not thick (top part of culm or small-sized *Phyllostachys heterocycla*), a board must be made of 5 or more layers. Sometimes multi-layer plywood (5 layers or more) can be used as inner part, and be covered with a thin bamboo piece as a surface layer. Such a structure is quite stable because the plywood itself is stable, of course, a layer of similar properties must be adhered to the bottom face of plywood.

(2) Symmetry of fiber of strips

The distribution of vascular bundles in bamboo texture is not uniform. Vascular bundles near green face are dense and close, while near yellow face are loose. The density difference between green and yellow parts makes the unevenness of mechanical strength in a strip.

In the manufacturing process of combined bamboo and bamboo flooring, close attention should be paid not only to the symmetry of board structure, but also to the symmetry of vascular bundles of fiber. The symmetry of vascular bundles can be achieved by proper arrangement of green and yellow faces. For producing floorboard of radial-cut face (side pressed) green face should be jointed with green face, and yellow with yellow. For producing floorboard of chord-cut face (right pressed) the green face of strips in surface layer must be arranged outwards, consequently, the green face of those of bottom layer also be arranged outwards for symmetry. As the vascular bundles are parallel to each other without crosswise connection, the lengthwise strength of bamboo material is high, while the crosswise strength is low. The ratio of lengthwise strength to crosswise strength is 30:1. If the direction of vascular bundles of core layer is the same as that of the surface and bottom layers, the crosswise strength of floorboard is low, which leads to crosswise deformation. Therefore it is better to arrange the fiber of core layer perpendicular to that of surface and bottom layers. Bamboo flooring of such a structure can be manufactured in greater width without deformation. The wood core layer can also be arranged in this manner.

(3) The evenness and balance of water content

As all other kinds of panels, combined bamboo and bamboo flooring expand when moisture is absorbed, and shrink when the moisture is released. If the water content of strips in one and the same board is different, it will deform in the process of storage or utilization. If the water content of products differs from air humidity greatly, the expansion and shrinkage also lead to cracks, warp and deformation. Therefore the influence of water content is of two aspects: the evenness of water content of strips in one and the same board; the balance between water content of products and air humidity.

To control the water content of bamboo strips, efforts should be made to achieve the scientific structure of kiln dryer, rational technology of drying and even temperature in kiln. The water content of strips must be around 8% when they are unloaded. The strips must be precisely shaved right after unloading when their plasticity is rather high. The precisely shaved strips must be stored indoors for 48 hours for cooling and evenness of water content. Then they can be assembled and hot-pressed. The water content of products manufactured in such a way is even and balanced.

The balance between water content of products and air humidity can be achieved by adjusting the water content of products before painting. If the products are to be used in an area of marine climate, the water content should be in the range of 10 ~ 12%. It should be 8 ~ 10% in hinterland and below 8% in a very dry area. The water content of products can be regulated in the following way: store the products indoors to raise the water content by absorbing moisture; pile the products in a room of 40 ~ 50°C to be dried further, the water content can be reduced to less than 8%. The method of adjusting depends on the season of operation. When the water content of products is well-adjusted, they should be painted and packaged as soon as possible. Attention should be paid to both ends and bottom of floorboard. Vascular bundles of bamboo fiber are cross-cut at the ends, these are the entrance and exit of moisture into and from the products. The pores should be stuffed with paint by means of a spray gun. In this way the expansion and shrinkage of bamboo flooring can be avoided in its service life.

4. Color control

One of the main factors influencing the appearance of bamboo flooring is the color difference between the strips of one and the same board. Due to the different age and growth conditions of bamboo culm, and different location of strips in a culm, the color of strips differs evidently. The color of strips can be regulated in the process of manufacturing. Except for the special demands from consumers, only the color difference of surface layer is controlled.

(1) The processing of bamboo strips

Bamboo strips are to be boiled-bleached or carbonized. Along with the anti-insect and anti-mould effects, the aim of these operations is also to harmonize the color of strips. To achieve this aim, it is important to select proper raw material.

(2) After precise shaving, the strips must be checked and sorted one by one. First of all is to select the strips for surface layer. During the selection of strips for surface layer, the following point should be taken into consideration: a. Good-looking color and tidy fiber; b. Without insect holes, mould traces, black spots and lines. c. Precise dimensions, without cracks, chips, residual green and yellow matter. The selected strips for surface layer are to be piled separately, the rest are to be used for core and bottom layers.

The selected strips for surface layer should be checked further. Strips of similar color are to be put together for assembling into one and the same set. If the strips are not selected correctly but pressed together, it is impossible to remedy.

Sometimes strips of one and the same bamboo culm are processed together, and are arranged in one and the same surface of a floorboard, in this way the color of strips is identical. But the operation is quite complicated and the surface seems a little monotonous.

(3) Surface treatment

By means of boiling-bleaching the color of strips is made identical. But the bleacher penetrates into strips unevenly, sometimes only 0.5 mm from the surface. After shaving and sanding operation the color difference may appear again. Smear the darker strips with hydrogen peroxide solution (50%) and put them into a drying room of 40 ~ 50°C to have a partial bleaching. The bleacher of surface treatment penetrates into the strips only 0.2 mm. Therefore the strips must undergo the sanding operation to achieve the thickness of the final product with just a very little margin. The strips after surface treatment can be processed on sanding machine once more, and the color difference can be reduced greatly.

Section 4: Bamboo flooring: paving and maintenance

Bamboo flooring can be paved without milling and painting. They can be paved and put to use directly. As the floorboards are processed with high precision, they must be paved precisely. Correct paving and regular maintenance are the pre-conditions for the successful use of bamboo flooring.

1. Proper places for using bamboo flooring

Bamboo flooring are decoration material of high grade, in recent years they are widely used in private houses, office buildings, hotels, and places of recreation and sports. Theoretically, all the places with good ventilation are suitable for using bamboo flooring. Bamboo flooring can be used in areas of different climate conditions, including coastal areas of high temperature and high humidity. Concretely speaking, the following places are suitable for using bamboo flooring:

- (1) Household decoration: bamboo flooring are mainly used here, particularly sleeping rooms, cabinets and gyms.
- (2) Office building: office rooms, meeting rooms, reception rooms and exhibition halls.
- (3) Guest houses and hotels: suites, health center, recreation center, meeting center etc.
- (4) Commercial buildings: business halls, sales counters.

Bamboo flooring can also be used for decorating walls.

The following places are not suitable for using bamboo flooring: the ground floors with bad ventilation, basements, ground surface often watered, public indoor places of large area, public paths.

The paving of bamboo flooring must be arranged as the last operation of interior decoration in order to avoid the possible pollution caused by other operations.

2. Steps to pave floorboards

(1) Moisture-proof

Cover the ground with moisture-proof material, such as asphalt felt, plastic film, etc. Moisture-proof material must be complete, the joints and torn parts must be overlapped. The aim of this step is to keep the condensed steam on ground away from floorboards. This is most important in newly built houses.

(2) Keels laying

Bamboo flooring must be supported by and fixed on keels. The keel can be made of pine, fir or broadleaf wood species. The width and thickness of keel are 30mm x 30mm. The length depends on the area of floor. The wood for making keels must be dried naturally or in kiln. Keels are arranged in the crosswise direction of the room. The space between neighboring parallel keels is about 300 mm. The ends of floorboards must be fixed on keels. The laid keels must be adjusted by level, and fixed on the ground with cement nails of 5 cm.

Some customers like to cover the keels with plywood or fiberboard of mid density. But if the ceiling of the room is not high enough or the budget is limited, such a cover can be neglected, and the quality of floor will not be affected.

(3) Paving

Bamboo flooring are to be paved in the form of staggered joint, just as the bricks laid in a wall.

Bamboo flooring can be fixed on keels with nails of 2.5 cm long. The nails should be hammered through floorboards into keels at an angle of 45°. Before hammering it is necessary to drill holes with a small-sized bit to avoid the possible cracks.

Bamboo flooring should not contact walls of the room closely, there must be gaps of 1 ~ 2 mm between them to prevent the moisture from penetrating into floorboards from walls.

3. Maintenance

Proper ways to maintain bamboo flooring are very important for their successful utilization. With the development of bamboo industry bamboo flooring are being used widely. But some of the users know little about their maintenance, which may cause troubles. Attention should be paid to the following:

(1) Keep the room dry and well ventilated.

Ventilation promotes the volatilization of the chemicals from floorboards, and the interchange of air. The windows and doors should be opened regularly, or to turn on the air-conditioner.

(2) Avoid the sunshine and raindrops

In some kinds of houses sunshine and raindrops penetrate into rooms, which may quicken the aging process of adhesive and varnish, cause the shrinkage and extension of floorboards, and moulds even.

(3) Prevent damages to the surface of floorboards

The varnish coat of bamboo flooring is a decorative and a protective layer as well. Therefore it is necessary to avoid the knocks of hard articles, scratches of sharp tools and friction of metal. Chemicals should not be stored in the room. When move furniture, it should be put down gently. In public halls the passageways should be covered with rugs.

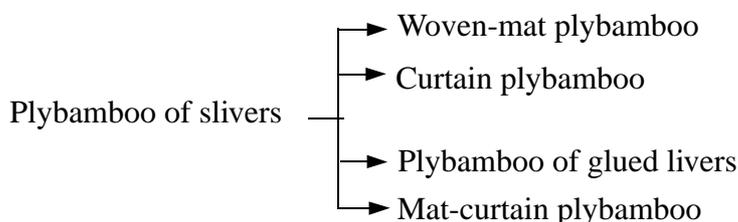
(4) Regular cleaning

Bamboo floor must be cleaned regularly. Sweep the floor with a dry broom at first, then wring a soaked duster cloth and wipe the floor with it. If the area of bamboo floor is great, it is recommended to clean a mop in water, hang it to drip and wipe the floor with it. Bamboo floor can not be cleaned with water directly, or with a soaked duster cloth or a mop.

Bamboo flooring may be waxed regularly if possible. If the varnish coat is damaged somewhere, it may be coated with ordinary varnish, or inform the manufacturer for mending.

Chapter III. Plybamboo of slivers

Plybamboo of slivers is a kind of bamboo-based panels, which contains the most diversified and most popular products of bamboo industry. All this kind of products are made of thin chips. They can be divided into following forms:



Section 1. Woven-mat plybamboo

Woven-mat plybamboo appeared in 1940s to 1950s. The technology of its production is rather simple and the investment for building a factory is insignificant. The supply of raw material for making such products is abundant, the utilization ratio is high and the production cost is low. Woven-mat plybamboo has high mechanical properties, and it is widely used in packaging, furniture making, construction and vehicle making. Factories producing woven-mat plybamboo are distributed in Sichuan, Hunan, Zhejiang and Jiangxi provinces.

1. Definition and classification

The woven-mat plybamboo is manufactured by means of strip-making, weaving, adhesive coating (impregnating), hot pressing. The appearance of woven-mat plybamboo is shown in Fig 2-29.

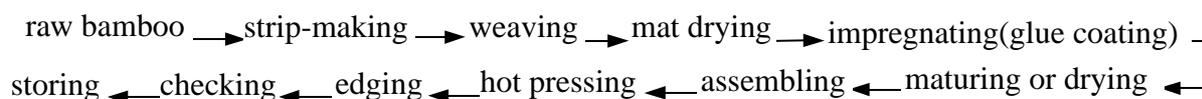


Fig. 2-29: The appearance of woven-mat plybamboo

Woven-mat plybamboo is classified according to its uses: package board, top board of railway wagon, furniture board, construction forms, bottom board of vehicles.

2. Processing technology

The processing technology of woven-mat plybamboo is as follows:



Woven-mat plybamboo for furniture making and decoration must meet higher requirements. The strips must undergo sanding, bleaching or coloring operations before weaving.

The processing technology depends on the uses of final products. Package boards and boards for vehicles are made of rough mats. Such mats can be woven in peasant families, and purchased by manufacturers for the further processing. If the products are to be used for making furniture and decoration, the strips must be processed, bleached or colored. Therefore, the strip-making and weaving operations of these products should be carried out in factories for effective quality controlling.

3. Preparation of raw material

Raw bamboo species must be suitable for making strips and have larger inter-joint length. These species are *Phyllostachys heterocycla*, *Dendrocalamus latiflorus* Munro, *Neosinocalamus affinis* (Rendle) Keng f. *Phyllostachys glauca* McClure, *Phyllostachys heteroclada* Oliver and *Dendrocalamus membranaceus* Munro. For making fine slivers it is better to choose *Phyllostachys heteroclada*, *Phyllostachys glauca* and *Neosinocalamus affinis*. While *Phyllostachys heterocycla* and *Dendrocalamus latiflorus* can be used for producing rough slivers. The suitability of bamboo material for making slivers reduces with aging of bamboo. Bamboo 3 ~ 4 years old can be used for making slivers easily, but the strength is lower, these slivers can be used to weave fine mats for decoration. The slivers of bamboo 5 ~ 8 years old have higher and stable mechanical properties, they are fit for making ordinary woven-mat plybamboo.

Sliver making is easy when the water content of bamboo material is high, consequently, it is better to choose fresh bamboo with higher water content.

4. Making slivers

This operation consists of the following steps: cross cutting, joint removing, splitting, sliver making and sorting.

(1) Cross cutting

Cut bamboo culm into sections according to the dimensions of product with a margin of about 15 mm. The incisions must be plane and smooth, and be arranged 3 ~ 5 cm from joints.

(2) Remove joints and split sections

Remove outer joints of section, split the sections into slivers 1.5 cm in width. At the same time remove the inner joints from the yellow face. This operation can be done manually or on a splitting machine.

(3) Making slivers

When make slivers, the incisions must be parallel with the chord of bamboo culm. Remove the yellow layer at first, then split one sliver into two, two into four and further. Slivers from green surface are called green slivers, all the others are called yellow slivers. Those near green surface can be very thin and more slivers can be made in this part. The texture near yellow face is loose and the slivers must be thicker. Green slivers are used to weave and make handicrafts, not to make bamboo-based panels. The thickness of yellow slivers for weaving mats is 0.5 ~ 1.2 mm.

Sorting and storing. Slivers are sorted into piles of green, second yellow, third yellow, fourth yellow and so on. Sorted slivers are bundled up, dried by airing, and then stored.

5. Weaving

Slivers are used to weave mats of pre-determined dimensions. At present bamboo mats are woven only by hand. Mats for making bamboo-based panels are woven by passing slivers crosswise over and under lengthwise ones. Crosswise slivers are called warps and lengthwise

wefts. For weaving rough mats, warps pass over three wefts first and then under three wefts, for making fine mats, warps pass over and under only one weft.

The mats must be even and smooth, and rectangle.

6. Drying

Bamboo mats are woven separately. Due to the difference of raw material, the water content of mats is not even. In order to achieve the evenness of water content for further processing, the woven or purchased mats should be dried immediately.

The water content of mats must be kept in the range of 6 ~ 12%. It can be higher for urea-formaldehyde resin and lower for phenol resin.

Mats can be dried naturally or artificially. The effect of artificial drying is better, and great batches can be dried in this way for industrial production. Artificial drying can be implemented in kiln dryers or on drying machines. It is acceptable to use ordinary wood-kiln-dryer for bamboo mats, the heat energy may be steam or stove gas. Drying machine of single tier or double tier for plywood can be applied to dry bamboo mats, the drying time is 10 ~ 15 min, and temperature is 140 ~ 160°C.

If there are no possibilities of artificial drying, bamboo mats can be dried naturally, by airing. But this method depends on the weather, the effect is not stable and can not be done in great batches.

7. Adhesive coating (impregnating)

Mats are coated or impregnated with adhesive for hot pressing.

Urea-formaldehyde resin (solids content 48 ~ 65%) is used for coating. The coating amount is 200 ~ 275 g/m² for single surface and 400 ~ 550 g/m² for double surface. The adhesive coat must be thin and even.

Phenol resin is used for impregnating. Impregnate bamboo mats with resin pool for a certain period of time, fetch them out and extrude surplus resin from them with upper and lower rollers. When the solids content of resin is 28%±2%, and the water content of mats is 4 ~ 6%, the impregnating time can be kept in the range of 2 ~ 2.5 min, when the water content is 10 ~ 12%, the impregnating time can be 2.5 ~ 3.5 min. Under these conditions the impregnating rate achieves 6 ~ 7%. If other kinds of adhesives are applied, the impregnating time must be determined by tests. The impregnating rate is a ratio between solid matter of resin absorbed by mat and the weight of the mat itself. It is an important factor for evaluating impregnating quality. Generally speaking, if the adhering effect is achieved, the lower impregnating rate is the better. The quality of panels improves with the raise of impregnating rate, but if the impregnating rate exceeds 10%, the effect is not evident. Therefore the impregnating rate should be kept in the range of 6 ~ 7%.

8. Maturing or drying

The coated mats must be laid for a certain period of time in order that the resin permeates the surface of slivers and weaving crosses, and the moisture evaporates by airing. This process is called maturing. The length of maturing time depends on the viscosity of adhesive and the room temperature. Maturing time must be longer if the viscosity is higher and the room temperature is lower, it can be shorter under opposite conditions.

The impregnated mats can be laid for several hours (not longer than 24 hours) for natural drying. For the sake of high quality and batch production, the mats can be dried artificially, the temperature of drying medium should not exceed 80°C, the final water content kept in the range 15 ~ 18%.

9. Assembling

Mats are woven of wefts and warps, their crosswise and lengthwise mechanical properties are quite similar. Therefore they can be assembled not only in odd number, but also in even number.

Both surfaces of assembled sets should be covered with a metal plate respectively to avoid the possible pollution of platens and the mat surface.

If metal plates stick to mat surfaces upon unloading, it is recommended to smear ungluing agent on the plates.

10. Hot pressing

The hot pressing indexes of woven-mat plybamboo are shown in table 2-12.

Table 2-12: The hot pressing indexes of woven-mat plybamboo

Type of adhesives.	Temperature. (°C)	Unit pressure. (MPa)	Hot pressing time (min)			
			double-l	triple-l	quadruple-l	penta-l
phenol resin	140 ~ 150	2.5 ~ 4.0	3 ~ 4	5 ~ 7	8 ~ 12	10 ~ 15
urea-formaldehyde	110 ~ 120	2.5 ~ 4.0	3 ~ 4	4 ~ 5	5 ~ 7	6 ~ 7

For the sake of further solidification of adhesive inside the pressed panels, they should be piled tidily right after the unloading from pressing machine, this also helps to eliminate the inner stress of panels and reduce their deformation.

11. Edging and checking

Hot pressed panels are piled tidily right after unloading from pressing machine. After 12 ~24 hours of hot piling. They are cut in crosswise and lengthwise directions according to the product standards or the requirements of customers. The dimensions and tolerances, appearance, physico-mechanical properties of panels are checked after cutting. Then they are packaged and stored.

12. Physico-mechanical properties

Physico-mechanical properties depend on the type of adhesive, hot pressing conditions, number of layers, thickness of panel, etc. The MOR of thinner panels can be over 90 MPa. The MOR of thicker panels is lower than that of thinner ones of same sort and same adhesive. Samples of woven-mat plybamboo can hardly be gripped firmly, their adhering strength can not be tested as usual plywood. To solve this problem, the samples of products are treated in the way of “boiling (impregnating) – freezing - drying”, then their MOR is tested.

Section 2. Curtain plybamboo and mat-curtain plybamboo

1. Definition, classification and uses

Curtain plybamboo is formed of bamboo curtains, curtain plybamboo and mats is formed of bamboo curtains and bamboo mats. Impregnated with adhesive (generally phenol resin), the curtains and mats are hot-pressed into bamboo-based panels according to their uses.

Curtain plybamboo is mainly used as the base to be covered with a surface of high strength for making concrete forms. Mat-curtain plybamboo is used as ordinary concrete forms.

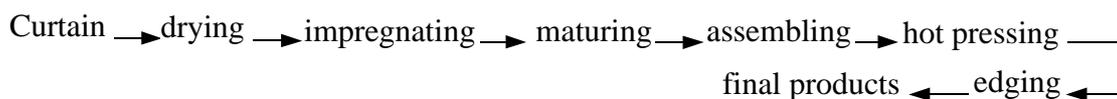
Mat-curtain plybamboo is made of mats as surface layers and curtains as core layer. This kind of panel can be divided into “thick-curtain” and “thin-curtain” according to the thickness of curtains. In comparison with traditional materials for making concrete form, such as steel, wood and plywood, mat-curtain plybamboo has larger dimensions, higher rigidity and strength. It is widely used on construction sites of high buildings, engineering constructions and industrial buildings, where many cement components are made on the spot and finalized with cement mortar. The appearance of mat-curtain plybamboo is shown in Fig. 2-30



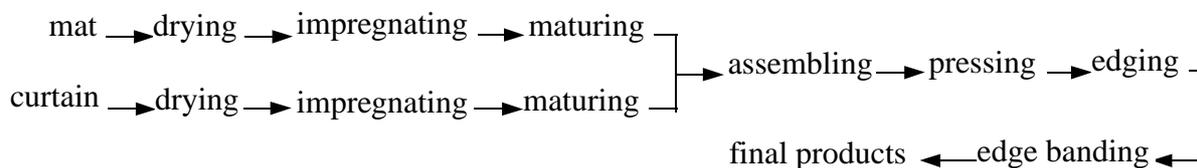
Fig. 2-30: The appearance of mat-curtain plybamboo

2. Production technology

The production technology of curtain plybamboo is as follows:



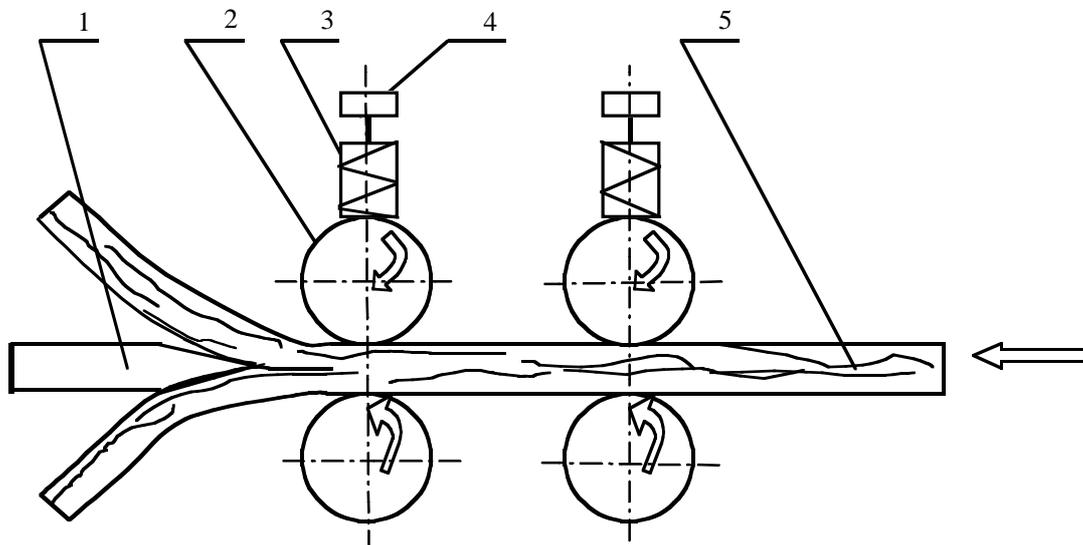
The production technology of mat-curtain plybamboo is as follows:



3. Raw material

The curtains for making plybamboo are about 1 mm thick, the sliver making and weaving are carried out on machines. The trips of curtain are arranged very closely, the thickness of curtain is uniform. The mats used for making mat-curtain plybamboo are the same as those used for making woven-mat plybamboo. Thin curtains are made of slivers 1 mm in thickness, with warp threads of polyester fiber, the space between two adjacent warps is 300 mm. The thick curtains are made of slivers 2 ~ 3 mm in thickness.

Most of the curtains used for making mat-curtain plybamboo are woven and dried in scattered peasant families. These curtains are purchased and processed further by factories of plybamboo. Curtains for making curtain plybamboo have to meet higher thickness and evenness requirements. The sliver making and weaving operations are carried out on machines in factories. Slivers are made on a bamboo splitting machine of single cutter as shown in Fig. 2-31



1. Cutter. 2. Feeding roller. 3. Pressing spring. 4. Adjusting bolt. 5. Bamboo strip

Fig. 2-31: Bamboo splitting machine of single cutter

4. Drying

Bamboo mats and curtains must be dried to reduce their water content to less than 12% before impregnating. They are dried as those for making plybamboo of weaving.

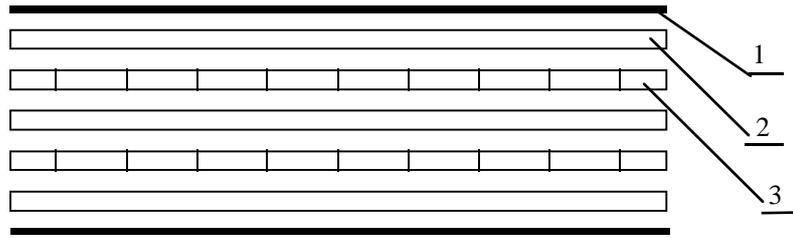
5. Impregnating

The adhesive consumption is significant if it is applied to coat curtains, because there are many pores and chinks in them. The curtains and mats are loaded vertically in steel cages. Let the cages down into an adhesive pool to impregnate by means of an electric hoist. Lift them up after 2 ~ 4 min of impregnating and hang them above a dripping tank. The impregnated curtains and mats are to be dried or matured as those used for making woven-mat plybamboo, because they are also moisturized by adhesive in the process of impregnating.

6. Assembling

Bamboo mats are applied as surface layers, while curtains as core layers. The number of layers and the arrangements of crosswise and lengthwise curtains are decided in accordance with the uses of products and strength requirements. The structure must be symmetrical for the stability of dimensions. The structure of mat-curtain plybamboo is shown in Fig. 2-32

Along with the structure shown in Fig. 2-32, where one crosswise curtain is piled on one lengthwise curtain alternately. It is also permitted to pile several crosswise curtains on several lengthwise ones alternately. In such cases several crosswise curtains or several lengthwise curtains are regarded as one layer.



1.Bamboo mat. 2. Lengthwise curtain. 3. Crosswise curtain
Fig. 2-32: The structure of mat-curtain plybamboo

7. Hot pressing

The hot-pressing conditions are similar to those for manufacturing plybamboo. But because of the high water content of thin curtains and the high unit pressure, the pressing process is “cold loading and cold unloading”. It means the process consists of 3 steps:

Pre-heating: load the assembled sets into pressing machine and raise the temperature and pressure to the pre-determined extent.

Setting up and forming: operate according to the pre-determined conditions.

Cooling: inject cold water into hot platens to cool them, keeping proper pressure. Release the pressure when the temperature declines to 50 ~ 80°C and unload the pressed sets then.

This process of “cold loading and cold unloading” lasts longer than usual, consumes a great deal of water and more energy. But it makes the dimensions stable and surfaces even, and prevents the peeling of layers.

8. Edging and edge banding

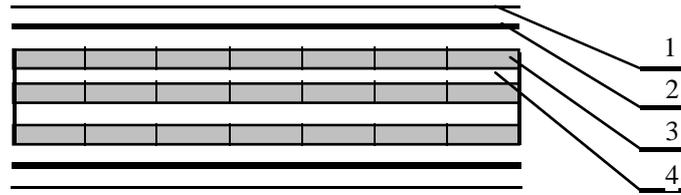
The crosswise and lengthwise edges of pressed sets must be cut to achieve the pre-determined dimensions and tolerances. In order to improve the water resistance and outward appearance of products their edges can be coated with waterproof agent.

9. Main quality indexes

Mat-curtain plybamboo of “thin curtain” type has higher quality indexes. Its MOR reaches 100 MPa, MOE reaches 10000 MPa, density approaches to 1.0, and its adhesive consumption is also higher. The adhesive consumption of “thick curtain” type is lower, the density is 0.75 ~ 0.80, quality indexes are inferior to those of “thin curtain” type. But they meet the quality requirements on construction sites.

10. About mat-curtain plybamboo covered with impregnated paper

Mat-curtain plybamboo of “thin curtain” type can be covered with impregnated paper for making “clean water” concrete forms. The technological process of such products is similar to that of ordinary mat-curtain plybamboo. The only difference is to cover the upper and lower surfaces with a piece of impregnated paper in assembling respectively. Before hot pressing a stainless steel plate is placed on the assembled set and another one under the set. In this way a film can be formed on the surfaces of products, which makes the unloading easy. The paper can be impregnated with melamine resin or phenol resin, or melamine-phenol mixed resin. The structure of mat-curtain plybamboo covered with impregnated paper is shown in Fig. 2-33. The physico-mechanical properties of mat-curtain plybamboo covered with impregnated paper are shown in table 2-13.



1. Impregnated paper. 2. Bamboo mat. 3. Lengthwise curtain. 4. Crosswise curtain

Fig. 2-33: Structure of mat-curtain plybamboo covered with impregnated paper

Table 2-13: Physico-mechanical properties of mat-curtain plybamboo covered with impregnated paper

Property	Index
Density (g/m ³)	0.80
MOR (Mpa)	104.5
MOE (Mpa)	11100
Adhering strength (Mpa)	≥ 2.5
Attrition resistance of surface	0.05g/100r

Section 3. Glued sliver plybamboo

1. Definition and uses

Glued sliver plybamboo is formed of bamboo slivers or livers joined together as a whole piece. After drying, impregnating and maturing, the strips and strip pieces are assembled all in lengthwise direction and hot pressed.

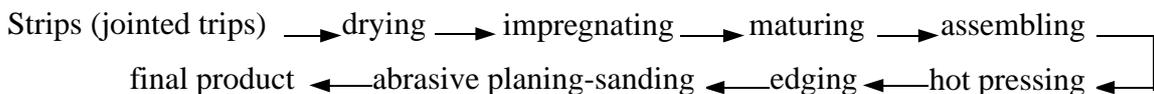
The lengthwise strength and rigidity of glued sliver plybamboo are high, it is a good material for engineering construction, mainly used for making bottom boards of railway wagons and trucks. The appearance of glued sliver plybamboo is shown in Fig. 2-34



Fig. 2-34: The appearance of glued sliver plybamboo

2. Production technology

The production technology of glued sliver plybamboo is simple in comparison with that of plybamboo of weaving and mat-curtain plybamboo.



3. Raw material

Plybamboo is made of slivers 0.8 ~ 1.4 mm in thickness. If strips are too thick, the adhering effects will be affected. Thick strips have higher rigidity, they can hardly be deformed to fill up the blank space between strips even under high pressure. The MOR and adhering strength of plybamboo of thicker strips are lower. It is suggested to apply thinner strips. The width of strips is 15 ~ 20 mm generally. The length should be the length of final product plus the margin of processing. It is permitted to use some short strips, the ratio between long strips and short ones is 1 : 0.2 ~ 0.3. Short strips should not be shorter than 30 mm. Strips are produced in peasant families separately and purchased by manufacturers.

To improve the product quality, it is proposed to join the strips together to make a whole piece for mechanized and continuous processing, to weave the strips into a curtain with threads-warps. Curtains can be woven manually or on weaving machines. The quality requirements for such curtains are similar to those for mat-curtain plybamboo.

4. Drying and impregnating

The water content of strips after drying must be kept within the range 10 ~ 12%. Strips can be dried naturally or in kiln dryers.

The impregnating rate is the ratio between the weight of solid adhesive and the absolute weight of strips. It is an important factor that influences the adhering quality. A low rate leads to poor adhering strength and peeling of layers. Too high rate causes the waste of adhesive. In general, the impregnating rate is fixed at 6 ~ 7%, and water-soluble phenol resin can be applied for impregnating.

The impregnating rate is determined by means of weight calculating. To measure the water content of curtain W_0 and its weight G_0 at first, then calculate the absolute weight of strips G_1 ,

$G_1 = G_0 (1 - W_0)$; lift the impregnated strips, measure their weight after dripping and artificial drying G_2 . The impregnating rate will be $\frac{G_2 - G_1}{G_1} \times 100\%$.

Strips are bundled with wire ropes before impregnating. Let the bundles down into an adhesive pool to impregnate by means of an electric hoist. Lift them up after 1 ~ 2 min of impregnating and let down again to impregnate for 2 min. After that hang them above a dripping tank.

5. Drying after impregnating

Impregnated strips are hung for dripping and drying. The final water content of dried strips should be fixed at 10 ~ 12%. The impregnated strips are dried naturally or in kiln dryers. The temperature of kiln must be at $\pm 65^\circ\text{C}$, higher temperature may lead to the solidification of adhesive. The drying time should last 4 ~ 5 hours. Measure the weight of impregnated strips after drying as G_1 , measure the absolute weight as G_0 , the water content will be: $\frac{G_1 - G_0}{G_0} \times 100\%$.

6. Assembling

Glued sliver plybamboo is assembled on a worktable manually. Separated strips are assembled in a frame after weighing, while jointed strips can be assembled on the plate. Long strips are used for surface layers and short ones for core layers. Compared with separated strips, jointed strips are assembled more effectively, with even thickness and density.

The amount of strips for assembling depends on the density, thickness and dimensions of products.

If the dimensions of products are 2440mm x 1220mm x 30mm, the margin of cutting is 100mm, the margin of thickness processing is 2mm, the dimensions of assembled set will be 2540mm x 1320mm x 32mm. If the pre-determined volume weight of products is 1.1g/cm^3 and the impregnating rate is 7%, the strips to be used for assembling will be:

$$G_1 = l \times b \times d \times r = 254 \times 132 \times 3.2 \times 1.1 = 118018.56 \text{ g} = 118.02 \text{ kg}.$$

G_1 : weight of bamboo strip board; l: length of board; b: width of board; d: thickness of board; r: volume weight of board.

The absolute weight of strips used for making a bamboo strip board

$$G_2 = \frac{G_1}{1 + W_2 + P} = \frac{118.02}{1 + 0.1 + 0.07} = 100.8 \text{ kg}$$

G_2 : absolute weight of strips needed. W_2 : water content of product, 10%.

P: impregnating rate.

Weight of adhesive used for every bamboo strip board:

$$G_3 = P \times G_2 = 0.07 \times 100.8 = 7.07 \text{ kg}$$

G_3 : adhesive needed

If the water content of impregnated strips after drying W_3 is 14%, the weight of impregnated and dried strips needed for making a bamboo strip board G_4 will be:

$$G_4 = (1 + W_3) \times (G_2 + G_3) = (1 + 0.14) \times (100.87 + 7.06) = 123.04 \text{ kg, or}$$

$$G_4 = (1 + W_3) \times (1 + P) G_3 = (1 + 0.14) \times (1 + 0.07) \times 100.87 = 123.04 \text{ kg.}$$

7. Hot pressing

The hot pressing conditions are: temperature: 140 ~ 150°C; unit pressure: 4.5 ~ 6.0 MPa; pressing time: 1.3 min/mm of thickness of final products.

