

Potential of Bamboo-based Panels Serving as Prefabricated Construction Materials

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Abstract: In the development of prefabricated construction, the selection of the construction materials has a great influence on prefabrication technique. Through the comparison of various construction materials, the paper shows that bamboo-based panels are one kind of prefabrication materials with great utilization potential. And also, the paper poses some suggestions about the further development of bamboo-based panels considering some specific problems of the construction industry.

Key words: Bamboo-based panels; Prefabrication technique; Sustainable development

1. INTRODUCTION

At present, prefabrication, as a modern construction technique, which means making the whole or part of an unit in some other place rather than its final position, is attracting a ever-increasing attentions worldwide. In some developed countries, such as Japan, Canada, USA, and some EU countries, prefabrication is becoming more and more popular. Prefabrication is an efficient construction technique and it dramatically reduces the need for on-site work, lessens time and cost during the construction process, and helps to enhance the construction quality and lower the harm to environment. This technique has a wide range of application during the construction process, from the simple prefabricated houses to advanced fully-finished modular buildings.

One of the major concerns that influence the development of prefabrication is the selection of construction materials. Not only do the construction materials influence the efficiency and smoothness of the prefabrication process, but also decide the quality and life expectancy of prefabricated houses.

2. THE COMPARISON OF MAINSTREAM CONSTRUCTION MATERIALS

Many kinds of materials have been applied to construction industry, including clay brick, steel, concrete, wood/wood composite, and chemical synthetic materials (foam and plastic), etc. All of these materials have exhibited their own advantages in some certain stage in the history of construction. However, as people are paying more and more attention to environmental protection and the policies of construction industry have been adjusted, the

defects of many materials have emerged.
And some kinds of materials have been replaced.

2.1 Traditional Materials

Traditional materials such as steel, concrete and clay brick are not suitable for modules in fabrication construction since their self weight is so high. What is more, the raw materials of steel, concrete, and clay brick are unrenovable resources, and the process of production of these construction materials will consume large amount of energy resources, such as fossil fuel and electricity. At the same time, it also generates lots of CO_x and SO_x, which intensify the influence of green-house effect and cause the formation of acid rain. And it is also a problem to dispose of these materials when they are disused, which will aggravate the burden of environment dramatically. In addition, the concrete and clay brick contain some radioactive elements which are very harmful to our health. For example, radon is a main cause of lung cancer, second to smoking. In China, clay brick, as construction material, has been forbidden to be utilized by government since 2003, since the production of this construction material destroys a large area of farmland.

2.2 Sandwich Panels

Sandwich panels, consisting of two metal or wood faces positioned on either side of a core of a thermally synthetic insulating material, have been widely utilized in prefabrication construction. However, the prices of these materials are relatively high and the raw materials of the core usually come from crude oil which is unrenovable comparing to the short history of human beings. What is more, it may also become a headache when facing the problem of disposal since they (mainly the core layer) are difficult to biodegrade. In addition, once fire accidents happen, these synthetic materials may release noxious chemicals which do harm to human health and also pollute the atmosphere.

2.3 Wood Based Panels

Wood based panels with good properties are relatively proper materials which can be used in the construction industry. In developed countries, the proportion of wood based panels serving as construction materials is between 40% and 60%, especially as wall materials. However, this proportion in China is relatively low, only about 26.3%, which is still far from developed countries. Nowadays, the trend of construction industry is the standardization of design, prefabricated manufacturing, and assembly construction. And the assembly construction can reveal advantage of wood based panels remarkably. In addition, the trend towards large space and capacious room in the construction structure also leads to the transition from brick-like materials to panel-like products, from single wall to composite wall, and from on-site construction to on-site assembly. Wood based panels have well met the requirement of these functions (Yao Changtian, 2002). Wood based panels as wall materials have occupied a large share in western countries, since these countries have recognized that wood based panels are thin and lightweight, which can lessen the weight of buildings, meanwhile enlarge the construction spaces. The proportion of wood based panels used as wall materials is very high. For example, in Japan the proportion is 64%, USA, 47%, Germany , 41%, and Southeast Asia , above 30%. But in China, the proportion is only 3%, the

application of wood based panels in construction industry has a broad market prospect and very promising future. At present, except wood based panels, the application of other plant based panels is very limited in the field of construction. It is an important direction for researchers worldwide to further enlarge the sources of raw materials, enhance the production, and develop various construction panels with multifunction, which will make the plant based panels a promising construction materials in the future.

