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Research on Preparation Methods of Ultrafine Softwood Powder

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Abstract

Pine wood sawdust is used as raw materials for experimental processing into ultrafine wood powder. Sizes of ultrafine wood powder particles serve as a standard for measuring ultrafine processing. The core part of the experimental processing equipment is the millstone which can exert great shear force and grinding force on strong fiber materials so as to ensure the successful preparation of ultrafine particles. The "equilibrium orbit" model is used to simulate processed superfine particles in calculating separation performance. Moreover, the CFD is chosen for simulating separation performance of wood powder particles with different sizes in the two-phase flow field, so as to ensure the successful separation and grading of wood powder particles with different sizes in the practical processing. Research is made on physical properties of collected wood powder as samples with different sizes and influence on composite material properties when ultrafine wood powder is taken as padding. Research on ultrafine wood powder provides meaningful experimental data and theoretical support for the future research on micro-nano fibrils.

Keywords: *ultrafine wood powder, experimental preparation, separation performance, powder particles*

1. Introduction

As different raw materials are used in different processing industries, wood powder particles whose sizes range from 9μm to 23μm are defined to be ultrafine [1]. Sizes and shape of ultrafine wood powder have a significant impact on research and application of ultrafine wood powder in the future [2]. As requirements for environmental protection in the international market have become increasingly high, natural plant fiber as composite materials have attracted more and more and more attention. As natural fibers are renewable, biodegradable, low-density, and low-cost, with high strength and modulus of elasticity, performance of natural fibers would become better, if they are added to composite materials [3]. When ultrafine wood powder is added to composite fiberboards, along with the increase in the concentration of wood powder in composite fiberboards, the static bending strength and elasticity modulus of composite fiberboards would become increasingly high. In this condition, people can devote themselves to research on biodegradable wood composite materials [4].

In Japan, micro-nano fiber materials are used as filling for developing high-performance fiber structural materials which can used for making the car body so as to reduce the weight of the car body and finally achieve the goal of fuel saving [5].

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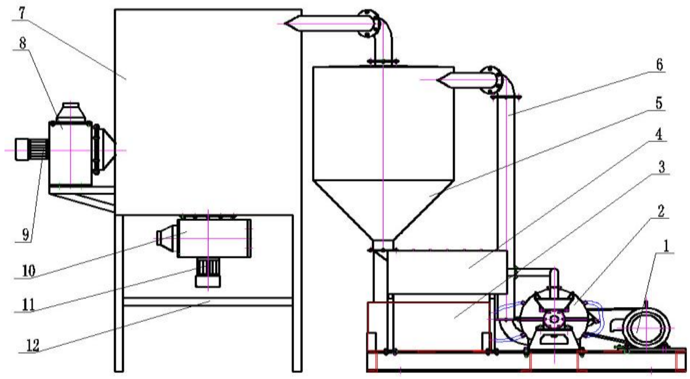
Research on preparation of ultrafine wood powder provides valuable reference for the preparation of fibrils with hemp, bamboo, straw and other materials, and provides guidance and serves as a basis for the preparation of biomass nano materials.

2. Experimental Preparation of Ultrafine Wood Powder

2.1. The Structure of the Superfine Wood Flour Equipment



1. Motor; 2. grinding box; 3. water tank; 4. wood powder cooling tank; 5. spiral separator; 6. connector; 7. wood powder collection box; 8. precipitator I; 9. centrifugal fan I; 10. precipitator II; 11. centrifugal fan II; 12. bracket.

Figure 1. Structural Diagram for Preparation System of Ultrafine Wood Powder

Pipeline sawdust which can be easily obtained in the native place is used as raw materials for ultrafine wood powder after being dried. The physical mechanical method is adopted for ultrafine processing of fiber materials. Pipeline sawdust receiving drying treatment can be seen as raw materials with brittleness and linear elasticity. Under the action of high-speed shearing forces, the length-size ratio of sawdust particles decreases rapidly and tends to become stabilized. In research made by Spence [6] and other scholars in 2011, the ultra-high pressure micro-jet method, high-speed grinding and high-speed shearing as three methods used for machining were adopted for micro-nano fiber processing. According to research results, ultrafine particles processed with high-speed shearing forces have a greater specific surface area [7]. The greater the specific surface area of a kind of materials is, the higher the surface activity of this kind of materials would be and the better its catalytic performance would be. If this kind of materials is added to composite materials, performance of composite materials can be improved. Therefore, in the design of the experimental equipment for this research, a special millstone capable of imposing high-speed shearing forces is chosen as the core part in the processing. The diagram 1 is a structural diagram for the preparation system of ultrafine wood powder. The core working part within the grinding box 2 of this equipment is the grinding millstone. So as to realize the rapid splitting of fibers in the processing, the surface of the grinding millstone is designed into alveoli with a certain angle and the grinding stone is divided into the upper part and the lower part. Raw materials with no impurity are sent to the grinding box through the charge door. After raw materials are put into the grinding box, grinding millstones in the grinding box would start to rotate, so that raw materials would be split and grinded into ultrafine particles under the action of shearing, grinding and friction forces. Under acting forces in repeated cycles, sawdust particles are cut in the axial direction of fibers and split into devillicate in the radial direction. Varying by different processing requirements and raw materials, the rotational speed of grinding millstones and the gap between the upper and lower millstones can be adjusted, with limit values.

