Dielectric Characteristics of Poplar Powder under High-Frequency Electric Field

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Dielectric properties of poplar tree powder were measured at frequencies from 5 to 30 MHz. The effects of moisture content, frequency, and bulk density on the dielectric constant and dielectric loss factor were analyzed. The polar groups of wood powder were characterized by infrared spectroscopy to reveal the response mechanism of wood powder in the high-frequency electric field. The results showed that, in general, wood powder's dielectric constant and dielectric loss factor increased with increasing bulk density and moisture content. In the moisture content range from 0 to 24%, the dielectric constant ε' of wood powder decreased with the frequency increase with 5 MHz as the maximum value of ε'. When the moisture content was $0 \le w < 20\%$, wood powder's dielectric loss factor ε'' varied as a quadratic function with increasing frequency, corresponding to a maximum value of ε'' at 13.4 to 17.7 MHz. When the moisture content was >20%, the dielectric loss factor ε'' of wood powder decreased linearly with increasing frequency, and the maximum value of ε'' was 5 MHz. The infrared spectrum showed that the polar groups in the wood powder were mainly -OH, C=O, C-O, and -CH, with the highest percentage of -OH.

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Keywords: Poplar powder; High-frequency electric field; Dielectric properties; Moisture content; Bulk density

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INTRODUCTION

As a common forestry residue, wood powder is widely used in the industry of wood processing. It adds significant value to forestry processing and plays a vital role in many fields. For instance, it can be used as cement-based composites (Zhou 2019), paper (Zhang *et al.* 2017), filler for adhesives in plywood processing (Ong *et al.* 2018), *etc.* Recently, with the development of science and technology, high-frequency electric fields are gradually being combined with the research and production of wood powder products for powder concentration monitoring (Sun 2018), electrostatic field trapping, and powder removal (Hao *et al*. 2012). The higher the wood powder's dielectric constant, the more charged it is and the better the electrostatic trapping effect. Raw material wood powder can also be used to produce wood-plastic composites (Nadali and Naghdi 2022) and wave-absorbing materials (Miura *et al*. 2016). The higher the dielectric loss factor of the wood powder during high-frequency heating and drying (Wei *et al*. 2013), the stronger its heating and drying effect. However, there needs to be more basic data on the dielectric properties of wood powder in AC electromagnetic fields.

Scholars throughout the world primarily have focused on the dielectric properties of composites made from wood and bamboo powders, analyzing their composition,

relaxation strength, and interfacial compatibility. Zhu *et al*. (2015) showed that the decrease of dielectric relaxation strength in wood-plastic composites with the increase of silane coupling agent content is due to the reaction of silane coupling agent with the hydroxyl group of the wood powder, which reduces the number of dipoles such as the hydroxyl group of the wood powder, further revealing the mechanism of interfacial compatibility of wood-plastic composites. A study by Li *et al*. (2021) has shown that composite materials (CF3) had excellent magnetic and dielectric loss capacities, and its polarization at the material interface could improve the microwave absorption function. Marathe and Joshi (2010) investigated the dielectric properties of composites with polyvinyl chloride as the primary matrix component, ethylene vinyl acetate (EVA) as a polymer plasticizer, wood powder (WF), and fly ash (FA) as fillers. Using an impedance meter, they analyzed the dielectric constant ε' and dielectric loss angle tangent tan δ. The results showed that the composition of the composites strongly influenced their properties, and WF helped reduce their loss angle tan δ. The effect of FA content on these properties is not significant; the increase of WF content increases ε'. Zhu *et al.* (2014), in order to quantitatively evaluate the interfacial compatibility between wood and polymer in MAPP as coupling agent composites, determined the dielectric constant and dielectric loss factor of six poplar powder/polypropylene (PP) composite materials with different maleic anhydride grafted polypropylene (MAPP) content and the results showed that the dielectric relaxation strength decreased with the increase of MAPP loading amount, reaching its lowest at 2% MAPP loading, and subsequently remaining unchanged.

In summary, current research by domestic and foreign scholars has focused on using wood powder or bamboo powder as raw materials to study the electrical properties of composite materials, providing a theoretical basis for their applications. However, there needs to be more research and primary data on the electrical properties of wood powder particles themselves, which limits the production and utilization of wood powder products in high-frequency electric fields. To this end, this paper considers the effects of moisture content, frequency, and stacking density on the dielectric properties of poplar wood powder, which is commonly used in wood processing. It analyzes the mechanism of influencing factors on the dielectric response of wood powder by quantifying the types and contents of polar groups in wood powder through infrared spectroscopy. The aim is to provide theoretical guidance and essential data for the applications of high-frequency heating, drying, electrostatic field trapping, and powder removal of wood powder.

