

Brief Introduction to Properties of Wood and Application of Wood in Architectural Structures

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Abstract. Wood's existence in earth is much earlier than human beings' appearance, after thousands of years' evolution, many kinds of wood are strong enough to support humans' basic needs. Since the mid-20th century, scientists had made a great progress in chemistry and civil engineering, which made types of materials for architecture become abundant. However, despite of all the advantages that wood has got, the inflammability and mildew are the main reasons that wood cannot be largely used in the super high-rise building or huge building. The passage mainly introduced the excellent architectural properties of wood with detailed data, wood-based structure along with its characteristics and the typical wooden structures worldwide. From the current situation, wood is widely used in the medium and small-scale building for its good properties and well performance on many respects, including the ancient masterpieces. The typical and contemporary wood building structures system have shown the ingenious ideas and connotation within the structure. Furthermore, modified materials based on wood are developed to adapt the higher standards and requirements for architecture. In this way wood shall overcome the disadvantages of inflammability and mildew and other flaws due to congenital defects and acquired defects caused by environment. Finally, the thesis puts forward simple ideas on how to bring the superiority into full play and expects that the adoption of wood-based composite technology for the prospect of wood products in the construction industry.

Keywords: Wood, physical properties, wood building structure system, application, construction.

1. Introduction

Wood's existence in Earth is much earlier than human beings' appearance, after thousands of years' evolution, many kinds of wood are strong enough to support humans' basic needs. People use wood to build places to live, with its excellent properties, it could protect people from wind and cold. Thus, the buildings in ancient time are almost made of wood, even the magnificent the Forbidden City used a mass of wood. The passage introduced the extraordinary performance of wood and the typical wooden structure. Until today, with reinforced concrete and steel are widely used in architecture, wood is still a good option for people to build something. The deterioration of the ecological environment and the production of non-recyclable industrial products make it very risky to continuously use underground energy and minerals, therefore, a concept called Sustainable Development is accentuated repeatedly by the governments and international organizations. Although wood couldn't be fully recycled, it is reproducible. With the continuous development of new technologies for wood processing and utilization, newer wood engineering materials and more advanced processing technologies have emerged, which provide material guarantees for design, bringing new forms and styles, enriching the content of design, and promote the emergence of new methods, new functions and new concepts of design [1]. In other words, wood is completely an ecological, environmental architectural material.

Previous reviews and researches have shown the outstanding performances by setting up the experiments and doing field visits. Naomi Stungo's Novel Wood Architecture, compiled by Yan Yang and Yan Cheng, offers a detailed look at 30 finished wooden buildings, including gymnasiums, textile museums, artists' studios and theaters. It shows the unique style and charm of the wooden structure building node. In the book Japanese Modern Space and Material Expression compiled by Professor Wang Jing of Southeast University, Japanese architects' application methods of several basic structural materials, such as wood, mainly analyzed Japanese architects' application methods of

wood and other new materials, their conception of architectural space, and their understanding of materials [2]. The related material technology and the history of the material are briefly introduced. In the academic papers related to the research of new wooden materials, Wang Kun from Beijing Forestry University studied the physical properties of veneer laminated wood. However, despite of all the advantages, wood is flammable, the life and property security would be greatly threatened once the wooden structures catch on fire. Meanwhile, wood contains lots of cellulose and lignin, many fungi would break them down and turn them into something they can use. In this way, the quality and mechanical properties of wood would go down so that the structural strength would be deeply influenced. Besides, threat from insects bothers as well. It is always found that insects and parasites live inside the wood, which make certain part of wood become brittle. Compared to works mentioned above, this passage also shows the advantages of wood as well as the brilliant structures made of wood, yet it is more from the perspective of material, rather than singly focusing on structure.

The paper mainly focuses on two parts, which are the basic physical performances of wood and wooden structures. Firstly, the physical performances of wood would be discussed in detail. Secondly, typical wooden structures would be analyzed to show the merits of this kind structure.