2.2. Processing Raw Material of Ultrafine Wood Powder

Processing raw material of ultrafine wood powder is sawdust. In the test process, need a lot of sawdust. The main raw material is Xingan larch in this area. In it will max a lot of barks, length ranging from small logs, small lumps and various impurities. Before the test, dust removal must be required. Removed the bark, clods and impurities, can begin to test processing.

The processing raw materials of ultrafine wood powder were sawdust after the dust. The diameter is about 3mm. According to micrographs of sawdust particles can see, particles are mainly in the form of a small rectangular body and the cross section of particles showed irregular shape. It is clear that the cross section of the tube is similar to the hexagonal section, as shown in Figure 2. And the pits and intercellular channels can be clearly seen in the tracheid radial wall, as shown in Figure 3.

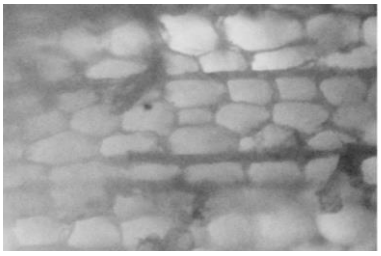


Figure 2. Tracheid Cross-Sectional View

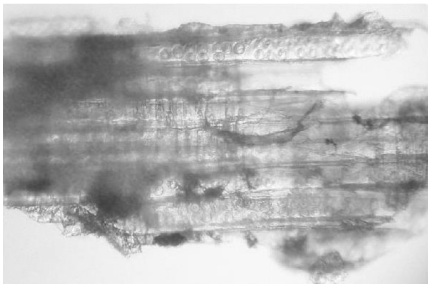


Figure 3. The Pits and Intercellular Channels in Tracheid Radial Wall

Tracheid diameter wall pits of most wood are single column in soft wood. But in the larch, the early wood of larch passage wall has bordered pits, it mainly is two columns and some arranged one or three. Visible from the Figure 3, bordered pits are given priority to with 2 columns. Singan larch appear more pit of column type, namely multiple columns of tracheid wall pit are in pairs or in a short row. As local amplification for the Figure 3 can also see bordered pit is a thick flat disc, pit significantly, from the pit to membrane edge thickness difference is obvious.

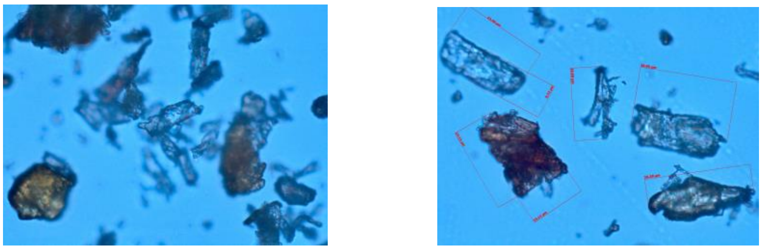
Around the grain to plug the microfibril is arranged in clear or slightly more obvious concentric rings, membrane edge to the microfibril mainly is radial alignment and sparsely to moderately. On the surface of pit chamber or pit edge of outer surface, nodular layer is lack of or rare.

Intercellular channels also are known as resin channels. Intercellular channel is a secretory function of plant secondary metabolites secretes fat cells of tubular channel between cells. According to the channel between cells form, it can be divided into normal intercellular channels and trauma intercellular channels. Normal intercellular channel is usually a single or by 2 ~ 3 into a short column, its diameter is small, and its surrounding secrete fat cell wall is thin or thick, no pit or no lignifications, located in the middle-late wood growth ring part. However trauma intercellular channel is usually long string to the column, it is bigger than normal intercellular channel, the shape is irregular, often is on the string to the direction of integration, the surrounding secrete fat cell wall is thickness, and is with pit and wood. Normal intercellular channel exists only in the Pinaceae genera: for example, Keteleeria (only the axial), Larix, Picea, Pinus and Pseudotsuga. There are normal radial and axial intercellular channels in larch, spruce, pine and fir trees.

