EFFECT OF MOISTURE CONTENT AND FREQUENCY VARIATION ON DIELECTRIC PROPERTIES OF BAMBOO (*Phyllostachys heterocycla* cv. *pubescens*)

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SUMMARY

Moisture content of bamboo and frequency are the most important factors that affects dielectric properties of bamboo material. Dielectric properties of bamboo is one of the most important factors to determine the high-frequency hot pressing process parameters of glued laminated bamboo... Therefore, study on dielectric properties of bamboo has important significance. Bamboo was adjusted moisture content under laboratory conditions for 0-18%. Effect of moisture content and frequency variation on dielectric properties of bamboo was determined by using the 4294A Precision Impedance Analyzer with the 16451B. Dielectric properties including dielectric constant (ε’) and dielectric loss tangent (tan δ) have been done in the moisture content range from 0% to 18% and in the frequency range from 60 Hz to 6 MHz. The results showed that the dielectric constant (ε’) and tan δ increase with the increasing moisture content and decrease with the increasing frequency. Dielectric constant and tan δ increased slowly with the moisture content below fiber saturation point (FSP), increased sharply with the moisture content around the FSP. Dielectric constant and tan δ decreased obviously with the frequency below 6 kHz, but changed slowly when it above 6 kHz.

Keywords: Bamboo, dielectric constant, dielectric loss tangent, frequency, moisture content.

I. INTRODUCTION

Bamboo is a natural material. It has been used traditionally as an engineering-structural material for fabrication of village houses in all stages of human culture development. In order to utilize bamboo effectively under modern scientific and technological conditions it is necessary to study its properties. Bamboo is a main material for bamboo-based panelsand a wide range of bamboo products, including bamboo articles for daily uses and bamboo carbon (Zhang, 1995; Zhang et al., 2001).

Dielectric constant and dielectric loss tangent is important factor of the dielectric properties of bamboo. It has important implications in the high-frequency and microwave heating technology of bamboo processing applications. Applications of dielectric properties of bamboo and wood in high-frequency and microwave heating technology to determined drying, glueing, softening and moisture content of bamboo and wood (Yin, 1996).

Electric properties of both wood and WPC were measured under different moisture contents and relative humidities. It showed that dielectric constant of wood increased significantly with moisture content but no significant difference was observed in the case of WPC within the range of moisture contents studied (Khan et al., 1991).

Dielectric constant and tan δ values of different sections of bamboo cut from outer skin to the central core have been determined at different temperature range and frequency range (Chand et al., 2006). It has been found that dielectric constant and tan δ increased with increase of temperature and decreased with from the center core to periphery outer surface with increase of frequency.

The estimation of dielectric loss factor which is considered a very important feature for bamboo industry and wood industry, properties of different wood species was done by using soft computing algorithms as a function of both ambient electro-thermal conditions applied during drying of wood and basic wood chemistry (Iliadis et al., 2013).

Dielectric constant and dielectric loss tangent of bamboo culm increased slowly with the moisture content below fiber saturation point (FSP), increased sharply with the moisture content around the FSP, and when above the FSP, it had a linear relation with the moisture content. Dielectric constant of grain direction was higher than that of other two directions. It decreased obviously with the increase of frequency, but changed slowly when it above 6 kHz. Bamboo culm age, different part of culm had no evident effect on dielectric constant (Xu et al., 2012).

Bamboo or wood-like materials such as WPC can be used as an important insulating material for special applications. All untreated woods had a higher dielectric constant than their polymer composites. It is therefore postulated that the presence of polymers has led to a decrease in the number of polarizable units (Chia et al., 1986).

Dielectric properties of wood block treated at various temperatures up to 800°C were measured in the range from 20Hz to 1MHz and from -150 - 20°C. These results suggested that the electric conductivity decreased with increasing temperature up to 400°C and a small volume fraction of particles with large conductivity is formed at microscopic levels in the cell walls (Sugimoto et al., 2004).

At present, study on dielectric properties of wood quite widely. However, very little work has been done on the dielectric properties of bamboo.

This study determined dielectric constant and dielectric loss factor of bamboo at different moisture contents and frequencies. The main purpose is to provide the dielectric properties of bamboo to determine the parameters of high frequency press technology.

