Investigation on Gradient Dielectric Characteristics of Bamboo (*Dentroclamus strictus*)

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ABSTRACT: Dependence of dielectric constant (ε') and dielectric dissipation factor (tan δ) on distance from outermost skin to the center of bamboo has been determined. Dielectric measurements have been done in the temperature range of 24–120°C and in the frequency range, 4–100 kHz. Gradient behavior in ε' and tan δ has been found in bamboo. It has also been observed that ε' and tan δ increase with increasing temperature and decrease with increasing frequency. Relaxation times have been calculated for the four samples at 80, 90, and 100°C temperatures, which show that relaxation time decreases with the increase of temperature because of the increased molecular mobility. A continuous increase in the hardness from center (48) to outer surface (70) and density from 0.45 to 0.80 g/cc has been observed. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 102: 380–386, 2006

Key words: dielectric constant; tan δ; bamboo (*Dentrocalamus strictus*); hardness

INTRODUCTION

Bamboo is a natural material, and is an abundantly available natural resource in Asia and South America. It has been used traditionally as a structural material for fabrication of village houses. Shin et al.[1] reported that it is possible to use bamboo as a reinforcing member in a composite.

Different types of woods and wood-like materials such as bamboo are being increasingly used for insulation and lamination applications by using different polymers such as methyl methacrylate (MMA) and butyl methylacrylate (BMA). Electrical properties like resistivity and dielectric constant of both wood and wood composites have been reported with different moisture content in the past by Khan et al.[2] It has been found that dielectric constant of wood increased significantly with moisture content but no significant difference was observed in the case of wood-filled polymer composites.

Bamboo or wood-reinforced polymer composites can be used as an important insulating material for special applications such as spacer panels and switchboards. Chia et al.[3] reported that untreated wood had a higher dielectric constant than their polymer composite. They concluded that the presence of polymers has decreased the number of polarizable units to use bamboo for insulating applications. Chia et al.[3] made another important observation that the dielectric constants of untreated wood increased with density.

Among the natural fibers,[4–6] bamboo has low density, which have been used as reinforcement[7] and has high mechanical strength.[8,9] Specific gravity of bamboo is approximately 0.66 g/cc as compared to that of glass fiber, which is approximately 2.5. The reported specific tensile strength of bamboo fiber is 0.28 GN m^{-2}, which is less than that of glass fiber, which is heavily 1.3 GN m^{-2}.

Bamboo stem is composed of three parts: bamboo skin, bamboo timber, and pith. Bamboo skin is the outermost part of cross section of stem wall, where no vascular bundles are present. Pith is the part of stem wall next to bamboo cavity, it also does not contain vascular bundles. Bamboo timber is the part between skin and pith. Vascular bundles are observed on its cross section. The density of vascular bundles decreases from outer side of stem wall to inner side. The outer part where vascular bundles are dense is called bamboo green, while the inner part where vascular bundles are rare is called bamboo yellow.

Chand and Joshi[10] have reported the dielectric properties of sisal fibers in their earlier paper. The electrical properties of some natural fibers, such as volume resistivity and dielectric strength, have been studied by Kulkarni et al.[11] However, very little work has been reported on the electrical properties of bamboo.

Determination of dielectric behavior of different sections of bamboo cut from the outer skin to center of

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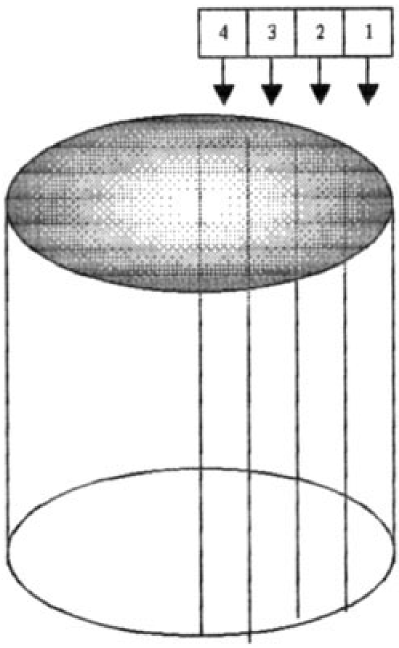

Figure 1 The schematic diagram of bamboo gradient.

the bamboo is very necessary for finding its proper applications. In this paper, dielectric constant (ε') and tan δ values of different sections cut from outer skin to the central core have been determined at different temperatures and frequencies. Shore D hardness, density, and relaxation time of the bamboo are also determined.

