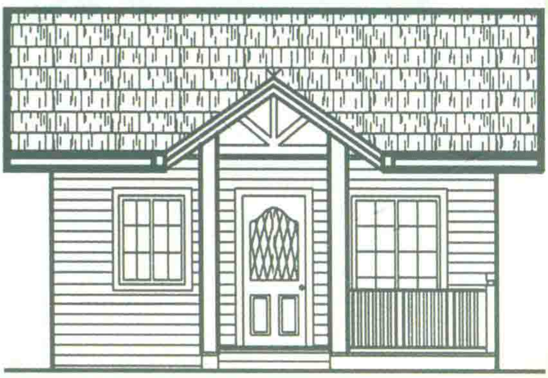
TECHNICAL MANUAL

Prefabricated Modular Bamboo Houses

Chief Editor Jiang Zehui



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PREFACE

Bamboo is a fast growing renewable resource and a good substitute for wood. Prefabricated modular bamboo panel houses can be easily packed flat, shipped and quickly assembled at sites, with good market potential for both low-cost and high-end houses under all kinds of climatic conditions, and also would be an ideal solution for disaster victims.

This technical manual is jointly prepared by International Center for Bamboo and Rattan (ICBR), Research Institute of Wood Industry, Chinese Academy of Forestry and Jiangsu Building Science Research Institute Co Ltd for training technicians from AEC, Nepal and FeMSEDA, Ethiopia, funded by the Project "Development and Commoditization of the Pre-fabricated Modular Bamboo Housing in Asia and Africa" sponsored by CFC and supervised by INBAR.

This technical manual mainly introduces:

- Technology and equipment for making structural grade bamboo plywood products
- Standards of structural grade bamboo plywood products
- Properties of bamboo plywood products made from Nepal and Ethiopia bamboo species
- Construction and maintenance of bamboo panel prefabricated houses

This manual is a collection of advanced and practical technology on production and utilization of structural grade bamboo based panels, and will be a good reference for scientists and professionals in bamboo based panels industry in tropical Asia and Africa and the rest of the world.

On the occasion of publishing, we would like to express our heartfelt thanks to all individuals and organizations that have showed interests and rendered support to this Manual. Any comments from readers are very much appreciated.

Prof. Jiang Zehui

Director General

International Centre for Bamboo and Rattan

Sept 2015

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1. INTRODUCTION

Bamboo is a fast growing renewable resource. Compared with wood, bamboo has a higher strength/weight ratio and it can be a good substitute for wood.

Bamboo has long been used for both structural and decorative uses, mainly as culms. Because bamboo properties vary among species, between culms of same species, and between pieces of the same culm, bamboo culms cannot match reconstituted bamboo regarding the properties that can be controlled by processing. When the variables for processing are properly selected, the end result can sometimes surpass nature's best effort. Panels are good examples of this processing.

Bamboo based panels are made from bamboo-based materials through a series of mechanical and/or chemical processes (including addition of adhesives); they are pressed at a certain temperature and pressure, and featured in large standard sizes, with good and stable physical and mechanical properties. There is a big potential for bamboo based panels to be used as engineering materials for decorative and/or structural purposes.

1.1 Categories of bamboo based panels

1.1.1 Categories based on composition of panels

(1) Bamboo based panels made from the same and/or similar basic bamboo elements, such as bamboo flooring, bamboo fiberboard, bamboo particleboard, bamboo plywood, bamboo laminated lumber, etc.

(2) Bamboo based panels made from bamboo and other lignocellulosic materials, such as bamboo wood composite flooring, wood veneer faced bamboo plywood, laminated paper, veneer faced bamboo plywood, etc.

1.1.2 Categories based on adhesive used

(1) Bamboo based panels for indoor uses. Bamboo based panels made with UF or other adhesive with similar performance.

(2) Bamboo based panels for outdoor uses. Bamboo based panels made with PF or other adhesive with similar performance.

1.1.3 Categories based on shape of panels

(1) Flat-pressed bamboo based panels. Panels are made by the pressing method in single or multiple-opening hot presses, and the surfaces of the panels are flat. Most of the bamboo based panels are flat-pressed panels.

