

EFFECT OF POSITIONAL DENSITY ON DC CONDUCTIVITY OF BAMBOO FIBRE

Navin Chand,^a Janu Sharma,*^a M. N. Bapat,^b and Archana Nigrawal^a

In the present communication, the effect of positional density on the DC electrical conductivity of bamboo fibres was studied. A comparative study was made between the DC conductivity behavior of bamboo fibres taken from upper and lower portions of bamboo. Four samples from each portion going from centre to periphery were taken. Bamboo fibers taken from the upper portion were less dense, hence showing lower values of DC conductivity. In spite of the lower portion of bamboo being more dense, it showed higher values of DC conductivity, which is attributed to moisture content. Bamboo fibres from centre to periphery were taken from the strips cut at 2 mm distance from centre. The DC conductivity increased from centre to periphery. A theoretical model was developed and verified with the experimental results. It was also found that experimentally determined σ_{dc} values of bamboo fibres taken from different radial locations from center to periphery were in agreement with those values obtained from the proposed equation.

Keywords: Bamboo fibre; DC conductivity; Diffusion coefficient

Contact information: a: Advanced Materials and Processes Research Institute,(CSIR) Hoshangabad Road, Habibganj Naka, Bhopal-462064 (India)

b: Regional Institute of Education, Shyamla Hills, Bhopal (India)

*Corresponding author: janu.sharma87@gmail.com

INTRODUCTION

Bamboo is a natural composite (Ray et al. (2004), which is preferred in construction over wood because of its strength and straightness. Further, it can be split into strips more easily than wood. It is also possible to use this material as a reinforcing member in a composite (Barton et al. 2002). A good deal of work has been done on electrical properties of natural fibers (Van De Velde and Kiekens 2002; Walter 1992; Alekseeva 2007; Titok et al. 2006; Datta et al. 1980). Chand et al. (2006a) have reported the dielectric behavior of bamboo.

Mechanical properties of bamboo in radial and longitudinal direction were determined experimentally by (Chand et al. 2006b). They found systematic variation in density due to difference in fiber concentration across its cross-section. The mechanical properties including density of bamboo varies from the center to the periphery due to the change in composition at different radial positions.

Studies on electrical properties of lingo cellulosic materials indicated their suitability as insulating materials for applications such as bushings, studs, gaskets, and switch boards. No standards are available to measure the electrical parameters of natural fibres (Kulkarni et al. 1981). Small currents observed in natural fibres were due to moisture content and presence of minor impurities (Kulkarni et al. 1981). Electrical

conductivity is responsive to any alteration in chemical composition and structure of a material (Kubisz et al. 2007). However, there has been a lack of published work concerning the positional dependence of DC conductivity of bamboo fibre.

It is expected that the electrical conductivity of bamboo fibre is a function of density and moisture content. There is possibility of variation of DC conductivity at different distances from the centre to the periphery in the bamboo fibre. The objective of this study is to develop a model for DC conductivity of bamboo fibre based on position of fibres in bamboo. A theoretically developed model is validated against experimentally determined DC conductivity values.

MATERIALS AND METHOD

The bamboo (*Dentrocalamus strictus*) used in this study was collected from Sehore, India. Cylindrical bamboo fiber samples were taken out from a bamboo stem of 16 mm diameter and from four different rectangular strips of 2mm thickness vertically sliced from centre to periphery. Cylindrical fibers of 1.6 cm length were taken out from the entire strip, as shown in Fig. 1.

Sample Preparation

Cylindrical fibers also were taken from the rectangular strips cut from known distances from the center to outer periphery and from upper and lower portions. Uniformity of cylindrical fibre sample surfaces was achieved by polishing the samples. Ends of fibres were coated with conducting silver paint to provide proper contact.

DC Conductivity Measurement

Sliced samples were coated by an air-drying type of conductive silver paint on both sides. Resistance values of the sliced bamboo samples were measured by using a Keithley Electrometer model 610C with a two-probe setup. The DC conductivity was calculated from resistance by using following equation,

$$\sigma_{dc} = l/\rho = \frac{L}{RA} \quad (1)$$

where, σ_{dc} is the dc conductivity of bamboo, R is the resistance, A is the area, and L is the thickness of the sample. Sample designations are shown in Table.1 and 2

Density Measurement

Test samples were cut in the form of cylindrical fibres of approximately $0.1 \times 1.76 \text{ cm}^2$ area from the rectangular bamboo strips. The density was determined by dividing the weight by the volume.