EXPERIMENTAL

Materials

The bamboo (*Dentrocalamus strictus*) used in this study was collected from Sehore, India. Density of the bamboo was 0.66 g/cc.

Sample preparation

Different strips at fixed distance from the outer periphery to center were cut from the bamboo stem as shown in Figure 1. Test samples were cut from these strips. Uniformity of surfaces was obtained by polishing the sample by using a polishing cloth. Both sides of the sample were coated by using an air-drying type graphite conducting paint before dielectric measurements.

Testing

Dielectric measurements

Capacitance (C) and tan δ values of bamboo samples were measured by using a Hewlett–Packard, LCR Meter, model 4274 A in the temperature range 24–120°C and frequency range 4–100 kHz. Heating rate was kept constant at 1°C/min. ε' was calculated by using the following relation

$\varepsilon' = C/C_o$,

where C and C_o are the capacitance values with and without dielectric, respectively; C_o in given by $= [(0.08854\ A)/d]$ pF,

where A (cm^2) is the area of the electrodes and d (cm) the thickness of the sample, tan δ is the dielectric dissipation factor and is defined as follows tan $\delta = \varepsilon''/\varepsilon'$ where ε'' is the dielectric loss.

Hardness

Hiroshima hardness tester (Durometer) model RHT-1 is used to determine the hardness of bamboo specimens. The hardness is defined as the resistance of a specimen to the penetration of hardened steel truncated cone (Shore-A), radiuses cone (Shore-D) or a spherical flat indenter. For this test, the samples were cut from outer surface to inner core side. The hardness was measured at room temperature from skin outer side of bamboo to the central inner core side.

Density

For this test, samples were cut in to the form pellets of 2 mm thickness from the bamboo strips. The density was determined by dividing weight with volume.

Microstructure

Scanning electron microscope model JEOL JSM 5600(Japan) was used to observe the microstructure of bamboo samples 1–4.

RESULTS AND DISCUSSION

Figure 1 shows the schematic diagram of bamboo sections, slicing is shown from outermost surface to center core of bamboo, which are numbered as sample 1, 2, 3, and 4, respectively.

Figure 2(a)–2(d) shows the variation of ε' with temperature for bamboo samples 1–4 at 4, 10, 20, 40, and 100 kHz.

Figure 2(a) shows the variation of ε' with temperature for sample 1. It was observed that ε' increases initially with increasing temperature up to 50°C and then ε' decrease with increasing temperature. ε' decreases with increasing frequency from 4 to 100 KHz. This initial increase of ε' is due to the increased mobility of water dipoles present in the bamboo. When the water content reduced, the value of ε' decreased with increase of temperature.

The peak height of ε' decreases with the increasing frequency in samples 1–4. Goodmen et al.[12] reported that the lossy dielectric can be represented by the