The process of hot pressing is “cold loading and cold unloading”, as used for making mat-curtain plybamboo. The pressure is raised gradually or in stages.

8. Further processing

The semi-finished product after hot pressing must be processed further on pressing plane or sanding machine to adjust its thickness, then cut or milled according to the dimensions of bottom board of truck or railway wagon.

9. Physico-mechanical properties

In general, the density of plybamboo board of glued strips is over 1.0. The lengthwise

MOR of glued sliver plybamboo board 30 mm in thickness exceeds 100 MPa, and the MOE exceeds 8000 MPa. As all the strips of the glued sliver plybamboo are assembled in one and the same direction, its lengthwise strength is great, while the crosswise strength poor.

Chapter IV. Bamboo chipboard and bamboo chip-strip board

Section 1. Bamboo chipboard

1. Definition and uses

Bamboo chipboard is formed of bamboo shavings as elementary units, which are dried, mixed with certain amount of adhesive and waterproof agent, spread, shaped and hot-pressed at a proper temperature with proper pressure.

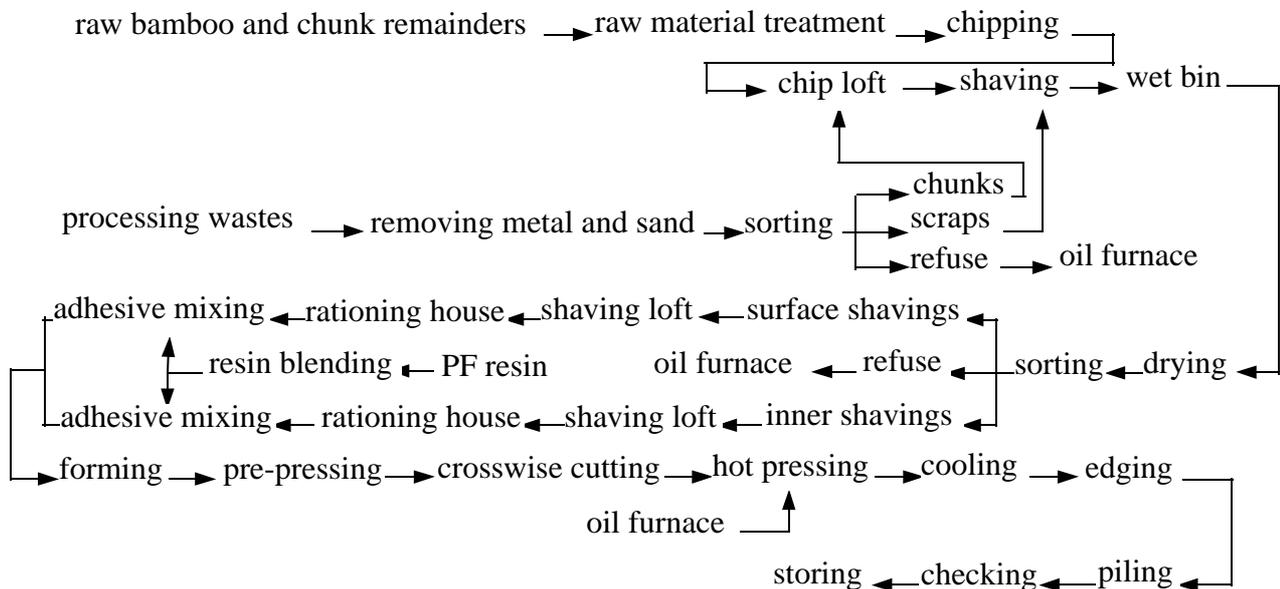
Shavings are made of small-sized bamboo culm and bamboo wastes. As negative effects of green and yellow matter on adhesion are weakened after shaving, the adhering quality of bamboo chipboard is high. The supply of raw material for making bamboo chipboard is abundant and its production is an effective way to raise utilization ratio of bamboo resources.

Bamboo chipboard is produced using water-soluble phenol resin, such a product has higher water tolerance, higher modulus of rupture and modulus of elasticity, and lower moisture expansion in thickness (compared with wood chipboard). Bamboo chipboard can be used as a kind of material for engineering construction. At present, it is mainly used for making ordinary concrete forms. The external appearance of bamboo chipboard is shown in Fig. 2-35.

Fig. 2-35: The external appearance of bamboo chipboard

2. Production technology

Bamboo chipboard is made of three layers with high density. Its production technology is similar to that of wood chipboard. The production technology with hot oil as heating medium is as follows:



3. Raw material and its treatment

Raw material for making bamboo chipboard includes raw bamboo and processing wastes. Raw bamboo means bamboo culm of different diameter, processing waste can be divided into chunks and scraps. Chunks are bamboo culm tops, joints and nodes; scraps are bamboo chips, threads and broken bits. Chunks are to be made into special shavings, while scraps are sorted and regarded as factory shavings. The amount of factory shavings should not exceed 4/10, otherwise the strength of bamboo chipboard may be reduced.

The optimum water content of bamboo material for processing is 40 ~ 60%. Low content leads to the increase of broken bits, which may affect the quality of products. High content prolongs the drying time and energy consumption. If the water content is less than 40%, the material is suggested to be soaked in warm water of 50°C in winter, and in tap water in other seasons. The impregnating time depends on the water content, it is about 2 hours in general. If the content is higher than 60%, the piling time must be longer, the material can be processed when its water content decreases to less than 60%.

To guarantee continuous production the storage of raw material must be enough for 15 ~ 30 days' use. Raw material can be stored in an economy house. For keeping the freshness of raw material and avoiding moulds, the principle "first come, first used" should be observed.

4. The preparation of shavings

The lengthwise pulling strength of bamboo material is great while the crosswise is poor. The width of shavings is always larger than their thickness. Raw bamboo and chunks are made into pieces 30 mm in length. These pieces are converted further into special shavings 0.3 ~ 0.8 mm in thickness and 1.2 ~ 2.0 mm in width. The production practice has proved that cutter cylinder chipper and ring-type shaving machine are suitable for making shavings. The shape of shavings made on such machines is fit for producing bamboo chipboard, and broken bits are less in comparison with other machines.

Scraps from which metal and sand have been removed and sorted are transported into wet bin simultaneously with special shavings for proper mixing. The amount of scraps should not exceed 10% of the total weight.

5. Drying and sorting

Shavings are to be dried on a rotary dryer, the water content of dried shavings should be maintained at 2 ~ 6%.

The dried shavings are sorted. Chunks are transported to shaving machine to be shaved further. Proper shavings are conveyed pneumatically to shaving lofts for surface and core layers respectively. Wastes are conveyed to oil furnace as fuel.

6. Mixing adhesive

For bamboo chipboard production water soluble phenol resin with higher primary viscosity is applied. The primary viscosity is extremely important when continuous pre-pressing is practiced on roll pressing machines and the hot pressing is implemented without metal plates.

The quality indexes of adhesive used on a certain factory:

Solid content: 47% ± 2%.

Viscosity (20°C): 0.26 ~ 0.3 Pa.S; pH: 10 ~ 12; Free formaldehyde: ≤ 0.6%

Storage period: 2 months;

The recipe of waterproof agent (wax emulsion) by weight.

Wax: 100; Synthetic fatty acid: 5 ~ 2 (acid value ≥200)

Water: 150 ~ 200

Ammonia solution: 4.5 ~ 5.5

The quality indexes of wax emulsion:

pH: 7.0 ~ 8.5

Volume weight: 0.9 ~ 0.94g/cm³

Wax density: 20 ~ 40%

Granularity: more than 90% of granules are $\leq 1 \mu$

Storage period: 3 days, not layered and not condensed.

Mix phenol resin with emulsion wax according to the recipe. The rate of wax utilization (the ratio between weight of solid wax and the absolute weight of shavings) depends on the quality of the product, it is usually 0.3 ~ 1.0%

The rate of resin utilization (the ratio between solid weight of adhesive and the absolute weight of shavings) is 9 ~ 12%. The rate should be lower if the shavings of core layer are larger; it should be higher if the shavings of surface layer are smaller. The amount of adhesive is calculated in accordance with the weight of shavings and the utilization rate; it is controlled with an adhesive pump.

The water content of shavings mixed with adhesive must be maintained at 9 ~ 16%. The water content of shavings in core layer should be a little lower than that of surface layer. The mixed shavings should not stored more than 2 days.

7. Forming and pre-pressing

Shavings are spread by means of airflow or on forming machine, which guarantee the evenness of density and smoothness of surface. Manual forming may cause the unevenness of density and deformation of products. The feeding and measuring system should be adjusted according to the density, thickness and structure of final products.

If the shavings are hot-pressed without metal plates, the pre-pressing can be implemented on a continuous rolling machine, connected with forming machine. If shavings are hot-pressed with metal plates, the pre-pressing can be implemented on a pressing machine of single tier (or to be hot-pressed without pre-pressing). The pre-pressed sets are more grain-closed, of certain strength, which may prevent the crack and rupture in transportation. During pre-pressing the air is extruded from shaving sets and the thickness of sets is reduced, which decreases the space between hot-plates. The indexes of pre-pressing are:

Linear pressure of rolling machine: 1000 ~ 2000 N/cm

Unit pressure of pressing machine of single tier: 1.0 ~ 1.6 MPa

Compression rate of sets: 30 ~ 50%

Reversion rate of sets: 15 ~ 25%

$$\text{Compression rate} = \frac{h_1 - h_2}{h_1} \times 100\%$$

$$\text{Reversion rate} = \frac{h_2 - h_3}{h_1} \times 100\%$$

h_1 – thickness of spread sets

h_2 – thickness of sets after reversion

h_3 – minimum thickness of sets during pre-pressing

8. Hot pressing

Hot pressing is one of the key links in bamboo chipboard production, which influences the efficiency of production and quality of products directly. Hot-press can be of great size and single- or multiple-tier. At present pressing machines of multiple-tier are widely used.

As the density of bamboo is higher than that of wood, higher pressure must be exerted to join the shavings together closely. In the process of hot pressing, three factors: pressure, temperature and time are influencing one another. If raise the temperature of hot pressing, the temperature gradient will be increased, the thermal transmission fastened and the heating time shortened. But too high temperature solidifies the adhesive over the surface shavings before the closing of platens and pressing operation. This leads to the loosening and shedding of surface shavings. The hot pressing indexes in bamboo chipboard production are as follows:

Pressing temperature: $T = 160 \sim 180^{\circ}\text{C}$

Pressing time: $t = 0.4 \sim 0.7$ min/mm of thickness of final product. In general it is fixed at $0.5 \sim 0.55$ min/mm of thickness of final product

Unit pressure: $P = 4.0 \sim 4.5$ MPa

The final thickness of bamboo chipboard is controlled with a steel gauge.

9. Physico-mechanical properties

The density and strength of bamboo material are higher than those of wood, consequently, the density and mechanical properties of bamboo chipboard are also higher than those of ordinary chipboard. The physico-mechanical properties of bamboo chipboard are shown in table 2-14

Table 2-14: The physico-mechanical properties of bamboo chipboard

Properties	Unit	Index
Density	G/cm ³	0.85 ~ 0.95
MOR	Mpa	27~ 40
MOE	Mpa	3000 ~ 4000
Plane pulling strength	Mpa	0.7 ~ 0.8
Swelling rate of thickness	%	≤ 8

Section 2: Bamboo chip-strip board

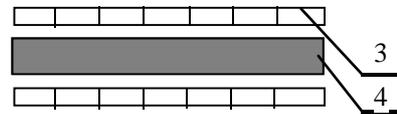
The utilization ratio of raw material in bamboo chipboard production is high, and its production process is also highly mechanized. But its mechanical strength is low, volume weight is great and dimension stability is poor. In addition, it can be easily covered with mould. To eliminate these shortcomings, bamboo chip-strip board is developed.

1. Definition, classification and uses

Bamboo chip-strip board is formed of bamboo fibers as main elementary units, its core layer is made of shavings, while the surface layers are of bamboo strips or bamboo mats. Before hot pressing, shavings are mixed with, strips are coated with, and mats are impregnated with adhesive. There are two types of bamboo chip-strip board; mat-covered board and strip-covered board. Mat-covered board is used to make concrete forms, strip-covered board is used as floorboard and bottom of trucks and buses. The structure of bamboo chip-strip boards is shown in Fig. 2-36 and 2-37.



1. Bamboo mat. 2. Shaving layer.
Fig. 2-36: Structure of mat-covered board.

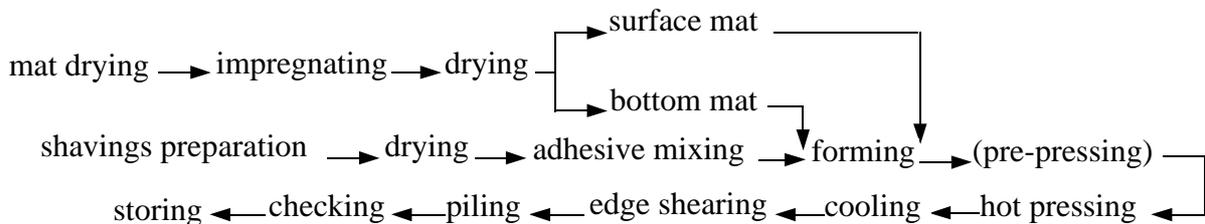


3. Bamboo strips. 4. Bamboo chipboard
Fig. 2-37: Structure of strip-covered board

2. Production technology

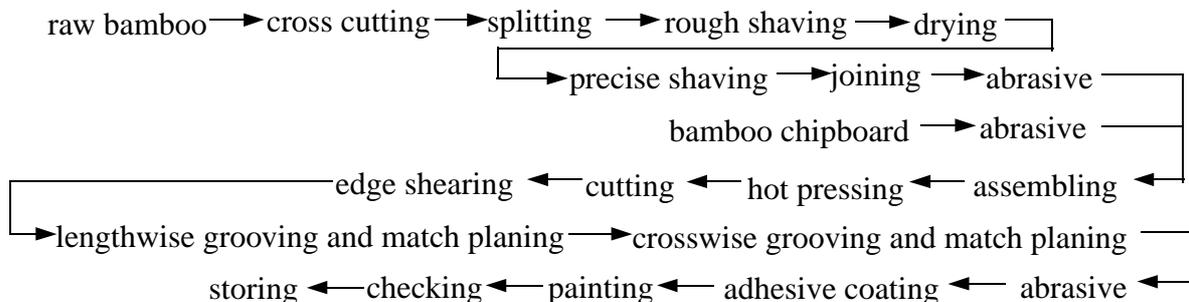
(1) Production technology of mat-covered board

The first step is to lay a impregnated and dried mat for forming shavings. Spread shavings on the mat and cover the shavings with another impregnated and dried mat for hot pressing and further processing. The flow scheme is as follows:



(2) Production technology of strip-covered board

The production technology of strip-covered boards depends on their uses. The flow scheme of product to be used as floorboard is as follows:



3. Main points of mat-covered board production

As the surface layers are made of bamboo mats, the shavings can be spread not so precisely. In general machines with two forming heads are used. The assembled sets are hot-pressed with protecting plates. Before moving into forming machine the base plate must be covered with one or two impregnated and dried mats. Move the base plate with mats into forming machine. Spread bamboo shavings and cover them with other one or two mats. It is also suggested to lay a bamboo curtain when the shavings are spread to half of the pre-determined thickness. This improves the shock resistance of products. The shock resistance is one of the most important parameters for judging the quality of concrete form.

4. Main points of strip-covered board production

For making strip-covered board the strips can be joined together with adhesive to form a whole layer, then to be assembled in the way as that of mat-covered board. It is also possible to produce bamboo chipboard first, sand and coat it with adhesive, then assemble it with coated lengthwise strip layers. The production process of strip layers is the same as that of bamboo strip of single layer. If the product is to be used as floorboard, attention should be paid to the color of strips. They can be bleached or carbonized in case of need.

5. Physico-mechanical properties

The indexes of physico-mechanical properties of bamboo chipboard and bamboo chip-strip board are listed in table 2-15.

Table 2-15: The physico-mechanical properties of bamboo chipboard and bamboo chip-strip board

Property Product	Density (g/cm ³)	Moisture expansion rate (%)	MOR (Mpa)	MOE (Mpa)	Plane pulling strength (Mpa)
Mat-covered	0.85 ~ 0.96	≤ 8	40 ~ 65		
Strip-covered	0.96	2 ~ 3	70 ~ 90	7000 ~ 8000	2.0 ~ 3.0

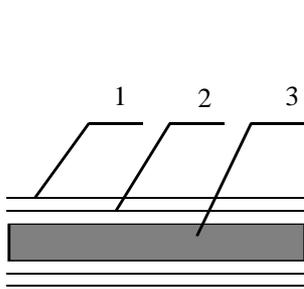
Notes: 1. The MOR and MOE of strip-covered board are measured in lengthwise direction. 2. The thickness of strips is 4.5 mm, the thickness of strip-covered board is 18 mm.

This table demonstrates better mechanical properties of bamboo chip-strip boards as a result of strengthened surface layers. The lengthwise strength of strip-covered board is especially improved because of the strips of proper thickness arranged in one and the same direction. This kind of board is suitable for making floorboard and bottom of vehicles. Mat-covered board is fit for making concrete forms due to its uniform strength.

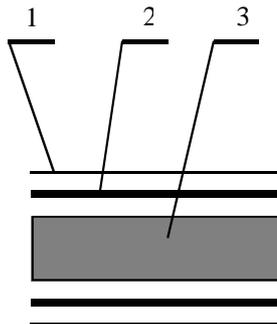
Section 3. Bamboo chip-strip board coated with impregnated paper

1. Classification and uses

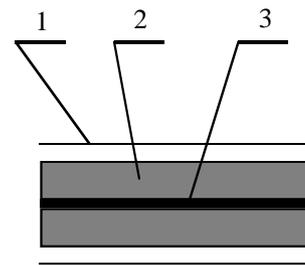
Strip-covered board coated with impregnated paper is mainly used for making concrete forms. Cement components produced by such concrete forms have fine surface, and there is no need to mend them with cement mortar. These coated boards can be divided into three types in accordance with their structure: concrete forms of bamboo chipboard coated with impregnated paper; concrete forms of bamboo mat chipboard coated with impregnated paper; concrete form of bamboo-curtain chipboard coated with impregnated paper. The structures of these boards are shown in Fig. 2-38, 2-39, 2-40.



1.Surface paper impregnated with melamine or phenol resin. 2. Sub-surface paper impregnated with phenol resin. 3. Bamboo chipboard.
Fig. 2-38: Structure of bamboo chipboard coated with impregnated paper



1.Surface paper impregnated with melamine. 2. Impregnated mat. 3. Bamboo chipboard.
Fig. 2-39: Structure of bamboo-mat chipboard coated with impregnated paper

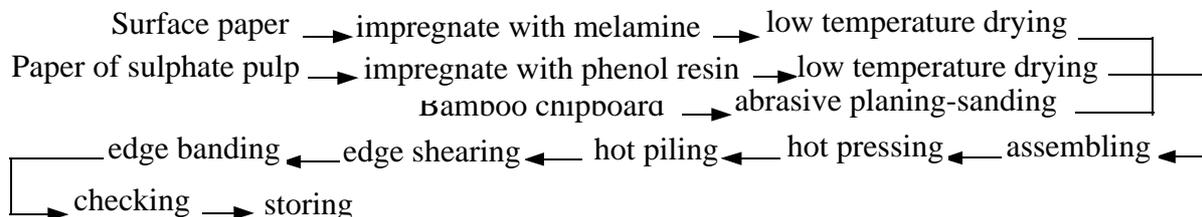


1.Surface paper impregnated with melamine or phenol resin. 2. Bamboo chipboard. 3. Impregnated bamboo curtain
Fig. 2-40: Structure of bamboo-curtain chipboard coated with impregnated paper

1. Main points of production

Bamboo chipboard coated with impregnated paper and bamboo curtain chipboard are manufactured by means of two-step molding. It means that the bamboo chipboard and bamboo curtain chipboard are produced, processed on shaving and abrasive machines at first, then to be coated with impregnated paper. In this way the thickness tolerance can be controlled. Bamboo mat chipboard is manufactured by one-step molding, because the surface mats can not be processed on abrasive machine.

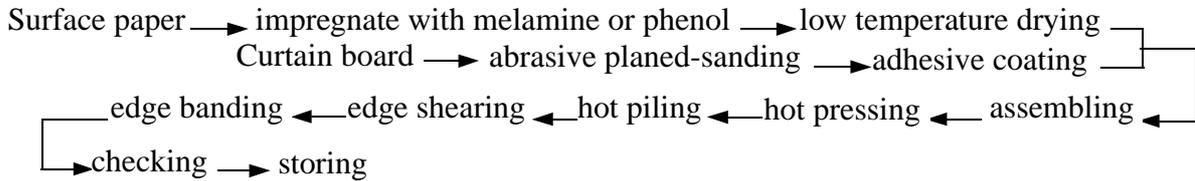
(1) Production technology of bamboo chipboard coated with impregnated paper



(2) Production technology of bamboo mat chipboard coated with impregnated paper

The production technology is the same as that of mat-covered board, the only difference is that the mats should be laid together with impregnated paper before and after forming shavings.

(3) Production technology of bamboo curtain chipboard coated with impregnated paper



2. Raw material and main points of production

(1) Impregnated paper

Titanium white paper is selected as surface paper, and sulphate pulp paper as sub-surface paper, about 100g/m². If the supply of titanium white paper is short, it is permitted to use sulphate pulp paper as surface paper for reducing production cost. The resin content of impregnating is 80 ~ 120%, the content of volatile matter after drying should be 10 ~ 15%. To increase the alkali, acid and attrition resistance of the surface, the surface paper should be impregnated with melamine resin.

(2) The base-plate of bamboo chipboard and curtain chipboard

The base-plate must be of desired mechanical properties and fine appearance. It is preferable to smear phenol resin on the base-plate after abrasion if it is to be coated with only surface paper

(3) Hot pressing

Bamboo mat chipboard coated with impregnated paper is manufactured by one-step molding. The pressure temperature is 135 ~ 145°C, and the pressure is 4.0 ~ 4.5 MPa. To make the surface smooth and bright, the hot pressing should be implemented in the way of “cold loading and cold unloading”. Bamboo chipboard coated with impregnated paper and bamboo curtain chipboard coated with impregnated paper are manufactured by means of two-step molding. The pressure is 1.5 ~ 1.8 MPa and the pressing time is 10 ~ 12 min.

(4) Edge banding

After shearing, the four edges are to be banded with phenol resin or other kind of waterproof paint, which may improve its water vapor resistance and external appearance.

Chapter V. Bamboo-wood sandwich composites

Section 1. General survey

With the development of bamboo research and utilization, bamboo-based panel industry has just begun to take shape. But it is facing some problems, which must be resolved in this process. 1. The physico-mechanical properties of ply-bamboo, ply-bamboo of weaves and bamboo strips are satisfactory, but the utilization ratio of raw material in their production is low, the efficiency is poor and the scale of production is limited. 2. The utilization ratio of material in bamboo chipboard production is high, but the mechanical properties of products are low, their dimensions are not stable and moulds occur on their surface easily, these negative factors affect their uses. 3. Bamboo processing is more difficult than wood processing due to the unique structure and dimensions of bamboo material, which restrict the diversification of products. To counter these problems, products of different elementary component units and different materials are being worked out. These products can be designed in accordance with their uses and service conditions, to bring the strong points of bamboo and wood into play simultaneously.

1. Definition and classification

Bamboo-wood sandwich composites are formed of different components of two or more raw materials, pressed together with adhesives.

There are a great variety of such products, which can not be classified according to one and the same standard. The existing products on market are as follows:

- a. Bamboo-wood sandwich composites coated with impregnated paper for making concrete forms;
- b. Bamboo-wood sandwich composites coated with impregnated paper for making container bottom;
- c. Bamboo sliver-wood sandwich composites;
- d. Bamboo-fir sandwich composites for making flooring.

2. Characteristics

Properties of bamboo-wood sandwich composites depend on the properties of their component units and the location of units in the product, meanwhile the properties also depend on the production technology. Therefore sandwich composites have the following features:

- (1) Combine the advantages of different components of different materials, creating varied properties of a product;
- (2) Design and manufacture the product complying with the quality requirements of users;
- (3) Utilize various raw materials of abundant supply effectively.

The successful combination of different materials leads to the improvement of product quality, rationalizes production technology, raises the productivity and utilization ratio, and decreases the production cost.

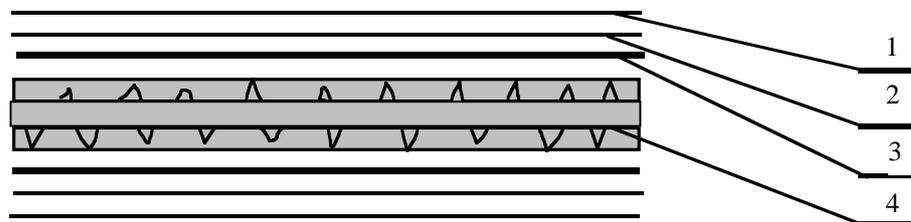
Section 2: Sandwich composites coated with impregnated paper for making concrete forms

1. Introduction

With the rapid development of building industry more and more cement components of high quality are to be made on the construction sites. Consequently, the concrete form boards have to meet higher quality requirements: 1. Higher modulus of elasticity and modulus of rupture, the pouring of cement is accompanied by significant side pressure (about 8t/m₂ regularly). If concrete form boards are not rigid and strong enough to bear such a pressure, it is necessary to add props which increases the weight of form boards and affect the work efficiency. 2. Even and smooth surface with proper rigidity, which can be used repeatedly. 3. Higher water-, heat-, alkali- and aging-resistance, because alkaline concrete releases heat when it solidifies, and outdoor conditions are severe. Concrete form boards must be of the same properties as those of plywood of first class. 4. Greater dimensions for raising work efficiency. Among various kinds of boards bamboo-wood sandwich composites coated with impregnated paper is most suitable for meeting the above-mentioned requirements.

2. Definition and uses

Sandwich composites coated with impregnated paper is made of ply-bamboo and impregnated paper. Ply-bamboo of phenol resin is used as a base-plate and the paper impregnated with phenol resin or melamine is used to coat the board. Such board is applied to make concrete forms of high quality and high strength for producing “clean water” cement components. In comparison with ordinary plywood and ply-bamboo this sandwich composites has lower moisture expansion rate and smoother surface, it can be widely used on construction sites of bridges, express-way overpasses and elevated ways, where cement components of great dimensions are made on the spot without further processing. The structure of bamboo-wood sandwich composites coated with impregnated paper is shown in Fig. 2-41.

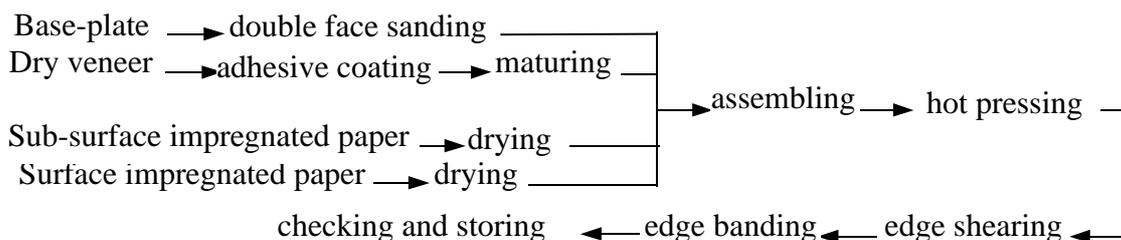


1.Surface paper. 2. Sub-surface paper. 3. Crosswise wood veneer. 4. Base-plate (ply-bamboo)

Fig. 2-41: Bamboo-wood sandwich composites coated with impregnated paper

3. Production technology

The flow chart is as follows:



4. Material and process

(1) Base-plate

Two kinds of bamboo-based panel can be used as base-plate. The one is ply-bamboo manufactured with “softening – flattening” technology. The other is ply-bamboo of curtains, which are woven on weaving machines.

The surface of base-plates must be checked strictly, all the cracks wider than 3mm must be filled with glued bamboo chips. The strips of curtains, especially of the surface curtains should not be too thick, desirably less than 3 mm. The number of warp threads should be increased in order to reduce the gap between strips.

(2) Veneer

Veneers of soft wood (poplar or birch) are placed between base-plate and impregnated paper. Their functions are: 1.Reduce the surface defects caused by uneven pressure, in practice, the surface of product is smooth and bright when wood veneers are sandwiched. 2. Decrease the difference between lengthwise and crosswise strength. Ply-bamboo is of three layers in general, the difference between lengthwise and crosswise strength is quite great (the crosswise strength is only 20 ~ 30% of lengthwise). Boards for making concrete form of high quality must be of sufficient and uniform strength, the crosswise strength must exceed 40% of lengthwise strength. The use of crosswise wood veneer improves the crosswise strength greatly. The wood veneer must be 1.1 ~ 1.2 mm in thickness, with a water content < 8%, without any knots, bark, holes or dry rots.

(3) Impregnated paper

The sub-surface paper must be of sulphate pulp without waterproof agent, 80 ~ 100 g/m², impregnated with phenol resin. The resin content should be 80 ~ 120%, and the content of volatile matter after drying be 14 ~ 16%. The use of sub-surface paper increases the thickness of surface film and improves the abrasive resistance of products.

The surface paper must be of titanium white, 100 g/m², impregnated with melamine resin with disjointing agent. The resin content should be 80 ~ 120%, and the content of volatile matter after drying be 14 ~ 16%. The surface paper impregnated with melamine resin creates a well-developed surface film, which is abrasive-resistant, alkali and acid resistant, but its toughness is inferior to that of phenol resin.

(4) Hot pressing

Hot pressing can be implemented in the way of “cold loading and cold unloading”, or “hot loading and hot unloading”. The pressing temperature is 135 ~ 145°C, unit pressure 1.5 ~ 2.0 MPa, the time of pressing depends on the thickness of boards.

The process of “cold loading and cold unloading” is: 1. Load the pressing machine with assembled sets when the temperature of platens is 60 ~ 70°C, close the platens, raise the temperature and pressure. 2. Maintain the temperature and pressure at the required level. 3. Close the steam valve, release the steam from platens, cooling with cold water. 4. Unload the pressed sets when the temperature declines below 70°C. Pressed in this way, the surface film is well-developed and bright, the board is even, the warp is insignificant. But the consumption of energy and cold water is great, and the pressing cycle is longer.

The process of “hot loading and hot unloading” is: 1. Load the machine when the temperature of platens is raised to 135 ~ 145°C, raise the pressure and keep the temperature. 2. Close the steam valve and force pump 5 ~ 10 min before reducing pressure. 3. Reduce the pressure slowly and gradually after hot pressing. Products made in this way can be of good quality, if all the operations are implemented complying with the rules. The consumption of energy is lower and economic performance is better.

5. Quality indexes

The quality indexes of bamboo-wood sandwich composites covered with impregnated paper for making concrete forms include: physico-mechanical properties, utilization characteristics of concrete forms, outward appearance and thickness tolerance, etc.

(1) Physico-mechanical properties

Physico-mechanical properties of bamboo-wood sandwich composites covered with impregnated paper are listed in table 2-16.

(2) Utilization characteristics of concrete forms are:

- a. Smoothness and brightness of surface, which doesn't need any processing.
- b. High strength, rigidity and abrasive resistance of products, which can be used repeatedly, up to 100 times if all the operations are implemented correctly.
- c. Low moisture expansion and stable dimensions.
- d. Great dimensions for mechanized processing.
- e. Proper water-, heat-, alkali- and aging-resistance to be guaranteed under outdoor conditions.

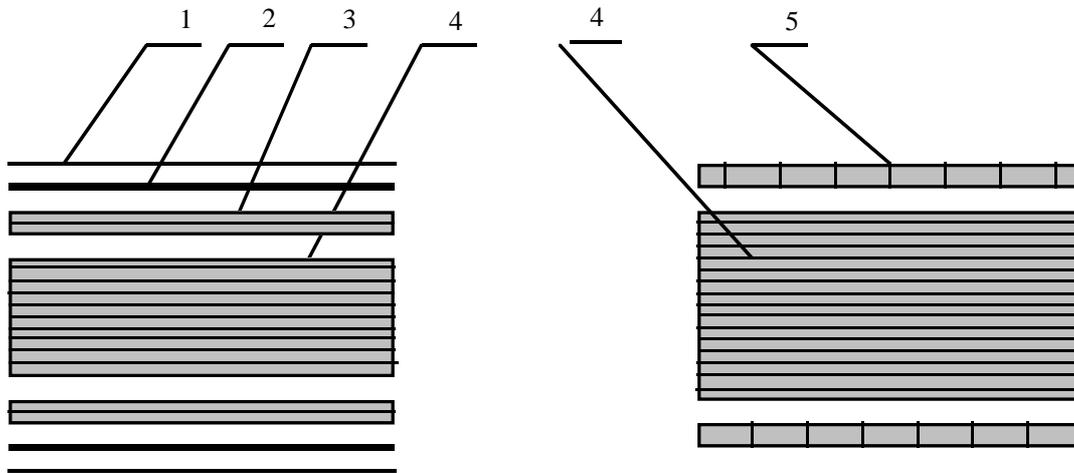
Table 2-16: Physico-mechanical properties of bamboo-wood sandwich composites

Property	uUnit	Value
Density	G/m ³	0.78
MOR	Mpa	108
Lengthwise MOE	Mpa	10300
Crosswise MOE	Mpa	7000
Adhering strength	Mpa	≥ 2.5
Surface adhesive resistance		2000 times, 0.05 g/100 r
Moisture expansion rate	%	2.3 (soaked foe 24 h)

Section 3. Bamboo-wood sandwich composites for making container bottom

1. Definition and uses

Bamboo-wood sandwich composites for making container bottom is a special kind of thick ply-bamboo-wood. It is developed by Bamboo Research Engineering Center of Nanjing Forestry University and Techni-Con International Development Ltd. Hong Kong jointly, a patent has been taken out in China to protect this invention as an intellectual property. The core layer of this product is veneers peeled off from masson pine and larch; the surface layers are impregnated paper, thin strip curtains and mat, or strips of same width and same thickness. These components are assembled scientifically, hot pressed and processed. Thanks to its high quality, bamboo-wood container bottom has been approved by French Ship Service. It becomes widely used in container manufacturing industry. The structure of two kinds of bamboo-wood container bottom is shown in Fig. 2-42.