With the Figure 2 and Figure 3, it can be seen that the cross section of the Xingan Larch tracheid has a similar hexagonal structure; the radial wall of the tracheid is a type of cross hole, which has normal intercellular channels. The hexagonal structure is determined in the study of the stress analysis.

2.3. Preparation of Ultrafine Wood Powder

The preparation work order of ultrafine wood powder first is to remove the impurity in the sawdust. From the feeding port 2 of the grinding box shown in Figure 1 add sawdust. Motor 1 is through the pulley to drive high speed rotary tool group in grinding box 2. Tool group in grinding box 2 and tool group fixed in the grinding box will shear, impact, and blow the materials intensely to concentrate them between the groups of rotary tool and the fixed cutter. High frequency force impact, shear, grinding produce between the material particles and particles, the energy is through the high-speed rotation of the rotor directly to the particles, while the high speed rotating air flow to the smaller particles, such as the transfer of energy, so that the particles are always in the grinding of the work piece. When the processing of raw materials is a larger mesh size, it will be into the spiral separator 5 in the high speed rotating airflow. The relatively coarse particles will be gathered in the feed inlet of wood powder cooling box 4 under the action of gravity and will enter into the wood powder cooling box. Then make the wood powder cooling box to cool the already warming wood powder and make the wood powder to reenter into the grinding box 2 for processing again. In the spiral separator 5, very fine particles will be into the wood powder collecting box 7 through the connecting pieces by the high speed rotating air flow. A set of spiral pipe is installed in the wood powder collecting box. On the spiral pipe has distributed different mesh wood powder collecting tube. In the joint action of the dust catcher 8 (driven by centrifugal blower fan 9) and the dust catcher 10 (driven by centrifugal blower fan 11), collect the different mesh wood powder into the porous fiber bag. Special fine wood powder will be adsorbed on the inner wall of the wood powder box 7. Some powder will be adsorbed on the outside of the collection bag, and through the vibration plate of wood powder collection box 7 to beat, so that the wood powder whereabouts and deposit to the bottom of the boxes. The water tank 3 and motor 1 work together to make the temperature inside the grinding box 2 hold constant. In the first experiment, the size range of wood powder particle collected from wood powder boxes within 7 was larger. Size range is from a few microns to dozens of micrometers. Figure 4 (a) is superfine wood powder morphology and Figure 4 (b) is the size of the superfine wood powder.



(a) (b)

Figure 4. (a) The Morphological Photo of the Superfine Wood Powder (b) The Photo of the Superfine Wood Powder Size

3. Separation of Ultrafine Wood Powder

The problem of micro nano powder separation and classification is an important part of powder technology development. But now, the problem has become the key problems restricting the development of powder technology. The requirements of this international project test is not only making the micro nano wood powder and at the same time to achieve collected wood powder of different particle size classification, finally realizes that the collected wood powder particle size is narrow distribution, high yield and high efficiency. At this stage the micro nano powder grading methods are mainly include wet grading and dry classification. According to the existing test equipment, used dry separation classification in the project.

3.1. Selection of the Separator.

America, Germany and Japan have advanced technologies in powder. They mainly use a cyclone separator to realize the separation and grading of drying-processed powder. In China, the cyclone separator is also used for the separation of drying-processed powder [8]. The combined actions of the inertia force field and centrifugal field are used for separation and grading of powder with dry process, so as to achieve the separation and grading of particles with different particles. In this paper, the countercurrent cyclone separator with “double vortexes” is used, as 5 in the diagram 1. It can make the inlet airflow slowly into the separator and make airflow capable of making rotational movement while making upward movement along the central axis in the cone part.

3.2. Calculation of Separation Performance.

Separation efficiency is one of the main performances of cyclone separation. The orbital balance model and the residence time model are the main basis of its calculation method. The cyclone separator cutting particle size calculated by the residence time model is slightly bigger than the particle size calculated by the orbital balance model.

In this design and experiment, an “equilibrium orbit” model is mainly used for powder separation. The “equilibrium orbit” model is built in this way. Based on an assumption that the air-lift pipe of the cyclone separator is extended to the bottom to form a cylindrical surface at the bottom, an equilibrium analysis is made of forces imposing on particles on the cylindrical surface so as to gain a force trajectory. Rotated particles in this force trajectory are under actions of both the outward centrifugal force and the inward airflow resistance which are in a dynamic equilibrium. As the centrifugal force is proportional to the mass of particles and resistance (that is, Stokes force) is proportional to the size of wood powder particles, particles with greater sizes move towards the wall of separator and finally into the discharge port while particles with smaller sizes are brought to the air-lift pipe for separation. In the equilibrium orbit, the size of particles is the cutting size of the cyclone separator, as a measure for separation performance of the cyclone separator.