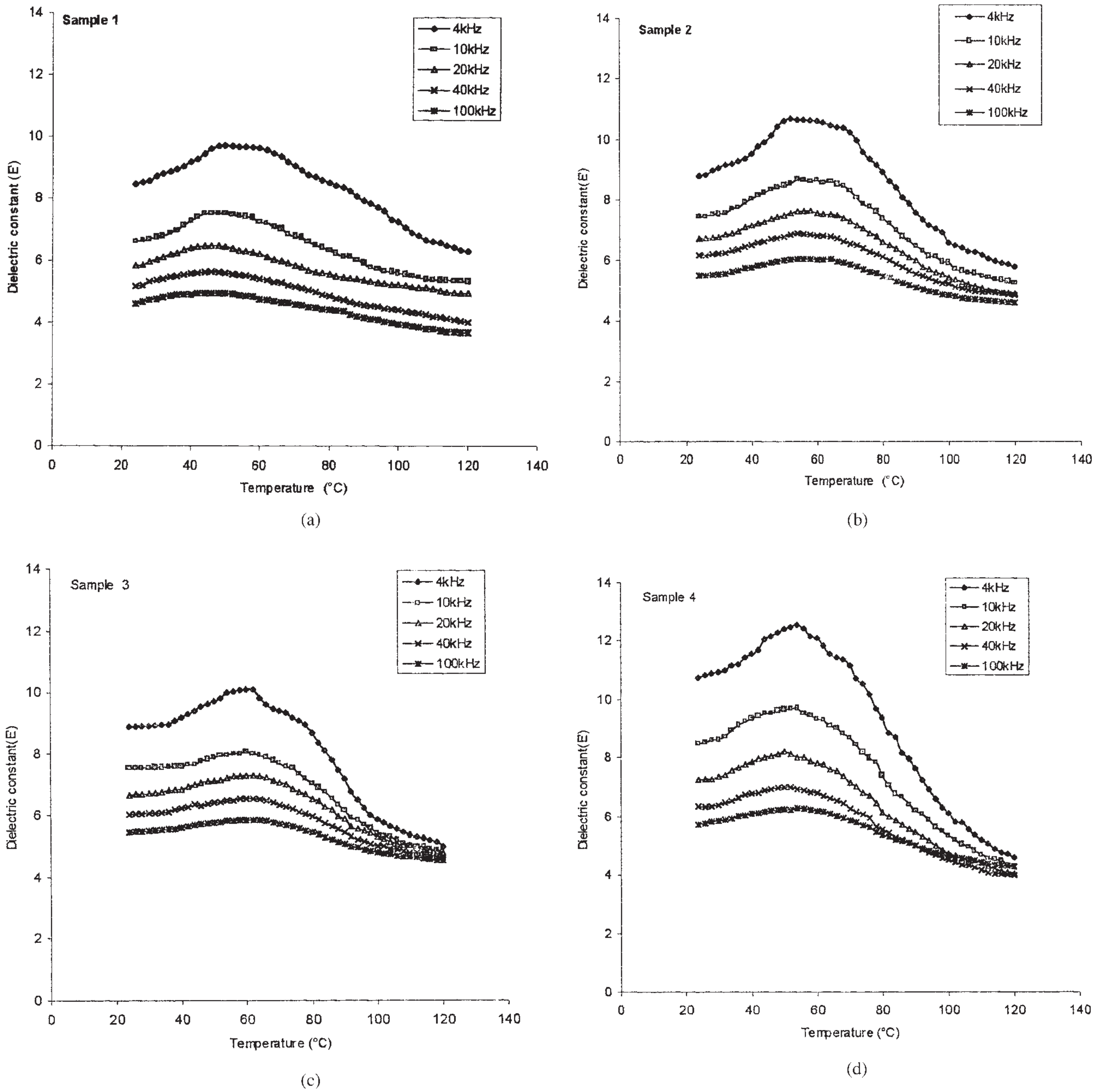

Figure 2 Variation of ε' versus temperature at 4, 10, 20, 40, and 100 kHz frequency for (a) bamboo sample 1, (b) bamboo sample 2, (c) bamboo sample 3, (d) bamboo sample 4.

circuit analog of a resistance in parallel with a capacitor. At higher frequency, the capacitor offers low reactance to the sinusoidal signal, which minimizes the conductance losses in the resistor. Hence value of dielectric loss decreases at the higher frequencies. The present observations were found in good agreement with the results reported earlier.[13]

Another interesting observation in the variation of ε' with temperature is that at higher temperatures, difference in ε' values between at all frequencies has decreased as compared with low temperature ε' values for samples 1. Similar trend has been observed for samples 2, 3, and 4.