II. RESEARCH METHODOLOGY

2.1. Materials

The bamboo (*Phyllostachys heterocycla* cv. *pubescens*) trees [6 years old, diameter ranging from 7 to 12 cm] were collected from Zhejiang, China. Approximately, the same amount of bamboo semicircular fragments was cut from the bamboo stem to prepare flat-rolled. Bamboo samples were cut from these bamboo strips with a diameter of 50 mm and thickness of 5 mm. Uniformity of test sample surfaces were polished by using a sanding paper. Total of test samples were 12 samples.

2.2. Experimental methods

2.1.2. Moisture adjustment

Moisture adjustment was conducted in drying cabinet. Based on experimental requirements, all samples were put into drying cabinet and the use of thermostat humidity cabinet to adjust moisture content of bamboo samples. All samples were conditioned for 0% to 18% relative humidity to adjust. Moisture adjustment times were 3 times, every time was 3 days. Moisture content adjustment parameters of bamboo samples in Table 1.

Table 1. Moisture content adjustment parameters of Bamboo

Moisture content (%)	Adjustment parameters			
	Time 1		Time 2	
	Temperature (^{0}C)	Humidity (%)	Temperature (^{0}C)	Salt solution
0	100±2	0 ÷ 2	20	-
6	35	40	20	KNO_3
12	35	78	20	NaCl
18	35	98	20	$MgCl_2$

The moisture content (MC) of the samples were calculated according to the following formula: MC (%) = $[(m_1-m_0)/m_0]\times100$, where m_1 is the weight of the sample before drying, and m_0 is the weight of the sample immediately after drying.

2.1.2. Experimentalmethod

Figure 1 displays the flow chart when using the 16451B for permittivity measurements.

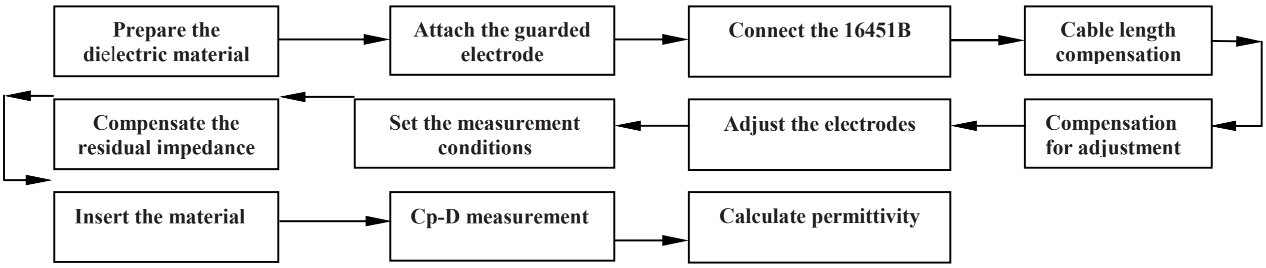

Figure 1. Measurement procedure flow chart for the 16451B

When using an impedance-measuring instrument to measure permittivity, the parallel plate method is usually employed. An overview of the parallel plate method is shown in Figure 2.

The parallel plate method, also called the three terminal method in ASTM D150, involves sandwiching a thin sheet of material or liquid between two electrodes to form a capacitor. The measured capacitance is then used to calculate permittivity. In an actual test setup, two electrodes are configured with a test fixture sandwiching dielectric material. The impedance- measuring instrument would measure vector components of capacitance (C) and dissipation (D) and a software program would calculate permittivity and loss tangent.

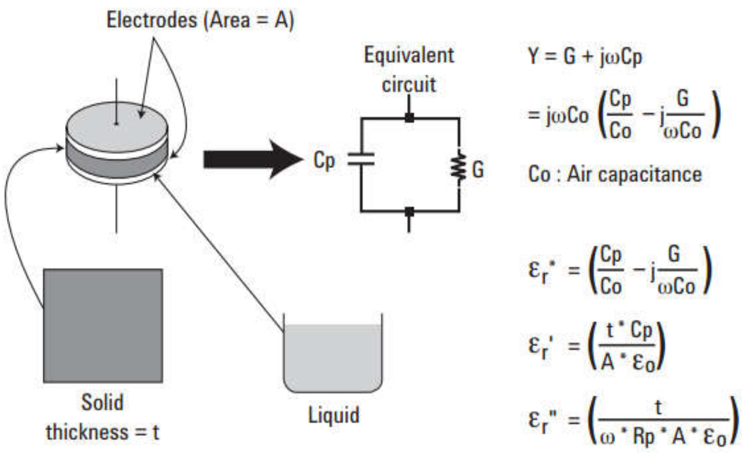

Figure 2. Parallel plate method

2.1.3. Measurement of Dielectric

The measurements of dielectric constant (ε’) and tan (δ) values of bamboo samples were made by using a Agilent 4294A Precision Impedance Analyze with the 16451B, in the moisture content range from 0% to 18% and frequency range from 60 Hz to 6 MHz.