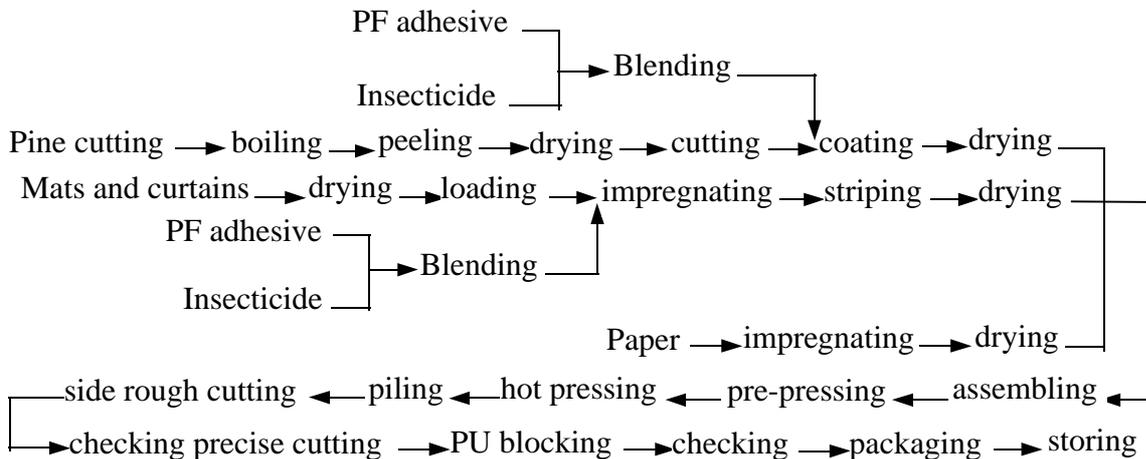


1. Impregnated paper. 2. Bamboo mat. 3. Thin curtain (2 to 3 layers). 4. Pine veneers.
5. Strips of same width and same thickness.

Fig. 2-42: Structure of bamboo-wood container bottom (type a, type b)

2. Production technology

The structure of bamboo-wood container bottom is designed complying with the principles of structural mechanics of complex materials. Its core layer is made of pine veneers 1.6 ~ 2.0 mm in thickness, compressed together in the way of plywood production. The surface layer of type a is made in the way of producing ply-bamboo of curtain-mat, while that of type b is in the way of bamboo flooring production. At present the structure of type a is applied in production, the manufacturing process is as follows:



3. Main links and materials

A. Bamboo mats and curtains

As the container bottom has to meet strict quality requirements, the thickness of strips of mats and curtains must be checked carefully when they are being purchased. The thickness tolerance of strips in a mat or curtain should not exceed ± 0.2 mm. The strips for making curtain must be straight, otherwise they can not be paralleled, which causes the overlapping of strips. Such overlapping should be avoided in production. Bamboo mats must be woven closely, without big chinks. The strips must be dried before weaving. Wet strips used in weaving lead to chinks in the mat. Besides, the curtains and mats should not go mouldy, and the raw bamboo must be four or more years old.

B. Drying

To guarantee the quality of bamboo-wood container bottom, veneers, mats and curtains must be dried before coating and impregnating with adhesive.

(1) Veneers

The water content of veneers after drying depends on the further treatment after the coating with adhesive. The water content should be maintained at 4 ~ 6%, if the strips are to be matured after coating. It can be about 8% if the strips are to be dried under low temperature, the temperature must be $\leq 60^{\circ}\text{C}$.

(2) Mats and curtains

The water content of purchased mats and curtains is not even, which may cause moulds. Therefore they must be dried right after purchasing in kiln dryer or on drying machine. The final water content of mats must be $\leq 8\%$, while that of curtains $\leq 10\%$. The water content of mats and curtains increases when they are impregnated with adhesive. Consequently they must be dried after impregnating. As the impregnated paper will be pressed on bamboo mats directly, and the cross of warps and wefts make the evaporation of moisture difficult, the water content of mats must be lower than that of curtains. In general, the water content of mats should be 6 ~ 8%, that of curtains be 10 ~ 12%.

C. Adhesive blending

According to the AQIS of Australia, there must be certain amount of residual insecticide in container bottom. As the wood veneers, bamboo mats and bamboo curtains are very thin, the anti-insect treatment must be done by resin coating, it means to add insecticide to adhesive and mix them. By means of impregnating or coating, the insecticide permeates the wood and bamboo material. For blending the resin, it is necessary to calculate the ratio between insecticide and adhesive according to the adhesive amount and the required amount of residual insecticide and all the possible losses. This ratio varies with the difference of adhesive consumption and the method of adhering (impregnating or coating).

D. Pre-pressing

The assembled sets can not be made into a panel in the process of pre-pressing, because the coated veneers have been dried at a low temperature and matured for long, the impregnated bamboo mats and curtains have been also dried, they can not be glued together by cold pressing. The aim of pre-pressing is to eliminate the gap between veneers and curtains, to flatten the sets and make them thinner for easier loading.

E. Hot pressing

The physico-mechanical properties of container bottom should meet strict requirements in use. These properties can be achieved only by means of proper hot pressing. If the water

content of materials can be controlled effectively, a shortened cycle of “hot loading and hot unloading” is suitable for the operation, which may reduce the consumption of steam and water for cooling. But if the water content can not be controlled well, it is suggested to apply the technology of “cold loading and cold unloading” or “hot loading and cold unloading”. In case of “hot loading and hot unloading” the moisture can not be released easily due to the large pressing ratio, and the time for reducing pressure and exhausting steam must be lengthened to avoid the possible bubbling. The hot pressing conditions in production are:

Temperature: 135 ~ 145°C.

Pressure: 3.0 MPa.

Time: “hot loading and hot unloading” – 55 ~ 60 min

“hot loading and cold unloading” – 80 min

4. Quality indexes

Containers are transported all over the world under different environmental conditions. As a load-bearing component the container bottom must have superior properties. Therefore every batch must be tested.

(1) Strength test

Test the bottom boards according to ISO1161 in the following steps: 1. Load steel ingots of 2R-T (R = loading capacity of container, T = empty weight of container) into the container, placing them evenly on the bottom board. Test the top and bottom of container by hoisting them up respectively. 2. Unload steel ingots, drive a special wheelbarrow (7260 kg in weight) into the container in all directions more than three times, test the distortion, the remaining distortion should not exceed 3mm.

(2) Physico-mechanical properties

Table 2-17: Physico-mechanical properties of bamboo-wood sandwich composites and Apitong (*Dipterocarpus*) plywood

Property		Unit	Standard value	Standard document	
Moisture content		%	≤ 12.0	GB8846 11-88	
Density		g/cm ₃	≤ 0.85	GB4899 - 85	
MOR	//	Mpa	≥ 0.75	JISZ13-63Z	
	⊥	Mpa	≥ 0.30	JISZ 13.63Z	
MOE	//	Mpa	≥100000	JISZ 13.63Z	
	⊥	Mpa	≥3000	JISZ 13.63Z	
Aging Property	MOR	//	Mpa	≥37.5	ASTMD 1037-78
		⊥	Mpa	≥15.0	ASTMD 1037-78
	MOE	//	Mpa	≥5000	ASTMD 1037-78
		⊥	Mpa	≥1500	ASTMD 1037-78
Adhering strength		Mpa	≥ 0.70	JAS plywood 1 st grade	

The widely used container bottom boards are made of tropical broadleaf hardwood such as Apiton and Crown from Southeast Asia. The physico-mechanical properties of bamboo-wood sandwich composites are determined complying with those of Apiton plywood. They are shown in table 2-17. (3) Outward appearance

The oil rub resistance and cleanness are the main index of outward appearance.

The container bottom of bamboo-wood sandwich composites is coated with impregnated paper, which is highly oil rub resistant and cleaned easily. The factors influencing outward appearance are: color and quality of impregnated paper; volatilizing matter of impregnated paper; quality of mats (even thickness, close weaving, no residual green matter and moulds); hot pressing technology; further processing (smoothness of edge shearing, surface cracks, chips etc.). It is necessary to establish a system to guarantee the quality of products, and implement comprehensive quality control.

Section 4. Bamboo strip-wood panel

1. Definition and uses

Bamboo strip-wood panel is made of: bamboo strips or mat of high strength and high rigidity as surface layer; masson pine or larch board as core layer; phenol resin modified with resorcin of high resistance to elements as adhesive. Several layers of pine boards (usually 3) and bamboo strips or several thin bamboo curtains are all arranged in lengthwise direction. A crosswise wood veneer or thin curtain can be inserted between lengthwise pine boards. The product is noted for its high lengthwise strength, high resistance to elements and lower density. It is suitable for making bottom board of railway wagons, for scaffolding and for shipbuilding. The weight of scaffolding board is limited strictly, therefore a kind of cavity board is designed. The outward appearance of bamboo strip-wood panels is shown in Fig. 2-43. The structure of bamboo strip-wood is shown in Fig. 2-44.

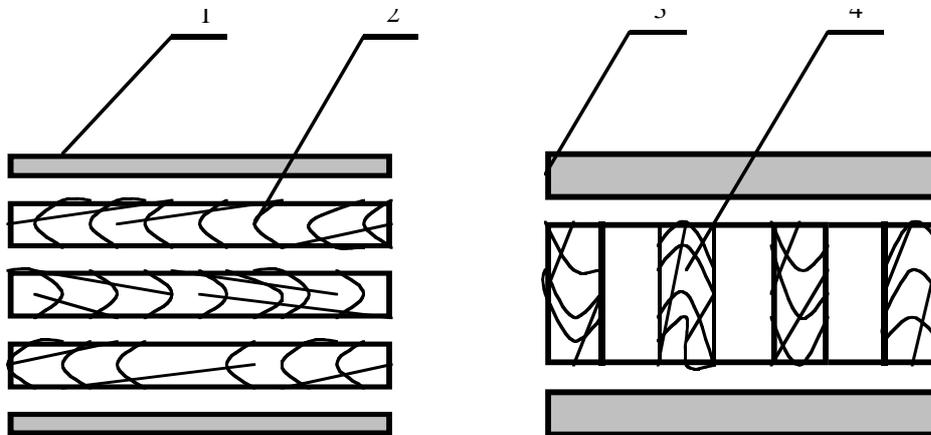


a. Solid bamboo strip-wood panel.



b. Cavity bamboo strip-wood panel.

Fig. 2-43: The outward appearance of bamboo strip-wood panels



a. Solid bamboo strip-wood panel.

b. Cavity bamboo strip-wood panel.

1. Bamboo curtain board of high density, including a crosswise curtain.
2. Thin wood board.
3. Bamboo curtain board of high density.
4. wood bricks.

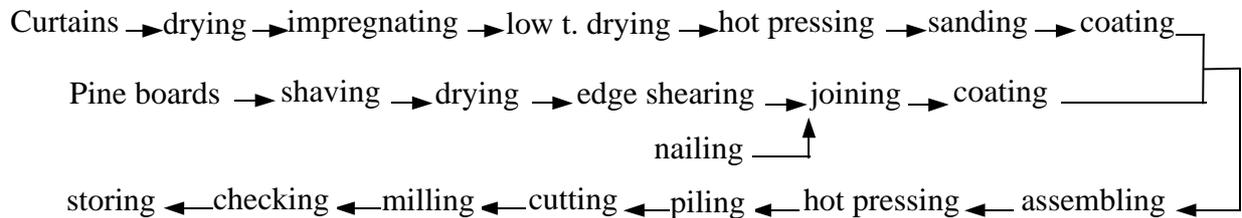
Fig. 2-44: The structure of bamboo strip-wood panels

The solid bamboo strip-curtain-wood panel is 45 mm in thickness, it can be used as bottom board of railway wagons to substitute for Korean pine board 70 mm in thickness. The cavity bamboo strip-wood panel is noted for its light weight, excellent strength and high rigidity. It is 2, 3 or 4 m in length, 50 to 60 mm in thickness, mainly used as scaffolding material in shipbuilding.

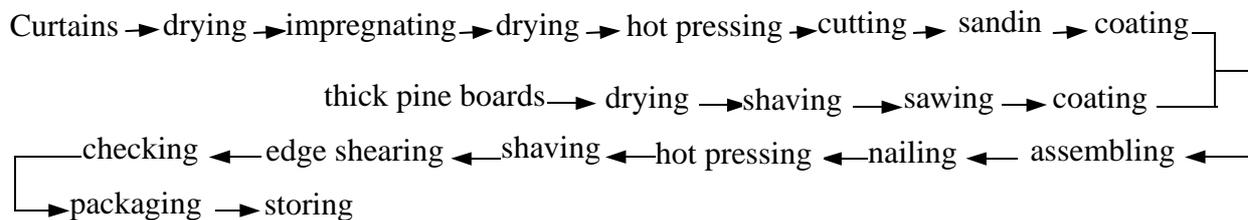
2. Production technology

A. The technological flow sketch of bamboo strip-curtain-wood panel

Press 5 – 7 impregnated thin curtains into a complete board and sand it. Shave the pine boards, adjust their thickness, and join them together with nails. Assemble these components and hot-press them into bamboo strip-wood panel.



B. The technological flow sketch of cavity bamboo strip-curtain-wood panel



3. Main operations and materials

A. Materials

Raw bamboo used for making strips and curtains should be more than 4 years of age. Pine boards (15 mm in thickness) of solid bamboo strip-wood can be produced from timber of intermediate cuttings or small-diameter timber, slight distortion by drying does not affect the processing. Thick boards (45 mm in thickness) of cavity bamboo strip-wood should be made of masson pine or larch of high quality, with fewer and smaller knots, because knots influence the rigidity of cavity bamboo strip-wood panel greatly.

B. Drying

Thin boards are usually shaved and cut after drying, while thick boards are dried before shaving and cutting for guaranteeing the straightness and uniform thickness. The final water content of wood boards must be $\leq 12\%$. The water content of bamboo curtain before impregnating must be $\leq 12\%$, and its final content after impregnating and drying must be $\leq 12 - 14\%$. The water content of wood veneer must be $\leq 8\%$.

C. Coating and impregnating with adhesive

The adhesive consumption during the coating of veneers and impregnating of curtains must be kept at a required level. The phenol resin modified by resorcin is the adhesive to be used. The adhesive for coating can be added with certain amount of wheat flour or wood powder and mixed evenly. The adhesive for impregnating must be diluted with water to achieve proper solid content, without adding wheat flour or wood powder. The impregnated curtains must be matured and dried under low temperature until they are not sticky before assembling.

D. Hot pressing of bamboo curtains

Surface curtain layer of solid bamboo strip-wood is made of 5 ~ 7 curtains by means of hot pressing, while that of cavity bamboo strip-wood is of 13 ~ 15 curtains. The unit pressure

is 4.0 ~ 5.0 MPa, and the temperature is 130 ~ 140°C. The time of pressing operation depends on the thickness of sets and the technology of pressing (hot loading and hot unloading, or cold loading and cold unloading).

E. Surface sanding

As the curtains compressed into a curtain layer have been impregnated with adhesive, there will be a film of solidified resin on its surface, which affects the effect of further hot pressing. Therefore it is necessary to sand the resin film down from the surfaces to be adhered, and it is desirable to use a wide belt sander.

F. Assembling

The wood boards of solid bamboo strip-wood adjacent to surface paper are to be coated with adhesive on both sides before assembling. The inner wood boards are not to be coated. The sanded face of curtain layer must be also coated with adhesive. The surface and bottom of 3 ~ 4 wood bricks (4 bricks are better) of cavity bamboo strip-wood should be coated with adhesive. Meanwhile the appropriate parts of curtain layer (to be joined with bricks) must be coated with adhesive. When the relative position of curtain layer against wood bricks is determined, it is advised to drill holes with a hand drill, and to hammer bamboo nails to fix them. On the length of 2 ~ 4 m 7 ~ 12 bamboo nails with adhesive should be arranged for transporting and secondary hot pressing.

G. Molding and hot pressing

The pressure of molding and hot pressing can be comparatively low thanks to the previous shaving and sanding of curtain layers. The pressure of 1.5 MPa is enough to adhere the components with lower compressive rate. The temperature of hot pressing is about 130°C, the time is about 0.8 min per 1 mm of thickness of assembled set.

H. Further processing

Solid bamboo strip-wood panel for making bottom board of railway wagon should be cut into board 300 mm in width, shaved and milled to meet the installation requirements. Cavity bamboo strip-wood should be shaved, its edges should be sheared and banded with varnish.

4. Physico-mechanical properties of bamboo strip-wood

A. Physico-mechanical properties of solid bamboo strip-wood

As a weight-bearing component of railway wagon, the bottom board must have high lengthwise strength, proper crosswise strength, sufficient impact resistance and aging resistance. Meanwhile it is desirable to have enough nail-holding capacity.

The physico-mechanical properties are shown in table 2-18

B. Physico-mechanical properties of cavity bamboo strip-wood panel

(1) Indexes of strength

The mechanical properties of cavity bamboo strip-wood panel: Rigidity test:

Measure the warp under the conditions of pre-determined span, weight and centralized loading

. The standard value of warp of scaffolding board for shipbuilding is shown in table 2-19.

Table 2-18: Physico-mechanical properties of solid bamboo strip-wood panel

No.	Item	Unit	Standard value	Test method
1	Density	g/mm	≤ 0.8	GB/T 4897.5.2
2	Moisture content	%	≤ 12	GB/T 4897.5.3
3	MOR lengthwise	Mpa	≥ 70	GB/T 4897.5.7.
4	MOR crosswise	Mpa	≥ 10	GB/T 4897.5.2
5	MOE	Mpa	≥ 6000	GB/T 4897.5.8
6	Impact resistance	Kj/m ²	≥ 80	GB/T 1940.
7	Pressure resistance	Mpa	≥ 10	GB/T 1939.
8	Nail holding capacity	N	≥ 1400	GB/T 4897.5.9
9	Adhering strength	Mpa	≥ 1.0	LY/T 1055.6.2.2
10	MOR after acid treatment	Mpa	≥ 40	Soak in HCl of 5% for 7 days
11	MOR after alkali treatment	Mpa	≥ 40	Soak in NaOH of 1% for 7 days
12	Impact resistance under low temperature	kJ/m ²	≥ 60	- 50°C for 3 h
13	High temperature resistance		Without cracks and peeling	120°C for 3 h
14	MOR after aging	Mpa	≥ 60	Soak in water 25°C for 16 h and dried in chamber 65°C for 8 h. repeat 4 cycles

Notes: Standard values are taken from enterprise standard “Bamboo strip-wood panel for making bottom board of railway wagon” complied by Qieshuye Factory of Locomotives and Vehicles of the Ministry of Railways and Bamboo Engineering and Research Center of Nanjing Forestry University

Table 2-19 Standard value of warp of scaffolding board for shipbuilding

Standard Value (mm)	Load (kg)			Notes
	75	159	225	
Length (m)				
2	3.5	7.0	10.5	Thickness 50 mm
3	8	16	24	Thickness 50 mm
4	12	24	36	Thickness 60 mm

Note: The width of board is 300 mm

b. Static loading test: Load a static weight of 450 kg for 5 min. Peelings, cracks or plastic distortions are not permitted.

c. Dynamic loading test: Raise a weight of 75 kg to the height of 2.5 m over the scaffolding board and drop it as a freely falling body. Peelings, cracks or serious damages on surface are not permitted.

(2) Weight requirements

Along with the strength requirements the scaffolding board should meet strict weight requirements. The standard weight is L = 3 m, W ≤ 23 kg; L = 4 m, W ≤ 33 kg.

Chapter VI. Technological design for factories of bamboo-based panels

Technological design means the plan to make final product from semi-product or raw material, including its process, technology and methods.

Technological design is the core of planning for factories of bamboo-based panels.

Section 1. Principles and procedure of technological design

1. The determination of production program

The production program consists of production scale, working system, number of workers and production organization. It is the guideline of technological design.

A. Production scale

The production scale should be determined by means of detailed investigation and study, complying with the economic and industrial policies of the state, and the following subjects should be taken into consideration:

(1) Market demands

The size of market, the scope and way of sales are important factors for determining the production scale.

(2) The supply of raw material

The supply of raw material, energy and subsidiary conditions should be considered for determining the production scale.

(3) Optimum investment

The goal is to achieve maximum profit by means of minimum investment. During the quantitative analysis of the scale of economy, it is recommended to apply the method of profit-and-loss analysis, or linear programming.

(4) The productivity of equipment

The production scale should be determined in accordance with the productivity of equipment. The capacity of main machines on production line can not be changed liberally, a subjective approach to determining production scale without considering the capacity of equipment may cause the idleness of machines.

(5) The calculation of production capacity

The calculation of production capacity of a factory or a workshop is based on the assortment and amount of products made annually. There are two methods for such calculation. The one is to select the main machine on production line (e.g. hot-press) as the base of calculation, the second is to put forward the amount of production and compare it with the capacity of main machine, then work out a realistic annual production capacity.

If the first method is applied it is recommended to take the annual work force of hot-press to calculate is annual productivity Q .

$$Q = \frac{60 \cdot T \cdot n \cdot F \cdot b \cdot K}{t_d (b + \Delta b) + t_f} \quad (\text{m}^3/\text{year})$$

T – annual working time (h)

n – number of tiers in hot-press

F – format of bamboo product after edge shearing (m²)

b – thickness of bamboo product after sanding (mm)

Δb – sanding margin (mm)

t_d – unit pressure time (mm/mm)

t_r – time of subsidiary operation (min)

K – utilization coefficient of working time, depends on the situation of the factory, usually fixed at 0.8 ~ 0.85.

If the production program defines several sorts of products, and the percentage of each product, the productivity of hot-press can be calculated by means of weighted average.

The weighted average productivity of hot-press can be calculated according to the following formula:

$$Q_p = \frac{100}{\frac{a_1}{Q_1} + \frac{a_2}{Q_2} + \dots + \frac{a_n}{Q_n}}$$

$$A_i = \frac{a_i}{\frac{a_1}{Q_1} + \frac{a_2}{Q_2} + \dots + \frac{a_n}{Q_n}}$$

Q_p – weighted average productivity

A_{1,2,...n} – percentage of each sort of products

Q_{1,2,...n} – productivity of hot-press for producing each sort of products.

A_i – amount of each sort of products made in every shift according to the percentage defined in production program (m_i/shift)

The second method is widely applied in designing. Calculate the productivity of main machine complying with the specifications of products defined in the production program. If the calculated productivity conforms to the amount of output defined in the program, it can be used as a designed productivity. But in general the calculated productivity may be lower than the pre-determined output amount, which can not meet the quantity requirements of the program; or may be higher than it, which leads to low utilization ratio. If the difference does not exceed 10%, the calculated productivity can be accepted. If the difference is too large, it is necessary to revise the output amount or to choose another type of hot-press.

In designing production scale a margin of 5 ~ 10% must be taken into account.

B. Related Standards

The production program also defines the assortment of products, their specifications, quality indexes and features. The specifications of products and their percentage should be listed clearly in the technological design, considering the supply of raw materials, their utilization ratio and the uses of final products, and consulting related standards. .

Standards provide technical basis for production, quality control, purchase, check and acceptance, utilization and maintenance, and trade talks. The contents of standards include: sphere of uses, assortment, specifications and structure; characteristics (physico-chemical properties, performance, quality indexes); the test, check and acceptance of products; package, storage and transport. Therefore the design of products should comply with related

standards, i.e. international, national, professional standards, and standards of enterprises. In case there are no standards related to certain product, its production, check and acceptance should be organized according to the agreements signed by supplier and demander.

The national and forestry standards related to bamboo products in China are as follows:

GB/T 13123-1991 Woven mat ply-bamboo

GB/T 13124-1991 The test of woven mat ply-bamboo

LY/T 1055-1992 Plybamboo for bottom boards of trucks and buses

LY/T 1061-1992 Bamboo chopsticks

LY/T 1072-1992 Technical specifications of plybamboo ofslivers

LY/T 1073-1992 The test in physico-mechanical properties of plybamboo of slivers

LY/T 1573-2000 Bamboo flooring

LY/T 1574-2000 Plybamboo for concrete-form

LY/T 1575-2000 Strip plybamboo for bottom boards of trucks and buses

Besides, there are standards related to bamboo products in railway and building industries. Some factories of bamboo-based panels also compiled related standards of their own.

C. Working system, production organization and number of workers

Most of the bamboo-based panel factories work five or six days a week. As the heavy repair of equipment takes about one month a year, there are 230 ~ 280 workdays a year. It is possible to increase the workdays to about 300 by arranging more work shifts.

The production is organized according to the types of work separately. Workers of one and the same type are formed into a specialized group. Different groups are organized into a comprehensive production team for manufacturing certain products. Every production team is divided into several shifts considering the production tasks and technical conditions. The preparation of materials is arranged in 1 ~ 2 shifts, other operations in 2 ~ 3 shifts.

Every shift lasts 8 h, the effective work time is 7 ~ 7.5 h.

The number of workers is defined taking into account the work efficiency and equipment conditions, the managerial and auxiliary staff members are defined correspondingly.

2. The production technology

A. Technological flow

For making every bamboo product there are more than one manufacturing methods. In designing its technological process the uses of product, the quality of raw material and the conditions of equipment should be taken into account.

All the technological processes narrated in other chapters of this book have their specific features. They can be analyzed and selected. The selected methods should be arranged rationally and in harmony with the concrete conditions. Generally speaking, the selected processes should be adjustable to fit the changing conditions and able to guarantee the normal production when the specifications of products are changed.

The technological design should be accompanied by a detailed description of the technological process. This is important part of design, which expresses the guidelines of the designer. In other chapters of this book all the operations for manufacturing every product are

described, all the technological parameters are listed, which provide the technical basis for designers. Meanwhile designers may consult the designing regulations, experience of advanced manufacturers, documents of technological transfer and exchange.

The technological design should include a technological flow chart, or a technological flow sketch.

B. The calculation of raw material

The amount of raw material consists of: material needed for making products, the processing margin, the technological loss and non-technological loss. Technological loss means shavings and saw dust occurred in mechanical processing, drying shrinkage and the volume decrease under pressure. Non-technological loss means waste product, losses caused by improper storage and transport, unqualified material and other non-technological factors. Most of these losses are not reasonable, but under existing conditions they are not avoidable, consequently, they should be taken into calculation. The results of calculation should be listed in a special table.

C. Equipment, its selection and determination

The equipment of bamboo processing comprises of the machines, installations and facilities used for making bamboo products. They must be durable in production.

The selection and determination of equipment is based on economic and technical analyses, accurate evaluation and comparison. Most of the equipment are manufactured by specialized factories, only a few simple tools can be made by own efforts.

(1) In selecting equipment the reasonableness of machines, their advancement and feasibility should be considered carefully.

a. The productivity of equipment must comply with the production program. The mechanization and automation of processing must be defined on a proper level. A higher working load of equipment must be maintained. It should not be under 55%.

b. The precision of equipment must comply with the technological requirements. It must guarantee the quality of products.

c. Low energy consumption, high utilization ratio of raw materials, easy to service, low maintenance cost.

d. Easy to use, simplified construction and reliable performance.

e. The main machine, auxiliary machines, control instruments and homemade devices should be combined properly.

f. The investment in equipment should be recouped in a short period of time.

All the selected machines and facilities should be listed clearly.

(2) The determination of equipment capacity needed for implementing the production program

For the determination of equipment capacity the productivity of equipment must be known. It can be found in the manuals of machines. The productivity Q (m^3/shift) can be calculated according to the following formula:

$$Q = \frac{T \cdot n \cdot m \cdot S \cdot F}{100 \cdot (Z_1 + Z_2)}$$

T – the time of a shift (min)

n – number of tiers in hot-press

m – number of bamboo sets loaded in every tier

S – thickness of panel (mm)

F – area of bamboo-based panel

Z_1 – pressing time (min)

Z_2 – time of auxiliary operations

The time of auxiliary operations depends on the way of loading.

The capability of equipment G can be calculated according to the following formula:

$$G = \frac{Q_n}{N \cdot R \cdot Q_b}$$

Q_n – annual production force of equipment

N – number of workdays every year

R – number of shifts every day

Q_b – shift production of the equipment

The capacity of equipment calculated in this way is a decimalised number, a margin will be made by turning it into a round number, the load rate of equipment η can be calculated according to the following formula:

$$\eta = \frac{G}{G'} \times 100\%$$

G' – The number of machines expressed in round number.

3. The technological layout of workshops

The technological layout is to dispose all the machines and facilities according to the technological flow; arrange the transportation route of raw material, auxiliary materials, semi-products and finished products; determine the way of ventilation and dust removing; define the area of workshops. It is an important part of technological design, which influences the running of workshop and the management of whole factory. The layout can not be changed easily when its construction is finished. Therefore it is necessary to consider all the related factors, to coordinate the construction, water supply and drainage, steam supply, power supply, ventilation, heating, safety and hygiene.

A. The distribution of equipment

The distribution of equipment must meet the following requirements:

(1) Guarantee the continuous process of production, the distribution of machines and technological pipelines must fit the technological flow, avoid the reverse and crisscross transportation. Minimize the hoist of materials in multistoried workshop and let them flow down automatically from higher location. The distribution of equipment must be conducive to effective operation and successful maintenance.

(2) The machines of one and the same type should be concentrated in one area, which makes the operations and monitoring activities more efficient.

(3) The machines and facilities should be arranged compactly to save the area and space, to guarantee the safety in production, to benefit the installation, examine and repair of equipment. The space between machines and the corridors in workshop should be defined in view of production activities. The space between machines is 1.5 ~ 3.0 m for operating surface, 1.0 ~ 1.2 m for non-operating surface. Space between machines and wall or pillars is 1.5 ~ 2.5 m for operating surface, no less than 0.8 m for non-operating surface. In order to guarantee normal transport and working conditions, a lengthwise corridor no less than 3 m in width should be laid. And a crosswise corridor or overpass should be arranged every 50 m of the main corridor. The key machines should be arranged on one side of the main corridor to guarantee enough space and area for installation and maintenance.

(4) The arrangement of equipment depends on the complexity of technology, number of machines, and the area of workshops. If the technology is simplified and the machines are few, the equipment can be distributed along the central lengthwise corridor in one line. If the machines are more, they can be arranged in two or more lines.

(5) The safety, environment protection and hygiene requirements should be taken into account. Insulation measures should be made against the sound of high-noise machines, these machines may be disposed in separate rooms. Protective covers of axes, transmitting wheels, shaft couplings, transmitting belts and chains should not be neglected, especially those arranged within 2 m over ground surface. The protective covers should be safe and reliable, uniform and durable, easy to install and easy to remove.

(6) The pits in workshop should not be arranged in the area of central corridor or the area of key machines. It is suggested to dispose higher installations on platform, surrounded by protecting rails.

(7) The location of pillars should be considered carefully during the distribution of equipment, otherwise they may obstruct the arrangement of machines and pipelines.

(8) The ventilation and lighting should be taken into account. It is desirable to guarantee the natural ventilation and lighting as much as possible. The key machines and high installations should be located in the central part of the workshop for better ventilation and lighting.

(9) Both the short term objectives and long range plan of production should be studied when the technological layout is compiled. The distribution of equipment should be rational and flexible to fit the future development.

B. Technological layout

The technological layout is of vital importance to the efficient technological process, continuous production, successful operation and maintenance, area of workshop and the investment. The technological layout is worked out in the following steps:

(1) Start the disposition of machines and installations in compliance with the technological process.

(2) Distribute reduced templates of machines and installations on the sketch plan of workshop. It is preferable to design the layout on computers. With the help of CAD (Computer Aided Design) all the calculations, analyses, tables and drawings can be made easily, and the results of design can be revised on screen. It is also possible to compare alternatives with the help of computer. The utilization of computer shortens the cycle of design, reduces the labor intensity of designers, improves the quality of design and cuts the cost.

(3) The arrangement of machines and installations may be carried out in the direction of technological flow, or in the inverse direction.

(4) Main machines are to be arranged first, then the installations of conveyor, transmission, ventilation and dust removing, and other auxiliary appliances.

(5) Several schemes of layout may be worked out for comparison and choice.

(6) The precise location of equipment can be decided after one of the schemes is chosen.

C. The drawings of technological design

In the process of designing a factory of bamboo-based panels it is necessary to work out the technological flow, define the location of machines and installations, the distribution of foundation bolts and pre-determined pits, and the nets of ventilation, dust removing, steam and power supplying. All these decisions are to be shown on specific drawings. These drawings can be divided into two kinds, the first one show only the direction of flow, such as technological flow chart, sketch of air conveying, sketch of ventilation and dust removing. The second kind show the location of machines and installations in the workshop and their relative position, such as plan of equipment distribution, drawings of lengthwise cutaway view and crosswise cutaway view, drawings of distribution of foundation bolts and holes. These drawings must be made in compliance with the rules of cartography. The dimensions, symmetrical center line, axis of transmitting wheel, and the feeding line of machines should be shown on these drawings. They are the basis for civil engineering design, and the installation of machines, and should be made precisely.

(1) Technological flow chart

The technological flow chart is to illustrate the equipment and technological flow by means of uniform symbols and signs.

In the technological flow chart the relative position of machines and devices, and the conveyance of materials are illustrated. Every machine or device is indicated by a number, and with a caption on the margin of the chart, and a brief explanation in case of need.

(2) Plan of equipment distribution

The plan of equipment distribution is a principal drawing of technological design, which illustrates the location of machines and devices and their relative position. For multistoried workshops there must be a plan of equipment for every floor, and the basement and terrace if necessary.

(3) Drawings of lengthwise cutaway view and crosswise cutaway view

The drawings of lengthwise cutaway view and crosswise cutaway view are elevation drawings, which illustrate the space distribution of equipment. The number of such drawings depends on the situation of equipment, they should be able to describe the situation clearly on one hand, and to avoid the overlapping on the other.

(4) Drawings of distribution of foundation bolts and holes

The drawings of distribution of foundation bolts and holes show the location of foundation bolts and the dimensions of holes in accordance with the plan of equipment distribution. These drawings are of great importance for civil engineering and the installation of equipment.

(5) Sketch of ventilation and dust-removing, sketch of pneumatic conveying

These sketches illustrate the net of ventilation and dust-removing, and the net of pneumatic conveyor of materials. In addition, the parameters are also listed.

Section 2. The technological design of ply-bamboo product line with an annual output of 4000 m³

1. Brief account

A. Production scale

- (1) Annual output: 4000 m²
- (2) Specifications of product: 2440 mm x 1220 mm x (10 ~ 30) mm

B. Uses of products

Plybamboo for bottom boards of trucks – 70%

Plybamboo for bus bottom of buses – 30%

C. Work system, number of workers and production organization

- (1) Workdays/year: 280
- (2) Shifts/day: 1 ~ 3
- (3) Effective work time per shift: 7 hours
- (4) Number of workers and production organization: see table 2-20

D. Main quality indexes

Products from this production line meet all the quality requirements cited in Standard LY/T 1055 – 1992 Ply-bamboo for making truck bottom.