Figures 3(a)–3(d) show the variation of tan δ with temperature for bamboo samples 1–4 at 4 10, 20, 40, and 100 kHz frequencies. It was observed that tan δ increases initially up to 60°C and then decrease with increasing temperature. Tan δ decreased with increasing of frequency from 4 to 100 kHz. The tan δ peak heights decrease with increasing frequency in samples 1–4. It was also observed that tan δ peak heights increase from samples 1–4 at all frequencies.

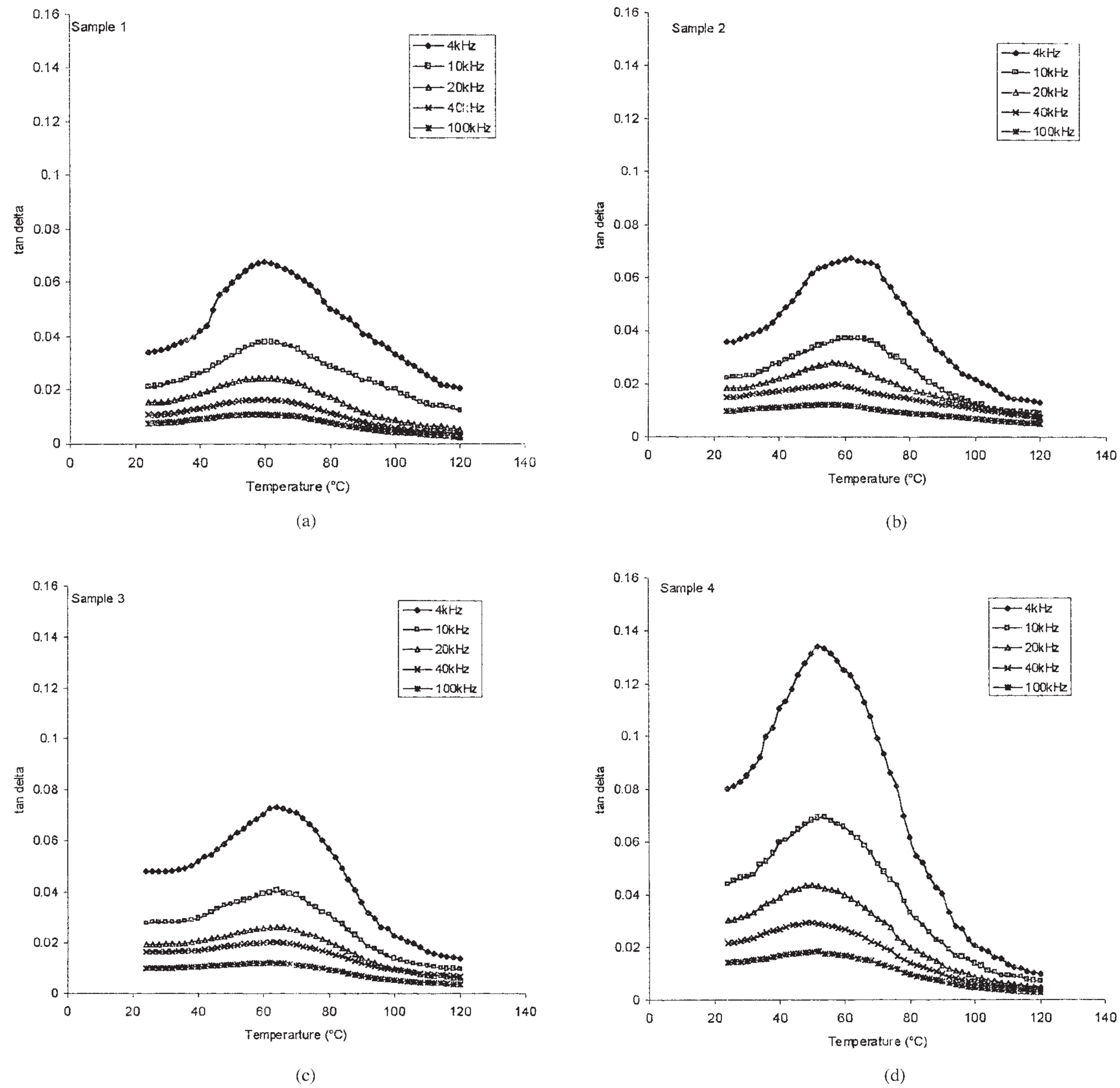

Figure 3 Variation of tan δ versus temperature at 4, 10, 20, 40, and 100 kHz frequency for (a) bamboo sample 1, (b) bamboo sample 2, (c) bamboo sample 3, (d) bamboo sample 4.