2. Physical Properties of Wood

2.1. Density and Specific Gravity

Density contains mass density and weight density, it usually refers to mass density when density is mentioned, such as mass per unit volume. Yet weight density is related to acceleration due to gravity, and the specific value changes when latitude and altitude change. Therefore, it is expressed as the ratio of the weight density of the object to the weight density of water at 4 degrees Celsius.

The change of specific gravity along the trunk radius of mature wood could be divided into 3 cases: (i) The average specific gravity increased linearly or curvilinear along the center of pulp; (ii) The average specific gravity decreased first along the center of pulp and then increased. The specific gravity of wood in the bark was higher or lower than that near the center of pulp; (iii) The average specific gravity decreased in a straight line or curve outward from the center of pulp, and the specific gravity of the center of pulp was higher than that of the bark.

Speaking of high specific gravity of a certain material, it means this kind of material weighs a little with high strength, also an index it is that material science and engineering mechanics pay more attention to. Good elasticity and toughness of wood could fully absorb vibration and impact energy, instant impact and the same fatigue damage resistance is strong, even if there is an earthquake, wood structure building can still maintain the stability and integrity of the structure to a certain extent [3]. Take *Picea jezoensis* (Siebold & Zucc) Carrière as example, its longitudinal tensile strength is 133Mpa and its basic density is 0.378g/cm^3 , the ratio of intensity to density is 351.8; the tensile strength of steel is 1,960Mpa, its density reaches to 7.8g/cm^3 , the ratio of strength to density is 251.3, which makes a great difference between wood based materials.

2.2. Electrical Properties

All materials could be classified into 3 types according to resistivity or electrical conductivity: conductor, semiconductor and insulator. The electrical property of wood generally refers to the material characteristics of wood under the action of DC electric field and alternating electric field, including the conductivity of wood in DC electric field, dielectric property in AC electric field, piezoelectric effect and hot spot effect caused by external force. The frequency for high-frequency electric heating is usually in the range of 1-10MHz, and the frequency for microwave drying is 915MHz or 2.45GHz. Wood exhibits dielectric properties at ratio frequency. Dielectric property refers to the property that charged particles of a substance can only produce microscopic displacement but not macroscopic migration when it is subjected to an electric field.

In the wood drying industry, high frequency drying technique used polarization of water molecules in wet wood in a high-frequency electric field to accelerate drying process. The mentioned drying

technique has advantages of fast drying speed, high thermal efficiency, small wood deformation, etc. In this way, relative processing cost is highly reduced, which makes mass production of wooden building materials become possible.

2.3. Thermal Properties

Specific heat is the amount of heat absorbed or given off by a change in temperature of one degree Celsius per unit of a substance. Since wood is a porous organic material, its specific heat is much more than metal materials (Table 1) [4].

Table 1. The average specific heat of various materials under 0~100°C [KJ/(kg·K)]

Material	Specific Heat	Material	Specific Heat
Aluminum	0.924	Oak	2.394
Plumbum	0.130	Picea Asperata	2.730
Steel	0.935	Charcoal	0.840
Iron	0.483	Water (10°C)	4.2084
Concrete	0.882	Water (20°C)	4.1945
Water	2.100	Water (30°C)	4.1887
Glass	0.840	Water (15°C)	4.2000
Granite	0.840		

As a highly important thermophysical parameter, thermal conductivity describes the ability of an object to transfer heat by conduction. Thermal conductivities of various materials are given in the Table 2 [4]. Since wood, which only has very tiny amount of free electron that could easily transmit energy, is a porous material with a lot of air pores, it is a poor conductor of heat for its small thermal conductivity. This is exactly one of the main reasons that wood is frequently used as thermal insulation materials in architectural structures.