(2) Molded bamboo based panels. Molded bamboo based panels are glued to the desired shape between curved forms. The corrugated roofing sheet is a typical kind of molded bamboo based panels.

1.2 Physical-mechanical properties of bamboo-based panels

Bamboo-based panels are a new type of panels that have been developed in the last two decades using bamboo as the major raw material. For the proper use and application of bamboo-based panels, their physical-mechanical properties are important, which are determined not only by the raw materials such as species and age of bamboo and type of adhesive, but also by the product structure and production technologies.

1.2.1 Physical properties

1.2.1.1 Density

Density is the most important indicator of the physical-mechanical properties of bamboo-based panels, as it has great influence not only on nearly all the other physical-mechanical properties, but also on the cost, and the consumption of raw material and energy in the production. Therefore, the product structure and production technologies have to be designed in such a way that it can not only ensure the required properties but also reduce the density to the lowest possible level.

1.2.1.2 Moisture content

The moisture content of bamboo-based panels is indicated by the absolute moisture content (H), which can be calculated according to the following formula:

$$H=\frac{M_H-M_0}{M_0}\times 100\%$$

Where, MH—the mass of specimen before drying, (g);

M_0—the mass of specimen oven dried,(g).

Usually the moisture content of bamboo-based panels produced with phenol formaldehyde resin should be lower than 10% and those with urea formaldehyde resin should be below 12%.

Besides, as bamboo-based panels can absorb moisture just as bamboo does, they also reach an equilibrium moisture content when the rates of absorption and loss of water balances in the air with a given temperature and relative humidity.

1.2.2 Mechanical properties

Since bamboo-based panels are mainly used as engineering materials for structural and decorative applications, their mechanical performance is an important indicator of the product quality.

1.2.2.1 Modulus of rupture (MOR)

The modulus of rupture (MOR) refers to the capacity of a material under bending stress and can be calculated according to the following formula, based on a three point bending test:

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

Where: *MOR*—modulus of rupture of specimen (MP_a);

P—maximum destructive load of specimen (N);

L—span between supports (mm);

b—width of specimen (mm);

h—thickness of specimen (mm).

1.2.2.2 Modulus of elasticity (MOE)

The modulus of elasticity (MOE) is the ratio of stress and strain of the material regarded as an elastomer, and can be calculated according to the following formula:

$$MOE=\frac{L^3}{5bh^3}\times\frac{\Delta P}{\Delta f}$$

Where, *MOE*—modulus of elasticity (MP_a);

L—span between supports (mm);

b—width of specimen (mm);

h—thickness of specimen (mm).

$\frac{\Delta P}{\Delta f}$—the slope of the load-deformation diagram within proportional elastic limit

1.2.2.3 Bonding Strength

The bonding strength refers to the capacity of the adhesive joint bearing shear stress and indicates the firmness of bonding.

$$I=\frac{P}{AB}$$

Where: *I*—bonding strength of specimen (MP_a);

P—maximum destructive load of specimen (N);

A—width of shearing face of specimen (mm);

B—length of shearing face of specimen (mm).

1.2.2.4 Impact toughness

The impact toughness refers to the energy absorbed by a unit surface area of the material when broken under impact and can be calculated according to the following formula:

$$T=\frac{A}{bh}$$

Where: *T*—impact toughness (J/mm^2);

A—energy absorbed by specimen (J);

b—width of specimen (mm);

h—height of specimen (mm).

1.3 Manufacturing process of bamboo-based panels

There are various kinds of bamboo-based panels, each kind having its specific manufacturing process. How different they are, all the processes include such essential steps as material preparation, drying, glue spreading, hot pressing and finishing.

1.3.1 Material preparation

Successful manufacture of any bamboo composite product requires control over raw materials. Ideally, raw materials are uniform, consistent, and predictable. Bamboo does not offer these qualities but instead varies widely between species and culms. For the purpose of producing a composite product, uniformity, consistency, and predictability are accomplished by reducing separated portions of the bamboo into small, relatively uniform and consistent basic elements, such as particles, fibers, veneers, strips, strands and slivers, where effects of differences would average out. The degree of size reduction and the size and shape of individual basic element will depend on the application and structure of the product.