3. THE POTENTIAL OF BAMBOO BASED PANELS AS CONSTRUCTION MATERIALS

Recently, the price-rising of wood and declining availability of wood resources have turned people to some other similar alternative. Similar to wood, bamboo is a kind of natural organism, which is strong, lightweight, renewable, and with a strong adaptability to the environment. This plant is widespread, from tropical zone to subfrigid zone, from Asia to Europe. The speed of its growth far exceeds that of most growing trees, but its properties are superior to most juvenile fast growing wood. For example, compared with wood, bamboo has a higher strength/ weight ratio, better abrasive resistance, and a lower swelling rate after absorbing moisture. The best way to utilize bamboo on a large scale is to design and produce a series of bamboo-based panels with different structures and functions according to the properties of bamboo.

3.1 Different Types of Bamboo Based Panels Used in Construction

Bamboo based panels are products made from raw bamboo through a series of mechanical and chemical procedures, such as spraying glue, laying up, and hot pressing. The bamboo-based panels have advantages of large size, high strength, stabilization in shape and size, and its parallel and perpendicular strength and property that can be adjusted according to different demands (Zhang et al, 1995). Bamboo based panels are relatively ideal engineering materials. At present, the main sorts of bamboo based panels which can be developed in the construction field are as follows.

3.1.1 Mat Plybamboo. Mat plybamboo is a product made of mats weaved with bamboo sliver, then with the mats assembled and pressed after drying and gluing. Usually, this product has 2-5 layers. The art of Mat plybamboo is simple, and the investment of equipment is small. However, the surface of mat plybamboo is not flat enough since the units of this panel are mats. Thus, the decorative effect of mat plybamboo will be decreased. But in terms of the lightweight, flexibility, and good impact resistance of this panel, it is a good substitute for steel, gypsum, and asbestos to be used as wall and roof material in prefabricated construction which will broaden the utilization of mat plybamboo greatly.

3.1.2 Curtain Plybamboo. In order to simplify weaving process, strips are arranged in parallel order, connected with strings to be made into curtains. After gluing and drying, curtains are to be assembled and pressed into curtain plybamboo. One of the advantages of this panel is that the thickness and width of strips can be adjusted according to the requirements of final products. In addition, its consumption of adhesives is smaller compared with mat plybamboo, but it has a better dimension stability and better mechanical properties.

Curtain plybamboo has been better developed, produced and utilized than other kinds of bamboo-based panels, As a construction material, curtain plybamboo can be used as wall, roof, and partition materials.

3.1.3 Laminated Bamboo of Strips. Strips are glued and dried, then assembled and pressed into laminated bamboo of strips. The strips are arranged in parallel order, for this reason, the lengthwise strength of this panel is high, but the crosswise strength is relatively low. Laminated bamboo of strips can become a substitute for steel, concrete, and woody panel and serve as load bearer, such as girder, pillar, door panel, banister, and wall materials in prefabricated construction.

3.1.4 Plybamboo. Soften bamboo fragments under high temperature, press and flatten them, then assemble them in lengthwise and crosswise direction alternately, and make into plybamboo by means of gluing and hot pressing. Plybamboo is excellent engineering material of great dimensions, high strength, small deformation and stable form. Now it has been utilized as material for the bottom board of trucks and buses and moulding board of construction. As construction material, plybamboo with good properties can lessen the self weight considerably, and be suitable as wall, roof and door panel materials.

3.1.5 Bamboo Particleboard. For the sake of improving the utilization ratio of bamboo resources, the stems of small diameter and of less known species, stem tops and all bamboo processing residues are used to make bamboo particleboard. The manufacturing process is designed similar to the technology of wood particleboard — rolling, cutting, chipping, re-drying, gluing, spreading and hot-pressing. The biggest advantage of this product is that the supply of raw material for making bamboo particleboard is abundant. But it also has relatively high strength and low swelling ratio. This product has been widely used in furniture manufacturing, construction, packing, and transportation. It will be a good material to replace wood based panel and sandwich panel in prefabricated construction, serving as wall panel, partition, and door panel.