EXPERIMENTAL

Test Materials

Poplar powder is a mixture of crushed aggregates obtained from the waste bin of the sanding section of the wood enterprise producing integrated materials, with a loose density of 0.16 g/cm^3 and a moisture content of 9.5%.

Test Equipment

A UN30 drying oven (Memmert, Schwabach, Germany), HCP 153 constant temperature and humidity oven (Memmert, Schwabach, Germany); 4294 Precision Impedance analyzer (Agilent Co., Ltd., Santa Clara, CA, USA); BS224S balance (Xusite Technology Co., Ltd., Suzhou City, Jiangsu Province, China); FW-4A tablet press (Tianjin Tianguang Optics Co., Ltd., Tianjin, China); and Nicolet Summit X Fourier infrared

spectrometer (Thermo Scientific, Waltham, MA, USA) Bettersize 2600 Laser Particle Size Distribution Instrument (Liaoning Dandong Baxter Instruments Co., Ltd., China) were used in this study.

Particle Size Distribution of Wood Powder

The particle size distribution of wood powder has an important influence on its void fraction and bulk density, which in turn influences the test results of its dielectric properties. The laser particle size tester used for the test was the Bettersize 2600 from Dandong Baxter Instruments, China, as shown in Fig. 1. The particle size measurement range was 0.1 to 2600 μm dry, the sampling rate was up to 1000 times/s, repeatability was better than ±0.5 %, accuracy was better than ±1 %, and the sample size was 0.2 to 10 g per test. The sample was first coarsely sieved, then the dry method used air as the dispersion medium. The principle of turbulent dispersion was used so that the sample particles were fully dispersed. The dispersed sample was then introduced into the optical path system for testing. The particle size volume percentage and cumulative volume percentage distribution of poplar wood powder are shown in Fig. 2.

Fig. 1. Bettersize 2600 laser particle size analyzer

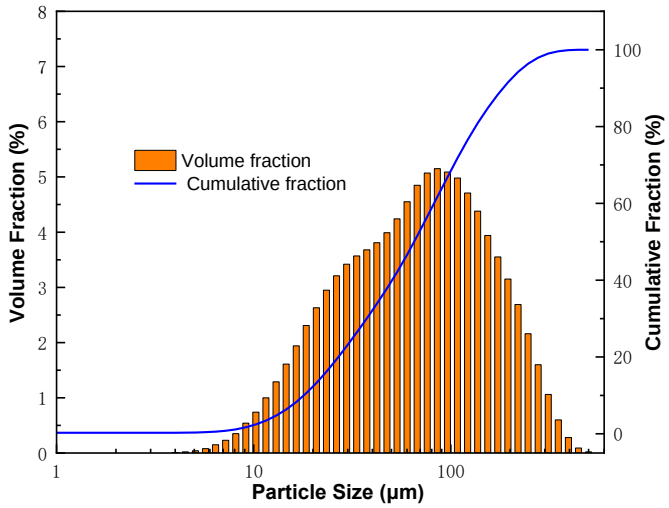


Fig. 2 Particle size distributions of wood powder

Table 1 lists the surface area mean particle size (D[3,2]), volume mean particle (D[4,3]), median particle size (D50), specific surface area, other parameters, and characteristic particle size information of wood powder.

Table 1. Characteristic Parameters of Wood Powder

Diameter Range	0–500 μm
Specific surface area *S* (m^2/kg)	63.95
Volume diameter *D* [4,3] (μm)	91.97
Sauter diameter *D* [3,2] (μm)	34.76
D (10) (μm)	20.35
D (50) (μm)	70.39
D (90) (μm)	199.2

Control of Density

The same mass of wood powder was taken, the density of which was adjusted by changing the volume of the wood powder. A container was filled with wood powder, and the loose density of the wood powder was calculated. According to the required bulk density of wood powder, pressure is applied to the container through a tablet press to change the thickness of the wood powder inside the container, as shown in Fig. 3. Finally, wood powder cylinders with different densities can be made based on the rebound of the wood powder under pressure, as shown in Fig. 4.

