Dielectric and Conductivity Properties of some Wood Composites

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Abstract. This study presents the dielectric and conductivity properties as function of temperature and frequency of wood based composites. These properties were measured by an open-ended coaxial probe at frequency range between 100 kHz to 100MHz, temperature from 30°C to 200°C which is fully computer interfaced. It has been observed that dielectric constant (ϵ') and dielectric loss factor (ϵ'') increase with increasing temperature and decrease with increasing frequency. At low temperature region, the conductivity depends significantly on the frequency. However, with the increase in temperature dielectric relaxation takes place and the dependency of the conductivity on frequency get reduced. The patterns of variation were established for the studied specimens and discrepancies were discussed. The study of dielectric properties will help in improving the drying, heating and gluing processes of wood and wood based products.

INTRODUCTION

The dielectric properties of wood are useful for the understanding of molecular structure of wood, instrumental and industrial applications. Recently many researchers are exploring the utilization of high frequency and microwave techniques for improving energy efficiency and quality of end product. The dielectric properties of wood have been studied in the past by using several techniques.

When dielectric (wood or wood composite) material in an electric field, the current-carrying properties of wood/wood composites are governed by certain properties such as moisture content, density, grain direction, temperature etc. The overall effects of these parameters interact with each other and add to the complexities of the dielectric properties. The temperature dependence of wood dielectric properties have been reported by many researchers by using different methods [James w.l. et al, James w.l.et al, D.W. Hamil et al] [1-3].

The dielectric properties of a non-conducting material describe the interaction of the material with electric fields. The two interactions of primary interest are the absorption and storage of electric potential energy in the form of polarization within the dielectric material, and the dissipation or loss of part of this energy when dielectric field is removed. The energy absorbed by dielectric is most easily measured in terms of capacitance, so the dielectric constant of material is usually defined as the ratio of capacitance with the material as the insulating medium to the capacitance of the same invacuum. The rate of energy loss in the dielectric is expressed commonly by the loss factor (or dissipation factor) dissipation factor is the product of loss tangent and dielectric constant.

One of the earlier studies of the dielectric properties of wood was studied by C. Skaar et al[4], who showed that the dielectric constant of wood increased continuously as the moisture content increased and decreased with increasing frequency of the applied field. His data do not show clearly recognizable trends in loss tangent. Dielectric properties at low frequencies and low moisture content have been reported by several researchers W.L. James et al, J. Rafalski et al [1, 5] it has been established that the dielectric behaviour of wood to an alternating electric field are governed by several factors such as frequency, temperature, moisture content, density and grain direction R.T. Lin et al, G.I. Torgovnikov et al [6,7]. The dielectric properties of were carried out for typical Australian wood based on Von Hippel's transmission line method in microwave frequency region by Ramaswamy et al [8]. As the studies of dielectric properties became more

sophisticated, other variables were considered such as temperature, Structural direction M Norimoto et al [9] and density J.Rafalski et al[5] with the results showing that these other variables also have important influence on the dielectric behaviour of wood. A notable weakness in the literature of dielectric and electrical properties of wood based composite materials have been lack of study that covered a wide range of all primary variables of sample completely.

In this present study the dielectric constant (ϵ'), dielectric loss factor (ϵ''), conductivity of some of wood based composite materials such as Fire Retardant Plywood (FR Ply), Moisture Resistant Plywood (MR Ply), Boiling Water Proof Plywood (BWP Ply), and Medium Density Fibre board (MDF). Data were taken at temperature from 30°C to 200°C and frequency range from 100 kHz to 100MHz.

MATERIALS AND METHODS

Specimen:

The specimen from each board were milled and cut into disc with 30mm diameter and 5mm thickness for testing. Two set of samples were prepared for each material. One specimen used as a control to calculate the initial moisture content and second specimen for the data measurements. The samples were placed in a conditioning chamber at recommended temperature ($27 \pm 2^\circ\text{C}$) and humidity ($65 \pm 5\%$) to achieve recommended moisture content 5-15%. After samples were conditioned, moisture content was calculated. The average moisture content variation was $\pm 3\%$.