As preparation requirements of the ultrafine wood powder machine, wood powder particles whose sizes are over 38μm should be separated from that less than 38μm. Wood powder particles with a 38-μm size are taken as an example for calculating sizes of separated wood powder particles. According to the experimental result, the density of wood powder particles with a 38-μm size ρ_p is 351.2 kg/m^3. The inlet velocity is set to $30\,m/s$ and inlet density is 2.5 g/kg. The Barth model is used for calculations.

$$|\upsilon_r(R_x)| \equiv \upsilon_{rCS} = \frac{Q}{\pi D_x H_{CS}} \quad (1)$$

In equation (1), where Q is the flow of the cyclone separator; D_x is the size of the air-lift pipe and also the size of the CS cylindrical surface; H_{CS} is the height of the CS cylindrical surface; $\upsilon_r(R_x)$ is the average radical velocity on the CS whose absolute value is υ_{rCS} .

On the equilibrium orbit CS, acting forces for rotating particles are:

Outward Centrifugal force:

$$F = \frac{\pi x^3}{6}\rho_p(\frac{\upsilon_{\theta CS}^2}{R_X}) \quad (2)$$

In Equation (2), where x is the mass of wood particles.

Inward (Stokes) resistance:

$$F_{stk} = 3\pi x \mu \upsilon_{rCS} \quad (3)$$

In Equation (3), where μ is the kinematic viscosity of air, $\mu = 14.8 \times 10^{-6} m^2/s$.

On the basis of establishing an equilibrium equation $F = F_{stk}$ between the centrifugal force and resistance, the cutting particle size is:

$$x_{50} = \sqrt{\frac{9\upsilon_{rCS}\ \mu D_X}{\rho_P \upsilon_{\theta CS}}} \quad (4)$$

Substitute relevant numbers in Equation (4) and then calculate that x_{50} is 68.73μm. After the primary processing of particles with great sizes as raw materials through the experimental preparation system, wood powder whose sizes are over 75μm would be delivered to the classification equipment where wood powder is classified according to their sizes. The greater measurement of a particle is used for judging which group it should belong to. That is to say, it would be ok if one measurement of a wood powder particle is within 23μm range. Based on the experimental measuring, it can be seen that wood powder particles whose sizes are over 23μm can be separated by the cyclone separator.

3.3. Analysis and Simulation of Movement of Wood Powder Particles

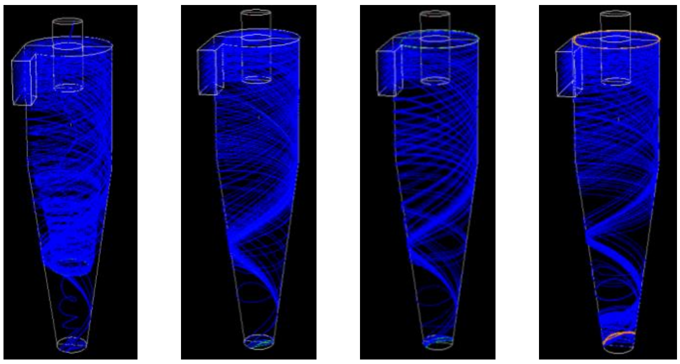
In the separation process of wood powder particle size in the cyclone separator, can make use of particle tracking technology of computational fluid dynamics (CFD) model to simulate the wood powder particles dispersed phase. The Euler-Lagrange method is adopted for simulating movement track of ultrafine wood powder particles. First to solve out the existing mobile phase of wood powder particles and calculate the continuous phase flow field, then put the wood powder particles as discrete existing particles; finally, the stress magnitude of each particle is obtained by combining the flow field variables. To gain wood powder particle velocity, thus to track a single wood powder particle trajectory, That is, simulate the second phase of the flow field in the Lagrange coordinates.

The Lagrange particle movement track method can be used to get the movement equation of particles based on the known gas flow field, by means of calculating position and velocity of the particle for each interval of time and analyzing the particle movement track in the cyclone separator. A wood powder particle enters into particular equipment with a given speed $u_{i,0}$ with respect to gas. After a time interval Δt, the movement velocity of this particle can be calculated by Equation (5).

$$u_i^{\cdot} = \frac{x^2(\rho_p - \rho)a_i}{18\mu}[1 - \exp(-\frac{18\mu\Delta t}{x^2\rho_p})] + u_{i,0}\exp(-\frac{18\mu\Delta t}{x^2\rho_p}) \quad (5)$$

After the gas velocity is calculated, the relative velocity between particles and gas can be used to calculate the absolute velocity of particles. Within the time interval Δt, the integral of the absolute velocity of particles can be used to identify the position of particles Δt later. The route of particle is set as $\int_{\Delta t} udt$. With calculations of positions of particles in a series of continuous time intervals, the move track of particles in the cyclone separator can be obtained.