Fig. 3. FW-4A tablet press

Fig. 4. Preparation of poplar powder specimens

Control of Water Content

According to the standard testing method for wood moisture content GB/T 36055 (2018), Firstly, three Petri dishes were selected, washed and dried, and cooled and numbered. The weight of each Petri dish was indicated as M_0. The sample plastic bag was opened, and the poplar wood powder specimen was laid evenly in a Petri dish of 200 mm in diameter with 2 mm layer thickness. Its total mass was measured with the Petri dish as M_2. The weighing cup was put into the oven. The oven temperature was set to (103 ± 2)

°C immediately after closing the door. It was opened every 2 h. The mass was weighed once until the difference in mass before and after two changes of less than 0.1%. The value then was substituted into the formula, and the moisture content was calculated and recorded as M_1. This was substituted into Eq. 1 to calculate the moisture content. (Mass unit taken: g)

$$M = \frac{M_2 - M_1}{M_1 - M_0} \quad (1)$$

In Eq. 1, M denotes the water content of poplar wood powder (%); M_0 denotes the mass of Petri dishes (g); M_1 represents the total mass of dried poplar wood powder and glassware, (g); and M_2 indicates the entire group of poplar wood powder and glassware containing water (g).

According to Eq. 2, the arithmetic mean of the three parallel specimens W is given as:

$$W = \frac{1}{3}\sum W_{gi} \quad (2)$$

The mean squared difference σ of the moisture content relative to its mean value is given by Eq. 3,

$$\sigma = \sqrt{\frac{1}{3}\sum (W_{gi} - W)^2} \quad (3)$$

where, σ is the mean variance; W_g is the wood powder moisture content (%); and W is the mean wood powder moisture content (%).

To ensure the authenticity and accuracy of the measurement results, three sets of parallel tests were set up, and the water content of poplar wood powder was 9.9%, 9.4%, and 9.2% in three trials, respectively. The water content values deviating from the arithmetic mean were discarded, and the equilibrium water content of the specimen was calculated to be 9.5%. For water contents of 4% and 8%, the moisture content of wood powder was adjusted using an oven set at 80 °C, and the moisture content was changed from high to low to the mass corresponding to the moisture content of the corresponding wood powder. For moisture contents of 12%, 16%, 20%, and 24%, the dry bulb temperature of the constant temperature and humidity box was set to 20 °C, and the humidity corresponding to the moisture content was set to 60% RH, 75% RH, 90% RH, and 9 % RH, respectively, until the quality of wood powder no longer changed.

Measurement of Dielectric Properties

The complex dielectric constant of poplar powder was measured using a dielectric parameter testing system with a testing range of 5 to 30 MHz. The precision impedance meter was turned on, the impedance meter and fixture were connected, and the test electrode was selected for rough leveling. An OPEN/SHORT compensation was carried out, and precision leveling of the test electrode was done. The wood powder was placed into the homemade paraffin ring (outer diameter 50 mm, inner diameter 40 mm, height 10 mm), as in Fig. 5. A non-magnetic straightedge was used to gently scrape along the upper surface of the ring mouth to keep the surface flat; then the paraffin ring containing wood powder was placed in the center of the lower surface of the test system electrode by adjusting the screw micrometer so that the upper surface of the electrode touches the upper surface of the ring. The cover was gently scraped along the upper surface of the ring opening with a non-magnetic ruler to keep the surface flat; subsequently, the paraffin ring containing wood powder was placed at the center of the lower surface of the electrode of

the test system, and the upper surface of the electrode was made to touch the upper surface of the paraffin ring by adjusting the screw micrometer. The space between the upper and lower electrode plates needs to be maintained equal during each measurement (Xie *et al.* 2021), as in Fig. 6. Finally, the equivalent parallel capacitance C_p and dissipation factor D can be read, and then the dielectric constant ε' and dielectric loss factor ε'' can be calculated according to Eqs. 4 and 5,

$$\varepsilon' = \frac{t_a \times C_P}{A \times \varepsilon_0} \quad (4)$$

$$\frac{\varepsilon''}{\varepsilon'} = D \quad (5)$$

where C_p denotes parallel capacitance, A is the electrode area, t_a is the thickness of test material, and D is dissipation factor.

Fig. 5. Home-made paraffin ring

Fig. 6. Dielectric parameter test system

Infrared Spectroscopy Measurement Analysis

Using the KBr compression method, the dried wood powder was ground and mixed with KBr in a 1:100 ratio before being compressed into a sample that is then analyzed using a Fourier transform infrared spectrometer (Thermo Scientific, Waltham, MA, USA). The test wave number ranged from 400 to 4000 cm^{-1}, as shown in Fig. 7. The instrument resolution was 4 cm^{-1}, and the scanning sum was 32 times.