In order to obtain reproducible data, it is necessary to eliminate variability in the electrochemical condition of the specimen surfaces. This was achieved by coating the flat surfaces (both) of the specimens with electrically conducting silver paste. After electrode specimen were dried at 50°C for 30mins.

Dielectric and conductivity properties of some wood composite materials have been studied those are Fire Retardant Plywood (FR Ply), Moisture Resistant Plywood (MR Ply), Boiling Water Proof Plywood (BWP Ply), and Medium Density Fibre board (MDF). Data were taken at temperature from 30°C to 200°C and frequency range from 100 kHz to 100MHz.

Testing:

Dielectric constant, loss tangent and conductivity data were taken by using HIOKI make LCR Hi-Tester, Japan with frequency range of 100 kHz to 120MHz. The system consisting of an open-ended coaxial probe (4mm diameter) and fully computer interfaced. The system measured the reflection coefficient data from open and short. For temperature variation hot air circulated oven range from Room temperature (RT) to 600°C attached to the system.

Accuracy and Errors

The instruments used in this study were capable of measuring the capacitance and dissipation factor of stable capacitors to high degree of precision and accuracy, so the predominant source of error here was the inherent instability of the quantities being measured. Data taken on specimens encapsulated as described earlier were generally constant and repeatable to within $\pm 10\%$ of the mean data.

RESULTS AND DISCUSSION

Each specimen was placed in sample holder and measurements were taken at different temperatures. The temperature was raised using a PID controlled heating system with an accuracy of $\pm 0.1^\circ\text{C}$. Before measurement at each temperature, the specimen was kept at this constant temperature for 5min to ensure that the sample stabilized at a uniform internal temperature and equilibrated with the surrounding cell temperature.

Dielectrics are the substances, which do not possess free electric charges under ordinary circumstances. In fact the most important property of dielectrics is their ability to become polarized under the action of an external electric field. An external electric field influences the atoms and

molecules of dielectrics and hence the positive charged particles are pushed in the direction of the electric field, while the negative charged particles are pushed in the opposite direction from their equilibrium position. Hence dipoles are developed and they produce a field of their own. The process of producing electric dipoles out of neutral atoms and molecules is referred to as polarization.

Dielectric constant and dielectric loss factor:

Dielectric constant (ϵ') was calculated by using the following relation

$$\epsilon' = C/C_0,$$

where, C and C_0 are the capacitance values with and without dielectric respectively. C_0 is given by

$$C_0 = [(0.08854 A)/d]$$

where, A is the area of the electrode surface of the specimen and d thickness of the specimen. Dielectric loss tangent ($\tan \delta$) is defined as follows

$$\tan \delta = \epsilon''/\epsilon'$$

where, ϵ'' is the dielectric dissipation factor.

Dielectric constant and loss factor of wood based composite materials have been measured by using LCR meter with temperature range from 30°C to 200°C with 10°C intervals and frequency from 100 kHz to 100MHz. Fig.1 shows the variation of dielectric constant (ϵ') with temperature for all the tested specimens. The dielectric constant increases with increasing temperature. The increase in dielectric constant with temperature can be explained by the fact that the dipolar groups are bound in the solid structures so that the dipole is a structural element of solid lattice and the rigidity of the lattice hinders (delay) the orientation of the dipoles A.Z. Nanassy et al [10]. At elevated temperatures, the dipoles acquire energy, which allows them to reorient, consequently an increase in the dielectric constant results. These results support the finding of J. Tsutsumi et al [11], who showed the dielectric constant of wood increased with temperature and also showed a strong relationship with frequency. Fig.2 shows the behaviour of dielectric loss factor (ϵ'') with temperature at different frequencies. The values are increased with increasing temperature due to orientation, space charge and interfacial polarization contributions.