2. Technological flow and technical conditions for production

A. Technological flow

The technological flow of ply-bamboo production can be seen in Fig. 2-45.

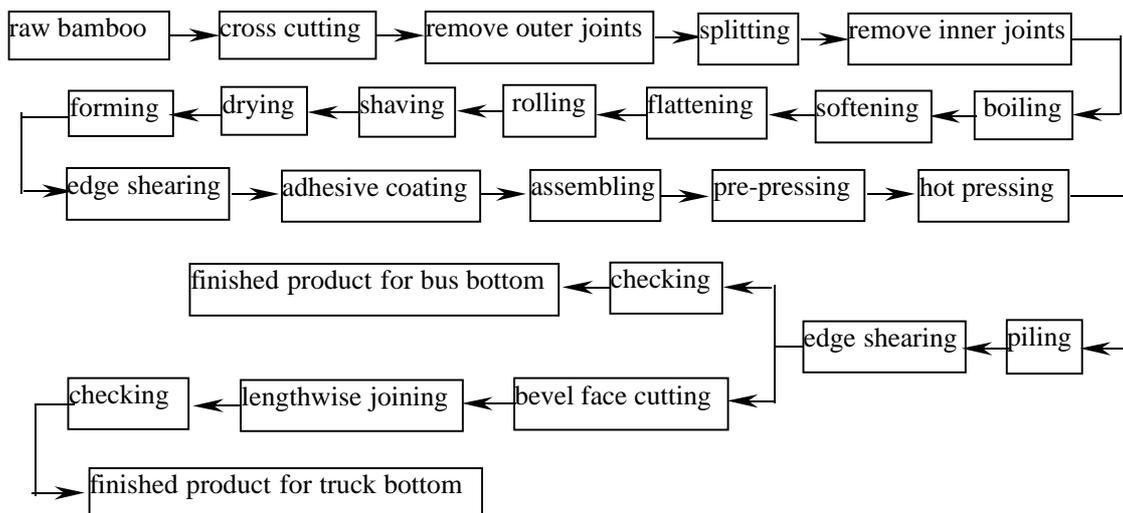


Fig. 2-45: Technological flow sketch of ply-bamboo production

B. Technical conditions for production

(1) Raw material: Raw bamboo must be 4 ~ 5 years of age, with a fresh culm no less than 100 mm in diameter, without insect pest or rottenness. Raw bamboo should be stacked into piles of different diameters. The main passage of the stack ground should not be less than 4 m in width, the pass between piles not less than 1.5 m. the height of piles should not exceed 2 m.

(2) Cross cutting: Cut the bamboo culm into sections according to the required length, the length tolerance should not exceed ± 3 mm. The diameter at small end of sections should not be less than 70 mm.

(3) Remove outer joints: Outer joints must be removed clearly, without any flanges.

(4) Splitting: Split the sections into 2 or 3 fragments. The sections with diameter of 70 ~ 85 mm can be split into 2, those of 85 ~ 120 mm into 3, while those more than 120 mm into 4 fragments.

(5) Remove inner joints: The inner joints must be removed clearly, without any flanges.

(6) Boiling: Put the fragments of same thickness in hanging cages. Lay down the cages in boiling pool for more than 3 hours. The boiling water must overflow bamboo fragments, the water surface must be about 100 mm above fragments.

(7) Softening: The softening temperature is 180 ~ 200°C and the softening time is 4 ~ 5 min.

(8) Flattening: The flattening pressure is 0.6 MPa.

(9) Rolling: After rolling, the height from chord to the arc top on the crosswise section should not exceed 5 ~ 8 mm. There should be more than 3 hair-like cracks within 1 mm of width of the crosswise section.

(10) Shaving: Shave the green face first, then the yellow face. The thickness tolerance after shaving is ± 0.2 mm. The width of residual green striations should be less than 3 mm. The number of green striations under 150 mm in length should not exceed 3 on every fragment. The continuous width of residual yellow striations should not be more than 20 mm, and the length should be less than 50 mm per fragment.

(11) Drying: The temperature of dry bulb in kiln dryer must be 100°C, the difference between dry and wet bulbs be about 10°C. The water content of fragments after drying should be about 12 ~ 15%

(12) Heat setting: The temperature of heat setting is 145 ~ 180°C, exhaust steam once in 2 min. The final water content should be about 8%.

(13) Shaving and edge milling: The clearance between adjacent fragments should not exceed 2 mm after shaving and edge milling.

(14) Adhesive coating: Water soluble phenol resin of 51# is used to coat the fragments of core layer only, the consumption of adhesive is 350 ~ 450 g/m².

(15) Assembling: Assemble the selected fragments for surface, inner and bottom layers in rectangular form complying with the required thickness of product.

(16) Hot pressing: To press the assembled sets, the temperature is 135 ~ 145°C, the pressure is 3.0 ~ 3.5 MPa, the pressing time is 11 min/mm of thickness of the set.

(17) Hot piling: Stack the sets into piles for 24 hours right after pressing.

(18) Edge shearing: Shear the edges according to the dimensions of bus bottom.

(19) Cut out bevel face: For making truck bottom it is necessary to cut out a bevel face on one of the ends of pressed sets for joining in lengthwise direction. The bevel rate is 1:5.

(20) Lengthwise joining: Join 2 bevel-faced sets on worktable and pre-fix them, convey them into pressing-joining machine for hot pressing. The temperature is 130 ~ 140°C, the pressure is 2.5 ~ 3.0 MPa, the pressing time is 1.1 min/mm of thickness of the sets.

(21) Checking: Check the products in compliance with the Standard LY/T 1055 – 1992 *Ply-bamboo for making auto bottom*. Package them and store.

3. The calculation of raw material

The annual output of ply-bamboo is 4000 m³, plus a margin of 10%, calculated output is 4400m³ per year.

A. The basis for calculation

(1) Annual output 4400m³, work shift 1 ~ 3 per day, 280 workdays per year, shift output 5.23 m³.

(2) Specifications: Dimensions: 2440 mm x 1220 mm. Thickness 10 ~ 30 mm, average thickness 15 mm.

(3) Consumption of raw bamboo: 200 culm/m³.

Table 2-20: Product line of ply-bamboo with an annual output 4000 m³, the number of workers and production organization

No.	Operation	1 st shift	2 nd shift	3 rd shift	Subtotal	Notes
1	Check & accept raw bamboo	2	4		6	
2	Cross cutting	4	4		8	
3	Remove outer joints	6	6	6	18	
4	Splitting	2	2	2	6	
5	Remove inner joints	12	12	12	36	
6	Boiling, softening, flattening	5	5	5	15	
7	Rolling	4	4	4	12	
8	Shaving	12	12	12	36	
9	. Drying	4	4	4	12	
10	Forming	4	4	4	12	
11	Edge shearing	9	9	9	27	
12	Sorting, storing	3	3	3	9	
13	Adhesive coating, assembling and pre-pressing	8	8	8	24	
14	Hot pressing	4	4	4	12	
15	Edge shearing	3			3	
16	Mending	3	3	3	9	
17	Bevel face milling	2			2	
18	Lengthwise joining	3			3	
19	Checking, packaging, sorting				8	
20	Adhesive blending	2			2	
21	Mechanist, electrician	3	2	2	7	1 electrician in 1 st shaft
22	Forklift	1			1	
23	Depository	2			2	
24	Auxiliary workers	4	4	4	12	
25	Boiler worker	2	2	2	6	
26	Electrician on duty (power distribution)	2	2	2	12	
27	Driver	1			1	
28	Workshop leader, dispatcher				9	
29	Managerial staff of factory				28	
	Total	107	90	86	332	

(4) The loss of raw material: Cross cutting and splitting: 1%, side milling: 0.5%, shaving and cutting: 10%.

B. The shift workload of every operation

(1) Number of fragments for producing one cubic meter of product (including the losses)

$$P = \frac{g \cdot m \cdot b \cdot k}{z} = \frac{200 \times 4.5 \times 3 \times 0.93}{2.6} = 1159 \text{ (fragments)}$$

Where:

g – number of bamboo culm for producing one cubic meter of product.

m – average length of culm cutting (m).

b – average number of fragments split from one section.

k – utilization ratio.

z – length of fragments.

(2) Shift workload of main operations

a. Softening and flattening

$$P_s = 1159 (1 - 1\%) = 1147 \text{ (fragments)}$$

$$P_s = 1147 \times 5.23 = 5986 \text{ (fragments)}$$

b. Shaving

$$P_p = 1147 \times (1 - 0.5\%) = 1141 \text{ (fragments)}$$

$$P_p = 1141 \times 5.23 = 5934 \text{ (fragments)}$$

c. Edge milling

$$P_m = 1141 \times (1 - 10\%) = 1026 \text{ (fragments)}$$

$$P_m = 1026 \times 5.23 = 5338 \text{ (fragments)}$$

d. Hot pressing

$$P_h = \frac{5.23}{1.22 \times 2.44 \times 0.015} = 117.13 \text{ (sets)}$$

4. The calculation and selection of equipment

a. Softening and flattening

$$Q_s = T \cdot N \cdot K_1 \cdot K_2 \cdot N_1 = 7 \times 60 \times 15 \times 0.8 \times 0.69 \times 2 = 6955.2 \text{ (fragments)}$$

T – work time of a shift (min)

N – number of fragments conveyed per min (fragments)

K_1 – utilization coefficient of work-time

K_2 – comprehensive coefficient

N_1 – number of machines

As $Q_s > P_s$, the equipment is able to meet the production requirements.

b. Shaving

$$P_p = \frac{T \cdot V}{L \cdot I} K_1 \cdot K_2 \cdot K_3 = \frac{7 \times 60 \times 12.6}{2.5 \times 2} \times 0.89 \times 0.90 \times 0.90 = 763 \text{ (fragments)}$$

where:

T – work time of a shift (min)

V – feeding speed (m/min) (middle speed)

K1 – utilization coefficient of work-time

K2 – utilization coefficient of equipment

K3 – coefficient of sliding

L – average length of fragments

I – average times of processing of a fragment

Twelve planers are arranged, $Q_p = 763 \times 12 = 9156$ (fragments)

$Q_p > P_p$, twelve planers are sufficient for meeting the production requirements.

c. Setting

$$Q_s = T \cdot N \cdot K = 7 \times 60 \times 7.3 \times 0.98 = 30059 \text{ (fragments)}$$

T – work time of a shift (min)

N – number of fragments conveyed per min (fragments)

K – comprehensive coefficient

Two machines of hot-setting are arranged, $Q_s = 3005 \times 2 = 6010$ (fragments)

$Q_s > P_s$, two machines of hot-setting are sufficient for meeting the production requirements.

d. Edge shearing and milling

$$P_p \cdot P_m = \frac{T \cdot V}{L \cdot I} \cdot K \cdot K_1 = \frac{7.0 \times 60 \times 30}{2.6 \times 2} \times 0.9 \times 0.7 = 1526.5 \text{ (fragments)}$$

where:

T – work time of a shift

V – feeding speed (m/min) (high speed)

L – average length of fragments

I – average times of processing of a fragment

K – comprehensive coefficient

K_1 – utilization ratio of work time

Three machines of edge shearing are arranged, $Q_{sh} = 1526.5 \times 3 = 4580$ (fragments).

$$Q_m = \frac{T \cdot V}{L \cdot I} \cdot K \cdot K_1 = \frac{7 \times 60 \times 23 \times 0.9 \times 0.7}{2.6 \times 5} = 468 \text{ (fragments)}$$

T – work time of a shift

V – feeding speed (m/min) (high speed)

L – average length of fragments

I – average times of processing of a fragment

K – comprehensive coefficient

K_1 – utilization ratio of work time

Two machines of edge milling are arranged, $Q_m = 2 \times 468 = 936$ (fragments)

$$Q = Q_{sh} + Q_m = 4680 + 936 = 5516 \text{ (fragments)}$$

$Q > P_m$, these machines are sufficient for meeting the production requirements.

e. Hot pressing

=

$$Q_h = \frac{T \cdot N \cdot K \cdot V}{Z} = \frac{7 \times 60 \times 15 \times 0.85 \times 1.22 \times 2.44 \times 0.015}{30} = 7.97 \text{ (m}^3\text{)}$$

T – work time of a shift (min)

N – tiers of hot-press

K – utilization ratio of work time

V – volume of ply-bamboo board (m³)

Z – cycle of hot pressing

The designed shift output is 5.23 m³, therefore the hot-press is sufficient for meeting the production requirements.

Table 2-21 demonstrates the equipment of this product line.

5. The technological layout of workshop

Fig. 2-46 demonstrates the technological layout of the main workshop of this product line.

Section 3. The technological design of bamboo flooring production line with an annual output 100,000 m²

1. Brief account

A. Product specification: length (mm) x width (mm) x thickness (mm)
= 910 x 90 x (12 ~ 18)

B. Color of product

Bleached bamboo flooring, 50%

Dark bamboo flooring (carbonized flooring), 50%

C. Structure of product

Radial-cut bamboo flooring, 50%

Plain-cut bamboo flooring, 50%

D. Work system: Workdays/year: 300, effective work time per shift: 7 hours, shifts/day:
3.

E. Output: Annual output: 100,000 m², shift output: 111m².

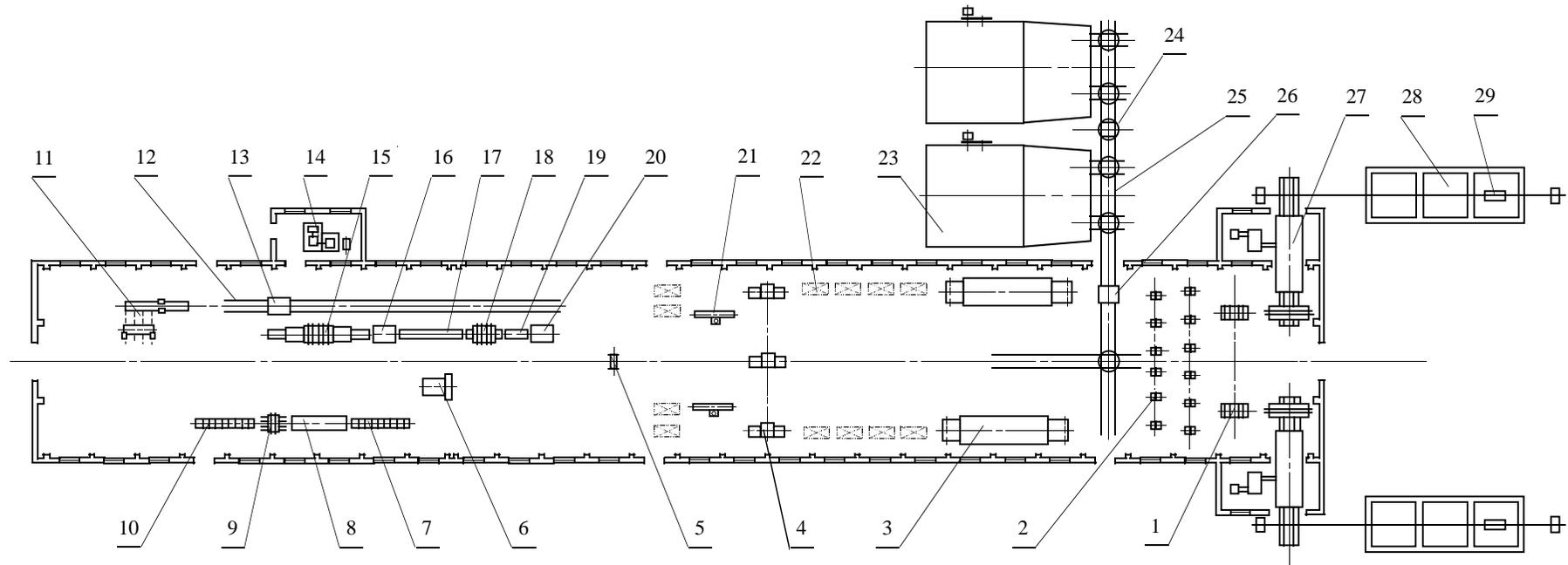
F: Main quality index: Meet the quality requirements stated in Standard LY/T 1573 – 2000 *Bamboo flooring*.

2. Technological flow and production conditions

The technological flow and production conditions are stated in sector 2 of chapter II.

Table 2-21: The equipment of ply-bamboo production line with an annual output of 4000 m²

equipment		electricity	steam		water
item	unit	kw	Pressure Mpa	consumption 10 ⁶ kj/h	ton/h
cross-cutting saw	2	2.2			
outer joint removing machine	6	1.5			
inner joint removing machine	10	0.55			
splitting machine	2	5.5			
electric hoist (3 ton anti blast)	2				
Continuous soften-flattening machine	2	30			
fragment rolling machine	2	11.5			
planer (remove green and yellow matter)	12	5.5			
Kiln drier	2	22.5			
Heat setting machine	2	8	0.5-0.8	1	1
Edge shearing machine	3	11			
Side milling machine	2	3.3			
Adhesive coating machine	1	1.5			
Hydraulic assembling table	1 set	5.5			
Pushcarts and railway	36				
Hydraulic elevator	2	5.5			
Pre-pressing machine and conveyor chain	1 set	19.5			
hot-press and loading, unloading machine	1 set 5 layers	66.5	0.588	1.86	0.8
Edge sawing machine	1	20			
Lengthwise joining machine	1	5.5			
Bevel edge milling machine	1	7.5			
Checking machine	1				
forklift	1				
Dust removing device	4 sets	Total volume 75			
Device for transporting underlying plates	1				



1.Rolling machine. 2. Planer. 3. Heat setting machine. 4. Edge shearing machine. 5. Adhesive-coating machine. 6. Bevel edge milling machine. 7. Conveying table. 8. Elevator. 9. Lengthwise joining machine. 10. Conveying table. 11. Edge cutting saw. 12. Railway. 13. Pushcart. 14. Hydraulic station of hot-press. 15. Hot-press. 16. Elevator. 17. Transporting table. 18. Pre-pressing machine. 19. Transporting table. 20. Elevator. 21. Edge milling machine. 22. Stack ground of semi-products. 23. Kiln dryer. 24. Steering gear. 25. Railway. 26. Pushcart. 27. Softening-flattening machine. 28. Electric hoist.

Fig 2-46: Technological layout of main workshop of ply-bamboo production line with an annual output of 4,000m³

3. Number of workers

Number of workers of this product line: see table 2-22.

Table 2-22: Number of workers of bamboo flooring production line with an annual output 100,000 m².

No.	Operation	Number of workers per shift
1	raw bamboo storage	2
2	cross cutting	3
3	splitting	24
4	rough shaving	10
5	carbonizing, boiling, bleaching.	3
6	drying	4
7	precise shaving	10
8	adhesive coating	2
9	assembling	6
10	hot pressing	4
11	cutting	4
12	abrasive planing	3
13	edge milling	3
14	making lengthwise groove and tenon	3
15	making crosswise groove and tenon	2
16	painting	4
17	checking	2
	total	89

4. Main materials

The consumption of main materials is shown in table 2-23.

Table 2-23. The consumption of main materials

Material	Unit	Amount
Raw bamboo	10,000 culm/year	32
Urea formaldehyde resin (solid content 50%)	ton/year	35
UV paint	ton/year	18

5. Equipment

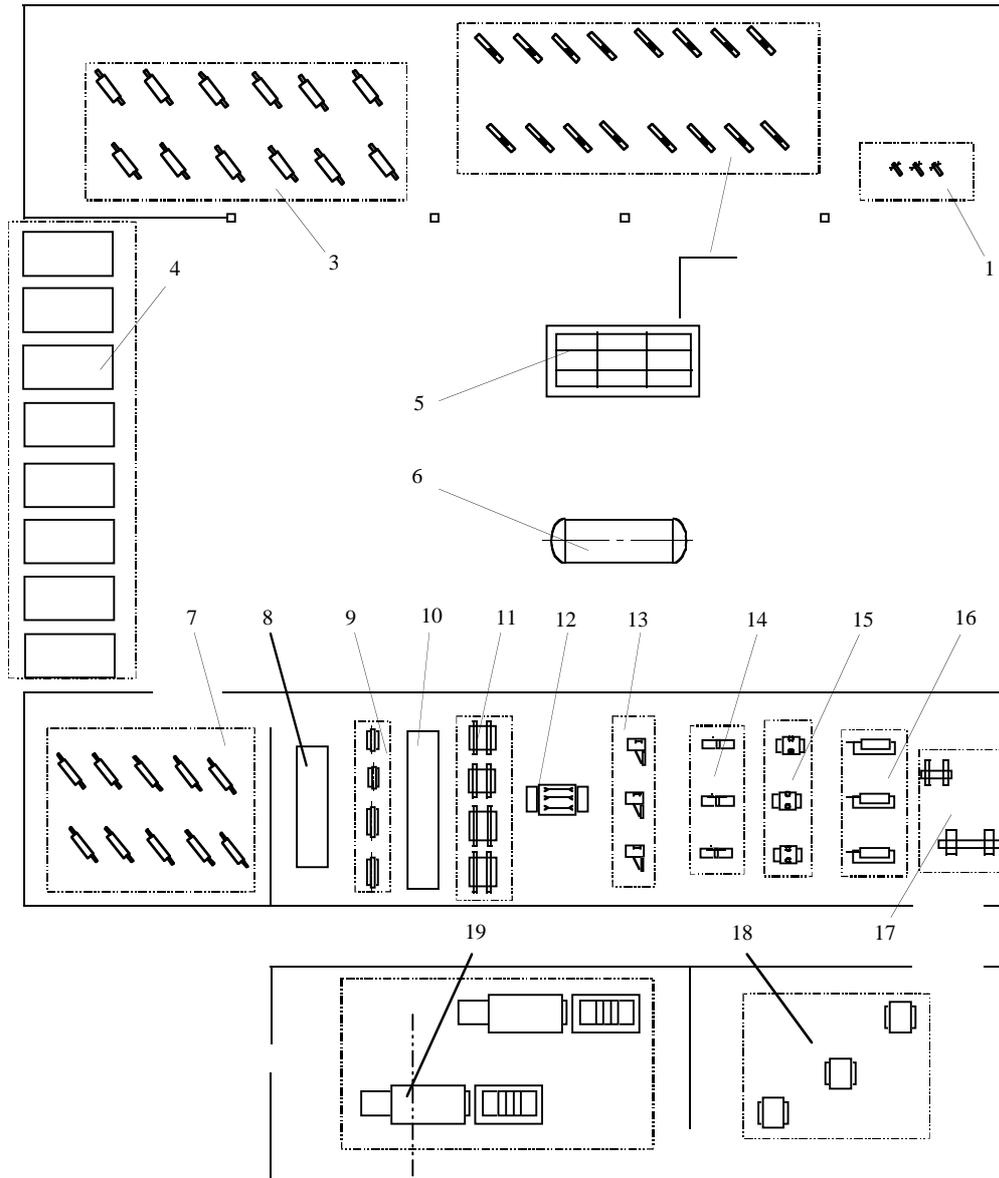
Complete sets of equipment for bamboo flooring production line with an annual output 100.000m² are shown in table 2-24

**Table 2-24 equipment for bamboo flooring production line with an annual output
100.000m²**

No	Item, type	amount	Power kw/unit	Subtotal Power kw
1	Cross cutting machine	3	2.2	6.6
2	splitting machine ZKT-101/135	4	2.2	8.8
3	splitting machine ZKT-101/135/2	2	4.4	8.8
4	splitting machine ZKT-101/225	8	4.4	35.2
5	rough planer ZTCB-101	10	10.4	104
6	Boiler (2 ton)			
7	Single girder truss crane 2 ton span: 9 ~ 12 m			
8	Boiling pool,	1		
9	carbonizer	1		
10	Kiln dryer 20 m ³	8	15	120
11	precise planer ZTJB-101	10	12	120
12	single-tier hot-press SDRY250	2	9.5	19
13	adhesive coating machine 1350	2	1.53.0	
14	single-tier hot-press SDRY500	2	13	36
15	adhesive coating machine 2250	2	1.5	3.0
16	width sawing machine ZQL-101	1	1.5	1.5
17	Single sawing machine MJ-350	3	3	9
18	Planer saw ZSJ-101	3	10.7	32.1
19	Strip shaver ZBG-101	3	10.7	32.1
20	crosswise tenon, grooving saw ZQL-101/200-600	1	8.95	8.95
21	crosswise tenon, grooving saw ZQL-101/600-1200	1	8.95	8.95
22	lengthwise tenon and grooving saw ZQL-101	3	9.6	28.8
23	UV painting and solidifying installation			
24	3-band abrasive planing-sanding machine DHKSG-3	3	12.5	37.5
25	Universal woodworking tool grinder MF2840	1	0.41	0.41
26	centralized dust collector	2	27.5	55

6. Layout of workshop

The layout of workshop is illustrated in Fig. 2-47



1.cross cutting machine. 2. Splitting machine. 3. Rough planer. 4. Kiln dryer. 5. Boiling pool. 6. Carbonizer. 7. Precise planer. 8. Sorting table. 9. Adhesive coating machine. 10. Assembling table. 11. Single tier hot-press. 12. Width sawing machine. 13. Single sawing machine. 14. Planer saw. 15. Strip shaver. 16. Lengthwise tenon and grooving saw. 17. Crosswise tenon and grooving saw. 18. Abrasive planing-sanding machine. 19. UV painting and solidifying installation.

Fig. 2-47: Technological layout of bamboo flooring production line with an annual output 100,000 m²

Section 4. The design of plybamboo production line with an annual output 3000 m³ for making concrete form

1. Brief account

- A. Production scale: 3000 m³/year
- B. Specification: Dimensions: 1220 mm x 2440 mm
 Thickness: 12 mm - 50%, 18 mm - 50%
- C. Work system:
 Workdays/year: 280
 Shifts/day: 1 ~ 3
 Work time/shift: 8 h.
 Effective work time per shift: 7 h.

2. Technological flow and production conditions

The technological flow and production conditions of this design are explained in section 2, chapter 3. (ply-bamboo of curtain-mat)

1. Number of workers

Production workers 74, managerial staff members 7, altogether 81, shown in table 2-25.

Table 2-25: Workers of the ply-bamboo production line with an annual output 3000m³

No	Operation	Shift/day	Person /shift	Total (person)	Notes
1	kiln dryer	3	3	9	
2	adhesive soaking	2	3	6	
3	drying after soaking	2	5	10	
4	assembling, hot pressing	2	5	10	
5	edge shearing	2	5	10	
6	quality checking	1	4	4	
7	examine and repair			4	
8	electrician			4	
9	boiler	2	2	4	
10	electrician on duty	3	1	3	
11	entrance guard	3	1	3	
12	checking and storing	3	1	3	
13	reserves			4	
14	managerial staff	1		7	
total				81	

2. The consumption of main materials and fuel

The consumption of main materials and fuel is shown in table 2-26.

Table 2-26 consumption of main materials and fuel

No	Item	Specification	Unit	Amount	Notes
1	Bamboo mat.	2520 x 1300 x 1.5	piece/year	133800	657.5m ₃
2	Bamboo curtain	1300 x 2500 x 3.5	piece/year	100350	1150.6m ³
		2520 x 1300 x 3.5	piece/year	167250	1917.7m ³
3	Adhesive	Solid content 50%.	ton/year	420	
4	Electricity		10,000 kwh/year	350	
5	Coal		ton/year	1500	
6	Water		ton/year	5000	

3. The selection of equipment

The selection of equipment is based on the annual output 3,000 m³, considering the possible increase of production scale, and a proper margin.

A. Hot-press

According to the production scale, product specifications and technological requirements the hot-press must be able to process the sets 4 feet x 8 feet, the total pressure be 1250 ton, the space between tiers be larger than 120 mm.

In this design:

$$Q = 3000 \text{ m}^3/\text{year} = 3000 / (250 \times 2) \text{ m}^3/\text{shift} = 6 \text{ m}^3/\text{shift}$$

$$T = 7 \times 60 = 420 \text{ min.}$$

$$m = 1$$

$$S = 12 \times 50\% + 18 \times 50\% = 15 \text{ mm (weighted average)}$$

$$F = 2.44 \times 1.22 = 2.98 \text{ m}^2$$

$$Z_1 = (15 \times 1.1) + (45 / 60) + 2 = 19.25 \text{ min}$$

$$Z_2 = 4 \text{ min}$$

Consequently,

$$n = \frac{1000 \cdot Q \cdot (Z_1 + Z_2)}{T \cdot m \cdot s \cdot F} = \frac{1000 \times 6 \times (19.25 + 4)}{420 \times 1 \times 15 \times 2.98} = 7.4 \text{ (tiers)}$$

According to the principle for selection of main equipment, n is fixed at 10. It means the hot-press is of 10 tiers.

B. Band dryer

According to the product specifications the working width of band dryer must be 2.7 m.

The productivity of band dryer Q (m³/shift) can be calculated with the following formula:

$$Q = \frac{T \cdot n \cdot m \cdot s \cdot b \cdot L \cdot K_1 \cdot K_2 \cdot K_3}{Z} \text{ (m}^3/\text{shift)}$$

where:

T – effective work time per shift

n – the number of mats and curtains on every tier

m – the number of tiers

s – the thickness of mats and curtains (m)

b – the width of mats and curtains (m)

K_1 – coefficient, the thickness difference between mats and curtains, usually fixed at 0.95.

K_2 – coefficient, the mats and curtains shrink lengthwise on hot-press, usually fixed at 0.98.

K_3 – coefficient, the effectiveness of work time, usually fixed at 0.98.

Z – time needed for drying mats and curtains of proper thickness (determined according to the technological process)

$$Q = \frac{657.5 + 1150.6 + 1917.7}{250 \times 2} = 7.45 \text{ m}^3/\text{shift}$$

$$T = 7 \times 60 = 420 \text{ min}$$

$$n = 1$$

m = 2 (there are 2 tiers in a hot-press as a rule)

$$s = 1.5 - \frac{657.5}{3725.8} + 3.5 \times \frac{1150.6 + 1917.7}{3725.8} = 3.15(\text{mm}) = 0.00315\text{m} \text{ (weighted average)}$$

$$b = 1.3 \text{ m}$$

$$Z = 4.5 \text{ min (fixed from experience)}$$

Consequently,

$$L = \frac{Q \cdot Z}{T \cdot n \cdot m \cdot s \cdot b \cdot K_1 \cdot K_2 \cdot K_3} = \frac{7.45 \times 4.5}{420 \times 1 \times 2 \times 0.00315 \times 1.3 \times 0.95 \times 0.98 \times 0.98} = 10.68\text{m}$$

In general, the length of a section of a continuous hot-press is 2.26 m, therefore, the number of sections should be $10.68 / 2.26 = 4.73$; accordingly, the hot-press must of 5 sections.

C. Kiln dryer

The production capacity of a kiln dryer is $V \times K$;

V – volume of kiln dryer (m^3)

K – coefficient of piling, fixed at 0.4 usually.

From experience the high-temperature kiln drying time for bamboo mats and curtains is 12 hours.

$$\text{The production capacity of a kiln dryer per day } Q = \frac{V \cdot K \cdot 24}{12}$$

$$\text{In this design } Q = \frac{657.5 + 1150.6 + 1917.7}{250} = 14.9 \text{ m}^3$$

Consequently,

$$V = \frac{12 \times Q}{24 \times 0.4} = \frac{12 \times 14.9}{24 \times 0.4} = 18.625 \text{ m}^3$$

It is possible to select a kiln dryer with a volume of 20 m³.

D. Other items of equipment

The production capacity of lengthwise-crosswise edge cutter and adhesive supplier is sufficient to meet the requirements of this design, but their main features must accord with the specifications of the product. It is optimal to select an edge cutter with a working format of 4 feet x 8 feet, an adhesive supplier with an operation length of 1,3 m.

E. A list of equipment

The list of equipment in this design is shown in table 2-27.

Table 2-27: The equipment for ply-bamboo production line with an annual output 3000 m³

No	Item	Specifications	Amount	Power	Notes
1	kiln dryer	20 m ³	1	25	Heat by stove
2	adhesive supplier.	width 1.3 m	1	3	Can be neglected
3	band dryer.	BG183 (5 sections).	1	45.2.	Steam 1.25 t/h
4	hot-press system	BY114 x 10/120	1 set	44	Steam 2 t/h
5	edge cutter	4 feet x 8 feet	1 set.	25	
6	dust removing device		1 set.	20	

Section 5. The design of bamboo chipboard production line with an annual output 10000 m³

1. Brief account

A. Designed output: 10,000 m³.

B. Product specification: dimensions: 1220 mm x 2440 mm, thickness 10 ~ 30 mm.

C. Work system

Workdays/year: 280; Shifts/day: 1 ~ 3

Number of shift-teams: 4 shift-teams for taking turns.

Work time/shift: 8 h; Effective work time per shift: 7.5 h.

D. Quality indexes of product

The outward appearance, thickness deviation, straightness deviation of edges, bending coefficient and the release of free formaldehyde of product accord with the values defined in GB/T 4897-92, while the rupture modulus, tensile modulus and elastic modulus are 1.5 times higher than those defined in GB/T 4897-92. The density is 850 ~ 1000 kg/m³, the moisture swelling ratio in thickness ≤ 8% (soaked in water for 24 h)

2. Technological flow

The technological flow is shown in Fig. 1-47.

3. Number of workers

Fixed number of persons – 148; number of production workers - 116, number of auxiliary staff - 24, number of technical and administrative staff -8. The details are shown in table 2-28.

Table 2-28: Fixed number of persons for the bamboo chipboard production line with an annual output 10000 m³

No	Operation	Shift/day	Person/shift	Subtotal	Notes
1	chipping	3	5=2+3	20=8+12	12 auxiliary workers
2	shaving	3	4	16	
3	sorting & transporting of industrial shaving	3	3	12	9 auxiliary workers
4	drying & sorting...	3	3	12	
5	adhesive blending & supplying	3	3	12	
6	adhesive mixing	3	3	12	
7	spreading & hot pressing	3	4	16	
8	cooling & edge shearing	3	3	12	
9	packaging & storing	1	4	4	3 auxiliary workers
10	transporting in workshop	3	2	8	
11	checking..	3	1	4	
12	tool & cutter grinding	3	1	4	
13	machinist & electrician.			8	
total				148	24 auxiliary workers

4. Main technological conditions

Main technological conditions are shown in table 2-29.