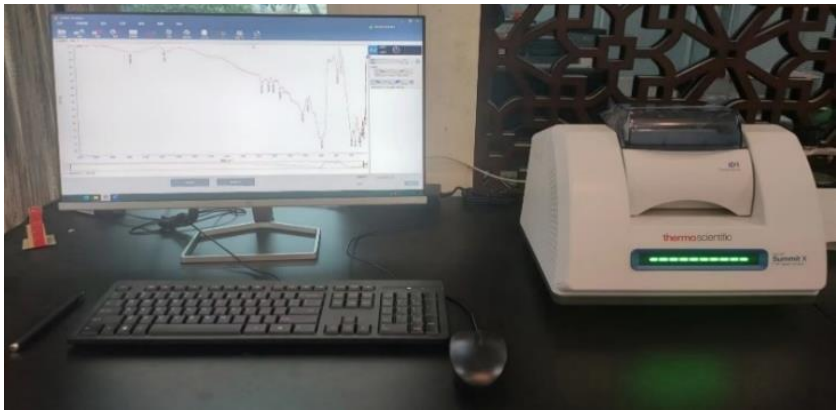


Fig. 7. Physical view of infrared spectroscopic measurements of poplar powder

RESULTS AND DISCUSSION

The Effect of Moisture Content on the Dielectric Constant of Poplar Powder

This study aimed to investigate the effect of moisture content on the dielectric constant of poplar wood powder, where poplar wood powder with a moisture content of 0 to 24% was tested at the frequency of 5 to 30 MHz at room temperature of 20 to 24 °C, and the ambient air humidity of 45%. The results are shown in Fig. 8.

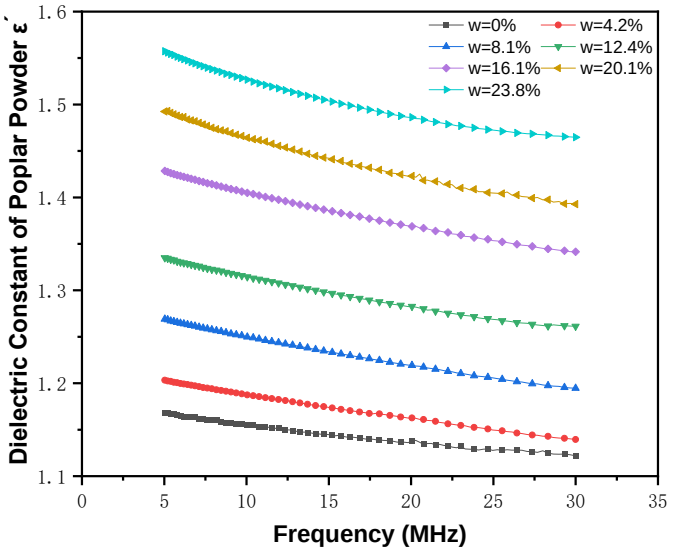


Fig. 8. The dielectric constant of poplar powder ε' as a function of moisture content and frequency

As shown in Fig. 8, the dielectric constant of poplar tree powder decreased with the continuous increase of electric field frequency, and the curve was approximately linear. In contrast, the dielectric constant of poplar powder increased with increasing moisture content continually and reached the highest dielectric constant and good electric field response at 5 MHz.

The wood powder comprises cellulose, lignin, hemicellulose, and other substances that respond differently to electric field frequency. When the moisture content of wood powder approaches 0, under the force of an external electric field, the direction of the electric moment of the internal dipoles of wood powder shifts towards the direction of the external electric field, arranged according to the direction of the electric field, resulting in the relative displacement of the electric moment, leading to directional polarization (Kol 2009). However, as the frequency increases, the polar molecules inside the wood powder are quickly polarized. Consequently, the direction of the internal polar molecules' electric moment cannot keep up with the changes in the electric field. Then polarization lags, and subsequently, the direction of the dipole movement is opposite to the frequency direction (Zhang *et al.* 2012), and the electric moment vector of the wood powder decreases, the polarization intensity weakens, and the dielectric constant of the wood powder declines. As the moisture content of wood powder increases, bound water, and free water gradually increase, and multiple water molecules begin to participate in orientation motion. As a result of a much higher dielectric constant of water molecules than that of wood powder, the internal orientation polarization of wood powder and its dielectric constant increase.

Effect of Moisture Content on the Dielectric Loss Factor of Poplar Powder

This study aimed to investigate the effect of moisture content on the dielectric loss factor of poplar wood powder, where poplar wood powder with a moisture content of zero to 24% was tested at the frequency of 5 to 30 MHz at room temperature of 20 to 24 ℃ and the ambient air humidity of 45%. The results are shown in Fig. 9.

