Development of Biomass Materials of the Byproducts of Sponge City Construction in Changde

Pei Li, Qingding Wu*, Yuqing He, Jian Yuan, Junhuai Liu, Kefei Liu and Liqiang Zhang

ABSTRACT

In order to drive the development strategy in response to innovate and promote the construction of sponge city in Changde, the green industrial chain model of new biomass material was constructed based on the byproducts of spongy city construction, such as reed and pennisetum were used as substrates. 18 invention patents were created, such as "A herbaceous plant based weatherproof stealth plate and its preparation method". The technical principles based on the series of invention patents were expounded, the innovation of core patent technology was analyzed, some works of patent technology transformation and application were presented, and the technical economic value and application prospect of core patents were discussed. The results show that the new biomass materials, such as 3D printing consumables, outdoor weatherproof materials, absorbing stealth plates and mechanical engineering materials, which are the base material for the construction of the spongy city, have a broad application prospect and great technical and economic value.

INTRODUCTION

From the adoption of the Framework Convention on Climate Change at the First United Nations Conference (1992) on Environment and Development in Rio de

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Janeiro, Brazil, to the 21st Global Climate Conference (2015) in Paris, France, will adopt the Paris Agreement to make arrangements for the global response to climate change after 2020, and then, China and the United States ratified the Paris Agreement on 2016 G20 summit in Hangzhou, China, proposing to build an innovative, energetic, linked and inclusive world economy. At the same time, it leaves endless thinking and heavy burdens for resource, environment, and material science and technology workers. On the one hand, human exploitation and plunder of forests, oil and mineral resources has reached a crazy point. On the other hand, people are suffering from environmental pollution, climate deterioration and secondary disasters caused by the indiscriminate cutting of forests, the mining of oil and mineral deposits. So, people began to consider how to improve the natural and livable environment and reduce the human dependence on forests, oil and mineral resources.

The wise Changde people grow reed, pennisetum and other fast-growing grass on the banks of the River Purple, purifying urban air by means of photosynthesis, and using fast-growing grass roots to absorb nutrients and gravel filtration to purify water sources. A spongy city famous for breathing has been built. As a material science worker, what can be done by the byproducts of spongy city construction such as reeds and pennisetum, which are produced by environmental protection and have considerable production? The authors first thought is to create a green new material industry chain.

The so-called green chain of biomass new material is that the original materials born from environmental protection, and its production process is low-carbon and environmentally friendly. Its waste materials can be recycled and reused, which shows a green industrial chain.

CONSTRUCTION OF GREEN INDUSTRY CHAIN MODEL

The reed, pennisetum and other fast-growing grass on the riverside of the River Purple are green, and achieved effective carbon sequestration of greenhouse gas carbon dioxide through photosynthesis. Then, the responsibility of the material science worker is to be a competent relay to extend the carbon sequestration period indefinitely. To this end, the green industry chain model based on spongy city construction by-products shown in Fig.1. This model is not only suitable for the high value clean utilization of fast-growing grass such as reed and pennisetum, but also applies to the high value clean utilization of bamboo and wood residue, crop straw and other weed vines. According to this model, not only the high-value clean utilization of cheap wood, lianas and herbaceous resources can be achieved, it also can achieve an infinite extension of its carbon fixation cycle.
SUBJECT FIELD AND TECHNICAL PRINCIPLE

The topic is aimed at the natural characteristics of woody resources such as cheap woody, lianas and herbaceous plants, through knowledge transfer, applying the theory of forming and strengthening of metal materials to the field of wood resources materials to harvest multiple effects [1].

The main technical principles involved in this subject include the following five aspects [1-3].

(1) Wood-Plastic Fusion Principle
The main points of this principle are that the basic composition of woody resources such as woody, lianas and herbaceous plants is much the same, including cellulose, hemicellulose, lignin and ash. Lignin is vitreous, a natural biological gum that softens gradually under the elevated. When the temperature reaches about 160 °C, it melts and flows over the surface of the fiber to eliminate the interface between the fibers, and integrates with the cellulose. After cooling, it will be tightly combined with cellulose to form a homogeneous composite.