Wood powder and air enter into the cyclone separator simultaneously. The experimental value of the density of wood powder with a 75-μm size is 322.95kg/m^3. Wood powder particles are divided into four groups: the 10-μm, 18-μm, 38-μm and 75-μm group. The mass flow rate of particles in each group is set to 0.05. Movement tracks of four groups of particles in the cyclone separator are simulated, as shown in Diagram 5.



(a)Z=10μm (b)Z=18μm (c)Z=38μm (d)Z=75μm

Figure 5. Schematic Diagram of Movement Tracks of Wood Powder Particles

As can be seen from the simulation diagram of movement tracks of wood powder particles, as the movement track, wood powder particles move downward along the separator wall to the discharge port, then move upward to the air-lift pipeline and finally are separated by in the cyclone separator. Wood powder particles with a 10-μm size have a good tracing ability. They rotate to move downward with air. Some of these particles would spiral along with ascending air after they reach the cone part of the separator and then enter into the air-life pipeline. As particles with smaller sizes suffer smaller centrifugal forces, some particles may spiracle to the air-lift pipeline along with the ascending air without reaching the separator wall. Based a comparisons of (b), (c) and (d) in Diagram 2, it can be seen that as particles with larger sizes would suffer great centrifugal forces, they would be pushed towards the separator wall, and then spiracle to slip down to the bottom of the separator, and finally be separated. Moreover, it can be also seen that particles with a 75-μm size are easier to keep their original movement tracks. Their tracks are different from that of particles with 38-μm and 18-μm sizes.

4. Research on Physical Properties of Ultrafine Wood Power Particles

A comparative analysis is made of physical properties of wood powder with different sizes. Diagram 6 is the form diagram of wood powder with different sizes. From this diagram, it can be seen that along with the decline in sizes of wood powder, the color of wood powder is gradually darkened. Based on statistics of sizes of wood powder, it can be concluded that sizes of wood powder mainly range from 20μm to 40μm. Sizes of the class interval are gradually reduced. According to measurement of the bulk density, along with the decline in sizes of wood powder, the bulk density of wood powder would become greater, but not make linear growth. When sizes of wood powder particles are less than 10μm, the bulk density would increase slowly. On the basis of calculating particle agglomeration of wood powder with different sizes, it can be seen that with the decline in particle sizes, the value of agglomeration would increase. Meanwhile on the basis of measuring adhesive forces, for wood powder particles whose sizes are less than 38μm, with the decline in particle sizes, adhesive forces of wood powder would increase rapidly, thus making wood powder easily agglomerate.

(a) 75μm b)38μm c) 18μm

Figure 6. Wood Powder Form Diagram

Based on research and relevant analyses, this change in physical properties of the wood powder is produced for following three reasons. Firstly, after large sawdust particles are processed by ultrafine wood powder machine, the specific surface area of particles becomes greater along with the decrease in particle sizes. As a result, along with the increase in mesh of wood powder, colors of wood powder would become darkened. Moreover, along with the decrease in particle sizes, the number of agglomerated particles and adhesive forces would sharply increase. Secondly, the processing time of particles with small sizes is longer than that with big sizes. As wood powder contain a large number of cellulose, lignin and other polyhydroxy compounds with high carbon contents, along with the increase in the temperature, it would make pyrogenic decomposition and suffer dewatering, thus showing a distinct charring trend [9,10]. Thirdly, both above-mentioned two factors may appear in the processing, thus possibly making combined actions. The more the amount of cellulose fiber contained in the composite materials, the more serious the color fading in the subsequent application process would be. However, the oxidation resistance of materials can be enhanced so as to increase the overall stability of composite materials [11].

5. Conclusions

Pine sawdust is used as raw materials for the processing of ultrafine wood powder in experimental preparation. The dry-type mechanical method is adopted for experimental processing. Taking characteristics of wood fiber materials into account, the author chooses millstones capable of imposing both great shearing and grinding forces as the core part in the processing, so that processed wood powder can achieve desired objectives. An analysis of physical properties of ultrafine wood powder obtained from the experimental processing is made. On this basis, it is concluded that different influence would be exerted on composite materials, if different amounts of cellulosic fiber are added to composite materials.

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