Table 2. Thermal conductivity of various materials [W/(m·K)]

Materials	Thermal Conductivity	Materials	Thermal Conductivity
Aluminum	203	Pine (perpendicular to grain)	0.16
Plumbum	348~394	Pine (parallel to grain)	0.35
Iron	46~58	Granite	3.1~4.1
Basswood (perpendicular to grain)	0.21	Concrete	0.8~1.4
Basswood (parallel to grain)	0.41	Glass	0.6~0.9

2.4. Humidity Controlling Property

The humidity-controlling property of wood is one of the unique properties of wood, which is also the advantage of wood as an indoor ecological decorative material and furniture material. The so-called material's humidity controlling characteristic is directly alleviating indoor space humidity change depending on the own hygroscopicity and the desorption function of the material [5]. As an ecological building indoor space, humidity should be in a certain range without sudden change. In this way, it is very beneficial for personal health and the preservation of objects. Wood and other interior decoration, decorative materials, to a certain extent, played a role in stabilizing humidity, and this is one of the important reasons that people like to use wood as interior decoration and to store things with wood products.

3. Typical Wood Building Structure System

3.1. Traditional Typical Structure System

3.1.1 Log cabin construction

Log cabin construction (Fig. 1) is a kind of Chinese house structure without columns and girders. In this structure, logs or rectangular or hexagonal timber are stacked in parallel to the upper layer. At the corner, the ends of the timber are crossed and occluded to form the four walls of the house, just like the wooden fence on an ancient well. Then, low columns bearing purlins are erected on the left and right walls to form the house. This kind of structure uses the volume of wood and the compression performance. It is worth noting that lots of wood would be needed to construct the structure and much wastes would be generated, therefore, it is not as common as the wooden frame structure [3]. In cold climates, solid walls made of wood can provide excellent thermal insulation.



Figure 1. Log cabin construction [3]

The form order of enclosure of primary log cabin construction type material structure is reflected in its consistency with the structure form, that is, the form of Slab Wall supporting system. According to the supporting system of Plate wall and the expression form of its auxiliary component, enclosure type can be divided into five forms: round structure, semi-round structure, multi-angle wood structure, square wood structure, board wood structure [6].

3.1.2 Column and tie construction

In Chinese and western architectural culture, they collectively chose the beam and frame construction. The linear member form of wood is decided by the action of the one-way force, the beam-column supporting system is the simplest and direct structural way to exert the wood performance. To be specific, the column and tie construction (Fig. 2) is appropriate for smaller spatial scales, its principle is to form various kinds of members into wood structure by means of pulling and tying. In ancient China, the main organization of the connecting frame was the horizontal frame pattern: the members first formed the horizontal frame, and then the longitudinal members pulled to form the whole wood structure, which was formed in the Northern and Southern Dynasties (420 A.D.-589 A.D.) [7].

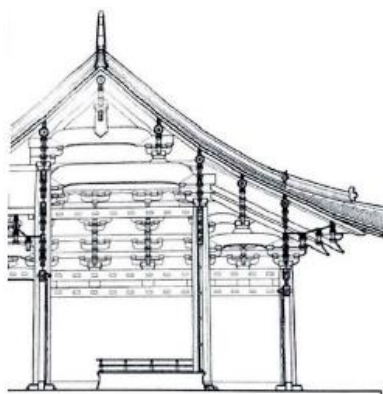


Figure 2. Column and tie construction [8]

3.1.3 Post and lintel construction

In the whole frame order, some timber structures are connected by different layers, and the connecting members pull the columns to keep the structure stable. According to the different shapes of the transition members between beams, they can be divided into two types: Double-bucket and King post (Fig. 3).

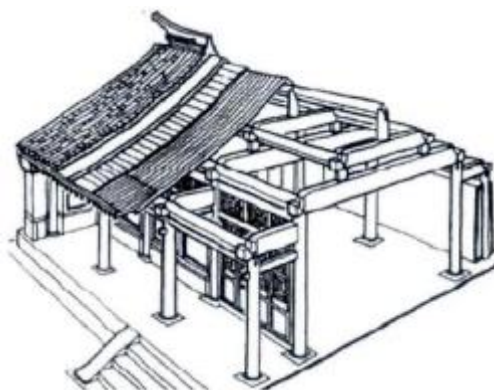


Figure 3. King post type [9]

3.2. Contemporary Typical Structure System

3.2.1 Post and beam construction

Before the appearances of cast iron, rebar and concrete, Chinese traditional buildings mostly take post and beam construction (Fig. 4), for it has many advantages. A clear division and rational stress condition in the construction make it more predominant in architectural field. It forms a conventional structure such as square or rectangle, the wall forms around column grid or between column grid, which only used for separation and protecting the doors and windows.