(2) Diffusion Welding Principle
The basic point of this principle is to tie together the surfaces of the two pieces of material that need to be connected. If the surface is tight enough (to an intimate level of 0.4 to 0.5 nanometers) and there is no surface film or adsorption layer that hinder the bonding of atomic bonds, then, according to the physical nature of the material, the two pieces of material can be permanently linked together. Specifically, by means of temperature (0.5-0.7Tm), pressure, time, environmental atmosphere and other conditions, the two solid materials is contacted closely and realize the solid phase bonding through the interdiffusion of atoms.

(3) Dispersion Strengthening Principle
The main points of this principle are as follows: dispersion strengthening is a means of strengthening engineering materials by adding fine hard particles to homogeneous materials, the fine hard particles which refers to the ultra-fine second phase strengthening engineering materials insoluble in matrix materials. In order to distribute the second phase uniformly in the matrix material, it is usually manufactured by powder material forming technology. Dispersion strengthening is a kind of material strengthening method, which can improve the strength and hardness of the material obviously, but also make the plasticity and toughness decrease littlely. The finer the particles, the more uniform distribution of dispersion, the better the effect of reinforcement.

(4) Bionic Hydrophobic Principle
The main points of this principle are that the natural wood material contains a large number of hydrophilic groups, which has a strong hygroscopicity led to its dry shrinkage, moisture expansion, cracking, mildew and even degradation, which seriously affects its scope of use and service life. However, hydrophobic surfaces exist extensively in nature, such as "lotus leaf effect" and "super hydrophobic insect feet", showing strong hydrophobic and self-cleaning properties.
The so-called hydrophobic is that the contact angle of surface water droplets is more than 150° and the rolling angle is less than 10°. The hydrophobic structure can not only reduce the contact between water and substrate to the greatest extent, but also slide away from the substrate easily under a certain external force, and remove the pollutants from the surface. If the wooden material is endowed with hydrophobic property, the water drop can hardly stay on the surface of the wood material, so as to isolate the wood material from water contact with moisture, and prevent the damage of moisture, insects and the process of using the wood material.

The methods of bionic surface construction of natural wood is mainly as follows: surface coating, hydrothermal method, sol-gel, layer-by-layer self-assembly, wet chemical method, chemical vapor deposition and so on. The most suitable method for constructing super-hydrophobic surface of woody resources, such as cheap woody, liana and herbaceous plants, is powder metallurgy. According to the forming process route of powder metallurgy (Preparation of powder → mixing → press forming → modification), the powder of cheap wood resources is uniformly mixed with specific biomass particles and non-biomass nanoparticles in a proper proportion. Construction of bionic wood new materials by means of rigid molds under the coordination of temperature, pressure and time.

(5) Temperature Compaction Principle

The concept of "warm compaction" is derived from the discipline of material processing engineering. In the field of metal materials, recrystallization temperature is usually used as the benchmark to divide the forming methods of metal materials into three categories: cold forming, warm forming and hot forming. In fact, wood materials also have characteristic temperatures similar to the recrystallization temperatures of metallic materials, such as the glass transition temperature of lignin, the softening point of lignin, and so on. For the forming of wood materials, the forming performed at a normal temperature is usually defined as cold forming, the forming performed at a higher temperature than the lignin softening point is defined as thermoforming, and the forming performed in the temperature range between the lignin glass transition temperature and the lignin softening point is defined as warm forming.

CORE TECHNOLOGY AND INNOVATIONS

Based on the above five technological principles, four types of core technologies including 18 national invention patents are successfully created according to the green industrial chain model shown in figure 1 [4-21].

(1) 3D printing wooden consumables forming technology

This kind of core technology includes two national invention patents: ① One kind of 3D printing red acid wood plastic composite wire and its preparation method (ZL201810238217.4); ② One kind of 3D printing blood sandal wood plastic
composite powder and its preparation method (ZL201810238155.7). The technical transformation application works are shown in Fig.2.