In Figures 4 and 5, variation of ε′ and tan δ with temperature for bamboo samples 1–4 are compared. Measurements were done at 4 kHz frequency. It was observed that ε′ increases with distance from outermost surface to inner core of bamboo up to 84°C and tan δ up to 88°C. This shows maximum ε′ and tan δ values for outermost surface and minimum for the center of the bamboo. This is because sample 1 has minimum lignin and moisture as compared with sample 4, which has maximum lignin, volatile content, and moisture. Between samples 1 and 4 there exists a gradient increase of lignin and moisture, and hence there is a gradual increase in ε′ and tan δ.

In Figures 6 and 7 variation of ε′ and tan δ with log of frequency for bamboo samples 1–4 are compared. Measurements were done at 24°C. This shows that ε′ and tan δ decreased with increasing of frequency for bamboo samples 1–4.

Figure 8 shows the variation of hardness and density with distance from outermost surface to the center of bamboo at 24°C. Maximum 70 and minimum 48 shore D hardness values were observed for samples 1 and 4 respectively (Table I). It is found that hardness values are very high at outermost surface where silica content and vascular fiber bundles density are highest as compared with center of

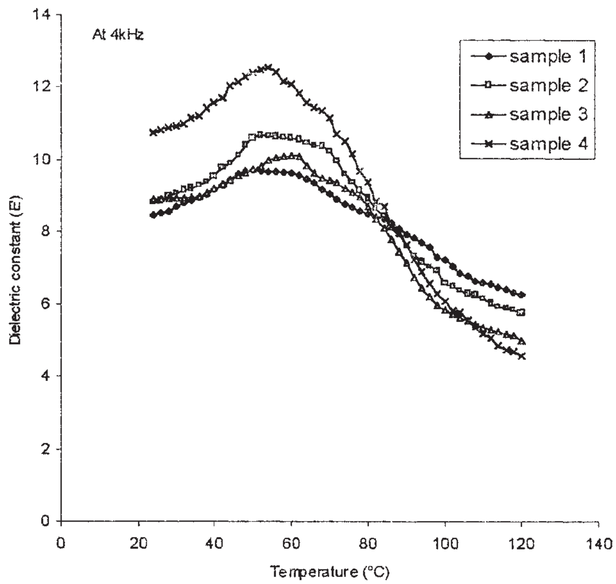

Figure 4 Variation of ε' versus temperature for bamboo samples 1–4 at 4 kHz frequency.

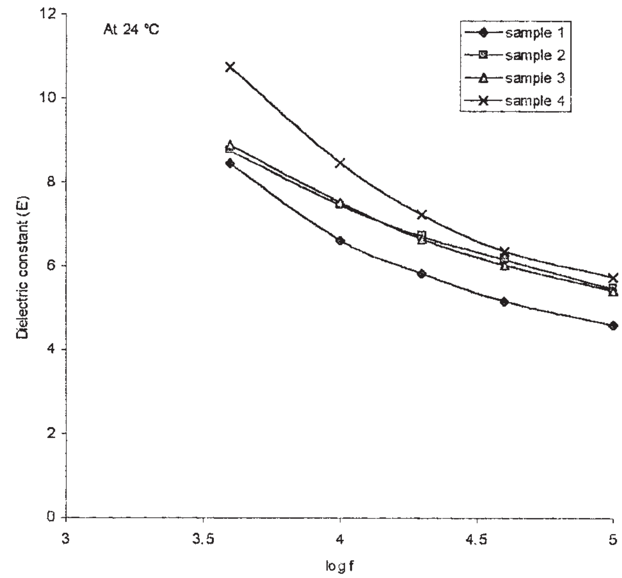

Figure 6 Variation of ε' versus log f for bamboo samples 1–4 at 24°C.

the bamboo. Similarly density was in the range of 0.80–0.45 g/cc.