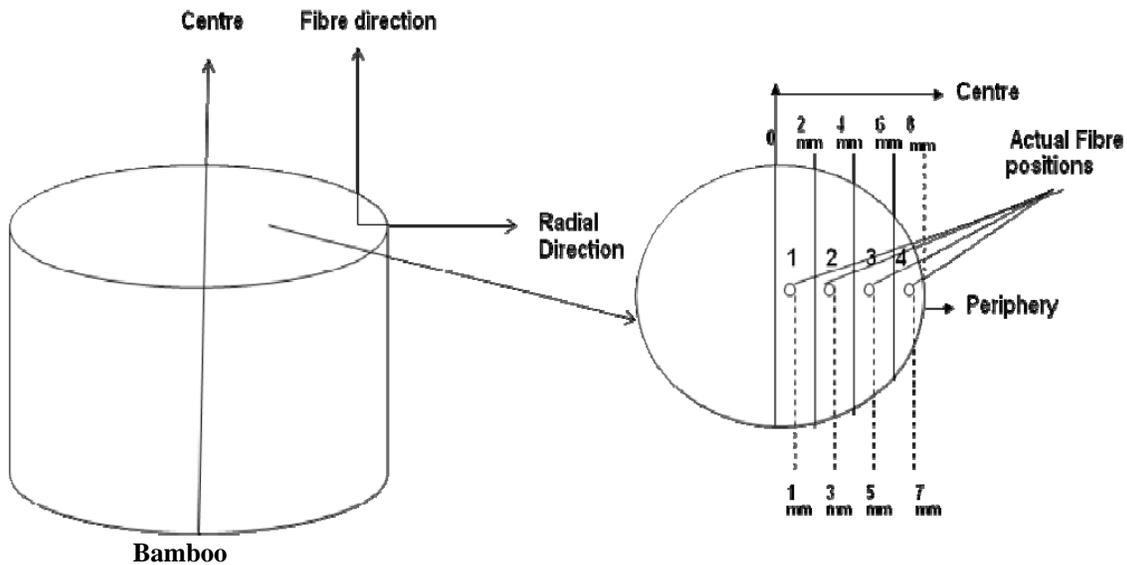


Fig. 1. Transverse view of bamboo with fibre position

THEORETICAL MODEL

Since the density of a fibre changes from its center to its periphery, it is assumed that conductivity depends on the fiber density. Bamboo always faces changes in moisture content. In most situations the changes in density are gradual and affect only the surface, but when a sample is briefly exposed to moisture, fluctuations are not pleasing, since moisture affects the physical and mechanical properties of bamboo (Annual Book of ASTM Standards Des. 1997).

Factors that influence conductivity have been considered in the development of a model. The relation between DC conductivity and the mobility of ions and their concentration can be calculated from Einstein's equation (Chand 1982).

$$\sigma_{dc} = ne\mu \quad (2)$$

Mobility (μ) is defined as

$$\mu = \frac{eD}{kT} \quad (3)$$

where e is a charge of an ion, D is the diffusion coefficient, k is the Boltzmann constant, T is the absolute temperature, and σ_{dc} is DC conductivity.

As the area (A) of the test sample of given thickness, is proportional to mass (w) of the sample,

$$A \propto w \text{ and } A = P_0 w \quad (4)$$

where P_0 is the proportionality constant.

Diffusion of ions can be calculated from the assumption that it depends on the density of fibers in the bamboo sample, the location from which the sample originated in the bamboo, i.e. its distance from the periphery. So we can assume that the DC conductivity will depend critically on location of the sample in the bamboo. We also assume that there is a polynomial relation between density (d) and the exact location of fibres (x),

$$d = 0.0008x^3 - 0.01x^2 + 0.0542x + 0.625 \quad (5)$$

Some of the factors such as thickness and weight of the samples are also considered. Based on the said assumptions, we define the diffusion of particles as a function of density/weight and function of density in relation to distance from periphery. The equation thus arrived at uses data from Fig. 2.

$$D = d \frac{(0.0008x^3 - 0.01x^2 + 0.0542x + 0.625)}{w} \times \frac{1}{P_0} \quad (6)$$