Table 2-29: Main technological conditions for producing bamboo chipboard

No	Operation	Technological indexes
1	Accepting raw bamboo	More than 3 years of age, without rottenness and moulds. moisture content 40 ~ 60%
2	chip cutting	15 ~ 25 mm in length, 8 ~ 12 mm in width
3	shaving	Less than 25 mm in length, and 3 mm in width, 0.5 mm in thickness, saw dust < 10%
4	drying	Absolute water content 2 ~ 8%
5	dried shavings storing	Storing time should not exceed 2 h
6	adhesive using	Phenol resin 9 ~ 12%
7	spreading	The density deviation of board blank should be within $\pm 15\%$. The blank must be uniform, without agglomerating
8	pre-pressing	The link pressure is 100 ~ 150 kg/cm; the compressing rate is 30 ~ 50%. The link speed of pre-pressing accords with the cycle of hot pressing.
9	crosswise cutting	The length is 2500 mm; lengthwise edges must be paralleled, and the format must be rectangular
10	hot pressing	Temperature 180 ~ 200°C; unit pressure 3.5 ~ 4.5 Mpa. Pressing time 0.3 ~ 0.7 min/mm of thickness of finished product.

5. The calculation of main materials

A. Bamboo material

The consumption of bamboo shavings for making a piece of bamboo chipboard 1220 mm x 2440 mm x 12 mm is G_0 , when the water content of shavings is 5%.

The shavings used for inner layers is G_{01}

$$G_{01} = \frac{0.9 \times 127 \times 250 \times (1.2 - 0.15 \times 2) \times (100 + 5)}{10 \times (100 + 8) \times (100 + 9)} = 22.94 = 23 \text{ kg}$$

The shavings used for surface layers is G_{02}

$$G_{02} = \frac{1.0 \times 127 \times 250 \times 0.15 \times 2 \times (100 + 5)}{10 \times (100 + 8) \times (100 + 9)} = 8.2 \text{ kg}$$

$$G_0 = G_{01} + G_{02} = 23 + 8.2 = 31.2 \text{ kg.}$$

n - number of finished boards (pieces) of the format 1220 mm x 2440 mm x 12 mm from the product of one m^3 .

$$n = \frac{1000000}{12^2 \times 244 \times 1.2} = 27.99 = 28 \text{ pieces}$$

G_1 - the amount of shavings needed for manufacturing one m^3 of product.

$$G_1 = G_0 \times n = 31.2 \times 28 = 873.6 \text{ kg.}$$

G_2 – the weight of raw bamboo with water content 50% needed for manufacturing one m^3 of product.

$$G_2 = G_1 \times (1 + 50\%) = 873.6 \times 1.5 = 1310.4 \text{ kg.}$$

G_3 – the weight of raw bamboo with water content 50% needed for manufacturing one m^3 of product, including technological and non-technological loss, which is fixed at 20%.

$$G_3 = G_2 \times (1 + 20\%) = 1572.5 \text{ kg.}$$

G – the weight of raw bamboo needed for manufacturing 10,000 m^3 of bamboo chipboard.

$$G = 1572.5 \times 10000/1000 = 15725 \text{ ton.}$$

B. Phenol resin

For making a piece of bamboo chipboard 31.2 kg of bamboo shavings with water content 5% is needed. The amount of adhesive used is 10%, with solid content 50%.

G_0 – amount of phenol resin needed for making a piece of bamboo chipboard.

$$G_0 = \frac{10\% \times 31.2}{50\% \times (1 + 5\%)} = 5.9 \text{ kg}$$

G_1 – amount of phenol resin needed for making one m^3 of bamboo chipboard.

$$G_1 = G_0 \times 28 = 5.9 \times 28 = 165.2 \text{ kg.}$$

G_2 – amount of phenol resin needed for making 10000 m^3 of bamboo chipboard

$$G_2 = 10000 \times 165.2 / 1000 = 1652 \text{ ton.}$$

6. Main technological indexes

The main technological and economic indexes are shown in table 2-30.

7. The selection of equipment

The complete sets of equipment for bamboo chipboard production line with an annual output 10000 m^3 are shown in table 2-29.

A. Chipping machine

The rated production capacity of a chipping machine $A = 2 \sim 3$ t/h, fixed at 2.5t/h.

The operating time of a machine per year $T = 280 \times 3 \times 7.5 = 6300$ h.

The production capacity of a machine per year $A = 2.5 \times 6300 = 15750$ t.

Table 2-30: Main technological and economic indexes of bamboo chipboard production line with an annual output 10000 m³

No	Item	Unit	Index	Note
1	Output	m ³	10000	
2	raw material			
	1. raw bamboo.	ton	10000 ~ 15725	
	2. industrial shavings	ton	5725 ~ 0	
3	phenol resin	ton	1652	
4	steam for drying	ton/h	1.5 ~ 2.0	1.0 ~ 1.2 MPa
5	water..	ton/h	8 ~ 12	
6	electricity	kwh/m ³	176	

The amount of raw material needed for manufacturing 10000 m³ is:

$$Q_{\min} = 10000 \text{ t.}$$

$$Q_{\max} = 15725 \text{ t.}$$

The maximum work load of a chipping machine is:

$$\eta = \frac{Q_{\max}}{A} \times 100\% = \frac{15725}{15750} = 99\%$$

B. Shaving machine

The rated production capacity of a shaving machine $a = 2 \sim 3$ t/h, fixed at 2.5t/h.

The operating time of a machine per year $T = 280 \times 3 \times 7.5 = 6300$ h.

The amount of raw bamboo processing for making a cubic meter of bamboo chipboard (the technological loss of this operation is fixed at 5%):

$$Q_{\min} = 10000 \times (1 - 5\%) = 9500 \text{ t.}$$

$$Q_{\max} = 15725 \times (1 - 5\%) = 14939 \text{ t.}$$

One shaving machine is arranged, The maximum work load of the shaving machine is:

$$\eta = \frac{Q_{\max}}{A} \times 100\% = 95\%$$

C. Rotary dryer

The rated production capacity of a rotary dryer $a = 2.5$ t/h.

The operating time of a dryer per year $T = 280 \times 3 \times 7.5 = 6300$ h.

The production capacity of a dryer per year $A = a \times T = 2.5 \times 6300 = 15750$ t.

The amount of bamboo shaving processing for making a cubic meter of bamboo chipboard (the technological loss of this operation is fixed at 5%):

$$Q = 14939 \times (1 - 5\%) = 14192 \text{ t/year}$$

One rotary dryer is arranged. the work load of the dryer:

$$\eta = \frac{Q}{A} = \frac{14192}{15750} \times 100\% = 90\% .$$

D. Vibrating sieve

The rated production capacity of a vibrating sieve $a = 20 \text{ m}^3/\text{h}$.

The weight of bamboo shavings of a cubic meter is fixed at 120 kg,

$$a = 120 \times 20 = 2400 \text{ kg} = 2.4 \text{ t/h}.$$

The operating time of a sieve per year $T = 280 \times 3 \times 7.5 = 6300 \text{ h}$.

The production capacity of a sieve per year $A = 2.4 \times 6300 = 15120 \text{ t}$.

The amount of bamboo shavings vibrating for making 10000 m^3 of bamboo chipboard (the technological loss of this operation is fixed at 2%):

$$Q = 14192 \times (1 - 2\%) = 13908 \text{ t/y}.$$

$$\eta = \frac{Q}{A} \times 100\% = \frac{13908}{15120} \times 100\% = 92\%$$

E. Spreading machine

Rated production capacity:

Speed of belt: $V = 1.5 \sim 2.5 \text{ m/min}$, fixed at 2 m/min .

Speed per hour: $V_0 = 2 \times 60 = 120 \text{ m/h}$

The length of spreading a board blank is:

$$L = 2.44 + 0.06 + 0.004 = 2.504 \text{ m}.$$

The number of blanks spread n

$$n = \frac{120}{2.504} = 48 \text{ blanks / h}.$$

The operating time of spreading machine per year $T = 280 \times 3 \times 7.5 = 6300 \text{ h}$.

The production capacity of spreading machine per year $A = 48 \times 6300 = 302400$ blanks.

The number of blank ξ ks (4 feet x 8 feet) spread per year M :

$$M = 10000 \times 28 = 280000 \text{ blanks}.$$

Select one spreading machine, its work load η

$$\eta = \frac{280000}{302400} \times 100\% = 93\%$$

F. Hot press

Select a hot press of 7 tiers, with working format 4 feet x 8 feet.

The calculation of production capacity:

Time for loading: $t_1 = 2 \text{ min}$

Time for closing platens: $t_2 = 1$ min

Time of high pressure and temperature: $t_3 = 1/6 \times (h + 1) \times (0.3 \sim 0.7)$ min

Time of medium pressure and temperature: $t_4 = 1/3 \times (h + 1) \times (0.3 \sim 0.7)$ min

Time for unloading: $t_5 = 1/5 \times (h + 1) \times (0.3 \sim 0.7)$ min

h – thickness of finished board, fixed at 12 mm, (0.3~ 0.7) fixed at 0.5 min.

$$t_3 = 1/6 \times (h + 1) \times 0.5 = 1.08 = 1.1 \text{ min}$$

$$t_4 = 1/3 \times (h + 1) \times 0.5 = 2.16 = 2.2 \text{ min}$$

$$t_5 = 1/5 \times (h + 1) \times 0.5 = 1.3 \text{ min}$$

Time for opening the hot press: $t_6 = 0.5$ min

Hot pressing cycle:

$$t =: t_1 + t_2 + t_3 + t_4 + t_5 + t_6 = 2 + 1 + 1.1 + 2.2 + 1.3 + 0.5 = 8.1 \text{ min}$$

The number of hot pressing cycles per year n

$$n = \frac{280 \times 3 \times 7.5 \times 60 \times 0.98}{8.1} = 45733 \text{ cycles/year.}$$

The amount of bamboo chipboard (4 feet x 8 feet, thickness 12 mm) pressed per cycle: $g = 1.22 \times 2.44 \times 0.012 \times 7 = 0.25 \text{ m}^3/\text{cycle}$

The reject rate is fixed at 5%, the annual production capacity of hot press Q :

$$Q = n \cdot g \cdot (1 - 5\%) = 45733 \times 0.25 \times (1 - 5\%) = 10861.6 \text{ m}^3$$

The designed production scale is 10000 m^3 , the production capacity of hot press is 10861.6 m^3 . The work load is:

$$\eta = \frac{10000}{10861.6} \times 100\% = 92\%$$

**Table 2-31: Equipment of bamboo chipboard production line
with an annual output 10000 m³**

No	Item.	Specification	Amount	Power (kwh)	Notes
1	belt conveyer	width B ≈ 300 mm; length L ≈ 20 m; link speed V ≈ 5m/min	1.	6	
2	metal detector	dimension of probe: 800mm x 600 mm			
3	chipper		1	45.5	
4	pneumatic conveyer		1	20	
5	chip loft	60 m ³	1	1.5	
6	gauging conveyer. screw		1	2.2	
7	shaving machine.		1	30	
8	pneumatic conveyer		1	20	
9	Depository of wet shavings		3	12.5	1 for shavings, 1 for inner layer, 1 for surface layer
10	rotary dryer		1	30	With a dust & moisture removing system
11	rationing depository		2	8.2	1 for inner layer, 1 for surface layers
12	adhesive mixer		2	37	1 for inner layer, 1 for surface layers
13	adhesive blending		1	10	Including an supply system of emulsifier
14	adhesive container	6 m ³	1		
15	electric hoister	1 ton, 18 m	1	1.5	
16	belt conveyer	L = 11 m	1	7.5	
17	Spreading machine		1	15	
18	Pre-pressing machine		1	11	
19	Crosswise cutter		1	5.2	
20	Disintegrating machine of mat edges.		1	2.2	
21	Pneumatic conveyer		1	20	
22	accelerated conveyer of assembled sets.		1	15	
23	loading machine		1	15	
24	hot press		1	51.5	
25	exhausting cover of hot press		1		
26	unloading machine		1	15	
27	conveyor of pressed. sets		1	1.5	
28	table for moving pressed sets		1	1.5	
29	lengthwise cutter		1	19	
30	Turning table		1	3.3	
31	Crosswise cutter		1	17	
32	hydraulic elevator		1	3	
33	cooling device			7.5	
34	forklift	3 ton			
35	Oil heater			2.5	
	total		36	432.4	

PART III. Bamboo articles for daily uses, bamboo carbon

The utilization of bamboo has a long history of thousands of years. Bamboo articles of daily use are of most long standing, they are widely used at present. Main bamboo articles manufactured in industrial scales are bamboo furniture, bamboo mats, bamboo chopsticks and bamboo slips.

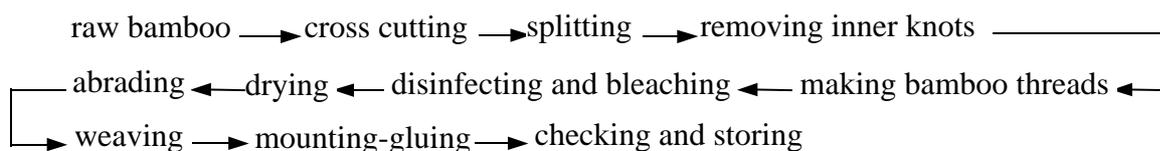
Chapter 1. Bamboo mats

Bamboo mats are produced in all the southern provinces of China in great scales. The most famous of them are those manufactured in Yiyang County of Hunan Province, and Shucheng County of Anhui Province. These mats are made of *Phyllostachys heteroclada*. The knots of *Ph. heteroclada* are plain, and the fiber is fine. More than 16 thin threads can be arranged in a space of 3 cm, sometimes 32 threads. The mats are smooth, brilliant and cool, of harmonious color. They were widely used as early as five hundred years ago, in Ming Dynasty. By means of various methods of weaving, many designs can be expressed on mats. Thanks to the excellent workmanship, better ones of the mats can be regarded as fine handicrafts, highly appraised by experts and users. But these mats were made manually, their production could hardly be industrialized. In recent years the production of some of the mats are mechanized.

Section 1. Mats of fine threads

Bamboo mats of fine threads are made in the following way: thread making, high temperature boiling, disinfecting and bleaching, mechanical weaving, mounting-gluing, hot pressing and edge processing. According to the quality of raw material, the mats can be divided into categories of “original green”, “first green”, “second green”, “colored threads”, “painted threads” and “spun threads”. They can be applied to cover pillows, beds, cushions of easy chairs and auto seats.

The technological flow for making mats is as follows:



1. Cross cutting

Mats of fine threads are made of *Phyllostachys pubescens* of required dimensions, proper thickness and proper width, which meet the quality requirements and raise the utilization ratio of raw material in industrialized production. In order to guarantee the quality of products, the raw bamboo must be more than 4 years of age. Withered, deformed and mildewed ones should be rejected.

Bamboo culm is cut with a circular saw. Cut off the irregular tip at first, then cut a section from the root part to make floorboard for more efficient utilization of raw material, because the culm wall of this part is thicker. Cut the sections according to the dimensions of final product, with a margin of about 10 cm.

2. Splitting

Bamboo sections are split into fragments of certain width in the direction of bamboo fiber, this operation can be implemented manually or mechanically from the small end. The number of knives on splitting head is decided by the width of fragments. The number of knives can not be changed automatically in operation, therefore, the width of fragments split by one and the same splitting head from culms of different diameter is different. The outward appearance of splitting machine is shown in fig. 3-1a and the operation in fig. 3-1b.



Fig. 3-1a: Bamboo splitting machine



Fig. 3-1b: Split bamboo culm on machine

3. Joints removing and cleaving

The joints on bamboo fragments are to be removed, and then to be cleaved into strips of proper thickness. The fragments are fed into removing and cleaving machine with the yellow face upwardly. The number of strips cleaved from a fragment is decided by the thickness of culm wall. Cleave a fragment into a green strip and a yellow strip, if the yellow strip is quite thick, it can be cleaved further into two strips.

The removing and cleaving machine is shown in fig. 3-2a and fig. 3-2b.



Fig. 3-2a: The outward appearance of removing and cleaving machine



Fig. 3-2b: Cut the fragments on removing and cleaving machine

4. Bamboo thread making

The strips are cut into bamboo threads on a threading machine shown in fig. 3-3. As one of the surfaces of strips is quite rough, a knife is arranged to smooth it before the thread cutting. The width of threads is 4.5 ~ 5 mm, and the thickness is 2 mm.



Fig. 3-3: cut into bamboo threads on a threading machine

5. Disinfecting and bleaching

The threads must be disinfected and bleached. This is an important link for protecting bamboo material and raising the quality of products. Raw bamboo plants grown under different conditions, transported and stored in different circumstances, have different colors. As bamboo material contains starch, protein and other kinds of nutrients, it is apt to be attacked by moulds and insects. In order to guarantee the quality of products, bamboo material must be treated against moulds. In general they are treated with hydrogen peroxide solution (H_2O_2). This solution possesses certain oxidizing and reducing abilities. It is a strong oxidizer in both acid and alkaline media, and also functions as a reducing agent when mixed with stronger oxidizer. By means of such features this solution delignificates bamboo material partly and extracts starch, protein and other nutrients it, thereby bleaching the surface of bamboo.

For the sake of better bleaching effect it is recommended to add some additive, such as sodium hydroxide or sodium phosphate. The amount of additive is about 0.5 ~ 1% of the total solution. The time of treatment depends on the temperature and the composition of solution. In general the industrial H_2O_2 with a concentration of 36% should be diluted to 5 ~ 10%, and heated to 70°C for bamboo thread treatment.

The hydrogen peroxide bleaching solution can be used repeatedly, adding proper amount of H_2O_2 . But the solution must be replaced when it turns red.

6. Drying

The water content of disinfected-bleached bamboo threads is quite high, it should be reduced to 10 ~ 12% by means of artificial drying. In general they are dried in kilns heated by burning processing wastes. In order to economize on energy resource and shorten the time of drying, it is possible to combine the kiln drying with air-drying.

7. Sanding

In order to the surface quality of products, the dried threads should be sanded on sanding machine.

The sanded threads are to be sorted, and the fined ones are to be used for weaving.

8. Weaving

The weaving operation is carried out on special weaving machine, which is shown in fig. 3-4. For weaving a bamboo mat the sorted bamboo threads are used as wefts and nylon or cotton strings as warps. The nylon or cotton strings are made of threads before weaving on special reels.



Fig. 3-4: Bamboo-mat weaving machine

9. Lining clothing

The back of woven mats is to be coated with adhesive, assembled together with lining cloth, and treated in a hot press. The adhesive will be solidified after hot pressing, the mat will be connected closely with lining cloth. This operation prevents the deformation of mats in use, and improves its value (see fig. 3-5).



Fig. 3-5: Lining clothing

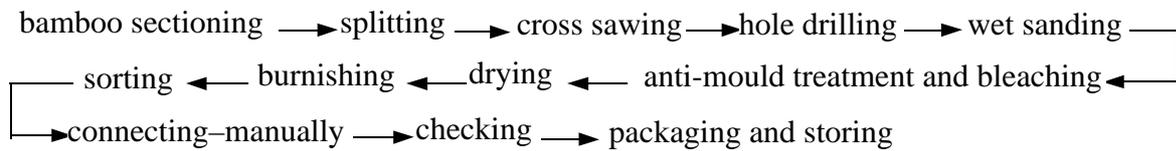
The adhesive used for lining clothing is urea formaldehyde resin, the strength of hot pressing is about 0.5 ~ 0.8 Mpa, the temperature is 110°C, and the pressing time 5 ~ 8 sec.

10. Cutting and edge blocking

The woven semi-products are to be cut according to the size of final products, and to be edged with special belts. After checking, packaging the final products is to be stored.

Section 2. Domino mats

Domino mats are newly developed commodity in recent years. Bamboo material is cut into small hollow pieces of pre-determined size like domino. Along with bleaching and sanding, they are to be treated with anti-pest and anti-mould chemicals. The treated domino pieces are connected together with nylon strings of high toughness. Domino mats are well aerated and durable. According to the requirements of users, domino mats can be made to cover pillows, chairs and car seats. The manufacturing process of domino mats is as follows:



1. Bamboo sectioning

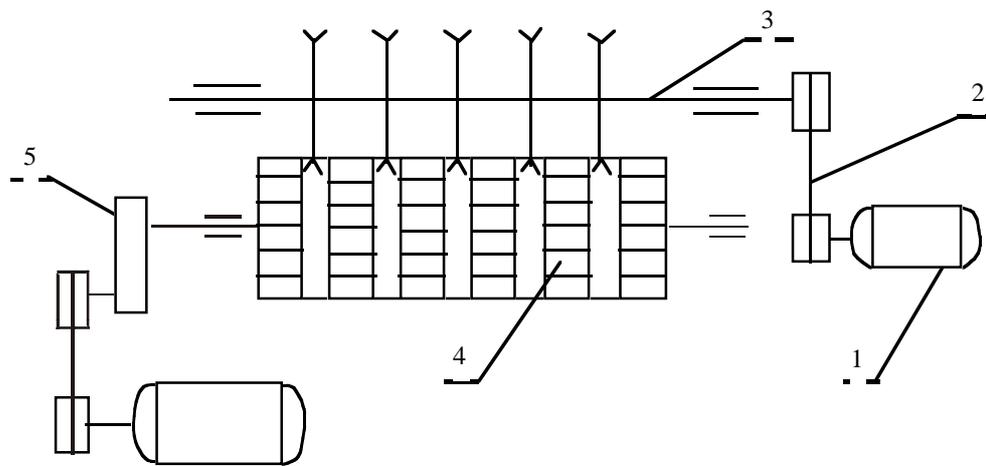
Domino mats are made of small bamboo pieces of similar color and appearance. In sectioning the joint parts should be eliminated, and only the parts of straight grain be selected.

2. Splitting

Selected bamboo sections are to be split into two fragments, then the semi-circular fragments into base belts, with three faces sanded, but the green face not processed. The thickness of base belts is decided according to the size of final products. It can be 7mm, 6mm or 5mm. The thickness of smaller pieces can be less than that of larger ones. But the manufacturing process of mats of smaller pieces is more laborious. The base belts are processed on cutting machines. In order to process two radial faces and yellow face, two sets of knives are arranged, one for rough processing and the other for precise processing, which make the base belts more fine.

3. Cross sawing

The base belts are to be processed on special drum sawing machines of continuous operation. The principle of sawing machine is shown in Fig. 3-6. In order to make the sawn faces more smooth, the saw-teeth should be sharp, and the speed of operation should be high.

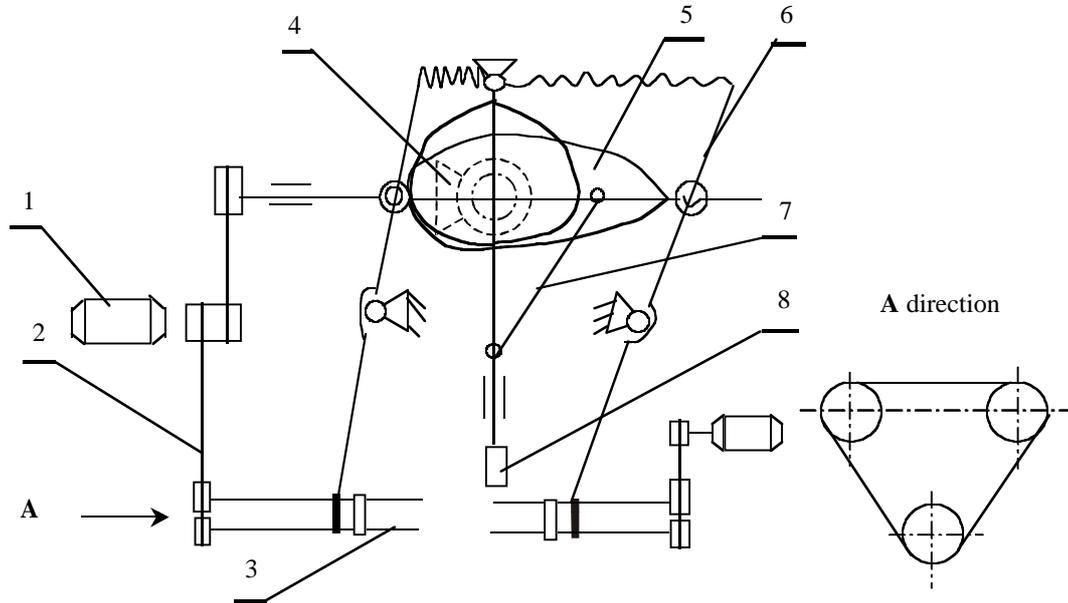


1. Electrical machine. 2. Transmission belt. 3. Saw blades. 4. Feeding roll. 5. Retarder.

Fig. 3-6: The principle of operation of cross sawing machine

4. Hole drilling

Two parallel holes of $\Phi 2.5\text{mm}$ should be bored through every domino piece along the grain direction. This operation can be done with a special double-bit driller, which is shown in fig. 3-7. Holes along grain direction can be made easily. The distance between holes depends on the size of domino piece.



1.electrical machine. 2. Transmission belt. 3. Bit set. 4. Awl gear.
5. Cam set. 6. Folding levers. 7. Crank and slide mechanism. 8. Feeding tongue.

Fig. 3-7 The operation principle of driller

In order to reduce the weight of mats and improve their ventilating capacity, some manufacturers use special circular saw to make cavities on both sides of domino piece.

5. Wet sanding

The drilled domino pieces are to be sand in a wet sanding roller together with abrasives, thereby the silicon matter from green face and the burs from other faces will be removed. The first step is rough sanding and the second is fine sanding. For the first step sand and stone flour are added, after 3 ~ 5 hours of sanding the abrasives should be removed. The rough sanded domino pieces are to be washed, and sanded further by rubbing each other with water (see fig. 3-8).



Fig.3-8. Wet sanding machine

The sanding time for domino pieces of fresh raw material is shorter and the result is better. Therefore it is necessary to keep the humidity of bamboo material.

6. Anti-mould treatment and bleaching

Domino pieces are treated with hydrogen peroxide solution generally. The operation is the same as that for making mats of fine threads.

7. Drying

The water content of treated domino pieces is quite high, it must be reduced to 8% ~ 10% by drying.

8. Burnishing

The dried domino pieces are to be burnished in a burnishing cylinder by means of mutual friction, and talcum powder can be added to improve the burnishing effect. The burnishing time is 6 ~ 8 hours.

The operation principle of burnishing cylinder is the same as that of sanding machine.

9. Sorting

The burnished domino pieces are to be sorted manually according to their color and processing quality. The qualified pieces are applied to make domino mats of high grade.

10. Connecting manually

The sorted domino pieces are to be threaded on strings $\Phi > 0.6\text{mm}$ of polyamide fiber to make domino belt, and the belts to be linked with PVC strings to form domino mats. The pulling strength of a single polyamide fiber string is not less than 40 N, while that of a single PVC string is not less than 80 N. The size of domino mats are shown in table 3-1.

Table 3-1: The size of domino mats (mm)

Length	Width
1900	900, 100, 1200, 1300
1920	1300, 1350, 1400, 1500

The tolerance of length is less than 12 mm, that of width less than 8 mm. The knots of strings should not be appeared on the surface of domino mats, and the space between domino pieces should not exceed 4 mm.

The mats are to be checked one by one, and then stored.

Chapter 2. Bamboo chopsticks

Chopsticks are in indispensable item of oriental tableware. Bamboo chopsticks are widely used. The demand for bamboo chopsticks is high both in China and abroad. .

1. Double sanitary chopsticks

Double sanitary chopsticks are the most popular ones at present.

A. Size

The cross section of the upper part of double sanitary chopsticks is oval. The length of ordinary chopsticks is 21 cm and 24 cm. that for children is 18 cm. The size of upper part is 14 mm x 7 mm. The lower end is 35 mm x Φ 3 mm

B. Manufacturing process

Cross cutting → splitting → side-cutting → chopstick shaping → sharpening → storing
 ← checking ← sanding ← drying ← bleaching ←

(1) Cross cutting

Double sanitary chopsticks must be made of bamboo material without knots, and the thickness of culm wall about 10 mm. Therefore the raw bamboo should be cut into bamboo sections according to these requirements.

(2) Splitting

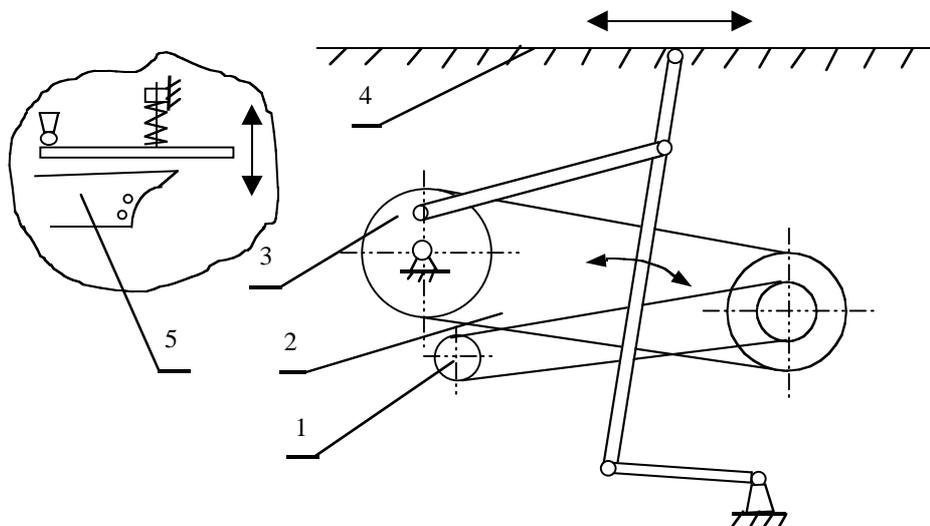
Bamboo sections are to be split into two semicircular fragments. It is suggested to split the section from the end where the culm wall is thinner, thus the split operation will be easier. While the length between knots is larger than the required length, it is better to take the upper part to avoid the groove-like defects.

(3) Side-cutting

Bamboo fragments are to be cut, on a special side-cutting machine, into pieces with green and yellow matter removed, 14 mm in width and 7 mm in thickness.

(4) Chopstick shaping

This operation is carried out on a special shaping machine. The work principle of shaping machine is shown in fig. 3-9a, and its appearance is in fig. 3-9b. Bamboo pieces are shaped by means of semicircular knives on shaping machine.



1. Electrical machine. 2. Transmission belt. 3. Crank and rocker mechanism.
 4. Sliding block. 5. Knife with adjusting device.

Fig. 3-9a: Work principle of shaping machine



Fig. 3-9b: Chopstick shaping machine

(5) Sharpening

Chopsticks are sharpened on special sharpening machine of continuous operation, the sharpness can be regulated on the machine. It is shown in fig. 3-10.



Fig. 3-10: Chopstick sharpening machine

(6) Bleaching

Chopsticks are bleached using hydrogen peroxide solution of density 9%, or using sodium sulfite solution of density 8 ~ 14%, treated for 48 h under normal atmospheric temperature. As a result of bleaching the color of chopsticks is harmonized, and the insect and fungus damages prevented.

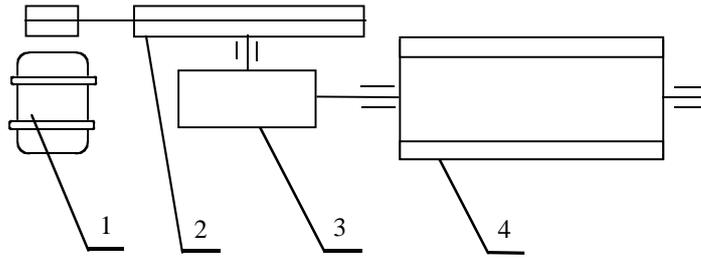
(7) Drying

In order to prevent mould damage occurring in the process of storage and transport, the water content of chopsticks should be reduced to 10 ~ 12%. They could be dried in drying kilns, at the beginning the temperature of drying media could be higher, then lowered gradually and fixed at 80° C for 12 h.

(8) Sanding

Dried chopsticks are to be sanded in a sanding cylinder by means of mutual friction between chopsticks to remove burrs.

The work principle of sanding is shown in fig. 3-11. For improving the sanding effect talcum powder can be added in the process of operation. The sanding time is more than 1 h. Sanded chopsticks are to be sorted, packaged and stored.



1.Electrical machine. 2. Transmission belt. 3. Retarder. 4.Cylinder

Fig. 3-11: Work principle of sanding cylinder

2. Yuanlu chopsticks

Yuanlu are of higher grade than ordinary double sanitary chopsticks. The cross section of their upper part is rectangular 8 mm x 5 mm. The length of yuanlu chopsticks is 240 mm and 210 mm.

Yuanlu chopsticks are shaped on special machine. The processing requirements are higher.

3. Edge-cut chopsticks

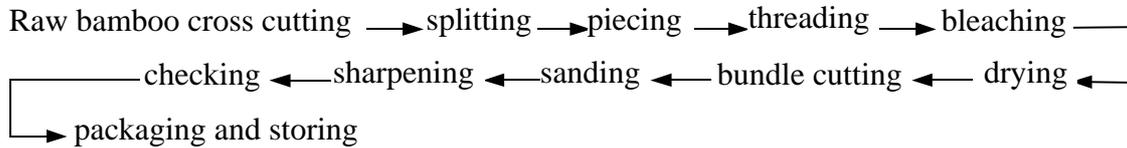
Edge-cut chopsticks are made in the same way as that of yuanlu, the only difference is the upper end is cut slantingly in an angle of 45° to form a sharp edge, which helps the user to blend mustard when eating sashimi.

The edge is cut on a special machine with a knife-disc rotating on high speed. The half of upper end of chopsticks can be cut rapidly.

There are many kinds of chopsticks, some of them are in novel style, or of brilliant color, and be used as ornamental articles.

Chapter 3. Bamboo slips

Toothpicks, meat skewers and flower are of different uses, but they are of similar shape, with one or two pointed ends, and are made in similar way. The process of making toothpick is an example.



1. Raw bamboo cross cutting

There are no special requirements concerning the diameter of raw bamboo and the thickness of bamboo culm wall for making toothpicks. In general, tip of *Phyllostachys pubescens* is used for this purpose. For the convenient further processing tips are cut into pieces 140 mm in length. Material with knots is acceptable.

2. Splitting

There are no special requirements concerning the width of bamboo pieces for making toothpicks, but they should be smooth and leveled. The width of pieces depends on the number of threads from them for making toothpicks. As the diameter of toothpicks is insignificant, bamboo pieces should not be too wide.