ε’ was calculated by using the following equations: $\varepsilon' = (ta\times C_p)/(A\times\varepsilon_0)$, where C_p (F) is equivalent parallel capacitance, ta (m) is average thickness of test sample, A (m^2) is area of Guarded electrode, and $\varepsilon_0 = 8.854\times10^{-12}$

[F/m]. Each sample had tested with 3 times. Value of ε' and tan δ were averaged.

III. RESULTS AND DISCUSSION

3.1. Dielectric constant (ε')

The change of dielectric constant as a function of moisture content at several frequencies for bamboo is shown in Figure 3. It is visible that dielectric constant of bamboo is directly related to treatment severity, which depends on the moisture content. ε' increased with increasing moisture content showing anomaly at the transition MC from 0% to 18%. ε' decreased with increasing frequency from 60 Hz to 6 MHz. ε' increased with increasing severity of moisture content treatment. With the same moisture content condition, in general, ε' of treated bamboo sample decreased in the order of the frequencies from small to large. It is quite the reverse, with different moisture content conditions on the same bamboo sample, in general, ε' of treated bamboo sample increased in the order of the treatment moisture contents (0%<6%<12%<18%). Moisture content is the dominating factor over duration of adjusting in increasing ε'. The same dielectric constant can be obtained at lower treatment frequency with lower moisture content or by using higher treatment frequency with higher moisture content. For example, with the same treatment time were nine days, dielectric constant of bamboo samples were about 6.0 ± 0.5 when moisture content at 6% for 60Hz but only required 20% at 6 MHz.

Dielectric constant of the bamboo in the dry state has lowest value (2.0) and has highest value 2.19 with different frequency.

Dielectric constant of the bamboo at MC 18% has the lowest value (6.68) with frequency at 6 MHz and it has the highest value (61.34) with frequency at 60 Hz.

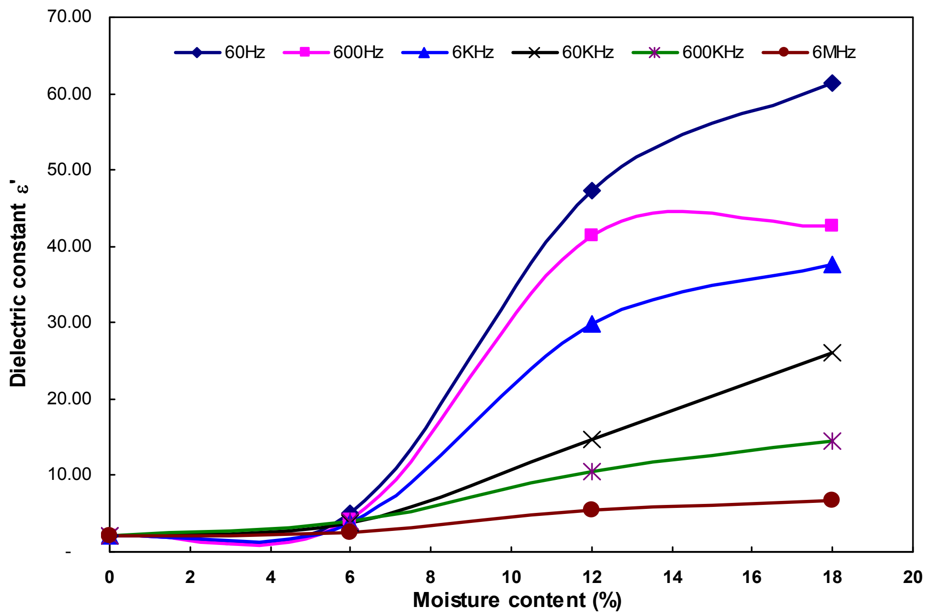

Figure 3. Variation of Dielectric constant e' for Bamboo at different moisture contents and frequencies

Table 2 presents the two-way analysis of variance (ANOVA) results of the ε' of bamboo. Moisture content and frequency showed significant effects on dielectric constant, (P-value < 0.0001). In addition, these two factors showed significant interaction on the dielectric constant of bamboo.