Figures 9(a)–9(d) show the microstructure for bamboo samples 1–4, respectively. These show that surface has maximum cellulosic cells, while as we go towards the center amorphous lignin and volatile content increases.

Relaxation time for different bamboo samples from the outermost surface to the inner core at 80, 90 and 100°C has been calculated by the equation reported by Chand (1980).[14]

$$\tau\,(s) = 1/\omega[\sqrt{((\varepsilon_0 - \varepsilon_\infty)/(\varepsilon' - \varepsilon_\infty))} - 1]$$

It has been found that increase of temperature decreased the relaxation time by increasing the molecular mobility (Table II).

CONCLUSIONS

1. Gradient in dielectric constant (ε'), tan δ, density, and hardness exists in bamboo.

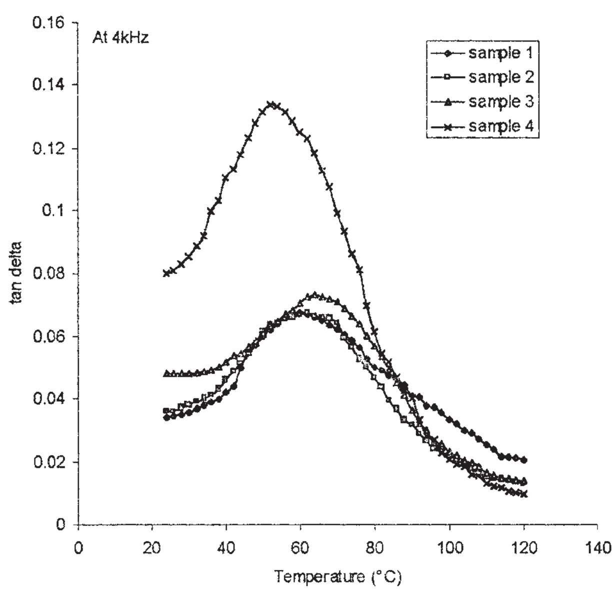

Figure 5 Variation of tan δ versus temperature for bamboo samples 1–4 at 4 kHz frequency.

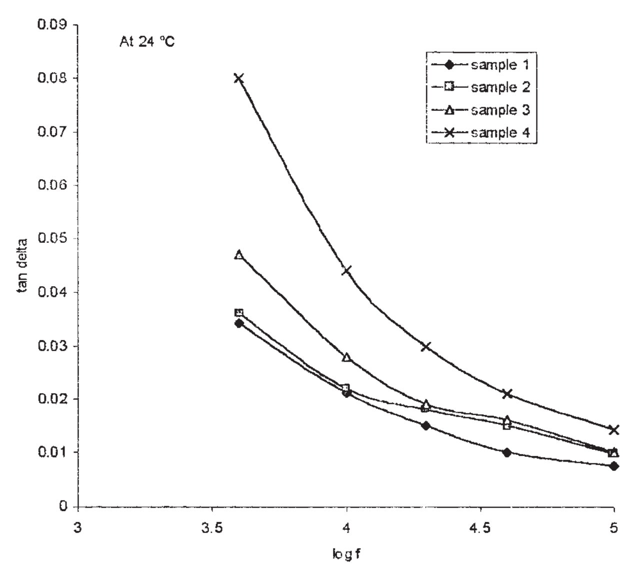

Figure 7 Variation of tan δ versus log f for bamboo samples 1–4 at 24°C.