3. Piecing

The thickness of bamboo pieces for making toothpicks is about 2.8 ~ 3 mm, the number of pieces depends on the thickness of bamboo culm wall. In general green pieces are cut at first, they can be threaded directly. If yellow pieces are too thick, they can be cut into two before threading.

4. Threading

Bamboo pieces are to be threaded into needles 1.8 mm in diameter. During threading the location of upper and bottom knives must be adjusted strictly, without any dislocation or gap. The number of needles depends on the form of knife set, 6 ~ 10 in general.

5. Bleaching

Needles are to be bleached to prevent mould or insect pest. Before bleaching they should be kept in clean water for avoiding color-change.

As a rule needles are soaked in hydrogen peroxide solution 9 ~ 13% of density. The solution can be heated or not heated. But the soaking time under normal air temperature must be longer, about 30 hours.

6. Drying

As the needles are very thin, they can be dried naturally when the air temperature is comparatively high. The water content of needles should be kept at 10 ~ 12%.

7. Bundle cutting and sanding

Needles are to be bundled and cut into 420 mm in length. They are to be sanded in a vibrating sanding machine by means of mutual friction for about 3 ~ 4 hours. Sanded needles are to be cut into 65 mm in length for making toothpicks.

The appearance of sanding machine is shown in fig. 3-12.

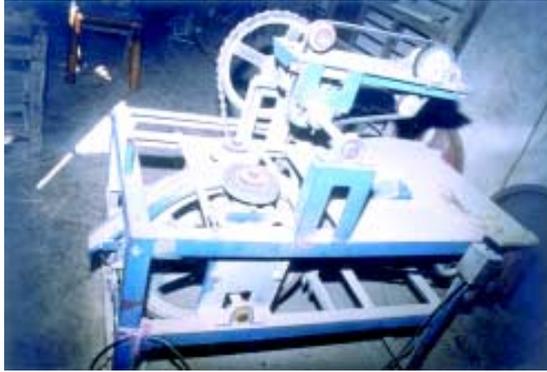


Fig. 3-12: The appearance of sanding machine

8. Sharpening

Semi-products are to be sharpened to form one or two pointed ends, and remove burrs. The sharpening machine is shown in fig. 3-13.



Fig. 3-13: Toothpick sharpening machine

9. Checking and packaging

Finished toothpicks are to be straightened out on vibrating plates, then packaged on packaging machines. These operations can also be done manually.

Chapter 4. Bamboo furniture

Furniture is one of basic necessities of human life, it should be both practical and decorative, and in harmony with the indoors environment. The production and use of bamboo furniture has a long history in China. Bamboo furniture is imbued with oriental local color, in simplified and elegant style, cool and comfortable. It is widely used in China and abroad.

Traditional bamboo furniture is made by means of traditional techniques such as crooking, reinforcing, connecting, holing, tenoning, mortising and board covering. Bamboo furniture includes stools, benches, chairs, tables, cupboards, beds and bookshelves. With the technological innovation and development of bamboo industry, particularly the research and development of bamboo based panels, the structure and modeling of bamboo furniture is being diversified and embellished. Modern bamboo furniture is full of traditional taste on one hand and convenient and comfortable on the other. The manufacturing technology of modern furniture of bamboo based panels is similar to that of wood furniture, therefore, it will not be discussed. In this chapter the technology of traditional-bamboo-furniture-making is introduced.

Bamboo grows rapidly, it is noticed for its high strength, toughness and rigidity. But it has some shortcomings, which can hardly be overcome, such as small diameter, hollow culm and numerous joints. Therefore, bamboo material can not be made into plain boards for furniture making as wood. Bamboo poles are to be crooked, reinforced and connected to make frames of furniture, then the frames to be covered with bamboo planks. To toast poles over fire and crook them, to make frames by means of tenon and mortise, to reinforce the frame with additional poles, to arrange bamboo planks on the frame and to embellish the furniture with curved pieces. All these operations are traditional techniques for making bamboo furniture.

Section 1. Techniques and tools for making traditional bamboo furniture

Traditional bamboo furniture items are made of *Phyllostachys pubescens* Mazel ex H. de Lahaie, *Pseudosasa amabilis* (McClure) Keng f., *Phyllostachys heteroclada* Oliver, *Bambusa textilis* McClure, *Neosinocalamus affinis* (Rendle) Keng f. or *Phyllostachys sulphurea* cv. Viridis according to their specific features. Traditional bamboo furniture items have a rich diversity, they are of different forms, but of similar structure. All of them are made of frames and planks. Frames embody the form of furniture and bear the load of furniture. Therefore the design of frame defines the quality of furniture directly.

1. Tools for making traditional bamboo furniture

“A workman must first sharpen his tools if he is to do his work well.” Traditional bamboo furniture is made with special tools. In order to make such furniture, it is necessary to know the special tools.

The techniques for making traditional bamboo furniture are a category of handicraft art. Although there are some special machines developed in this field, such furniture is made mainly manually. As the area of bamboo furniture making is widespread, the tools are also highly varied.

A. Knife for cutting thin strips

This is an important tool for bamboo furniture making. Culm cutting and slicing are carried out by means of such knives. The knife blade is 26 cm in length and the handle is 12 cm. The

end of blade is hook-shaped, which is applied to remove bamboo joints. The back of knife blade is quite thick, about 1.5 cm, which improves the efficiency of operation (Fig. 3 – 14).

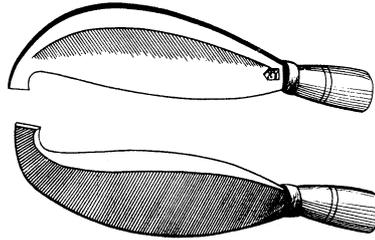


Fig. 3-14 Knife for cutting and making slivers

B. Pointed knife

Pointed knife is a tool frequently used for hole opening, peeling, sharpening, frame making, assembling and clearing. Pointed knives are small and easy to use. The blade must be sharp (Fig. 3-15).

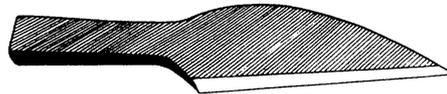


Fig. 3-15 Pointed knife

C. Scraper

Scraper is a specialized tool for removing wax cover of bamboo. The blade is of arc shape, with two wood handles for operation (Fig. 3-16).



Fig. 3-16 Scraper

D. Gouging tool

Gouging tool is specially applied to scoop out mortise for assembling (Fig. 3-17).

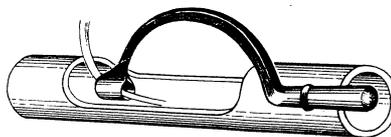


Fig. 3-17 Gouging tool for scooping out mortise

E. Plane for removing bamboo joints

This is a specialized tool for removing flange of bamboo joints (Fig. 3-18)

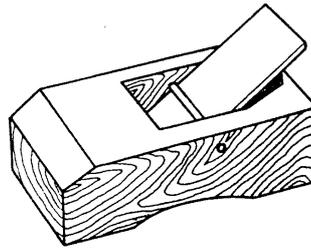


Fig. 3-18 Plane for removing bamboo joints

F. Line plane

This is a tool similar to planes used in woodworking, but it is comparatively light and handy (3-19)



Fig. 3-19 Line plane

G. Splitter and chisel

Splitter and chisel are used for splitting bamboo culm into strips of required width. The splitter is 12 cm in length and 3 cm in width. The width of splitter blade is about 0.5cm. The blade with an iron handle does not need to be very sharp. The chisel is similar to that used in woodworking, but light and handy (3-20).

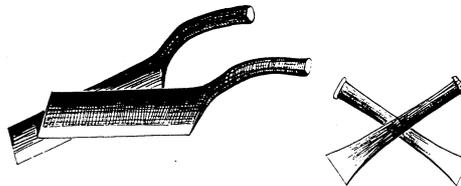


Fig. 3-20 Splitter and bamboo chisel

H. Round chisel and square chisel

Both the chisels are used for making round and square holes on bamboo material for assembling bamboo furniture. The size of square holes can be 3, 6, 10 mm and more (Fig. 3-21).

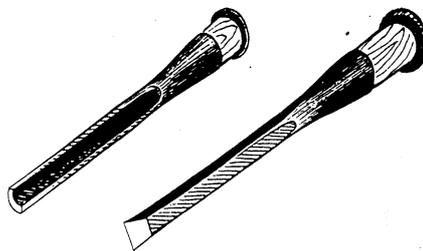


Fig. 3-21 Gouge and square chisel

I. Hand saw

Hand saw is applied to cut bamboo culm and bamboo pieces, or to slit bamboo material according to the requirements of furniture design. The saw blade must be thin and saw-teeth be fine (Fig. 3-22)

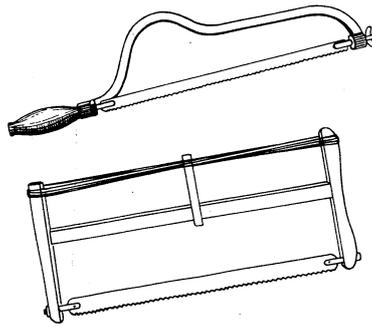


Fig. 3-22 Hand saw

J. Slitting saw

Slitting saw is applied to slit the surface of furniture parts for connection (Fig. 3-23)

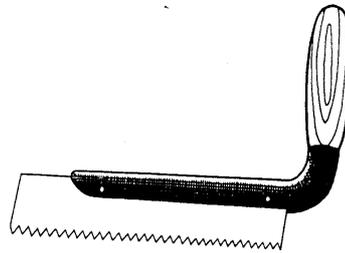


Fig. 3-23 Surface saw

K. Hand drill

Hand drill is applied to drill holes on bamboo material. Before pushing bamboo nails into bamboo strips or tubes it is necessary to make holes for them. Therefore hand drill is a kind of tools most in use. As bamboo culm wall is thin and can be broken easily, the bit must be very sharp and of different size (Fig. 3-24).

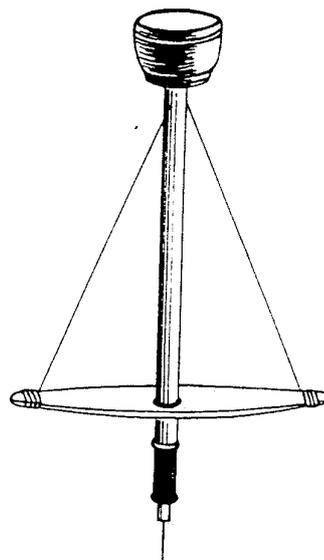


Fig. 3-24 Hand drill

L. Hammer

Hammer is applied to drive nails into furniture parts, it must be light and handy in comparison with that used in woodworking.

M. Bending column

Bending column is a kind of auxiliary tool for bending bamboo tubes. A wooden column is made in T shape, the width of column is about 13 cm and the length is about 250 cm. Several holes are made on the height of 120 ~ 140 cm. The diameter of holes is 3 ~ 5 cm. Bamboo tubes to be bend are inserted into holes and heated with fire for bending (Fig. 3-25).

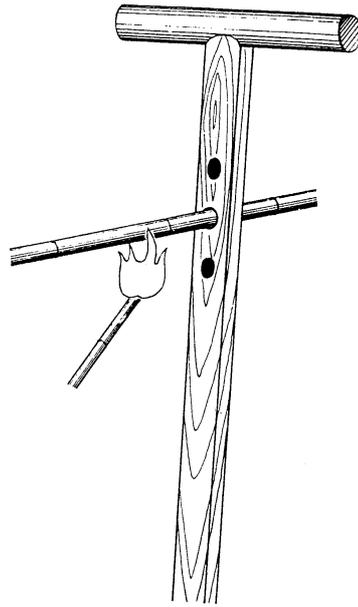


Fig. 3-25 Bending column

2. Bending bamboo tubes

Bamboo tubes can be bent by means of heating or making groove.

A. To bend bamboo tubes by heating.

Bamboo material is of certain plasticity. Its plasticity can be improved by raising temperature with enough water content. In this way the natural color of bamboo and its physical strength will not be seriously affected. Consequently, most parts of bamboo furniture are bent by means of heating. This method is particularly fit to bamboo tubes of smaller diameter.

There are several ways to bend bamboo tubes. The most popular one is fire heating. Put bamboo tubes over fire to raise its temperature, then bend them when warm. They will keep bent when cooled. Tubes to be bent should be of small or medium diameter. Their length is decided according to the furniture design with certain surplus. The green surface and wax cover are removed after bending. The fuel applied for heating must not cause black smoke, therefore the tubes will not be blackened by heating fume. Heat a selected part of bamboo tube over flame to soften it. When bright oil drops appear on its inner surface, bend it slowly to form the required curve. Soak the bent tube in cold water for 1 ~ 3 min to decrease its temperature rapidly and recover its physical strength. It should be mentioned that the tube over flame during heating must be moved back and forth to make the heating evenly. The heating time should not be too long, in order to avoid the charring of tube, which may affect the strength of tube and the service life of the final product. (Fig. 3-26)

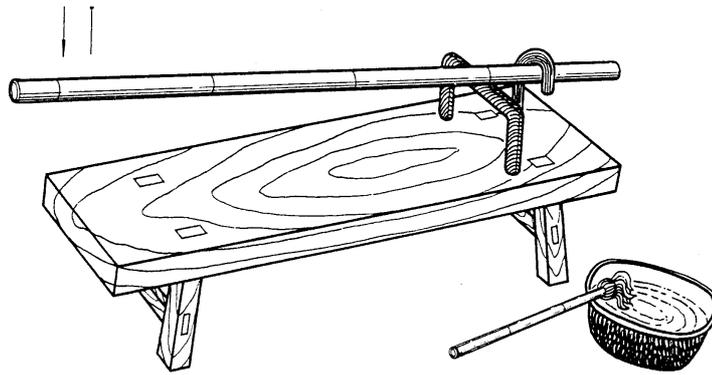


Fig. 3-26 Bamboo-straightening stand with fire

The heated tubes may be put in setting moulds for cooling in industrial massive production. Bamboo tube can also be heated and bent with steam. Insert bamboo tubes into mechanical moulds in heat vessel, bring in steam and bend the tubes under high temperature to form the predetermined curve. To avoid the breaking and deformation of tubes resulted from the change of stress, it is recommended to remove the inner partitions of bamboo culm and input hot sand for bending.

B. To bend bamboo tubes by making groove

This method is applied for bending tubes of larger diameter. The process is rather complicated and it may affect the strength of bamboo parts. The size of grooves is calculated in accordance with the predetermined curve.

There are several ways for bending:

(1) Broken line bending

This way of bending is shown in Fig. 3-27.

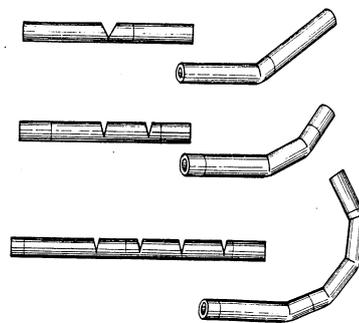


Fig. 3-27 Broken line bending

D – diameter of bent part

r – radius of breaking angle

$$D \geq r \frac{4}{3}$$

n – number and breaking angles

Depth of groove: $D/2 \leq h \leq 3D/4$

Radius of groove: $R = r = h$

Length of groove: $L = 2 \pi r + 2 (n - 1) r - 2R$

Regular breaking bending

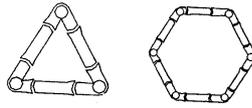


Fig. 3-28: Regular breaking bending (3 angles, 6 angles)

In this way tubes can be bent into several angles, three or six or more. The angle is expressed as α (Fig. 3-28)

Length of groove: $L = 2 \pi r - \alpha \pi r / 180^\circ$

Radius of groove: $R = r$

Depth of groove: $h \leq r + r \sin (\alpha / 2)$

Breaking angle: $\beta = 90^\circ + \alpha / 2$

In general, the form of 3, 4, 5, 6, 8, 12, 18 angles are most frequently applied. The data for such bending are shown in table 3-2

Table 3-2 Data for regular breaking bending

Number of angles	Angle α°	Length L	Angle β°	Height h
3	60	5.23 r	120	1.50 r
4	90	4.71 r	135	1.71 r
5	108	4.39 r	144	1.81 r
6	120	4.17 r	150	1.87 r
8	135	3.92 r	157.5	1.92 r
12	150	3.66 r	165	1.97 r
18	160	3.49 r	170	1.98 r

(3) Triangle bending

In the inner part of bending cut even triangle grooves, bend the part after heating over fire, then cool for recovering the strength. This method is also applied for processing tubes of larger diameter. The shortcomings of this method are as follows: the strength of tube may be affected and the process is quite complicated. The triangle bending can be carried out in round form and angle round form.

a. Round form

Turn the tube into round form after bending (Fig. 3-29). The bamboo tubes of this form are made ad part of round table, chair or stool. In general these pats are wrapped round with a belt. The number of grooves is n.

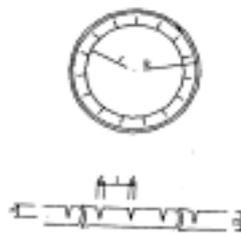


Fig. 3-29: Round bending

Length of wrapping belt: $L = 2\pi R + \text{length of joint}$

Net length of wrapping belt: $L_n = 2\pi R$

Depth of groove: $D/2 \leq h \leq 3D/4$

Width of groove: $d = 2\pi h/n$

Space between groove: $I = 2\pi r/n$

b. Angle round form

Turn the tube into an angle for making handrail of armchair or corner of side table (fig. 3-30).

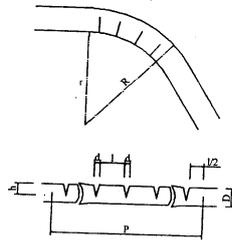


Fig. 3-30: Angle round bending

The data for bending are calculated as follows:

n - number of grooves

Length of bent part: $P = \pi R/180^\circ$

Depth of grooves: $D/2 \leq h \leq 3D/4$

Width of grooves: $d = \pi h/180^\circ n$

Space between grooves: $I = \pi h/180^\circ n$

Determine the length at first, then the number of grooves and the space between grooves. If the some grooves are made too large, it is necessary to fill in the gaps with bamboo pieces or glue.

3. The reinforcement of bamboo framework

It is difficult to make framework from single bamboo tubes for furniture. In order to improve the strength of bamboo furniture, the framework must be reinforcement by parallel connection of bamboo tubes.

The parallel connection of bamboo tubes improves the load capacity of furniture and makes it good looking and comfortable. To carry out parallel connection, the first step is to cut the surface of bamboo tubes for connecting and arrange them in parallel order, then bore holes through tube wall with hand drill and insert bamboo nails to connect them (Fig. 3-31).

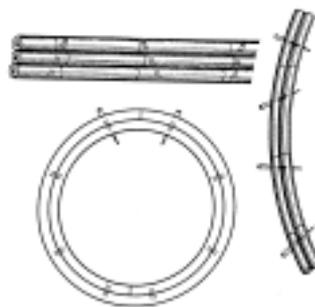


Fig. 3-31 Parallel connection

It is important that the bamboo nails must be driven in different directions to raise the connecting strength. After connection use a hand saw to mend the ends of nails and edges of connected parts, then sand their surface.

4. The combination of bamboo parts of framework

Bent parts are to be combined with other bamboo tubes or pieces to form a framework of furniture in the way of end combination, T combination, parallel combination, inlay combination, cross combination, L combination.

End combination is applied to prolong the tubes of same diameter or to close the framework. The ends of tubes to be combined must be cut evenly, then select a piece of bamboo tube with diameter similar to or smaller than the internal diameter of combined tubes. Glue the selected tube and insert it into the end holes of bamboo parts to be combined. Combine the two parts closely, drill holes in different directions and insert bamboo nails, cut the projecting ends of nails (Fig. 3-32-A).

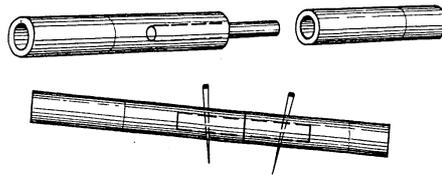


Fig. 3-32-A Ends connection with straight

If combined tubes are bent, the insert tube should be in the same bent form (Fig. 3-32-B).

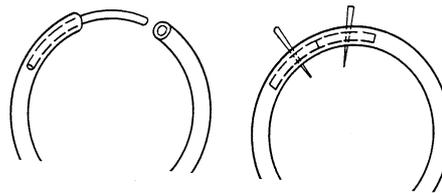


Fig. 3-32-B Ends connection with bent

If combined tubes are of different diameter, select a piece of bamboo according to the internal diameter of thicker one. Insert one end into the thicker tube, then cut the other end to fit the thinner one. The end of thicker tube must be mended to make it similar to the thinner one.

If the diameter of tubes to be combined differs greatly, the method of combination will be introduced in the next section.

Bamboo nails applied for combination are made of thick wall of dried bamboo culm. The nails are about 10 mm in length (Fig. 33-3).



Fig. 3-33 Bamboo nails

Section 2. Tenon and mortise joint

Bamboo furniture is basically composed of frame and liner material. These parts are assembled by means of tenon and mortise joints. For assembling bamboo furniture mortises are prepared in two kinds: bent mortise and plane mortise.

Bent mortises are made on frame to hold tube-tenon, plane mortises are to hold tenon of lining material.

1. Bent mortise and tube-tenon

Bent mortises and tube-tenon joint is very important in bamboo-furniture-making. They are made in following ways:

A. Elementary bent mortise

Elementary bent mortises are made in 3 steps. First of all, to make two paralleled slits on surface of bamboo tube, the space between slits is equal to the length of groove. Which is determined according to the thickness of tube-tenon. The depth of slits may be larger than the radius of the tube, but not exceed $\frac{3}{5}$ of its diameter. Then gouge out a groove on the tube between slits. The second step is to mend the groove to fit the predetermined tube-tenon. The third step is to remove the yellow part on the groove. After these operation bend the grooved tube to form a bent mortise. The thickness of bent part should be 0.2 ~ 0.5 cm (Fig 3-34). In order not to break the tube at bending, it is recommended to heat the tube by means of fire or boiling water.

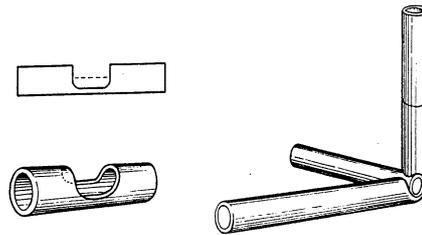


Fig. 3-34 Groove for making bent mortise

During the elementary bent mortise making the following points should taken into consideration:

- (1) Grooves must be arranged on the space between joint knots, not on the knots
- (2) There must be more than two grooves on one tube, arranged in the same direction.

B. Collective bent mortises

Three or more than three bent mortises arranged on one and the same tube, which is to be processed into an enclosed form is called collective bent mortises.

Collective bent mortises are essential part of bamboo-furniture-making techniques. The main frame of furniture is combined with lining parts and covering material by means of collective bent mortises.

The process of making collective bent mortises includes elementary bent mortise making and the connection of both ends of tube.

Collective bent mortises may be “equilateral triangle”, “square”, “pentagon”, “hexagon” and more.

- (1) Equilateral triangle bent mortises: The length of tube for making triangle bent mortises is equal to the sum of the length of three sides and three grooves.

The length of grooves must be calculated in advance, it should be about $\frac{5}{8}$ of the perimeter of tube-tenon. In practice the length can be reduced by 1 ~ 3 mm (Fig 3-35).

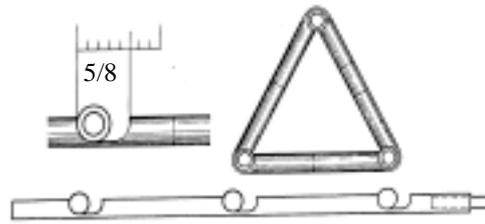


Fig. 3-35 Equilateral collective bent mortise

The included angle of equilateral triple bent mortises is 60° , if the triangle form is not equilateral, the length of grooves and the included angles should be regulated accordingly. But most of the triangle bent mortises for bamboo furniture is equilateral.

(2) Square bent mortises: The length of tube for making square bent mortises is calculated in the same way as that of equilateral triangle bent mortises. But the length of grooves is different. It is about $\frac{9}{16}$ of the perimeter of tube-tenon (Fig. 3-36).

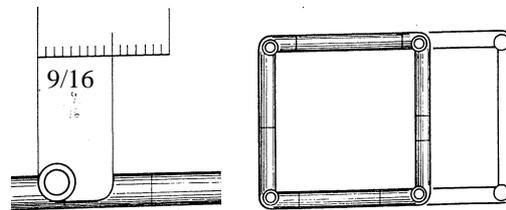


Fig. 3-36 Square collective bent mortise

(3) Rectangle bent mortises: The length of tube for making rectangle bent mortises is calculated in the same way as that of square bent mortises.

(4) Pentagon and hexagon bent mortises: The length of tube for making pentagon and hexagon bent mortises is calculated in the same way as stated above. But the length of groove is different. The length of groove for pentagon is $\frac{1}{4}$ of the perimeter of tube-tenon, the included angle is 108° . The length of groove for hexagon is $\frac{15}{32}$ of the perimeter of tube-tenon and the included angle is 120° .

C. Closed bent mortise: Closed bent mortise is to hold the tube-tenon closely. Cut a slit at 30 cm from the tube end, the depth of slit is half of the diameter of tube, cut out a groove, the length of groove is $\frac{7}{8}$ of the perimeter of the tube-tenon (Fig. 3-37).

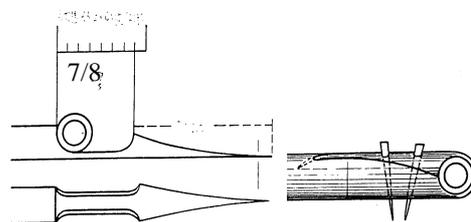


Fig. 3-37 Closed bent mortise

Remove half of tube wall from the groove to the end, cut the retained wall to form a thin piece for wrapping the tube-tenon and drive two nails to fix the joint (Fig. 3-38) The joint will be more firm if it is twined with rattan material. This is a method that's worth spreading.

D. Connection of both the ends of tube

The tube for making collective bent mortises is rather long, and the thickness of the two ends is different. They should be connected in a way similar to that for making closed bent mortise. The connection may be single (Fig. 3-38) or double (Fig. 3-39). But the following points should be taken into consideration:



Fig. 3-38 Single connection of mortise tube



Fig. 3-39 double connection of mortise tube

- (1) The direction of retained tube wall must be perpendicular to the direction of groove, while the direction of retained tube wall for closed bent mortise is in the same direction of groove. The retained tube wall on both ends should be in opposite directions.
- (2) The connective part of the tube forms a side of the geometric figure.
- (3) The connection should be fixed with oblique bamboo nails.

2. Dowel and plane mortise

Plane mortises are cut out on frame to hold dowels on lining material. They must be consolidated with bamboo nails. Bamboo material for making nails should be dried in advance to avoid the shrinkage of mails.

Dowels can be made in different forms:

A. Central dowel

Central dowel is made on the end of lining material. Make two slits with a hand saw, the depth of slits should be $\frac{3}{8}$ of diameter. Cut out dowels as shown in Fig. 3-40.

The mortise is made in the form of two holes on the frame. The dowels are to be insert through the holes and reach the tube wall, the length of dowel equals to the diameter of tube minus the thickness of tube wall (Fig. 3-41).

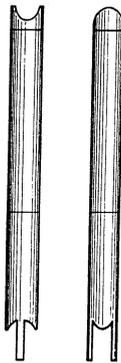


Fig. 3-40 Central dowel

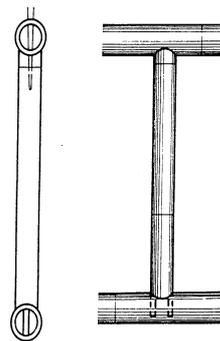


Fig. 3-41 Central dowel joints

Another form of central dowel is penetrating dowel, it is a little longer and wider than central dowel. It penetrates the frame tube, going through the tube wall twice.

B. Single dowel

Single dowel (Fig. 3-42) is made on the end of lining material. Make a slit at about 2 cm from the end of lining material. The depth of slit equals to the radius of frame tube. Cut out a dowel, the dowel must be long enough to go through the hole on tube wall and reach the opposite wall.

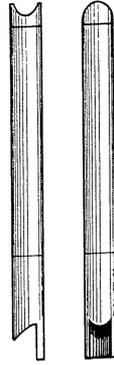


Fig. 3-42 Single dowel

The mortise on frame tube must be made in the form of semicircle to fit the dowel. It is important that the straight side of semicircular mortise must be parallel with the direction of bamboo fiber, otherwise the connection will be failed (Fig. 3-43).

The bent semicircular mortise and single dowel can be arranged horizontally or vertically. If it is made horizontally, the mortise hole must be cut upward, otherwise the strength of joint will be affected.

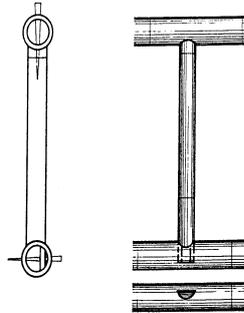


Fig. 3-43 Single dowel

C. “Fish mouth”

In bamboo furniture making the end of lining tube is often utilized to make a dowel on one hand, and a “fish mouth” on the other. It is arranged to stand on one horizontal frame tube and sustain another horizontal frame tube above.

The internal joint partition and outer flannel of tube must be kept undamaged. Cut out a V size end, mend it into a U size end with a pointed knife like a fish mouth (Fig3-44). “Fish mouth” is cut out upwardly as a rule.

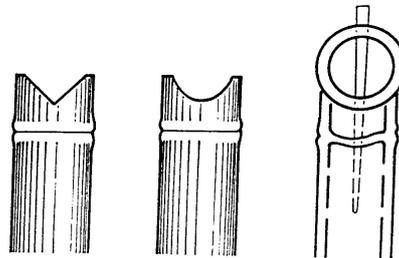


Fig. 3-44 Fish mouth

D. Connection without dowel making

Lining tubes are applied to connect with two frame tubes without making dowel on both ends, or to make dowel on one end and “fish mouth” on the other.

To fit one end of lining tube on one frame tube, move farther the opposite frame tube and turn the second end of lining tube into proper position, then move the opposite frame tube back and connect them. The joints must be strengthened with bamboo nails (Fig. 3-45).

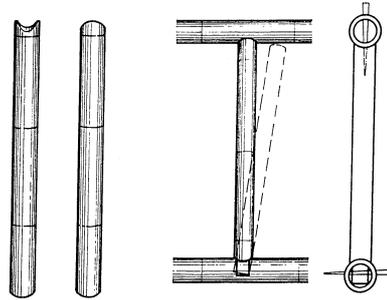


Fig. 3-45 Connection without dowel making

Such connections can be positioned vertically or horizontally between frame tubes. The lining tubes should not be too thick, otherwise the mechanical strength of frame will be affected.

E. Oblique dowel

One surface of oblique dowel is inclined (Fig. 3-46).



Fig. 3-46 Oblique dowel

Oblique dowel is rather long, in can not be insert into the mortise hole fully, and therefore, the joint is not so complete. Such joints are not applied in making furniture of high grade. Oblique dowels are applied n case when lining tubes are bent and can not be connected with frame tubes perpendicularly. .

It should be emphasized that the direction of inclined surface of dowel on one end of lining tube must be coordinated with the direction of “fish mouth” on the other end (Fig. 3-47)



Fig. 3-47 Oblique dowel joint

F. Swallow-tailed dowel

Swallow-tailed dowel is made in the form of swallow’s tail (Fig. 3-48).

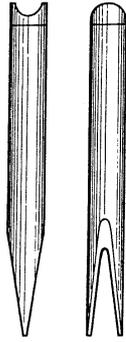


Fig. 3-48 Swallow-tailed

The mortise of swallow-tailed dowel is made in the form of two holes, the space between holes must be equal to that between two tips of dowel. When one end of lining tube is made into swallow-tailed dowel, the other end is “fish mouth” (Fig. 3-49).

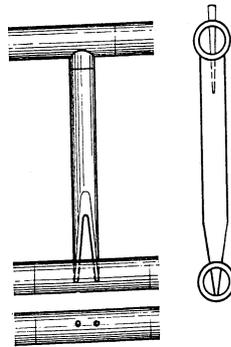


Fig. 3-49 Swallow-tailed dowel

Swallow-tailed dowel and mortise joints are not sturdy, they are not applied in making furniture of high grade. Such joints can be positioned vertically or horizontally, mainly vertically. The direction of dowel on one end of tube must be coordinated with that of mortise on the other end.

Section 3. Facial plate of bamboo furniture

Facial plates are indispensable parts of bamboo furniture, such as seat and back of a chair, top of a table, base of a bed, sideboards and shelves. All these plates are made of bamboo strips.

For making a facial plate it is necessary to set up a bamboo frame at first. Bamboo frames are rectangle in general, but they can be round, oval or of other form. Facial plates are sustained with bamboo sticks, which are perpendicular to plates. Facial plates can be made of bamboo fragments or of bamboo strips.

1. Facial plate of bamboo fragment

The making of facial plate from fragment is a kind of traditional technique in Chinese bamboo furniture production. As its production cost is low, it is widely applied in making small- and middle-sized furniture. The process consists of four steps:

A. Fragment cracking

Such plates can be made in the form of knot plate or non-knot plate.

Non-knot plates are made of bamboo material between joint knots. Usually they are for the production of small-sized furniture. First of all split a bamboo tube into two half fragments, make slits on the green surface of fragment, the length of slits should be $\frac{3}{5}$, and the space between slits be 0.3 ~ 0.4 cm. Then make slits on the surface of other side, the slits on this side should be positioned in the middle of space between slits on green surface (Fig. 3-50).

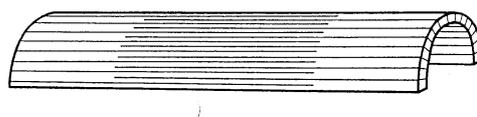


Fig. 3-50 Cracking bamboo fragment

Knot plates are made of material with knots, they are for the production of larger furniture. The process of cracking is similar to that of non-knot plate, but the space between slit should be 0.4 ~ 0.5 cm.

B. Montage

Collect the slit fragments into a plate material according to the design of furniture. The fragments of same size should be arranged together. The thickness of fragments should be even. They must be mended with a knife where the connection does meet the requirements.

C. Sewing up

Lay the slit fragment on an operation stool with the yellow surface upwardly. Put two sleepers under the fragment. The space between sleepers is adjusted according to the length of fragment. Fix one end of pressing rod on the stool, press the fragment pushing the other end of rod slowly. Bind the pushing end of rod to the stool with a rope when the fragment is pressed into a plane plate. Prepare a thin strip, which is 0.5 cm in width and 0.2 cm in thickness, and its length is somehow larger than the width of fragment. Make slits for sewing with a slit saw perpendicular to the slits for cracking, the depth of these slit should be $\frac{2}{3}$ of the thickness of fragment. Insert the thin strip into the sewing slit. There should be two sewing slits on small-sized plate and four slits for larger plate (Fig 3-51).