Table 2. Two-Factor Without Replication results of dielectric constant of bamboo

Source	df	F-value	P-value
f	5	42.70	< 0.0001
MC	3	158.29	< 0.0001
f×MC	15	13.66	< 0.0001

f – Frequency.

MC – Moisture content.

f×MC – Interaction of frequency and moisture content.

This increase of ε' is due to the increased mobility of water dipoles in bamboo. Water has OH molecules and OH of water acts as a dipole (Chand et al., 1994). These dipoles contribute to the ε' behaviour of the bamboo. The bound water content of bamboo gradually increased when the moisture content of bamboo increased, ε'of water is relatively high (≈ 81) (Liu et al., 2004), lead to ε' increases with increasing of water in bamboo. When moisture content of bamboo is lower than the fiber saturation point, the bound water of bamboo fibers has not been in a saturated state. Therefore, freedom degree of functional groups in bamboo molecules are quite small, kinetic energy of molecule is small that effect the electrical conductivity, the dielectric constant increases quite slowly. Dielectric constant decreased when moisture content is lower than 6% with frequency variation and which increased quickly when moisture content is larger than 12% with high frequency value (> 6 KHz). The moisture content of bamboo is near the fiber saturation point, the movement speed of molecules bamboo is faster, the electrical conductivity increased to make dielectric constant increased. At lower frequencies, because the water molecules's dipolar are absorbed, lead to ε' values in the bamboo is high.

3.2. Dielectric loss tangent δ

The change of tan δ value is shown in Figure 4. It is visible that dielectric loss tangent of bamboo was observed increasing with increasing moisture constant and decreasing with increasing frequency. Tan δ decreased when moisture content is lower than 6% and increased quickly when moisture content is larger than 12%. Tan δ increased slowly with the moisture content below fiber saturation point (FSP), increased sharply with the moisture content around the FSP. Tan δ decreased sharply at the low frequency (< 6 KHz) and decreased slowly at the high frequency (> 6 KHz).

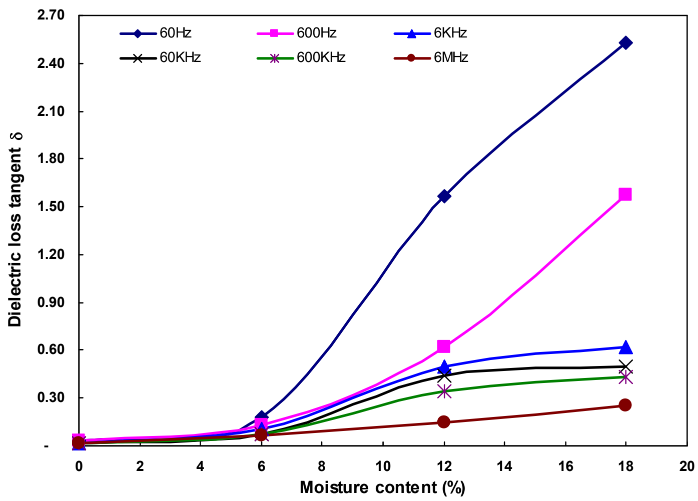

Figure 4. Variation of Dielectric loss tangent d for Bamboo sample at different moisture contents and frequencies

Table 3 presents the two-way analysis of variance (ANOVA) results of the tan δ of bamboo. Moisture content and frequency showed significant effects on dielectric loss tangent (P-value < 0.0001<). In addition, these two factors showed significant interaction on the dielectric loss tangent of bamboo.

Table 3. Two-Factor Without Replication results of dielectric loss tangent of bamboo

Source	df	F-value	P-value
f	5	14.85	< 0.0001
MC	3	37.60	< 0.0001
f×MC	15	5.69	< 0.0001

f – Frequency.

MC – Moisture content.

f×MC – Interaction of frequency and moisture content.