1.3.2 Drying

The prepared bamboo based lignocellulosic materials usually have a high moisture content and thus need to be dried to ensure the finished products' quality. The methods, techniques, equipment and heat supply for drying are different due to the varying sizes and shapes of the materials prepared. For example, hot air convection kiln drying is applied for bamboo floor sheets, a jet mesh dryer is suitable for bamboo curtains and mats, a rotary dryer for particles, and/or a bowline dryer for drying fibers.

1.3.3 Glue application

Commonly used resin–binder systems include phenol-formaldehyde, urea formaldehyde, melamine-formaldehyde, and isocyanate.

Phenol-formaldehyde (PF) resins are typically used in the manufacture of products requiring some degree of durability in exterior exposure. These resins require longer press times and higher press temperatures than do urea-formaldehyde resins, which results in higher energy consumption and lower line speeds (productivity). Products using PF resins (often referred to as phenolic) may have lower dimensional stability because of lower moisture contents in the finished products. The inherently dark color of PF resins may render them unsuitable for decorative product applications such as paneling and furniture.

Urea-formaldehyde (UF) resins are typically used in the manufacture of products where dimensional uniformity and surface smoothness are of primary concern, for example, particleboard and MDF. Products manufactured with UF resins are designed for interior applications. Their thermal behavior can be resistant from room temperature to 150°C; press times and temperatures can be moderated accordingly. Urea-formaldehyde resins are more economical than PF resins and are the most widely used adhesives for composite wood products. The inherently light color of UF resins make them quite suitable for the manufacture of decorative products.

Melamine-formaldehyde (MF) resins are used primarily for decorative laminates, paper treating, and paper coating. They are typically more expensive than PF resins. MF resins may be blended with UF resins for certain applications (melamine urea).

Isocyanate as diphenyl methane di-isocyanate (MDI) is commonly used in the manufacture of composite wood products; MDI is used primarily in the manufacture of wood OSB. Facilities that use MDI are required to take special precautionary protective measures.

These adhesives have been chosen based upon their suitability for the particular product under consideration. Factors taken into account include the materials to be bonded together, moisture content at time of bonding, mechanical property and durability requirements of the resulting composite products, and of course, resin system costs.

A number of additives are used in the production of conventional composite products. One of the most notable additives is wax, which is used to provide finished products with resistance to aqueous penetration. In particle- and fiberboard products, wax emulsion provides excellent water resistance and dimensional stability when the board is wetted. Even small amounts (0.5% to 1%) act to retard the rate of liquid water pickup. These improved water penetration properties are important for ensuring the success of subsequent secondary gluing operations and for providing protection upon accidental wetting to the product during and after construction.

The water repellency provided by the wax has practically no effect upon dimensional changes or water adsorption of composites exposed to equilibrium conditions. Other additives used for special products include preservatives, fire retardants, and impregnating resins.

Phenol formaldehyde resin and urea formaldehyde resin are the two most commonly used adhesives for gluing basic bamboo elements. Appropriate methods have to be applied in accordance with their sizes and shapes in order to spread an even and thin layer of glue on the adhesion joints. For example, a roller glue spreader can be used for bamboo strips, dipping in low concentration PF adhesive is used for bamboo curtains and mats, and blending is used for bamboo particles.

1.3.4 Assembling and hot pressing

After glue application, basic bamboo based lignocellulosic elements are assembled to mats according to product structures. Very often assembling is done manually, except bamboo particles and fibers that have to be formed into mats by mechanical and /or air-felting machines.

Hot pressing is an important step in the manufacturing process to make the formed mats into boards. The often-used equipment is a multi-daylight press with loading, unloading and caul plate system. The mats can be directly hot-pressed into finished panels or can be hot-pressed to raw boards first, which are then sanded and overlaid.