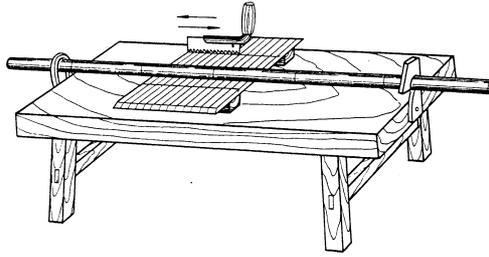


Fig. 3-51 Slitting bamboo fragment

D. Mending

Lay the sewn plate on a table with yellow surface upwardly. Press it with a pressing rod. Mend both edges of plate as shown (Fig. 3-52). The width of slope parts is 4 ~ 5 cm, the thickness of edge is 0.02 cm.

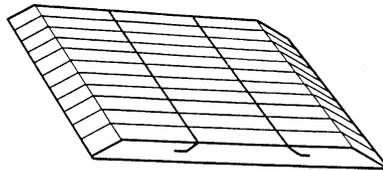


Fig. 3-52 Slit bamboo fragment

2. Facial plate of bamboo strips

Facial plates of bamboo strips are made of parallel bamboo strips. They must be of same width, same thickness and similar color. If they are not arranged closely, the space between every two strips must be also the same. The width of strips is 0.7 ~ 2 cm in accordance with the style the furniture. Strips for furniture of free and easy style may be wider and those for exquisite furniture be narrower.

There are three kinds of such plates: holes-fixed plate, slit-fixed plate and pressing-fixed plate.

A. Holes-fixed plate

Holes-fixed plates are made by inserting the ends of strips into the hole-mortises of frame tubes. Before inserting both the ends of strips must be cut into dowels. Make slits 2 cm in depth on the ends to shape dowels. The thickness of dowels must fit the mortise-holes. The strips can be arranged closely or sparsely (Fig. 3-53, Fig. 3-54).

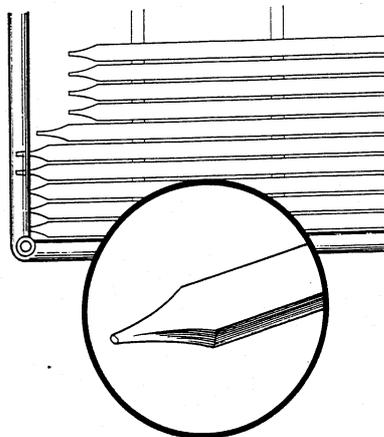


Fig. 3-53 Holes-fixed plate – 1

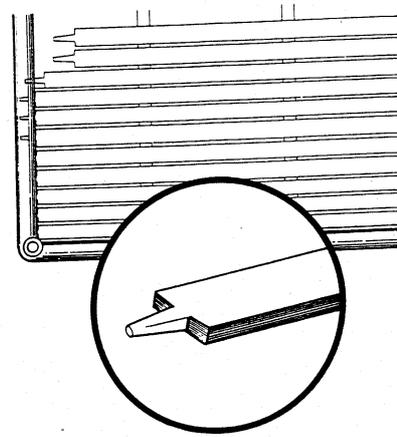


Fig. 3-54 Holes-fixed plate – 2

B. Slit-fixed plate

Slit-fixed plates are made by inserting the end of strips into the slit-mortise of frame tubes. The strips must be arranged closely.

The width of slits must fit the thickness of strips (Fig. 3-55).

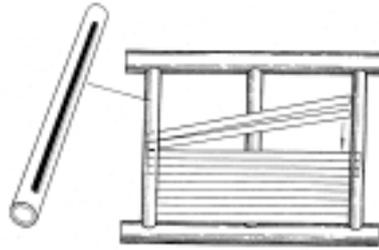


Fig. 3-55 Slit-fixed plate

C. Pressing-fixed plate

For making pressing-fixed plates the ends of strips are arranged between two frame tubes. The frame tubes must be stable, without mortise holes or slit. There should be certain space between tubes for arranging strips. Under the arranged strips it is necessary to lay a lining tube perpendicular to strips for sustaining the plate. In addition put one tube thinner than, and parallel with, the frame tube on the plate, and another one under the plate to fix the plate with bamboo nails. Such plates are selected in manufacturing furniture of high grade (Fig. 3-56, Fig. 3-57).

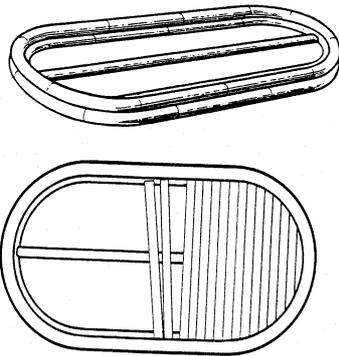


Fig. 3-56 Pressing-fixed plate

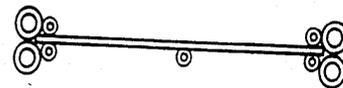


Fig. 3-57 Sectional drawing of pressing-fixed plate

Plates for furniture of high grade may be embellished with ornamental engraving. Ornamental engraving on bamboo furniture is easier than on wood furniture. Draw figures on the plate with a pencil, engrave the figures with a pointed knife on one side or both sides of the strips, the figures will be vivid (Fig. 3-58). Ornamental figures can be expressed by using sulfuric acid or nitric acid and carbonizing. They can also be expressed with fire processing.

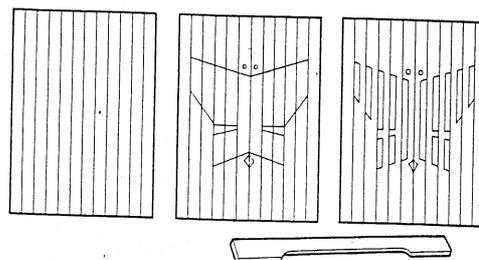


Fig. 3-58 Ornamental engraving on facial

D. Plate of strung and doweled strips

Such plates are fixed with a string in the middle part and dowels on both edges. The strips are strung through drilled holes on strips together with lining tube (3-59). For plates of large furniture, there should be two or three lining tubes and strings.

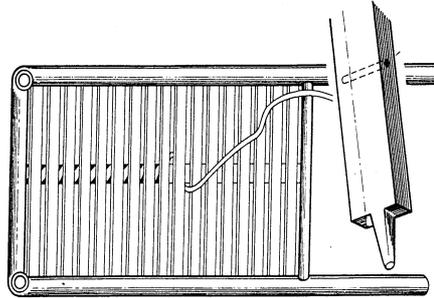


Fig. 3-59 Plate of strung and doweled strips

Sometimes the strips can be tied firmly together with lining tube using rattan string without drilling holes

As the strips are to be tied, they are arranged not closely.

There are lining pieces under facial plates of fragment and facial plates of strips (Fig. 3-60, Fig. 3-61), and pressing pieces on them (Fig. 3-62). All the lining pieces and pressing pieces must be tied firmly.



Fig. 3-60 Square lining bamboo Fig. 3-61 Semicircular lining bamboo piece



Fig. 3-62 Pressing bamboo piece

Tied thin bamboo tubes and tied domino-sized bamboo pieces can be used as facial plates on armchairs or sling chairs. With the development of bamboo-based panels industry, bamboo based panels are selected as facial plates of furniture, they are of high strength and stable size, but lacking the beauty of natural style.

Section 4. Decorative pattern on framework of bamboo furniture

The frameworks of bamboo furniture are to be reinforced and decorated after completion. Decorative pattern of small bamboo pieces is a frequently used variant.

Select the branch and top of thin bamboo culm to fill the gaps of frameworks. By means of decorative patterns, there will be small-sized frames within larger frames. This embodies the oriental artistic style.

There are a great variety of decorative patterns, most popular ones are “*” form pattern, “long life” pattern, “double foot” pattern, plum pattern. In general they are used for making furniture of high and middle grades (Fig.3-63 to Fig. 3-85).

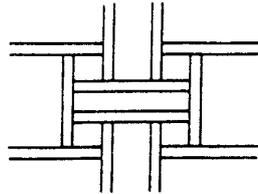


Fig. 3-63 “double foot” pattern

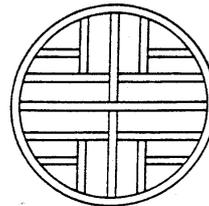


Fig. 3-64 “long life” pattern

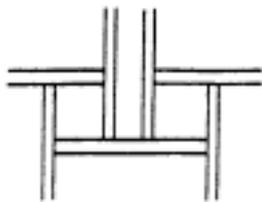


Fig. 3-65 Tied pattern

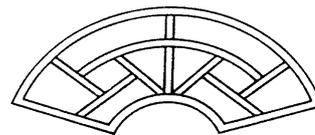


Fig. 3-66 Fan pattern

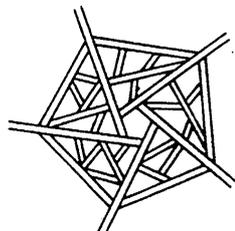


Fig. 3-67 Iced plum pattern

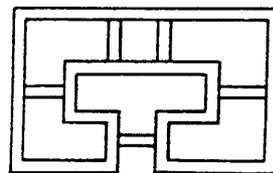


Fig. 3-68 “Satisfactory” pattern

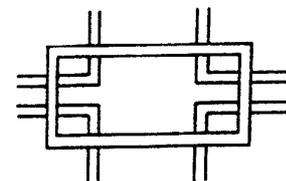
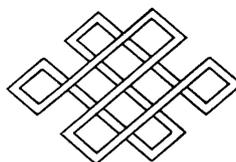
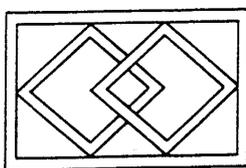


Fig. 3-69 Double diamond pattern Fig. 3-70 Winding paths pattern Fig. 3-71 connected rectangle pattern

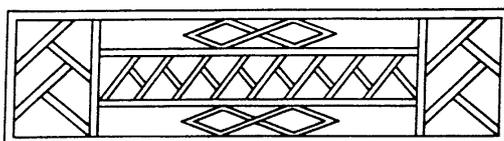


Fig. 3-72 diamond and “λ” form pattern

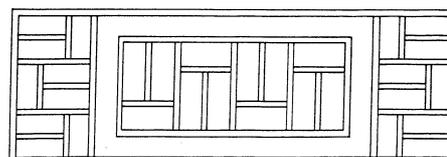


Fig. 3-73 rectangular road and bridge pattern

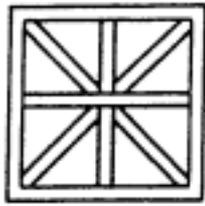


Fig. 3-74 “*”form pattern

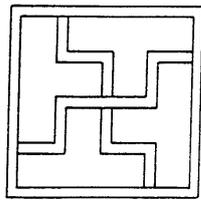


Fig. 3-75 “Ten thousand” pattern

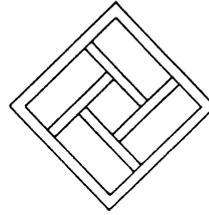


Fig. 3-76 Oblique pattern

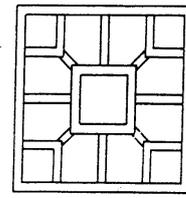


Fig. 3-77 Tortoiseshell pattern 1

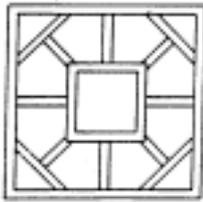


Fig. 3-78 Tortoiseshell pattern 2

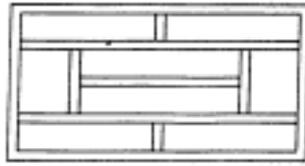


Fig. 3-79 Horizontal road and bridge pattern



Fig. 3-80 Vertical road and bridge pattern

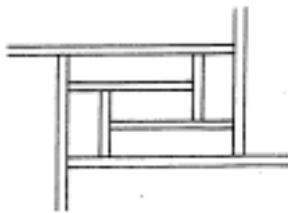


Fig. 3-81 Connected rectangle pattern

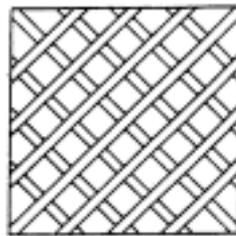


Fig. 3-82 Inclined square pattern

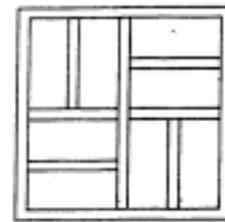


Fig. 3-83 Square road and bridge pattern

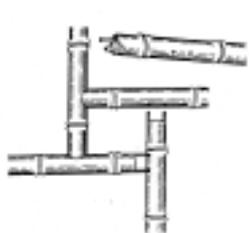


Fig. 3-84 Tube's dowel and joint 1

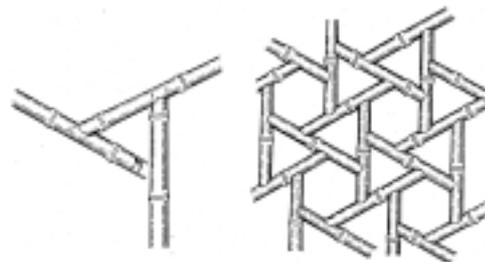
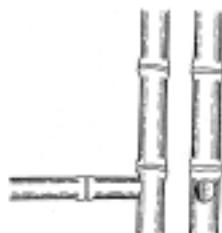


Fig. 3-85 Tube's dowel and joint 2

Techniques for making decorative patterns are comparatively complicated, the process for making different patterns are similar in some aspects, but different in others. They should be made in accordance with the furniture design.

Material for making decorative patterns is selected carefully. Branches for making one and the same pattern must be of same thickness, and cut and arranged in the light of design.

Decorative patterns are generally assembled by means of dowel and mortise joint. Before shaping the dowel, it is recommended to consider the direction of pattern and turn the better part of branch outside. Determine the position of dowel and mark signs with ink. Then make the dowel. If both the ends of a piece are to be made into dowel, they should be made at the same time.

Mortise holes should be made accurately, strictly according to the size of dowels.

Check every part of decorative pattern when they are put together, change or mend the unsuited ones.

Some of the parts can not be connected by dowel and mortise joint, they can be connected with glue joint. The bevel faces of pattern parts are jointed with glue and a bamboo nail as a rule.

The last step is the installation, it is to insert the decorative pattern into the framework of furniture. It is necessary to have a trial insert to make sure that the pattern is fit. Then mark signs of mortise holes on framework and drill the holes, separate the pattern into parts, install the pattern into the framework part by part reinforce the joints with nails

Section 5. The making process of traditional bamboo furniture

In this section the making process of traditional bamboo furniture is illustrated

1. Bamboo stool

Bamboo stool is an item of bamboo furniture of simple structure. One of it is shown in Fig. 3-86. Its framework, including legs are of single tube, without any sustaining tubes, thus saves labor and raw material. It is necessary to choose bamboo of larger diameter to make stools.

The stool shown in Fig. 3-86 is 30 cm in length, 22 cm in width and 30 cm in height.



Fig. 3-86 bamboo stool

The first step is to make the seat of stool.

Select two bamboo tubes 30 cm in length and 4 cm in diameter. Drill three mortise-holes 2~3 cm in diameter on each of them. One mortise-hole is in the center of tube and other ones are 6 cm from both ends.

Select three tubes 21 cm in length, their diameter must fit the above-mentioned mortise-holes. Insert the ends of these tubes into the mortise-holes. It is necessary to make mortise-slit on every side tube for forming seat plate. As the seat is of small size, it is recommended to select bamboo strips between joint-knots to avoid the knots appeared on seat plate.

The second step is to make legs of stool.

Select two main tubes 80 cm in length and 4 cm in diameter. Cut out two grooves on each of them for making bent mortise. Bend the main tubes and fit the ends of seat tubes into the bent mortises. The length of stool leg is 26 cm, from bent mortise joint to the end of main tube. Tie the legs of stool with a rope to avoid falling to piece until a rectangular collective bent mortise is made (Fig. 3-87). The third step is to make rectangular collective bent mortise.

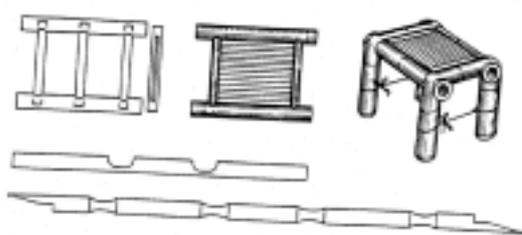


Fig. 3-87 The making process of bamboo stool

Select a tube 100 cm in length and 4 cm in diameter to make rectangular collective bent mortise, joint the legs on the height 5 cm from the earth (Fig. 3-87).

2. Bamboo chair

Bamboo chairs can be made easily. Light, sturdy and highly diversified, they are well received by consumers, and are a most popular item of bamboo furniture.

An armchair popular in Sichuan Province is shown in Fig. 3-88. It is of simple structure and plain shape, imbued with local color. Such a chair consists of two parts, the lower part is a square stool, the upper one is a back with armrest.



Fig. 3-88 Bamboo armchair

The first step is to make a square stool.

The square stool is made in the way mentioned above, its size is 50 cm in length, 45 cm in width and 40 cm in height. The legs should be slightly inclined outward to make the chair stable (Fig. 3-89).

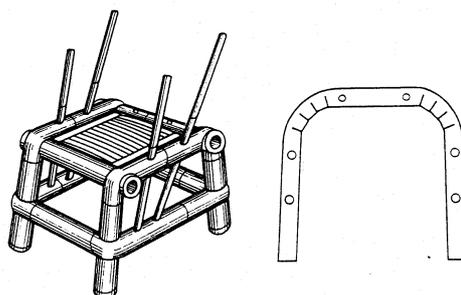


Fig. 3-89 The making process of bamboo armchair

The second is to make the back with handrail

Select a bamboo tube 5 cm in diameter, bend it into the form as shown in Fig. 3-89 with four saw kerves of acute angle on each bent part. This tube is used for armrest and to connect the back of chair.

Select 4 tubes 2 ~ 3 cm in diameter, install them on two sides of square stool reciprocally in the way as shown in Fig. 3-89.

Cut out mortise holes on the tube for armrest and connect it with 4 tubes by means of mortise joint.

The last step is to make the back of chair according to Fig. 3-88. Select 2 tubes, stand them upright on the rear edge of seat and connect them with the tube for armrest. Insert 2 parallel tubes between upright tubes horizontally. Make one slit on each of the parallel tubes, insert bamboo strips of proper length, form a facial plate for back (Fig. 88). Thus the chair is completed.

Fig. 3-90 shows a traditional bamboo chair very popular in the areas to the south of Yangtze River. The length of seat is 38 cm, width is 32 cm, the height is 36 cm. The height of chair back is 38 cm. Such a chair is made in the same way as making above-mentioned chair.



Fig. 3-90 Traditional bamboo armchair popular in Zhejiang

3. Square bamboo table

Square bamboo table is of comparatively simple structure. The top of table is on the height of 70 ~ 80 cm. The diameter of frame tube should be 3 ~ 4 cm.

The first step is to form the framework.

Select four straight bamboo tubes of same thickness to be used as legs, 70 ~ 80 cm in length.

Select three tubes with the same thickness as that of legs. They are used to provide upper, middle and lower closed bent mortises. Cut out 4 grooves on them for making bent mortise. The position of mortises is decided in accordance with the size of table.

The tube of upper closed bent mortises is to support the top of table. Therefore the ends of this tube is to be connected with bamboo plug to guarantee the evenness of top.

The legs must have knot joint on their upper part near the end, otherwise they may be damaged by bent mortise. If the upper part of leg does have knot joint, fill in a wood or bamboo plug to prevent the possible damage.

For making framework of table, connect the upper tube of closed bent mortise with four legs by means of bent mortise joint. Number the mortise grooves and bent them in order to joint them with legs. The tube of closed bent mortise should be perpendicular to legs. After the completion of bent mortises drive in bamboo nails for stable connection.

Connect middle and lower tubes of closed mortise in the same way as that for the upper one. The middle tube should be positioned closely to the upper tube. These two tubes are to be treated together for supporting the top of table.

The lower tube of closed bent mortise is to be put 15 cm under the middle (Fig. 3-91).

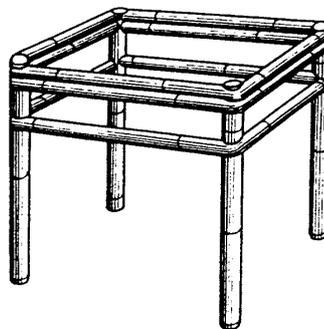


Fig. 3-91 Framework of square bamboo table

The second step is to reinforce the framework.

Three measures are to be taken:

A. The upper tube of closed bent mortise is for supporting the top of table. It should be reinforced with slightly thinner lining tubes. Two of them are positioned closely to the upper tube, other two of them are in the central part to support strips of top (Fig. 3-91).

B. Insert vertical short tubes between upper and middle tubes of closed bent mortise by means of single dowel joint on one end and without mortise joint on the other (Fig. 3-91).

C. Select four long tubes to support the framework, fix each of them closely to one leg and the lower tube and then to the opposite leg, forming a “doorframe” (Fig. 3-92).

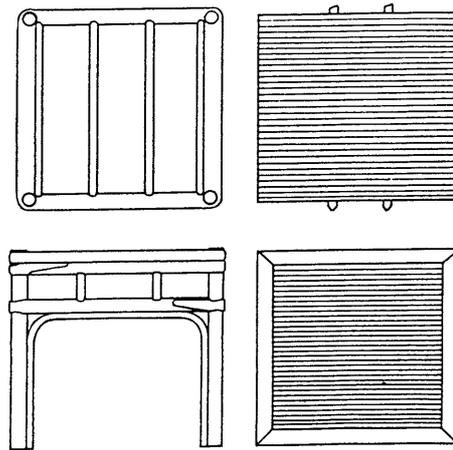


Fig. 3-92 Making process of square bamboo table

The third step is to make the top of table

The strips for making facial plate as the top of table are cut from bamboo culm of larger diameter. The area of facial plate is slightly smaller than the inner area within the upper tube of closed bent mortise. The direction of strips is perpendicular to that of lining tubes. The edges of facial plate should be arranged closely to the inner face of upper tube. Prepare four bamboo strips 4.5 cm in width, their length is equal to that of the edge of table. The ends of strips are cut into 45°, fix them to the upper tube with bamboo nails (Fig. 3-92)

The square bamboo table is made in this way (Fig. 3-93)

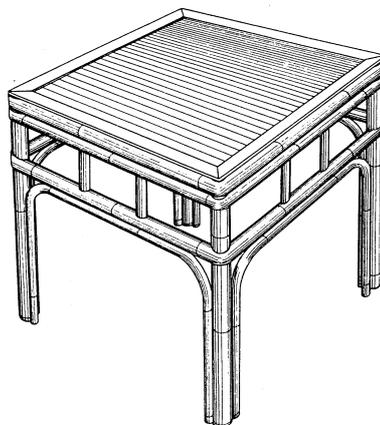


Fig. 3-93 Square bamboo table

4. Bamboo cupboard

As bamboo culm is a hollow tube, its strength is lower than that of wood, therefore the cupboard of bamboo can not be of large size.

Fig. 3-94 shows the making process of a popular bamboo cupboard, it is made in three steps.

The first step is to make the framework of cupboard.

Select four bamboo tubes of same thickness to be used as uprights, number them in a numerical order for connecting with a tube of closed bent mortise properly and firmly.

Select four tubes of the same thickness as that of upright tube, they are to be used to make closed bent mortises, the length of these tubes are decided according to the size of cupboard. Two tubes of closed bent mortise are positioned on the top of framework close to each other, and the other two tubes are on the bottom of framework, also close to each other (Fig. 3-94-1).

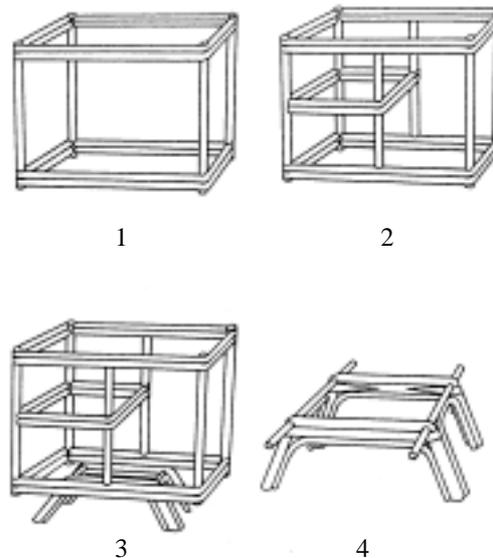


Fig. 3-94-1, 2, 3, 4 Making process of bamboo cupboard

Install one vertical tube in the center of the front frame and one in the rear frame. Select two tubes to connect the center of these vertical tubes by means of bent mortise, the ends of the tubes of bent mortise are to be inserted into the mortise holes on upright tubes of one side of the framework. Select two short tubes to connect the two upright tubes on the mortise holes. These tubes are used to support facial plates (Fig. 3-94-2).

The second step is to make the base of cupboard.

Install two crosswise lining tubes in the lower tubes of closed bent mortise. Two grooves are cut out on each of two thick base tubes to form pentagon bent mortise. The length of groove is $\frac{1}{2}$ of the perimeter of crosswise lining tubes. The ends of base tubes stretch outward to support the cupboard firmly. In order to reinforce the base tubes with bent mortise, two lining tubes are used to support them, and arrange lining tube between every two opposite legs. Tie these parts with rattan if possible (Fig. 3-94-3,4).

The third step is to make facial plates.

Prepare lining strips for facial plates on top, bottom, back, sides and partition, the length of lining strips equals to the lengthwise side of every rectangle form.

There are seven facial plates on this cupboard. The ends of strips are to be inserted into the shorter side tube.

The strips must be arranged correctly and closely. The ends of strips should be fixed in the slit or holes of side tubes.

As a rule, bamboo cupboards are not equipped with doors, because bamboo material is not fit for making a door. Instead of doors textile curtains are hung (Fig. 3-95).

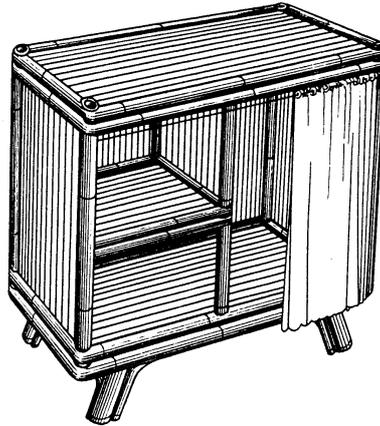


Fig. 3-95 Bamboo cupboard

5. Bamboo bed

Beds made of bamboo are cool, they are very popular in southern parts of China in summer.

Most bamboo beds are single because of their heavy load. Fig. 3-96 shows a single bamboo bed. It is made in three steps.

The first step is to make the framework of bed.

Select four bamboo tubes of same length, 5 ~ 6 cm in diameter to be used as legs of bed. Number them in numerical order.

Select six bamboo tubes of same length, 4 ~ 5 cm in diameter. Put three tubes together to make bent mortises for jointing two legs. The ends of every three tubes are connected to form rectangle closed mortise and fix them with bamboo nails (Fig. 3-96).

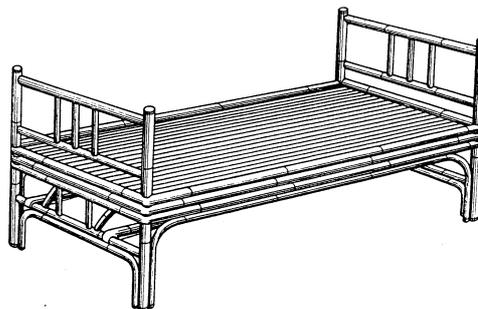


Fig. 3-96 Single bamboo bed

The second step is to reinforce the framework.

Select bamboo tubes of thick wall, 4 cm in diameter, use them as crosswise lining material on both short sides. Select tubes of thick wall to connect every two opposite legs with tube of bent mortise in the form of doorframe on four sides (Fig. 3-97).

Make 8 semicircular strips for inserting into the rectangular frame of bed as lining material (Fig. 3-97).

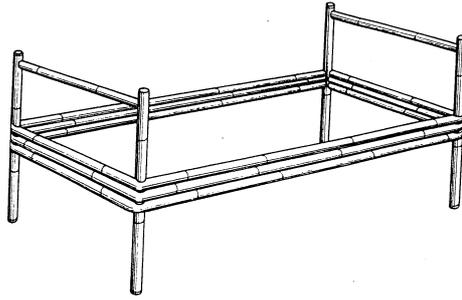


Fig. 3-97 Framework of bamboo bed

Select two tubes to reinforce the framework in bent form, they are used to support the crosswise semicircular strips, connected with the strips and other parts of framework by means of mortise joints.

The third step is to make the base of bed.

The area of base is quite great, therefore it is necessary to select bamboo of larger diameter to cut strips. The strips are to be connected with a string through drilled holes to form the base plate, this plate is to be fixed on the crosswise semicircular strips and connected with the upper tube of bent mortise (Fig. 3-96).

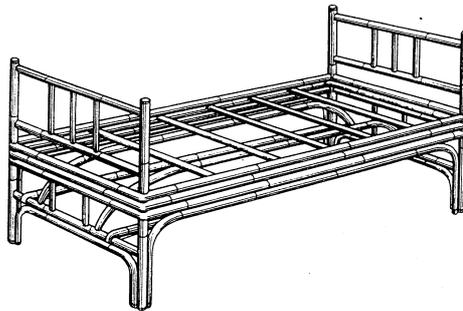


Fig. 3-98 Reinforce the framework

Fig. 3-99 shows a simple bed, which is common in Zhejiang, China. It is 190 cm in length, 72 cm in width and 46 cm in height. The framework is composed of single bamboo tubes, they should be thick, 6 ~ 7.5 cm in diameter, the diameter of lining tubes should be 3 ~ 4 cm.

Make such beds are quite easy. Select two bamboo tubes 190 cm in length, 6 ~ 7 cm in diameter. Cut out 7 ~ 8 semicircular on each of the tubes, insert 7 ~ 8 semicircular lining strips 70 cm in length into the holes of these two tubes to form a frame of the base.

Select two tubes 164 cm in length, 6 ~ 7 cm in diameter, cut two grooves for making bent mortise on each of these tubes. The length from bent mortise to the end is the leg of bed. Meanwhile make mortise holes on legs for jointing with lining tubes. The joints should be strengthened with bamboo nails.

Make base plate of bed according to the inner length and inner width of frame. Fix the plate on the frame with bamboo nails (Fig. 3-99).

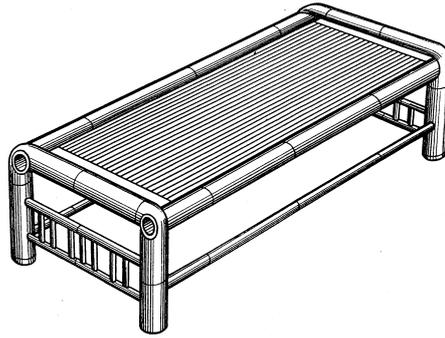


Fig. 3-99 Simple bamboo bed, Zhejiang Province

6. Bookcase and mini-landscape stand

Bookcases and mini-landscape stands embody the beauty of bamboo. By means of bending and connecting bamboo bookcases and mini-landscape stands can be made in diversified forms. They are well received by users.

Fig. 3-100 shows a common bookcase of four shelves. It is made in three steps.

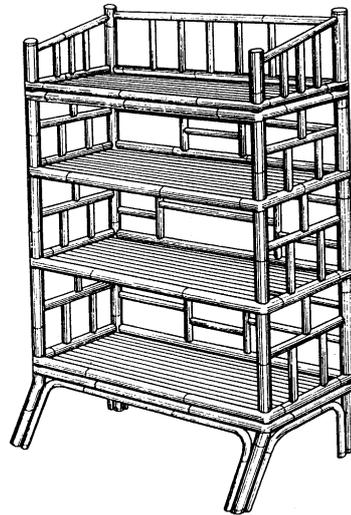


Fig. 3-100 4-shelfed bookcase

The first step is to make the framework of bookcase.

Select four tubes to be used as columns of the bookcase. The foot of two front columns must be bent forward to improve the stability of bookcase. Two rear columns are fixed vertically. Bookcase is to be put close to a wall to avoid falling backward. The space between shelves is decided according to the height of books, in general, it should be 3 cm higher than the book. The first and fourth shelves are equipped with two tubes of bent mortise, the others with one (Fig. 3-101).

The second step is to reinforce the framework.

Four tubes are used as lining tubes to connect every two opposite legs with the lower tube of closed bent mortise. Many short tubes are to form decorative patterns.

The third step is to make facial plates of close strips.

Fig. 3-101 shows a mini-landscape of high grade. The structure and method are similar to those of bookcase.

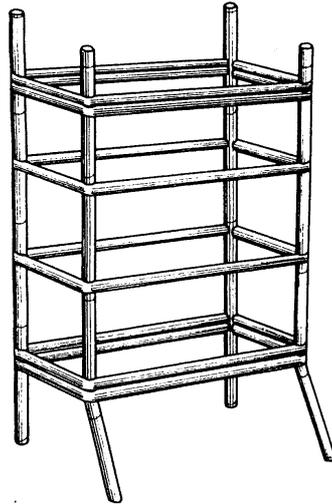


Fig. 3-101 Framework of 4-shelved bookcase

The height of min-landscape is more than 2 m in general. As a mini-landscape is put on its top, the upper part is heavy while the lower is light, the stability of stand is very important keep the mini-landscape on top. The tubes must be bent symmetrically.

As a rule, ordinary stands are equipped with tubes of closed bent mortise in upper and middle parts, those of high grade are with tubes of closed bent mortise in upper, middle and lower parts, of excellent workmanship.