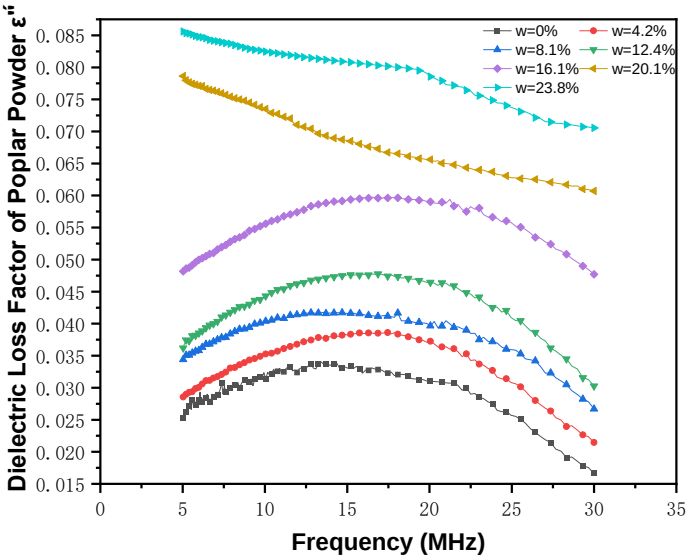


Fig. 9. Changes of dielectric loss of poplar powder with moisture content and frequency

It can be seen from Fig. 3 that the overall dielectric loss factor of poplar tree powder ε'' decreased as the frequency of the electric field continually increased, with the moisture content (w) of 20% as the obvious boundary. When w > 20%, the dielectric loss factor ε'' decreased approximately linearly with increasing frequency. In contrast, when the moisture content ranged from 0 to 20%, and the dielectric loss factor ε'' varied in a quadratic function relationship with increasing frequency. The corresponding peak varied from 13.4 to 17.7

MHz, where the electric field response was acceptable. The dielectric loss factor of poplar tree powder ε'' increased as the moisture content increased.

These findings can be attributed to the fact that when the water content is in the $0 \leqslant w < 20\%$ range, the moisture content in wood powder is less, but the chemical structure of wood powder contains a variety of polar groups, which are dipole groups in the alternating electric field and are closely related to the dielectric absorption. The most significant number of them, dominating the dipole loss, is the hydroxyl group in the non-crystalline region of cellulose, followed by the COOH group, which is more abundant in hemicellulose. Therefore, the relaxation time of the dipole should be concentrated in the relaxation time of the hydroxyl group. Still, the hydroxyl group and other groups have different polar strengths, different distribution positions in the molecular chain, and different binding forces with the surrounding molecules, so the relaxation time of the dipole group is divided under the influence of an electromagnetic field; these groups can move relative to the entire molecular chain. This process leads to dipole polarization loss, making the dielectric loss of wood powder loss increases with increasing frequency. As shown in Fig. 10, each glucose residue in cellulose contains three hydroxyl groups, which can move relative to the entire molecular chain under the influence of electromagnetic fields. This process leads to dipole polarization losses, and the scholar Norimoto (1976) deduced that the dielectric properties on the cell wall of wood depend mainly on the nature of cellulose. When the frequency continues to increase, the period of the applied electric field and the time required for dipole polarization become shorter. The dipole loss in the wood powder is too late to completely keep up with the change of the applied electric field, and the angle of dipole rotation with the electric field becomes gradually smaller in each cycle. The internal frictional motion is relatively reduced (He *et al.* 2017), so the overall dielectric loss of wood powder becomes smaller with the increase of frequency, resulting in a quadratic function of the dielectric loss of wood powder with the change of frequency change, and a dielectric absorption peak appears.