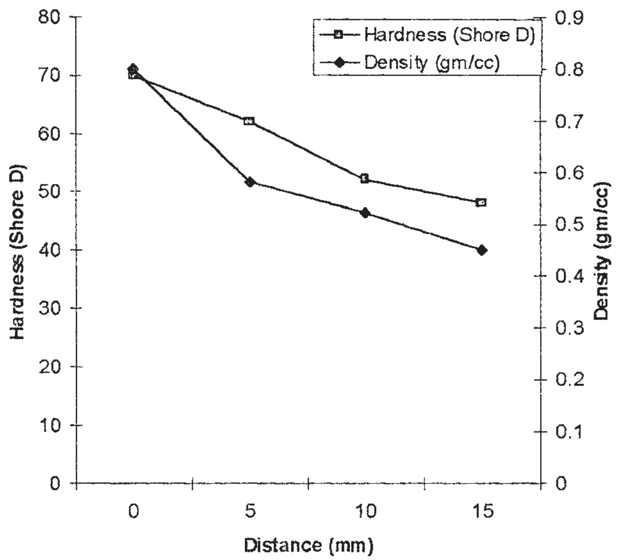

Figure 8 Variation of hardness and density versus distance for bamboo 24°C

TABLE I
Density and Hardness for Bamboo Gradient Samples at 24°C

Sl. no.	Hardness (Shore D)	Density (gm/cc)
1	70	0.8008
2	62	0.5822
3	52	0.5267
4	48	0.4568

TABLE II
Relaxation Time (τ) Values for Bamboo Gradient Sam\ples at 2 kHz

Sl. no.	Temperature (°C)	Relaxation time, τ ($\times 10^{-5}$ s)			
		Sample 1	Sample 2	Sample 3	Sample 4
1	80	1.7	1.4	1.63	1.57
2	90	1.69	1.42	1.56	1.75
3	100	1.60	1.26	1.32	1.64

2. A continuous increase in the hardness from 48 to 70 and density from 0.45 to 0.8 g/cc has been observed from central core to the outer surface of the samples.
3. ε' and tan δ decreased with distance from the center core to periphery outer surface.
4. ε' and tan δ increased with increase of temperature and decreased with increase of frequency.
5. Relaxation time decreased with increase of temperature.

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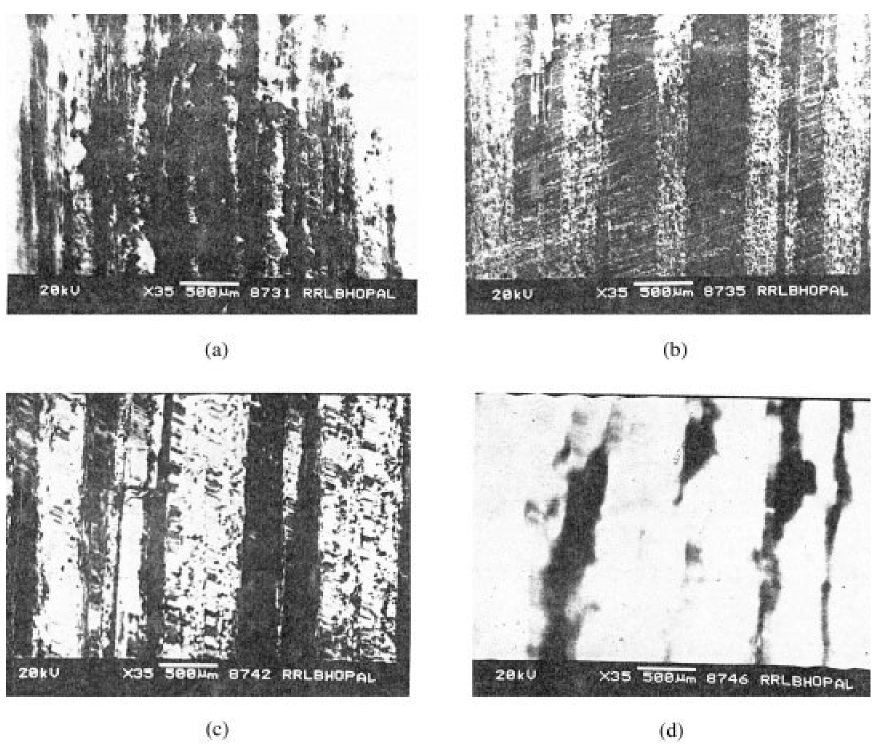

Figure 9 SEM of (a) bamboo sample 1, (b) sample 2, (c) sample 3, and (d) sample 4.

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