The upper tube of closed bent mortise should be fixed with a facial plate to support the mini-landscape. The decoration patterns are put between middle and upper tubes of closed bent mortise, because the line of sight of consumers is concentrated on this part (Fig. 3-102, 103)

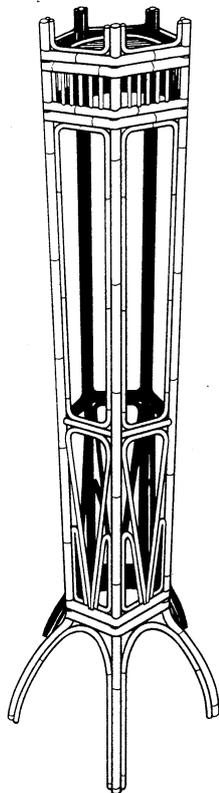


Fig. 3-102 Mini-landscape stand

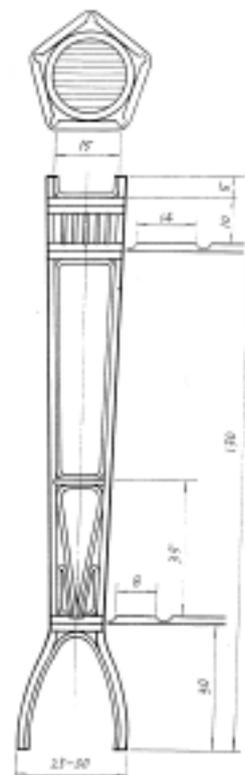


Fig. 3-103 Schematic drawing for making stand

Fig. 3-104 ~ 116 show bamboo furniture of different styles in different areas in China.



Fig. 3-104 Bamboo armchair and tea table, Zhejiang



Fig. 3-105 Small square table and small chair, Suzhou

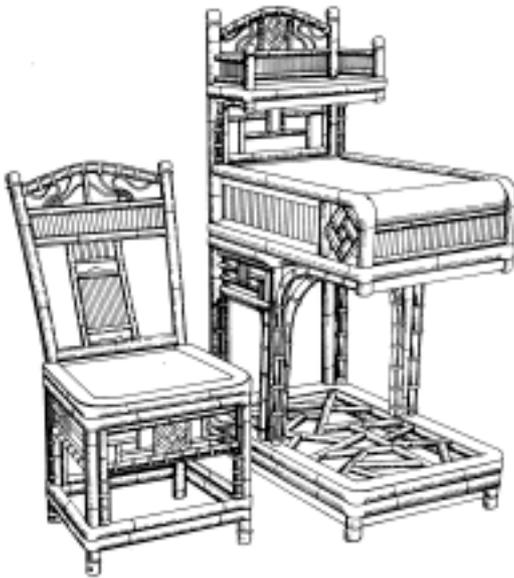


Fig. 3-106 Classic tea table and chair, Hubei



Fig. 3-107 Round table and stool, Sichuan

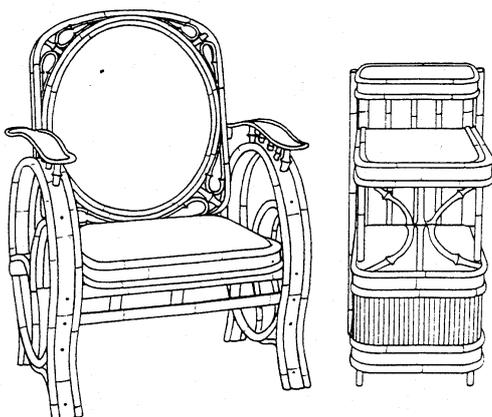


Fig. 3-108 Bamboo armchair and tea table, Sichuan



Fig. 3-109 Round table and stool, Guangdong



Fig. 3-110 Round table and chair, Hunan



Fig. 3-111 Armchair and tea table, Sichuan



Fig. 3-112 Hexagon table, Jiangsu

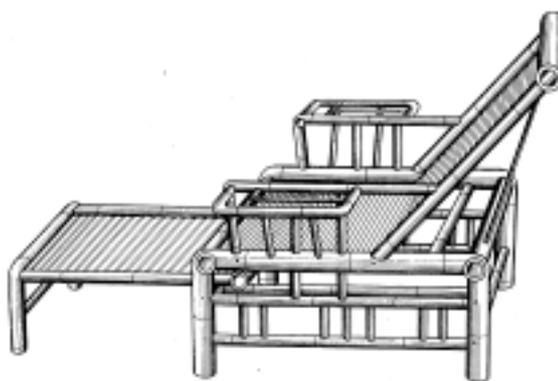


Fig. 3-113 Reclining chair, Sichuan



Fig. 3-114 3-shelved cupboard, Zhejiang

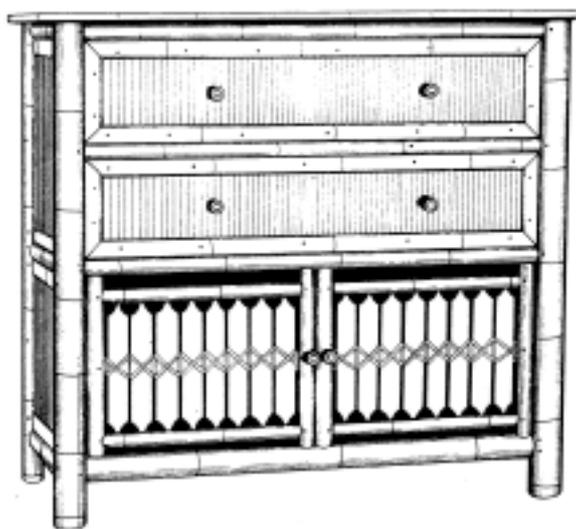


Fig. 3-115 Cupboard with drawers, Jiangsu

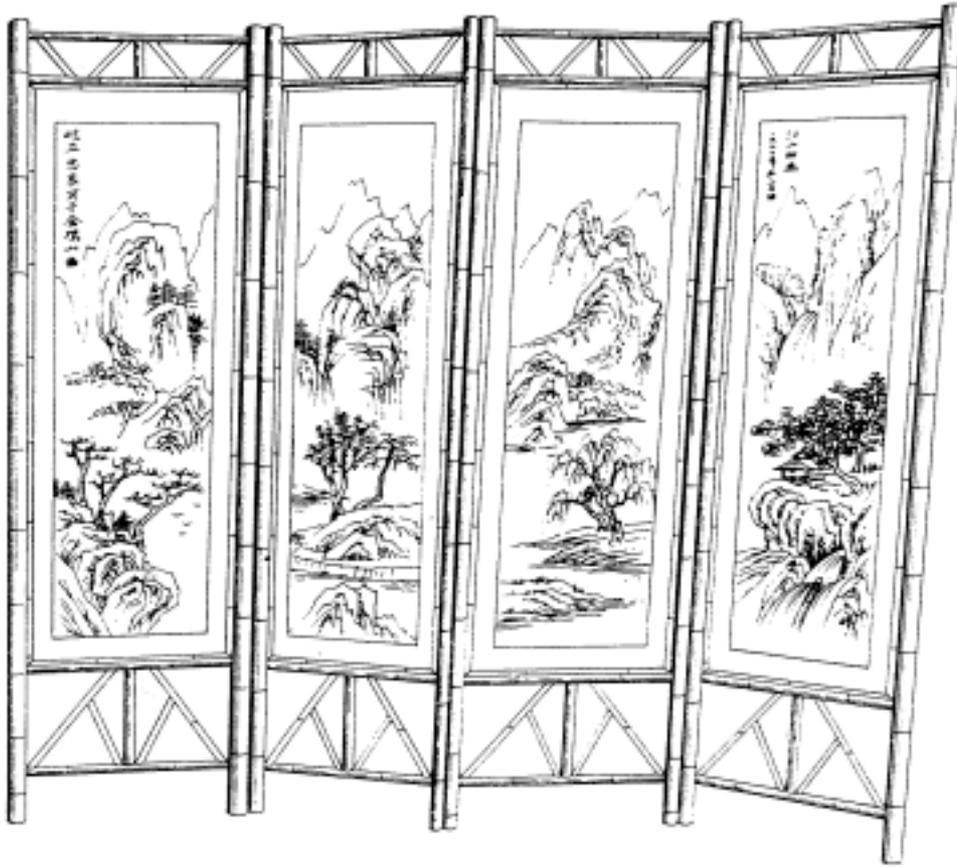


Fig. 3-116 4-piece screen

Chapter 5 Bamboo charcoal and bamboo active carbon

Bamboo charcoal and active carbon is an item of new product developed in recent years. Being of special microstructure, bamboo material possessed extreme absorbing and other special capacities after carbonization. Their uses in the areas of high and new technology are of importance.

1. The variety of bamboo charcoal

There are many kinds of bamboo charcoal. In line with their origin, bamboo charcoal can be divided into two parts: raw bamboo charcoal and charcoal stick of chips. Raw bamboo charcoal is made of small-sized bamboo, old bamboo, bamboo tops, roots, which are not fit for making other bamboo products. Charcoal stick of ships is made of residue from bamboo processing industry. In the process of making bamboo floorboards bamboo mats and other kinds of commodities, there will be vary much residue, they are of different sizes and forms, consequently, they must be broken into chips, dried and pressed into sticks before carbonization.

Charcoals are of different shapes: cylinders, pieces, chips and powder. In line with the temperature of carbonization charcoals can be divided into three groups: charcoal of high, medium and low temperature. Physical and mechanical properties of charcoals differ due to different temperature of carbonization. Charcoal for regulating humidity is made at temperature of 600°C, that for absorbing is at 700 ~ 800°C, and that of high electric conductivity is higher than 1000°C.

According to the their uses charcoals are defined as fuel, for purifying drinking water, for cooking, for bathing, for improving soil for regulating room humidity, for preserving freshness of vegetables, fruits and flowers, for deodorizing, for conducting electricity, etc.

2. The making process of bamboo charcoal

Bamboo material is organic matter of high polymer, composed of cells of different shapes and properties. In the period of growth, chlorophyll in bamboo leaves absorbs dioxide carbon from atmosphere, the root absorbs water, minerals and nutrients from soil. By means of photosynthesis, carbon, hydrogen, oxygen, nitrogen and other chemical elements combine bamboo material, which contains the following matters:

Polysaccharide - cellulose and semi - cellulose.

Lignin(aromatic compound).

Extractable matter - soluble fat and protein.

Ash content

Lignin, cellulose and semi – cellulose compose cell wall of bamboo. The content of cellulose in ordinary bamboo material is about 40~60%. It decreases with the growth of bamboo. For example, the cellulose content of young *Phyllostachys pubescens* is 75%, that of one year old is 66%, 3 years old is 58%. The cellulose content of young *Phyllostachys heteroclada* is 63.42%, that of one year old is 59.96%, 3years old is 59.26%.

The simple molecular formula is $(C_6H_{10}O_5)_n$, the simple chemical formula is $C_6H_{10}O_5$. It means the cellulose is a kind of carbohydrate composed of carbon 44.44%, hydrogen 5.17%, and oxygen 43.39%.

Semi-cellulose means the carbohydrate in polysaccharide matter. The content of semi-cellulose in bamboo material is about 14 ~ 25 %. It differs in different bamboo species, 23.68% in *Phyllostachys glauca*, 22.73% in *Phyllostachys pubescens*, 22.37% in *Phyllostachys sulphurea* and 18.51% in *Neosinocalamus affinis*. It also changes in connection with the growth of bamboo. The content of semi-cellulose in bamboo material of 1 ~ 2 years

old is higher, that in 3 years old is lower, for example, the content of semi-cellulose in *Phyllostachys pubescens* 2 years old is 24.9%, that of 4 years old is 23.65%.

Lignin is a kind of natural high-molecular compound, it does not exist separately in natural environment. It exists together with cellulose and semi-cellulose in cell wall of wood and bamboo. The lignin content in bamboo material is 16 ~ 34 %. It differs in different bamboo species. The lignin content in *Phyllostachys glauca* is 33.4%, in *Phyllostachys pubescens* is 26.41%, in *Bambusa pervariabilis*. As a rule, the content of lignin in older bamboo culm is higher than that in younger.

Along with cellulose, semi-cellulose and lignin, there are other matters, such as protein, starch, fat and gum. The change of these matter influences the color, smell, taste, pest resistance and durability of bamboo material, and its evenness as well. From bamboo material, the lixivium by cold water is 2.5 ~ 5.0%, that by hot water is 5.0 ~ 12.5%, by ether and alcohol is 3.5 ~ 9.0%, by sodium hydroxide of 1% is 21 ~ 31%. The quantity of lixivium decreases with the growth of bamboo. It is more from younger bamboo than that from older one.

The making process of bamboo charcoal is the process of heating and resolution, this process can divided into four stages according to the change of temperature:

A. Drying stage: the temperature in this stage is lower than 120° ~ 150°C, the resolution is very slow, the water content is evaporating continuously by the heat from outside, but the chemical composition remains unchanged. .

B. Pre-carbonizing stage: the temperature in this stage raises to 150° ~ 275°C, the hot resolution of bamboo material becomes evident, the chemical composition begins change and the unstable part of semi-cellulose begin resolve.

C. Carbonizing stage: the temperature in this stage raises to 275° ~ 450°C, the heat resolution develops rapidly, resulting in many disintegrant, the liquid of them are bamboo tar, bamboo acetic acid, the gas are flammable methane, ethylene. This is a stage of heat-release reaction. A great deal of heat is released.

D. Calcining stage: the temperature in this stage raises to 450° ~ 500°C, by heat from outside bamboo material is calcined, residual volatile matter is released, and the content of carbon is increased. In this stage, jar and other liquids are decreased to the minimum.

In the process of heat resolution lignin resolves at the temperature of 225° ~ 235°C, cellulose at 240° ~ 400°C, lignin at 280° ~ 550°C. Different temperature of carbonization influences the quantity and compound of charcoal.

3. Methods of charcoal making

There are two methods for charcoal making: dry distillation – pyrogenic decomposition, direct kiln burning.

The main equipment for dry distillation – pyrogenic decomposition is a cauldron for distillation. Bamboo material should be pre-dried to decrease the water content to $\pm 20\%$ before loading into the cauldron for pyrogenic decomposition. The mixed steam-gas is to be processed in jar-separator and in condenser for retrieving bamboo vinegar liquid and bamboo tar. In this process the oxidation of bamboo material is lower, and the rate of production is higher, it reaches $\pm 25\%$.

In the process of direct kiln burning, the heat resulted from fuel burning curls up to the top of kiln and spreads in the kiln. Most of the heat moves about in the upper part of kiln, the rest of it radiates on all sides, step by step goes down to dry and pre-carbonize bamboo material. In the process of carbonization a small part of bamboo material is being oxidized and burnt, raising the temperature in the kiln and removing volatile matter. The smoke and

steam move in circles, and regulating the temperature in kiln. Thus complete the carbonization and refining process, producing charcoal fine and close in texture. In this process bamboo material undergoes stages of pre-drying, drying, pre-carbonizing, carbonizing, refining and natural cooling. The temperature differs in different stages. It is 60° ~ 100°C for pre-drying, 100° ~ 150°C for drying, 150° ~ 270°C for pre-carbonizing, 270° ~ 450°C for carbonizing and 450° ~ 1000°C for refining. The temperature of refining stage influences the density and electric conductivity of charcoal greatly. The rate of production of this method is low, and the quality of charcoal is not stable.

4. Matters resulted from pyrogenic decomposition and their properties.

The matters resulted from pyrogenic decomposition are in solid, liquid and gaseous states.

A. Solid matter

The solid matter produced in pyrogenic decomposition is bamboo charcoal. Bamboo charcoal is made in the form of cylinders, chips or powder, depending on the shape of raw material.

The resistivity of bamboo charcoal can be high, middle or low. The electric conductivity of charcoal depends on its density, moisture content, ash content, refinement and other factors. Bamboo charcoal of higher density, better refinement, less ash content and low resistivity possesses higher electric conductivity.

There are many elements in the ash of bamboo material, among them are phosphorus, potassium, silicon, calcium, aluminium, magnesium, iron, sodium, barium, copper, strontium, nickel, etc. The content of silicon, aluminium, sodium and iron is comparatively high in outer part of bamboo culm wall, while the content of phosphorus, potassium and magnesium is higher in the yellow matter in inside part. SiO₂ mainly exists in silicon cells of surface part of bamboo material. These elements influence the electric conductivity of bamboo charcoal

The production of bamboo charcoal is still in its beginning stages at present. Their quality standards haven't been worked out yet. The main physical and chemical properties are shown in table 3-2

B. Liquid matter

Table 3-2 Main physical and chemical properties of bamboo charcoal

Items	Raw bamboo charcoal		Charcoal stick of chips	
	1 st grade	2 nd grade	1 st grade	2 nd grade
Moisture content %	<7	<7	<8	<8
Ash content %	<2.5	<3.0	<3.0	<4.0
Carbon content %	>88	>85	>86	>82
Volatile matter %	<6	<8	<8	<8
Calorie value of dried charcoal KJ/kg	>33000	>31300	>31800	>30100
Value of PH	8	8	9	9

The mixture of steam and gas emerges in the process of carbonization is condensed and separated to produce crude vinegar liquid. The liquid is divided into two layers after sediment. The upper layer is clean bamboo vinegar liquid, the lower layer is sediment bamboo tar.

The clean bamboo vinegar liquid is smells smoky, contains acetic acid, methyl alcohol and other chemical compounds. The sediment bamboo tar is a kind of black oily glutinous liquid, it contains a great deal of phenol matter, including organic matters. Its composition is very complicated and the techniques of its utilization are to be studied.

C. Gaseous matter

Carbon monoxide, methane, ethylene and other gaseous matters emerge in the process of bamboo pyrogenation. The composition and quantity of gaseous matters relate to the temperature of carbonization, speed of heating and other factors.

5. Methods for determining the physical and chemical properties of bamboo charcoal

A. Determine the moisture content

Key points; Moisture content means the total water contained in the samples when they are taken. Weigh the sample of certain quantity and dry it at the temperature 102~105°C to reach the constant weight. The moisture content is the lost weight divided by the primary weight expressed in percentage.

Apparatus

Drying chamber: with automatic temperature-regulating device and air-blower or ventilator.

Desiccator: with drying agent (undeliquescent calcium chloride cubes or silica gel)

Glass-faced dish: 190 mm in diameter

Industrial scales: precision up to 0.1 g.

Specific measures:

Homogenize the sample rapidly, the granule size must be less than 10 mm. Take 100 g (precision up to 0.1 g) of sample, put it into the glass-faced dish, (the weight is known). Put load the dish with sample into the drying chamber of temperature 102~105°C. Unload it after 2~3 hours of drying, and cover it closely. Put it into a desiccator to cool the sample to room temperature and weigh.

Dry the sample for 30 minutes and weigh it again, repeat these steps until the decrease of weight is less than 0.1 g, or the weight does not increase. In the latter case the weight measured before the increase is to be applied for calculation.

Calculation:

The moisture content W (%) is calculated according to the following formula;

$$W=(G_1/G) \times 100\%$$

Where: G_1 – the decrease amount of weight (g)

G – the weight of sample (g)

Allowable error

The allowable error of calculated moisture content $\leq 0.4\%$

B. Analyze the sample

(1) Sample treatment: rind the charcoal to be used as sample until it is completely sieved through pores of 0.3 mm. Dry it to constant weight at 102~105°C. The weight of sample must not be less than 50 g.

(2) Determine ash content: put the sample of proper weight into a electric furnace of high temperature to incinerate it at $815 \pm 10^{\circ}\text{C}$, weigh it after cooking, the weight of residual part is to be used to calculate the ash content.

Apparatus:

Electric furnace: with a temperature-regulating device maintaining $815 \pm 10^{\circ}\text{C}$, with a thermocouple and thermometer of high temperature.

Ash container: 45 mm in length, 22 mm in width and 14 mm in height.

Desiccator: as that for determining moisture content.

Specific measures:

Take 1 g of charcoal from the sample treated in B (1), the precision of weight is up to 0.0002 g. put the sample into a porcelain crucible with cover, load the crucible with sample the electric furnace, open the crucible and raise the temperature to 500°C . Keep the temperature for 30 minutes, raise the temperature further to $815 \pm 10^{\circ}\text{C}$, incinerate it at $815 \pm 10^{\circ}\text{C}$ for 1 hour. Take out the crucible, cover it and cool it in open air for 5 minutes, put into desiccator to cool to room temperature and weigh.

Incinerate the sample at 815°C for 30 minutes and weigh, repeat these steps until the decrease of weight is less than 0.001 g, or the weight does not increase. In the latter case the weight measured before the increase is to be applied for calculation.

Calculation:

The ash content A (%) is calculated according to the following formula:

$$A = (G_1/G) \times 100\%$$

Where: G_1 – the weight of residual part after incineration

G – the weight of sample

Allowable error:

The allowable error in one and the same laboratory is 0.2%, in different laboratories is 0.3%.

(3) determine the volatile matter: key points: take a sample of certain weight, put it into a porcelain crucible. Heat it at $900 \pm 10^{\circ}\text{C}$ without air for 7 minutes. Calculate the lost weight as the content of volatile matter. The operation must be repeated anew if sparks are observed.

Apparatus:

Porcelain crucible: 40 cm in height, the inner diameter of upper rim is 30 cm, outer diameter of base of 18cm, the out diameter of cover is 35 cm.

Electric furnace: the same as that for determining ash content.

Crucible rack: the rack is made of chrome-nickel steel, the base of crucible put on this rack must be 10~15 mm over the base of furnace.

Stopwatch or timer.

Analytical scales: the same as that for determining ash content.

Desiccator: the same as that for determining moisture content.

Specific measures:

Take 1 g of charcoal from the sample mentioned in B (1), the precision should be up to 0.0002 g. cover the crucible with a lid, wave it slightly to make the sample distributed evenly in crucible. Put it on the rack and load rack with crucible rapidly onto the electric furnace,

which must be preheated to 900°C. Close the door of furnace tightly and heat the sample for 7 minutes. At the beginning of test the temperature in furnace may decline. It must be return to 900± 10°C within 3 minutes. Otherwise the furnace must be preheated to 902°C. Unload the rack with crucible after the test and put them on a porcelain plate, cool them in fresh air for 5 minutes. Move the crucible from the rack and put it into desiccator, cool it for about 30 minutes to recover room temperature and weigh.

Calculation:

The content of volatile matter is calculated according to the following formula:

$$V = (G_1/G) \times 100\%$$

Where: G_1 -the decrease of weight after test

G – weight of sample (g)

Allowable error:

The allowable error in one and the same laboratory is 0.3%, in different laboratories is 0.5%.

(4) Determine the content of carbon:

The content of carbon C (%) is calculated according to the following formula:

$$C = 100 - (A + V)$$

Where: A – ash content of the sample (%)

V – volatile matter content of the sample (%)

(5) Determine the caloric value of dried charcoal:

Specific measures: take a sample of certain weight and put it into an oxygen container of calorimeter, burn it completely, record the raise the temperature accurately. Thereby calculate the caloric value.

The unit for calculation is J or KJ.

Apparatus:

The calorimeters usually used are of constant temperature or of heat insulation.

Main parts of calorimeter;

- Oxygen container: made from heat and corrosion resisting alloy steel of chrome-nickel or chrome-nickel-molybdenum.

- Inner cylinder: made of corrosion resisting metal, the inner and outer surface must be electroplated and polished.

- Outer cylinder; a double-walled metal container.

- Mixer; a propeller mixer, rotational speed 400~600 r.p.m.

- Thermometer for measuring heat: minimum scale value 0.01°C

- Ordinary thermometer, minimum scale value 0.2 °C, working range 0~50 °C.

Attached parts:

- Magnifying lens for reading thermometer with head lamp, magnifying five times.

- Vibrator, vibrating thermometer before reading..

- Container for burning, made of platinum or chrome-nickel steel, 17 mm in height, the diameter of upper part is 26 ~ 27 mm, that of base is 19 ~ 20 mm, the thickness of container wall is 0.5 mm.

- Manometer and oxygen pipe.

- Port-fire, 15 ~ 24 V.

- Depressor.

- Stopwatch.

- Scales

Analytical scales, the same as that for determining ash content.

Industrial scales, the same as that for determining moisture content.

- Reagents and materials

Oxygen.

Benzoic acid.

Acid pickling asbestos, to be burnt at 850 ~ 900°C for half an hour before using.

Port-fire wire of chrome-nickel, 1400 J/g.

Method for determination:

Apply Bunte formula for cooling and correcting to calculate the heat energy.

- Take 1 ~ 1.2 g from container for burning as analytical sample.

- Take a piece of port-fire wire, the weight of which is known.

- Add 10 ml of water into oxygen container, cover it with a lid carefully and tightly.

- Regulate the temperature of water in inner cylinder, make the temperature in inner cylinder higher than in outer cylinder by 0.5 ~ 1°C at the end of test. The temperature of water in outer cylinder should approach to room temperature, the difference should not exceed 1°C.

- Weigh the water in cylinder after temperature regulation on industrial scales, the precision up to 1 g. .

- Load the oxygen container into inner cylinder with water.

- Connect the oxygen container with port-fire electrode, with mixer and heat measuring thermometer, cover with the lid of outer cylinder.

- Connect with the mains and start the mixer.

- Apply Bunte formula to cool and correct, record the temperature at the beginning, main and ending stages.

Observe the temperature every minute after 5 minutes of mixing, until the difference between two close observations is less than 0.003°C. At the moment starts the beginning stage. Record the temperature, then record it once every minute, altogether 6 records in 5 minutes. Turn on the electricity to heat the sample, entering the main stage.

In the main stage, record the temperature every half a minute, until it begins to decline. The first record of declining temperature is regarded as the end of the main stage (tn).

In the ending stage record the temperature every minute, altogether 6 records in 5 minutes.

- Stop mixing and unload the oxygen from inner cylinder.
- Open the air-flow valve.
- Open the oxygen container, check the body of oxygen container and container for burning, if any residual carbon black, the test is invalid.
- Measure the length of residual wire of port-fire and calculate the actual consumption of the wire.

Calculation:

The formula for calculating the quantity of heat

$$\frac{Q}{DT} = \frac{KH[(t_n + hn) - (t_0 + h_0) + c] - \sum q}{G}$$

Where: $\frac{Q}{DT}$ — calorific value of sample in the oxygen container body, J/g,

G — weight of sample, g,

\sum — total quantity of heat released by port-fire wire and added matter, J,

K — heat capacity of thermometer,

H — average graduation value of thermometer, °C,

t_n — final temperature, °C,

hn — corrective value of graduation at temperature t_n , °C,

t_0 — ignition temperature, °C,

h_0 — corrective value of graduation at temperature t_0 , °C,

c — corrective value of cooling, °C,

$$\text{High calorific value } \frac{Q}{G_w} = \frac{Q}{DT} - (95 \frac{S}{DT} + \alpha \frac{Q}{DT})$$

$\frac{Q}{G_w}$ — phosphorus content determined in charcoal analysis of the water used to wash the oxygen container body, when the content of burnt phosphorus is less than 4%, or $\frac{Q}{G_w}$ is larger than 14636J/g, it can be replaced with full phosphorus or flammable phosphorus.

α — proportional decimal. $\alpha = 0.0016$

The demarcation of heat capacity of thermometer for measuring heat:

The heat capacity of thermometer for measuring heat is demarcated according to GB384.

The allowable error in calculating calorific value:

High calorific value $\frac{Q}{G_w}$ (J/g):

170 for operation in one and the same laboratory.

420 for operation in different laboratories.

6. The utilization of bamboo charcoal

The development of bamboo charcoal production is in its initial stage at present, the techniques of its production and utilization are to be researched. Bamboo charcoal is utilized in the following areas:

A. Purifying water

Thanks to its micro-porous structure, bamboo material possesses excellent absorbing capability after carbonization. Bamboo charcoal can be used to treat drinking water for eliminating organic impurities and offensive smells. This method is better than using chlorine or bleaching powder. Because, added with chlorine, hydrocarbon chlorides are formed in treated water, which are harmful to human health. It is better to combine the treating matters, at first disinfect water with chlorine, then eliminate the residual chlorine and chloride with bamboo charcoal.

Bamboo charcoal can be used not only for treating drinking water, but also for sewage and industrial water treatment.

B. Purifying air

Main pollution source of air is phosphorus dioxide, carbon monoxide, hydrogen sulfide released from chimneys and offensive smells formed in living environment. Proper amount of bamboo charcoal can absorb these offensive smells and harmful gases, and regulate air temperature, put down the multiplication of moulds and microorganisms.

Bamboo charcoal in refrigerator eliminates strange smells, it is propitious for preserving the freshness of foods. It also functions as dehumidizer, anti-mould agent and deodoriser in shop-windows or cupboards. When cooking rice, bamboo charcoal helps to eliminate the residual pesticides and improve the quality of rice. Bamboo charcoal positioned by computers, televisions and microwave ovens shelters users from the radiation of electromagnetic wave.

C. Absorbing unpleasant odors

Bamboo charcoal helps to eliminate the unpleasant odors of food in refrigerators, keeps rice fresh and dry.

D. Health-care capacity of bamboo charcoal.

Bamboo charcoal releases natural fragrance and radiates far infrared rays. The far infrared rays stimulate the network of passages of human body, along which acupuncture points are distributed. Therefore it protects human health. Bamboo charcoal pillows and mattress are good for health.

Bamboo charcoal performs some other specific functions, it may improve women's look, improve soil, promote the growth of root system of plants.

7. Bamboo vinegar liquid and its utilization.

A. The main content of bamboo vinegar

Bamboo vinegar liquid is a kind of by-product of bamboo carbonization. It contains many organic compounds. The quantity depends on the species and quality of bamboo material, and carbonization conditions. The content of liquid varies with the methods of its collection and storage.

Along with a great deal of water content, the liquid contains a lot of chemical compounds, such as acetic acid, formic acid, butyric acid, phenol, aldehyde, saturated alcohol and unsaturated alcohol. Its pH value is 2.20 ~ 3.01, and the specific gravity is about 1.02.

B. The separation and refinement of vinegar liquid

Laid aside for a certain period of time, bamboo vinegar liquid decomposed into two layers, the upper one is clean vinegar liquid and the lower one is bamboo tar.

The clean vinegar liquid contains 10 ~ 20% of organic matter. Acetic acid, butyric acid, methyl alcohol and other organic solutions can be obtained by processing this liquid. The sediment bamboo tar contains a great deal of phenol matter, which can also be obtained by processing the tar.

The development of bamboo charcoal and bamboo vinegar liquid is a newly born industry of certain scale. But their production and utilization technology is to be studied further.

The superior absorbing capability of bamboo active opens a vast range of prospects for environment protection. The consumption of active carbon for water and gas treatment is very high in developed countries. In the United States the annual consumption exceeds 70 thousand ton, while in Japan more than 50 thousand ton is used for environment protection annually. The problem of environment pollution is quite serious in China, the water in Huaihe River, Taihu Lake and Pearl River is being polluted seriously, therefore the production and utilization of active bamboo carbon will benefit the health of local people. Bamboo active carbon can be used to refine coarse sugar. The annual consumption of sugar exceeds 6 million ton in China, while the production is 4 ~ 5 million ton. As the coarse sugar is decolorized by using phosphorus, the refined sugar gets dump and agglomerated easily, furthermore, the residual phosphorus in sugar may cause cancer. With the improvement of living standards and awareness of self-protection in China, phosphorus will not be used for sugar refinement, and active carbon will be in great demands. The sugar industry needs about 20 ~ 40 thousand ton of active carbon. Active carbon decolorizes the sugar, and removes pigments, moulds and ash contents from coarse sugar, promotes the speed of its crystallization. Bamboo active carbon can be used for refining wines of high grade and edible oil. In pharmaceutical industry bamboo active carbon can be used to refine antibiotics, vitamins and sulfanilamide, and remove pigments and impurities.

Bamboo active carbon is widely used in civil and military industries for filling gas masks, for purifying discharged steam or gas, preventing environment pollution and recovering useful matters. It is also used as deodorant in refrigerators, bathrooms and pools. The function of cigarette filter tip can be improved by adding bamboo active carbon. Bamboo active carbon in filter tips not only absorbs air-soluble glue particles, but also removes methyl benzene, methyl alcohol, acrylic aldehyde and other harmful matters. This is the function which ordinary filter tips can not perform.

Bamboo active carbon can be used in many other ways. It can be used as filter of emergency ventilation system of atomic reactor, to absorb radiating xenon and krypton, to prevent the pollution by discharged gas. It can be used in cosmetic communication to absorb interfering gas for guaranteeing correct communication. It can be used in agriculture to promote the nitrogen fixation, to speed up the formation of ammonia and nitrate from organic nitrogen, to regulate the soil structure, raise soil temperature, absorb the harmful matters in soil. It can also be used as electrode material in microelectronic technology, as compound catalytic agent, for the storage of energy matter. It is evident that bamboo active carbon will be used widely in the area of high-tech as a kind of newly developed material.

References

- Zhang Qisheng et al. 1995. Industrial utilization of bamboo in China. China Forestry Publishing House, Beijing, China.
- Zhang Qisheng. 1988. Study on plybamboo I; Journal of Nanjing Forestry University, 12(4), 18-20.
- Zhang Qisheng. 1989. Study on plybamboo II; Journal of Nanjing Forestry University, 13(1), 32-38.
- Zhang Qisheng. 1989. Study on plybamboo III; Journal of Nanjing Forestry University, 13(2), 13-18.
- Zhang Qisheng. 1990. Improvement of gluing feature of bamboo; Wood Industry (Japanese). (1) 16-20.
- Zhang Qisheng; Sun Fengwen. 1990. Study on bamboo composite board; China Forest Products Industry, 17(1)
- Zhang Qisheng et al. 1990. Medium test of bamboo particle composite board; China Forest Products Industry, 17(6)
- Zhang Qisheng et al. 1991. Study on application of bamboo plywood to trucks; China Forest Products Industry, 18(6) 1-4
- Jiang Shenxue. 1995. Study of bamboo piece softening machine with conveying chain; Journal of Nanjing Forestry University. 19(1), 53-58
- Zhang Qisheng et al. 1995. Study on coated plybamboo concrete forming with high-strength; China Forest Products Industry, 22(3)
- Zhang Qisheng et al. 1995. Scientific and rational utilization of bamboo resource in China; Woodworking Machinery, 6(4)
- Zhang Qisheng et al. 1995. Wood and bamboo composite structure is scientific and rational way utilizing bamboo resource; China Forest Products Industry. 22(6) 4-6
- Zhang Qisheng et al. 1997. Study on bamboo and wood composite container floor; Forestry Science, 33(6), 536-542
- Zhang Qisheng et al. 1999. Development and prospect of bamboo industry in China; China Forest Products Industry, 26(4)
- Tang Yongyu. 2001. Research on present situation and exploiting direction of bamboo usage; Journal of Bamboo Research, 20(3), 36-43.
- Zhang Qisheng et al. 2002. Pay great attention on the chemical application and exploit bamboo charcoal technology; Journal of Nanjing Forestry University, 26(1), 1-3
- Jiang Shenxue et al, 2002. On structure, production and market of bamboo-based panels in China; Journal of Forestry Research, 13(2) 151-158