(2) Weather-resistant wooden building materials forming technology

This kind of core technology includes six national invention patents: ① One kind of high strength wood-plastic composite quick-loading anti-glare device and its manufacturing method (ZL201510207288.4); ② A kind of particles reinforced
wooden outdoor engineering materials and their preparation method (ZL201510212175.3); ③ An outdoor weathering engineering material based on fast-growing grass and its preparation method (ZL201710502744.7); ④ An artificial golden silk nammu and its preparation method (ZL201410154700.6); ⑤ A kind of artificial dalbergia odorifera and its preparation method (ZL201710756961.9); ⑥ A kind of catalpa tea table and its preparation method (ZL201410801322.6). The technical transformation application works are shown in Fig.3.

![Figure 3. Weather-resistant wooden building materials forming technology conversion application works.](image)

(3) Wave absorbing stealthy wooden plate forming technology

This kind of core technology includes four national invention patents: ① One kind of herbaceous plant-based weather-resistant stealth plate and its preparation method (ZL201710932831.6); ② A biomass copper-carbon composite material based on fast-growing grass and its preparation process (ZL201610208346.X); ③ A production method of metallized woody powder matrix composites (ZL201110029275.4); ④ A metallized wooden functional material and its preparation method (ZL201810238200.9); The technical transformation application works are shown in Fig.4.
(4) Wooden materials forming technology for mechanical engineering
This kind of core technology includes six national invention patents: ① Biomass mechanical engineering material based on fast-growing grass and preparation method (ZL201610208330.9); ② An isotropic wooden granular plate (ZL201710707326.1); ③ A cellulose nanofiberboard and its preparation method (ZL201710932833.5); ④ An artificial lignumvitae and its preparation method (ZL201210534753.1); ⑤ A wooden sliding bearing and its preparation process (ZL201410606391.1); ⑥ A kind of bamboo plastic composite sliding bearing and its preparation process (ZL201510132833.8). The technical transformation application works are shown in Fig. 5.
The innovations of the above four core technologies mainly include the following eight points [4-26]:

(1) Through the interdisciplinary intersection, the forming and toughening theory of powder metallurgy materials science and engineering, composite materials and engineering, wood science and engineering and other professional materials are comprehensively applied, this paper innovates the forming technology and method of a kind of cost-effective wood composite material.

(2) The density and tensile strength of the prepared metallized wood functional materials can reach 1.2 g/cm3 and 450 MPa respectively, and have obvious ductile fracture characteristics (shown in Fig. 6). They can be used as a substitute material for alloy steel, aluminum alloy and titanium alloy, widely used in electromagnetic shielding, system thermal management, broad-spectrum building materials and other fields, and they are a kind of environmental-friendly metallized wooden functional materials.
(3) The prepared cellulose nanofiber plate is fully plasticized (shown in Fig. 7), its specific gravity is only 12-16 percents of steel, its strength can reach 5-6 times that of steel, its color can be adjusted, it cannot fade and can be regenerated, and the ratio of performance to price is better than that of carbon fiber material. So it is an ideal engineering material for lightweight equipment and component manufacturing.

(4) The prepared herbaceous plant-based weatherproof stealthy plates can achieve sound insulation, weather resistance and corrosion resistance, good electromagnetic stealth. It is ideal building material for both military and civilian use. It can be used not only for construction of temporary barracks for field troops and temporary hospitals in the field and other facilities, but also for the construction of temporary shelters for earthquake relief and for industrial, civilian facilities and equipment.

![SEM, ×20000](image1.png) ![SDDM, ×100](image2.png)

Figure 7. Fracture morphology of cellulose nanofiber plate.

(5) The 3D printing wood-plastic composite material is noble and inexpensive, which is comparable to the rare natural wood such as red acid branch. It is low-carbon environmental protection, low cost, anti-mildew and flame-retardant. Its printing works are homogeneous and dense in texture, high in hardness, good in strength and strong in wooden feeling.