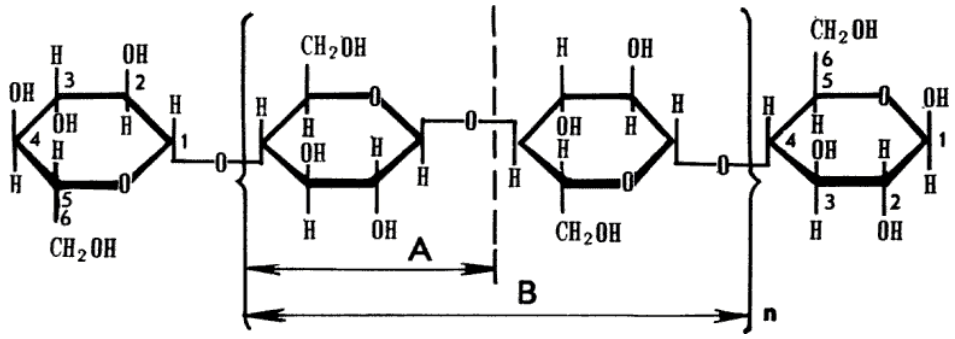


Fig. 10. Structural formula of cellulose: A one Q-D-glucose residue; B cellobiose

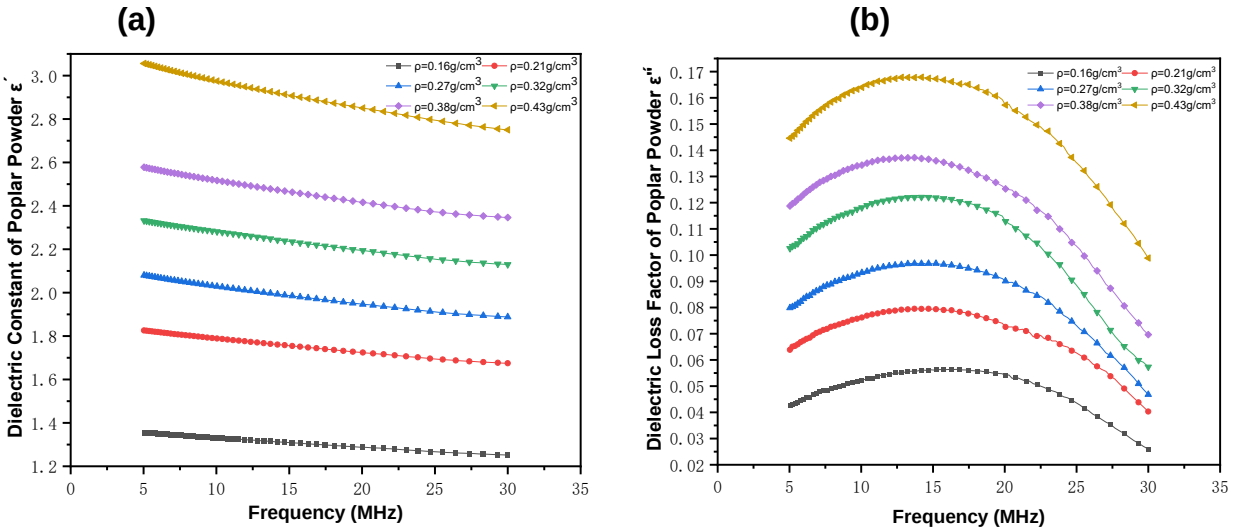
As the moisture content continues to increase, the number of dipoles per unit volume of wood powder increases, enhancing polarization loss (Hakam *et al.* 2019), and these dipoles are pulled by polar groups in the cell wall and fail to freely change with the electric field, leading to the increase in dielectric loss of wood powder. At the same time, the ions in the wood powder increase with the increase in moisture content, increasing dielectric loss and conductivity loss (Wang 2015). For another, there are three different phase interfaces in a wood powder containing water: air, liquid, and solid. When the wood powder is exposed to an external electric field, charge accumulation occurs at the interface,

resulting in interface polarization loss and increased dielectric loss of the wood powder under the electric field. As the frequency rises persistently, the time required for the polarization of water molecules in the wood powder and the period of the applied electric field will gradually shorten, and there will be insufficient time to fully keep up with the changes in the applied electric field. Within each period, the angle of dipole rotation with the electric field begins to decrease, and the internal friction movement relatively decreases, causing the dipole loss of the wood powder to fall gradually with the increase of frequency.

When $w \geq 20\%$, the dielectric loss of wood powder largely depends on the dielectric loss of water. The increase in moisture content leads the dipole loss of water to impose a more significant impact on wood powder than conductivity loss and interface loss. The polarization of water molecules in wood powder and the period required for the applied electric field sharply shorten. The dipole loss in wood powder fails to fully catch up with the changes in the applied electric field. Within each period, the angle of dipole rotation with the electric field declines, and the internal friction movement decreases relatively, resulting in a sharp decrease in the dielectric loss of wood powder with increasing frequency.