3.1.6 Bamboo Composite Board. In order to improve the product quality, increasing the resources of raw materials, and decrease the production cost, two or more than two kind of materials are selected to make composite boards, including bamboo-wood composite, bamboo-cement composite, and bamboo-gypsum composite, etc. bamboo composite contains merits of different raw materials, and the mechanical properties of composite board are better than that of plywood. Bamboo-cement composite and bamboo gypsum composite have higher strength and good weathering resistant ability. What is more, they are also fire resistant and sound insulating, containing no synthetic adhesives which will lead to free emission of formaldehyde and other noxious chemicals. Bamboo-wood composite is another kind of good construction material, as wood is cheap and widely available. to develop bamboo-wood composite board is a rational way to the successful exploitation of bamboo resources. various bamboo composites can be utilized as wall, partition, roof, and pillar materials, and it is a promising materials in prefabricated construction.

At present, bamboo based panels have been widely applied to the manufacture of bottom boards of vehicles, moulding boards of construction, scaffoldings, and has partly taken the place of wood, steel, plastic etc as raw materials of furniture and decorating materials. Bamboo-based composite may also be the suitable alternative as the materials of prefabrication in terms of the various advantages they contain. However, the application of bamboo based panels for this utilization is still very limited.

3.2 Properties of Bamboo Based Panels

3.2.1 Mechanical Properties. The materials used in the construction should be of sufficient mechanical resistance, to be able to bear the stresses resulting from self-weight, structural loads, snow, wind, and walking-on if they are used as roofs. Bamboo based panels can bear more load and have higher value of MOR than wood and common concrete. Hence, it is more suitable to be used as construction material than wood and concrete. In addition, with the increase of world population and the ever-increasing requirement of space utilization efficiency, the effective utilization of construction space is becoming one of the major concerns of developers. Bamboo based panels, with the characteristic of high strength/ weight ratio, may be more suitable to be used in multi-storey buildings, and it can also enhance the resistance of lateral load, which can decrease the possibility of collapse of the buildings in many natural disasters, like seismic activity or high winds due to hurricanes or tornadoes.

Table 1 Comparison of properties among some construction materials

Types of Materials	Properties	
	MOR (MP)	MOE (MP)
Bamboo Based Panels	15mm	113
	25mm	126
Common Timber	13-17	10000
Concrete(C25)	11.9	28000

3.2.2 Density. In the prefabrication process, the self-weight materials should be as small as possible in order to allow easy assembly and delivery. Traditional materials such as steel, concrete, and clay brick have very high densities and are not suitable for modules because of the big self-weight. Bamboo based panels, similar to wood-based panels, are relatively light construction materials. The average density of bamboo based panel is about 7.5 kN/m^3 , which is equivalent to 1/4 of that of concrete, or 1/3 of that of clay brick, so it can lessen the weight of buildings by about 30%.

3.2.3 Coefficient of Thermal Conductivity. Compare with clay brick and concrete, bamboo based panels have a lower coefficient of thermal conductivity. The average value is $0.640 \text{ kJ/m h}^\circ\text{C}$. This property makes bamboo based panels an ideal material for heat insulation, which can help to reduce temperature fluctuations in the buildings that accompany the temperature changes outside. And hence, it can reduce the energy requirements of air-conditioning. As the shortage of energy supply is intensifying, the energy-saving abilities of panel materials are more and more valued.

3.2.4 Dimensional Stability. As their external using properties, construction materials should have the ability to withstand the stresses of shrinkage or swelling due to the changes of temperature and moisture. If we adopt the unique hot- press technology, waterproof adhesives and make best of the physical properties of bamboo, bamboo based panels will have a better stability in shape and size compared with concrete and clay bricks, which make them more suitable to serve as construction materials.

Table2 Coefficient of thermal expansion of various construction materials

Types of Materials	Coefficient of Thermal Expansion (1/°C)
Concrete	1.08×10^{-5}
Steel	1.17×10^{-5}
Woody Materials	0.65×10^{-5}
Polyvinyl Chloride	7.0×10^{-5}

3.2.5 Sound Insulation. The external walls and roofs should have the necessary capability of sound insulation applicable to the intended use of the building concerning airborne noise from the outside (i e noise from industry, road and air traffic, etc). Bamboo based panels can meet the requirement of the sound insulation if designed properly, since they are very good materials to absorb sound waves and impacts. For example, to meet the requirement of special function, the wall will be designed to be a structure with two layers of composite board, and the air layer in the middle. This structure can improve the effect of sound insulation dramatically, functioning better than that of clay-brick structure.