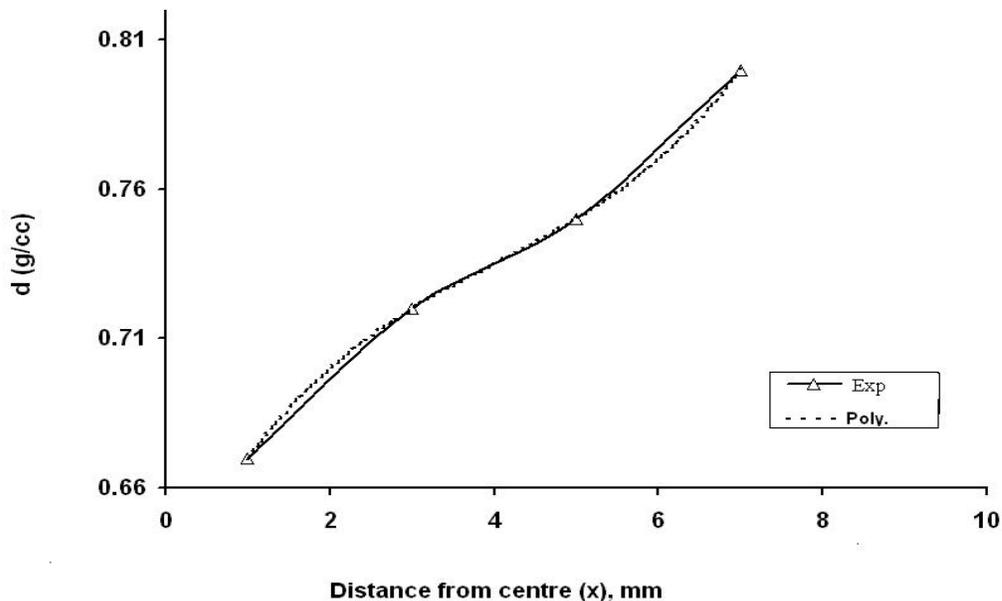


Fig. 2. Density of different fibre samples from centre to periphery

Here P_0 is an adjustable factor whose value is calculated from the slope of change in mass with distance of the sample from centre.

On substituting this value of D in equation 2 we get,

$$\mu = ed \frac{(0.0008x^3 - 0.01x^2 + 0.0542x + 0.625)l}{wkT} \times \frac{1}{P_0} \quad (7)$$

Substituting value from equation 5 to equation 1 we obtain an equation for the DC conductivity based on location of the sample in the bamboo.

$$\sigma_{dc} = \frac{(n_l + n_m)e^2(0.0008x^3 - 0.01x^2 + 0.0542x + 0.625)ld}{kTlw} \times \frac{1}{P_0} \quad (8)$$

Equation 8 can be used to calculate DC conductivity theoretically, where n_l is the lignin concentration in bamboo, n_m is the moisture content in samples, e is the ionic charge, k is the Boltzmann constant, T is the absolute temperature at which experimental values are evaluated, d is the density of samples, l is the thickness of the samples, w is the mass of the sample, X is the distance of the sample from the center, P_0 is a proportionality constant, and σ_{dc} is the DC conductivity.

RESULTS AND DISCUSSION

The conductivity of bamboo is of the order of $10^{-13} \Omega^{-1}cm^{-1}$ which is the same or is higher than that of glass fiber in GFRP (Reinforced Plastic Technology Swiety 1969). Same results are seen here dc conductivity of bamboo fibres are of the order of $10^{-10} \Omega^{-1}cm^{-1}$ and $10^{-8} \Omega^{-1}cm^{-1}$

Table 1. Resistivity and Conductivity Values of the Fibres of Lower Section of Bamboo Stem

S.N.	Distance of Sample from centre	Thickness of fibre (cm)	Cross sectional Area (sq. cm)	Resistance Ω	Resistivity Ωcm	Conductivity $\Omega^{-1}cm^{-1}$
1	S-1 C	0.16	0.20	2.5×10^{11}	0.3125×10^{11}	3.2×10^{-8}
2	S-2	0.17	0.22	2.2×10^{11}	0.3025×10^{11}	3.3×10^{-8}
3	S-3	0.17	0.22	2.1×10^{11}	0.28875×10^{11}	3.46×10^{-8}
4	S-4 P	0.17	0.22	1.7×10^{11}	0.23375×10^{11}	4.28×10^{-8}

Table 2. Resistivity and Conductivity Values of the Fibres from the Upper Section of Bamboo Stem

S.N.	Sample	Thickness (cm)	Cross sectional Area (sq. cm)	Resistance Ω	Resistivity Ω cm	Conductivity $\Omega^{-1}cm^{-1}$
1	S-1 C	0.135	0.15631	3.73×10^{11}	0.4329004×10^{11}	2.31×10^{-10}
2	S-2	0.158	0.206316	3.68×10^{11}	0.38022×10^{11}	2.63×10^{-10}
3	S-3	0.21	0.21714	3.61×10^{11}	0.374531×10^{11}	2.67×10^{-10}
4	S-4 P	0.236	0.238832	3.47×10^{11}	0.352112×10^{11}	2.84×10^{-10}