Effect of Bulk Density on the Dielectric Properties of Poplar Powder

This study aimed to investigate the effect of bulk density on the dielectric constant and the dielectric loss factor of poplar wood powder. Poplar wood powder with an air-dried moisture content of approximately 9.5% and thickness of 0.16 g/cm^3 to 0.43 g/cm^3 was tested at the frequency of 5 to 30 MHz at room temperature of 20 to 24 ℃ and ambient air humidity of 45%. The results are shown in Fig. 11.



(a) Dielectric constant of poplar powder ε´ varies with bulk density; (b) Dielectric loss factor of poplar powder ε " with the change of bulk density.

Fig. 11. Dielectric characteristics of wood powder at different bulk densities

It is shown in Fig. 11 that the dielectric constant of poplar powder continually increased with the increase of bulk density, reaching the highest at 5 MHz, where the electric field response was acceptable. The dielectric loss factor of poplar powder increased with the bulk density increase, achieving the most elevated range from 5 to 16.3 MHz,

where the electric field response was acceptable. To gain a deeper understanding of bulk density's influence on wood powder's dielectric properties, a double-layer dielectric model (Yuan *et al*. 2018) is introduced, as shown in Fig. 12 and Eqs. 6, 7, and 8.

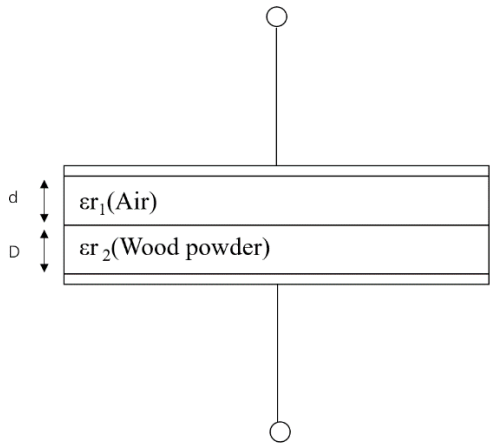


Fig. 12. Model of bilayer dielectric

$$C_1 = \frac{\varepsilon_0 \varepsilon_{r1} S}{d}, \quad C_2 = \frac{\varepsilon_0 \varepsilon_{r2} S}{D} \tag{6}$$

$$C = \frac{C_1 C_2}{C_1 + C_2} = \frac{\varepsilon_0 \varepsilon_{r1} \varepsilon_{r2} S}{D\varepsilon_{r1} + d\varepsilon_{r2}} \tag{7}$$

$$\varepsilon = \frac{C}{C_0} \tag{8}$$

where S denotes parallel plates area, εr_1 and εr_2 are relative dielectric constants of air and wood powder, respectively, d is dielectric thickness of air, D is dielectric thickness of wood powder, ε_0 is vacuum dielectric constant, C_0 denotes plate capacitance under vacuum, and ε is the permittivity.

According to Eq. 6, the gap within wood powder will decrease when the bulk density of wood powder increases. Then the thickness D of wood powder will fall, the capacitance of wood powder will increase, the thickness of air between wood powder will reduce, the capacitance of air will increase, and the overall capacitance between electrode plates will increase based on Eq. 7. When the capacitance between the plates increases, it can be inferred from Eq. 8 that the dielectric constant of the double layer dielectric of wood powder and air will also increase. As the bulk density increases, the gap between wood powder particles is reduced, the percentage of cell wall substance increases, the number of dipoles involved in polarization increases, and the dipole loss inside the wood powder also increases. At the same time, the dielectric loss of air is lower than that of wood powder, increasing the dielectric loss of wood powder (Pei *et al*. 2015).

Quantitative Analysis Based on Infrared Spectroscopy

The chemical structure of wood powder contains a variety of polar groups in the functional groups, which are dipole groups in the alternating electric field and are closely related to dielectric absorption; under the influence of the electromagnetic field, it makes the electric dipole moment inherent in these groups tend to align along the direction of the external electric field to produce polarization reactions. Analyzing the changes in the absorption peaks in the infrared spectrum makes it possible to infer which functional groups are present, as shown in Fig. 13. However, further analysis is complex due to the

overlap of each absorption peak. Therefore, it is necessary to use peak-splitting methods to extract each subpeak and obtain quantitative indicators that can reflect the content of functional groups, as shown in Table 2.