Fig.3 shows the behaviour of real part of dielectric constant (ϵ') versus frequency response at different temperatures. It is observed that ϵ' follows an inverse dependence on frequency, normally followed by almost all dielectric/ferroelectric materials. The higher values of dielectric constant found at low frequency is due to the presence of all types of polarization (atomic, electronic, space charge etc.) mechanisms Mike Golio et al [12]. At higher frequencies ϵ' are found to decrease, as it arises due to the contribution from electronic polarization, other contributions becoming insignificant and also fall in dielectric constant arises from the fact that polarization does not occur instantaneously with the application of the electric field because of inertia Mike Golio et al [12]. This takes place at the contacts or in the bulk of the material at the grain boundary. Charge is able to accumulate at these interfacial sites and thereby able to contribute to the total capacity or dielectric constant. At low frequencies, all types of polarization contribute. As frequency is increased, those with large relaxation times cease to respond and hence the decrease in dielectric constant. Dielectric and conductivity values of all the studied composite materials are shown in table 1.

Conductivity:

The mechanism of ionic conductivity in solids has been generally discussed in terms of the conventional hopping formalism A.B. Lidiard [13]. The conductivity of an ionic conductor is determined by both the concentration of the mobile ions and the rate at which they are able to hop from site to site in the material. Fig.4 shows the conductivity of tested specimens as a function of

frequency (100 kHz to 100MHz) at different temperatures. The characteristic features of these dielectric materials are

- (i) A Plateau region at low frequencies which reflects the d.c. conductivity of the samples and
- (ii) A dispersive region at high frequencies where the conductivity can be described by a power law.

$$\sigma(\omega) \propto \omega^n$$

where ω is the frequency and n is the exponential factor, which generally varies between 0 and 1. Both regions are separated by a cross-over regime. The conductivity in the low frequency region is associated with the short range translational hopping mechanism and conductivity in the high frequency region is associated with the reorientational hopping mechanism. This over all behaviour has been found for many ionic conductors and has been reported by many researchers K.Funke et al [14], W.Dieterich et al [15].

Temperature dependence of conductivity at different frequencies of studied specimens is shown in Fig.5. It was found that conductivity increased with increase in temperature. Orientation of fiber's in composite changes the structure of the total composite, due to which conductivity changes with the orientation. At low temperature region, the conductivity depends significantly on the frequency. However, with the increase in temperature dielectric relaxation takes place and the dependency of the conductivity on frequency get reduced.

CONCLUSIONS

Dielectric constant and loss tangent of wood based composite materials have been measured by using LCR meter with temperature range from 30°C to 200°C with 10°C intervals and frequency from 100 kHz to 100MHz. Higher values of dielectric constant (ϵ') and dielectric loss factor (ϵ'') found at low frequency is due to the presence of all types of polarization (atomic, electronic, space charge etc.) mechanisms. Observed conductivity is found to dependent on both temperature and frequency indicating the conduction mechanism is thermally activated process in all the studied materials. The results obtained using the coaxial probe appeared to be reasonable when compared with previous studies. This study help in improving energy efficiency and quality of end product are exploring the utilization of high frequency and microwave techniques.

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Tables:

Table 1: Dielectric and Conductivity values of wood and bamboo based composite materials

Sl.No	Specimen name	Moisture content at RT (before test), %	Dielectric constant (at 100 kHz)		Conductivity at RT (mho/m)
			low	Maximum	
1	MDF	7	0.94	1.31	1.029×10^{-7}
2	MR plywood	6	6.62	7.27	9.76×10^{-8}
3	BWP plywood	6	6.68	7.25	1.01×10^{-7}
4	FR plywood	6	7.12	8.63	9.76×10^{-8}

Figures:

Figure 1 (a-d): Dielectric constant verse temperatures at different frequencies

Figure 2(a-d): Dielectric constant verse temperatures at different frequencies

(a) MDF

(b) MR ply

(c) BWP ply

(d) FR ply

Figure 3(a-d): Dielectric constant variation with frequency at different temperatures

Figure 5 (a-d): Conductivity versus Temperature at different frequencies

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