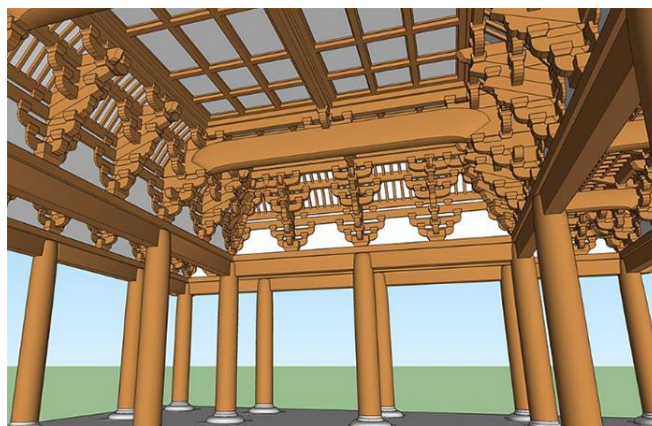


Figure 4. Traditional wooden architecture

Another advantage worth discussing would be the subtle vibration reduction mechanism. Under the construction, the arch method connects by wood frame structure and concrete has a certain extent of deformation to ensure the safety of the structure.

3.2.2 Light wood frame construction

The light wood frame construction system is a structural form consisting of a connection between the gauge timber and the timber-based structural plank. Its resistance is formed by the combination of the main structural components and the minor structural components, and the ultimate load is also transmitted to the foundation. The structure is one of the most durable structures in modern housing structures, with safety, economic, long service life, flexible layout and other characteristics. Structure of this kind has advantages of following: (i) High utilization rate of material. Different length and fracture surface product many varieties and specification materials in the same time during processing, so that wastes reduction become practical. The structure also uses oriented strand board made from

fast growth wood as wallboard and floorboards to reduce cost. (ii) Convenient construction and installation. The widely used platform frame at present is constructed floor by floor, the installed lower structure provides an operation platform for the upper construction, and no large lifting equipment is needed for a single wallboard that is a single floor high, which has a suitable size and light weight. All the accessories are assembled at construction site for they are prefabricated earlier, hence construction schedule is greatly accelerated. (iii) Well anti-seismic performance. The light wood frame construction mainly adopts reinforced concrete or brickwork as foundation, the upper structure connects foundation by anchor bolt. Horizontal seismic force transmitted to shear walls on each floor through transverse horizontal member when there is an earthquake, the seismic force would be finally transmitted to the foundation by transmitting to the bottom shear wall [10]. The light wood frame construction showed well anti-seismic performance in previous earthquakes for its characteristics such as light weight, high strength, higher order statically indeterminate structure, etc.

4. Conclusion

Wood plays an important role in architecture as well as in daily life, thousands of years has passed since human firstly used wood. In short, wood has got excellent density and specific gravity that gives it high mechanical strength; its characteristic of insulating property under over-dried condition makes the drying procedures much more simple to realize mass production as well; fantastic thermal properties provides the wooden structure an easeful environment to live. As for the typical wood building structure system, the passage introduced the log cabin construction, column and tie construction and column and beam construction with their unique characteristics. Contemporary structure such as post and beam construction with the advantages of a clear division and rational stress condition and subtle vibration reduction mechanism, the light wood frame construction system with its high utilization, convenience and well anti-seismic performance. For recent years, wood-based composite materials are taken more and more seriously. Since related performances are improved aiming at the defects such as potential inflammability or swelling when in a wet condition, wood-based composite materials not only has kept the advantages that wood has gotten but also overcame the disadvantages which might cause problems. Therefore, as the only environmental zero-load ecological building materials, wood-based composites will be re-favored by people. With the promotion of heat modified wood, the expansion of the demand for natural wood and the emergence of a large number of buildings using wood-based materials, the spring of traditional wood industry and wood architecture creation will surely come.

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