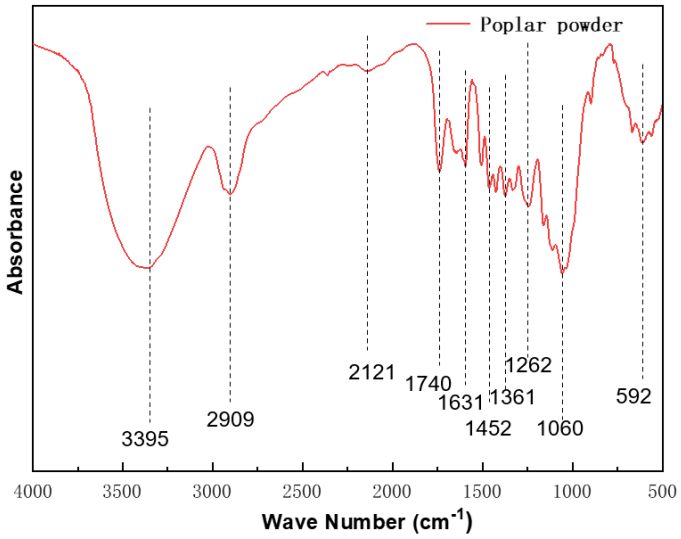


Fig. 13. FTIR spectra of poplar powder

Table 2. Quantitative Analysis of Poplar Powder Using Infrared Functional Groups

No.	Peak Shape	Wave Length (cm^{-1})	FWHM (cm^{-1})	Height	Peak Area	Area Ratio (%)	Functional Group
1	Gauss	3395	381.954	0.592	240.804	34.940	-OH Hydroxyl hydrogen bond association stretching vibration
2	Gauss	2909	927.835	0.158	146.598	21.27	$-CH_2$ Methylene vibrations of aliphatic groups
3	Gauss	2121	249.626	0.032	8.464	1.228	-C≡C stretching vibration
4	Gauss	1740	58.952	0.232	14.565	2.113	-C=O Carbonyl stretching vibration
5	Gauss	1631	104.897	0.227	25.326	3.675	-C=C Aromatic ring carbon-carbon double bond vibration
6	Gauss	1452	127.261	0.274	37.084	5.381	$-CH_2$ (Double critical telescopic vibration zone)
7	Gauss	1361	64.086	0.121	8.26189	1.199	$-CH_3$ (Double critical telescopic vibration zone)
8	Gauss	1262	166.414	0.303	53.647	7.784	-C-O, -C=O Stretching vibration (alcohol, phenol, ether)
9	Gauss	1060	166.27	0.635	112.363	16.303	-C-O, -C=O Stretching vibration (alcohol, phenol, ether)
10	Gauss	592	239.351	0.17	42.087	6.107	Halide

From Table 2, it can be seen that the polar functional groups in the wood powder were mainly -OH, -C=O, -C-O, and -CH, where the proportion of -OH type groups was 34.9% at a wavelength of 3395 cm^{-1}, the balance of -C-O and -C=O groups was 24.1% at wavelengths 1262 cm^{-1} and 1060 cm^{-1}, and the balance of -CH groups was 21.3% at wavelengths 1452, 1361, and 2909 cm^{-1}. The hydroxyl group had the highest proportion and had a noticeable influence on the polarization of wood powder in an electric field.

CONCLUSIONS

1. Given that moisture content ranged from 0 to 24%, the dielectric constant of poplar powder decreased with the continuous increase of electric field frequency, showing a negative correlation with frequency. The curve was approximately linear, while the dielectric constant of poplar tree powder increased with the continuous increase of moisture content, with the highest dielectric constant and better electric field response at 5 MHz.
2. As the moisture content continued to increase from $0\% < w < 20\%$, the dielectric loss factor ε'' declined, as the frequency of the electric field continued to grow. However, when $w > 20\%$, an obvious boundary, the ε'' decreased approximately linearly with increasing frequency. Within the moisture content range $0 \leq w < 20\%$, the factor ε'' changed in a quadratic function relationship with increased frequency. The maximum wave peak corresponding to poplar tree powder was 13.4 to 17.7 MHz, where the electric field response was acceptable. The dielectric loss factor of poplar tree powder ε'' increased as the moisture content increased.
3. When the air-dried moisture content was 9.5% and bulk density ranged from 0.16 g/cm^3 to 0.43 g/cm^3, the dielectric constant of poplar powder continuously increased with the increase of bulk density. The dielectric constant of poplar powder reached the highest at 5 MHz, where the electric field response was good. Likewise, the dielectric loss factor of poplar tree powder increases with the bulk density increase, ascending to the peak at 14.5 MHz to 16.3 MHz, where the electric field response was good.
4. The poplar powder functional groups in wood powder are mainly -OH, -C=O, -C-O, and -CH, among which -OH has the highest proportion, followed by -C-O, -C=O groups, and -CH groups.

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