(6) The shade and texture of the artificial golden silk nanmu from the edge to the core gradually changed from gray-black to warm yellow, or black and yellow were interspersed with each other. The amber cat's eye are visible on its surface. Meanwhile, artificial golden silk nanmu has a metallic luster and light wood fragrance, immortal, insect-free, never fading, can replace the natural golden silk nanmu to make a variety of high-grade crafts.

(7) The prepared wooden sliding bearings are light in weight and wear resistant, with a friction coefficient of only 0.1-0.2 (shown in Fig. 8). It can be used as solid lubrication bearing or water lubrication bearing instead of sintered copper base
sliding bearing and natural iron pear wood sliding bearing for medium/light load mechanical and electrical equipments (such as textile machinery, food machinery, medical machinery, civil ships, etc).

(8) The wooden particle board obtained by six-sided two-way non-simultaneous hot press forming has good toughness, high hardness, no cracking, no deformation, no moisture absorption. In addition, the density difference of each part increased from 0.05-0.15 g/cm$^3$ to 0.01-0.02 g/cm$^3$, so it is an ideal structural material for home hardcover, high-grade furniture and industrial field.

![Figure 8. Test curve of friction coefficient of wooden sliding bearing.](image)

TECHNICAL AND ECONOMIC VALUE AND APPLICATION PROSPECT

Through a series of patented inventions, the theory of material forming, strengthening and toughening is applied to low-cost carbon sink resources, then turning wastes into treasures. A set of green manufacturing technology of new biomass materials with energy-saving, low-carbon and environmental protection is achieved, which has important technical and economic value and attractive application prospects.

(1) Through the implementation of patent technology transformation and re-innovation, the carbon sequestration cycle of Changde sponge city construction by-products (reed, pennisetum, etc.) will be extended indefinitely by means of the product, use and recycle of 3D printed wooden consumables, weather-resistant wooden building materials, absorbing stealth wooden panels, mechanical engineering wooden materials and their products. This will not only effectively
reduce greenhouse gas emissions, but also reduce people's dependence on oil, minerals and forest resources, thus write a new chapter in the construction of sponge city and green economy in Changde.

(2) The green industry chain model based on spongy city construction by-products (reed, pennisetum, etc) is not only suitable for high value clean utilization of fast-growing grass, such as reed and pennisetum, but also suitable for bamboo and wooden residue, crop straw and other weed canes. When confronted with piles of crop stalks, weeds and rattans, sawdust, shavings, bamboo knots, bamboo green, bamboo yellow, and bamboo ash, farmers and business owners of bamboo and wooden products will no longer think about using them as fuel for boilers and direct incineration, but selling them as bulk raw materials and turning them into bonuses instead. At the same time, the urban and rural air pollution and fire hazards are partly eliminated.

(3) The application and popularization of the series patented technology of this project will undoubtedly drive the comprehensive high value clean utilization and high cost performance of cheap carbon sink resources such as bamboo, wooden residues, crop straws, weed rattan, etc. And then, the revitalization and development of new biomass materials and equipment industry with high performance-price ratio will certainly drive the new economic growth points, which is certainly good news for expanding employment channels.

CONCLUSIONS

In response to the innovation-driven development strategy to assist the construction of Changde sponge city, new biomass materials based on the by-products of sponge city construction in Changde were developed, the main conclusions are as follows:

(1) The green industry chain model based on spongy city construction by-product is not only suitable for cleaning utilization of fast-growing grass, such as reed and pennisetum, but also suitable for bamboo and wooden residue, crop straw and other weed canes. According to this model, not only the low cost woody, liana and herbaceous resources can be utilized with high value, but also the carbon sequestration cycle can be extended indefinitely.

(2) Through the interdisciplinary application of the theories of shaping and toughening of powder metallurgy materials science and engineering, composite materials and engineering, wood science and engineering, etc, 18 invention patents have been created to innovate a kind of high cost performance wooden composite material forming technology and method.

(3) New biomass materials, such as 3D printing consumables, weather-resistant wood building materials, wave absorbing stealthy plates and mechanical engineering materials, which are based on cheap carbon sink resources such as sponge city construction by-products, have broad application prospects and great technical and economic value.
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