This decrease of tan δ is mainly due to the reduction of the hydroxyl group content in bamboo. At lower frequency, a section of water molecules and free radicals in molecular organization of bamboo moved and actived when the electric current changes, tan δ decreased sharply. Water molecules and free radicals in molecular organization of bamboo moving speed to late to keep up with changing frequency, the number of actived free radicals are reduced, conduction of electric current inside bamboo decrease, tan δ decreased slowly. The lossy dielectric can be represented by the circuit analog of a resistance in parallel with a capacitor minimizes (Goodman et al., 1991). At higher frequencies, the capacitor offers low reactance minimizes the conduction losses in the resistor. Hence, value of dielectric loss decreases at the higher frequencies (Vijendra Lingwal et al., 2003; Shiraneet al., 1954). The tan δ decrease from at all frequencies.

IV. CONCLUSIONS

Dielectric properties that include dielectric constant (ε') and dielectric loss tangent (tan δ) have been done in the moisture content range from 0% to 18% and in the frequency range from 60 Hz to 6 MHz. From the above results, we can give some conclusions:

(1) Dielectric constant (ε') and tan δ exist in bamboo. Low moisture content (MC < 6%) and high frequency variation (> 6 KHz) are less effective on dielectric properties, but they are very effective on dielectric properties a thigh moisture content (MC > 12%) and low frequency variation (<6 KHz). Dielectric constant was small when the bamboo in the dry state with different frequency value. Dielectric constant of the bamboo at MC 18% was lowest value (6.68) with frequency at 6 MHz and it was highest value (61.34) with frequency at 60 Hz. Tan δ decreased when moisture content is lower than 6% and increased quickly when moisture content is larger than 12%.

(2) Dielectric constant (ε') and tan δ increased with the increase of moisture content and decreased with the increase of frequency. Dielectric constant (ε') and tan δ increased slowly with the moisture content below fiber saturation point (FSP) and they increased sharply with the moisture content around the FSP.

(3) Dielectric constant (ε') and tan δ changed obviously when the frequency is changing, and decreased with increasing frequency. At lower frequency, tan δ decreased sharply. At higher frequency, tan δ decreased slowly. Dielectric constant and tan δ decreased obviously with the frequency below 6 KHz, but they changed slowly when it is above 6 KHz.

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ẢNH HƯỞNG CỦA ĐỘ ẨM VÀ TẦN SỐ ĐẾN ĐẶC TÍNH ĐIỆN MÔI CỦA TRE (*Phyllostachys heterocycla* cv. *pubescens*)

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TÓM TẮT

Độ ẩm của tre và giá trị tần số là những nhân tố quan trọng nhất ảnh hưởng đến đặc tính điện môi của tre. Đặc tính điện môi lại là một trong những nhân tố quan trọng nhất dùng để xác định các thông số công nghệ của quá trình ép nhiệt cao tần ván ghép khối tre. Vì vậy, việc nghiên cứu đặc tính điện môi của tre có ý nghĩa vô cùng quan trọng... Trong bài viết này, độ ẩm của nguyên liệu tre được điều chỉnh từ 0 - 18% trong điều kiện phòng thí nghiệm. Sau đó sử dụng thiết bị 4294A kết nối với máy phân tích trở kháng 16451B để xác định ảnh hưởng của độ ẩm và tần số đến đặc tính điện môi của tre. Đặc tính điện môi bao gồm hằng số điện môi (ε') và góc tổn thất điện môi (tan δ) được xác định trong phạm vi độ ẩm từ 0 - 18% và tần số từ 60 Hz - 6 MHz. Kết quả nghiên cứu cho thấy, hằng số điện môi (ε') và góc tổn thất điện môi (tan δ) tăng khi độ ẩm của tre tăng và giảm khi tần số tăng. Hằng số điện môi (ε') và góc tổn thất điện môi (tan δ) tăng chậm khi độ ẩm dưới điểm bão hòa thớ gỗ (FSP), tăng mạng khi độ ẩm tre gần với điểm bão hòa thớ gỗ FSP. Hằng số điện môi (ε') và góc tổn thất điện môi (tan δ) không tăng rõ ràng khi tần số ở dưới 6 KHz, nhưng lại thay đổi chậm khi tần số trên 6 KHz.

Từ khóa: Độ ẩm, góc tổn thất điện môi, hằng số điện môi, tần số, Tre.

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