3.2.6 Flame Retardancy. Construction materials should be guaranteed for their abilities to resist flame. Compared with steel or clay brick, bamboo based panels have a poorer performance on flame retardancy, but perform better than most other synthetic materials such as Polystyrene and Polyurethane. And once burnt, bamboo based panels will not release noxious chemicals as those synthetic materials do. In addition, if inorganic gluing materials are adopted such as cement and gypsum as adhesive, the panels will exhibit better ability of fire retardancy. In Japan, the bamboo fiber-cement board was invented in the 1990s of the last century. In China, Fujian College of Forestry has done some research on bamboo fiber-gypsum board, and the products have been put on the market. In addition, Zhe Jiang Forestry University and Chinese Academy of Forestry have also done some interrelated researches in this field.

4. EXISTING PROBLEMS AND POSSIBLE SOLUTIONS

4.1 Enlargement of Raw Materials Supply

Despite the fact that bamboo has an extensive distribution worldwide, the total amount of bamboo reserve is relatively lower than wood resources. This will limit the raw materials supply when larger amount of bamboo products are required. Thus, the establishment of bamboo plantations is strongly required in those places suitable for the growth of this plant to grow in order to meet the ever-increasing demand on bamboo materials. At the same time, bamboo-wood composite, which will contain the properties of both bamboo and wood, may be also a good solution to solve this problem.

4.2 Development of Special Adhesives for Bamboo Based Panels

Now, the adhesives for producing bamboo based panels are UF and PF, which are widely applied in wood based panel production. However, since the structure and chemical composition of bamboo have some differences from that of wood, these adhesives are not so suitable for bamboo products. For example, the wettability of bamboo surface is very low, which will hinder the realization of adhesion. So, how to improve the adhesive manufacturing technologies and how to develop new prescriptions or improve the existing prescriptions to make them more environmental friendly and more appropriate for bamboo based panels are goals for researchers worldwide in future.

4.3 Upgrading Undeveloped Producing Technology

At present, the factories and enterprises engaged in the production of bamboo based panels are usually small-scale ones which apply few advanced techniques. What is more, most of the factories still adopt equipments which are used for producing wood based panels to produce bamboo based panels despite the fact that the structure of bamboo are different from that of wood. All these factors will affect the quality of the final bamboo products, increase the energy consumption and decrease the efficiency of production. In addition, panels serving as construction materials usually have high values of thickness, but the researches on the thick panels about 50mm is far from enough. How to improve the methods of processing and technologies of hot press is becoming one of the major concerns to companies and institutes.

4.4 Recycling

Just like all the other construction materials, the disposal and recycling of bamboo based panels also need to be considered when they are wasted. Firstly, bamboo based panels can be recycled as the raw materials of particle board or MDF. Secondly, these wastes can also be provided as raw materials of bamboo charcoal, which is a good purifying agent, and also has a good health-care function. Thirdly, bamboo is biomass, which can be biodegrade in the natural condition. It can also be burned as fuel without generating SO_x and NO_x, so it will generate little negative impact on environment. All these methods will greatly decrease the cost on disposal of waste, and swing the balance between economy and the recycling of materials, which is perfectly consistent with the requirement of sustainable development.

4.5 Strategy and Standards Establishment on Bamboo Based Panels Industry

Although the number of factories and enterprises engaged in the production of bamboo based panels is increasing, most of them lack the far-sighted prediction of market want, and often result in a blind production. And a low-level management are commonly existing. In addition, except for mechanical index, many other indexes also need to be met, like corrosion resistance, weather resistance and creep resistance etc. Thus the establishment of long -term development strategies and the improvement of existing standards for the industry of bamboo based panels are acutely important. In addition, the national macroscopic readjustment and government's instruction are also expected in the future.

5. CONCLUSION

Bamboo is a kind of fast- growing and renewable resource, which is cheap and widely

available. Compared with steel, concrete, wood and other construction materials, bamboo has its unique characteristics and advantages in bringing ecological and social benefits. Bamboo based panels have similar properties to wood based panels. Since the utilization of bamboo will be well consistent with the sustainable development, bamboo based panels will become very competitive construction materials when an extensive factors are taken account of.

At present, there is a large gap in the supply of prefabricated construction materials, and it is a very good opportunity for bamboo based panels to occupy the market, since they have so many merits compared with other building materials. However, a wide popularization of the utilization of bamboo needs to be done to make bamboo based panels better accepted by people around the world.

If bamboo based panels can be well utilized in the construction industry, they will contribute a lot to the sustainable development of the prefabrication industry and the protection of environment. On the other hand, the development of manufacturing bamboo based panels can provide many job opportunities for local people and increase the local fiscal income, accelerating the development of local economy.

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