Tables 1 and 2 list the variation in the DC conductivity with position. This study demonstrates that the position of the sample influences the conductivity i.e. as we go from center to periphery the DC conductivity increases. DC conductivity values of the lower section were higher as compared to the upper section of the same bamboo stem. This confirms the proposal that density is a main characteristic that influences the conductivity. As we go from the lower section of a bamboo stem to an upper section, the density of fibres decreases, and so does the DC conductivity. The same trend is seen when considering the variation in same section from periphery to centre.

Experimental data for the DC conductivity as a function of density for electrical insulation was studied. From the results it is clear that the density of fibre plays a most important role relative to the electrical conductivity of bamboo fibers. When density increases, the moisture absorption ability of fibers increases and so does the DC conductivity.

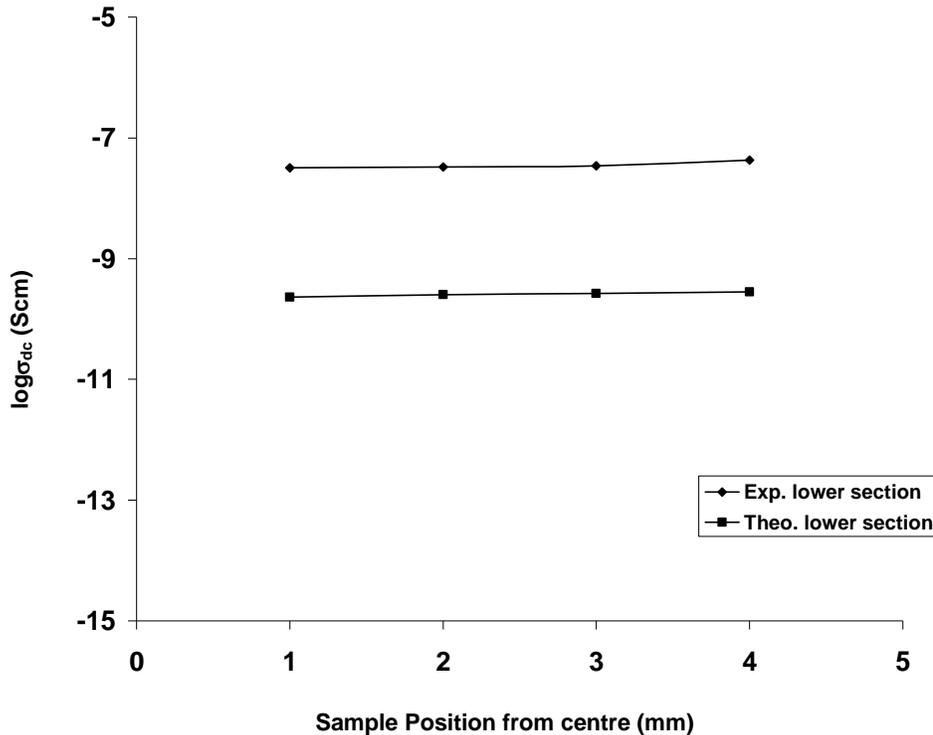


Fig. 3. Experimental DC conductivity (σ_{dc}) values of upper and lower portion of bamboo

We consider here that the conductivity of bamboo may be influenced by the surrounding conditions of measurement. The small currents resulting in the observed resistivity values may be due to moisture and minor impurities, and this may be the reason for the observed scatter in the resistivity values obtained for each section of bamboo obtained from different positions. The difference in the amount of impurities may be the main reason for the differences in the resistivity between the fibers of upper and lower section of the same bamboo stem.

To a satisfactory extent thus the DC conductivity for different bamboo samples from the outermost surface (periphery) to inner core can be calculated by the following equation:

$$\sigma_{dc} = \frac{(n_l + n_m)e^2(0.0008x^3 - 0.01x^2 + 0.0542x + 0.625)d}{kT_w} \times \frac{1}{P_0} \quad (9)$$

This study demonstrates that the position of the sample influences the conductivity, i.e. as we go from center to the periphery the DC conductivity increases. This model can find use in the interpretation of conductivity data obtained for samples taken from different locations and / or having different densities.

Figure 4 shows that in the upper section of bamboo the density of fibers was less as compared to the lower section, hence variation trend of DC conductivity from sample 1(C) to sample 4(P) was small but can be clearly seen when going from periphery to centre .

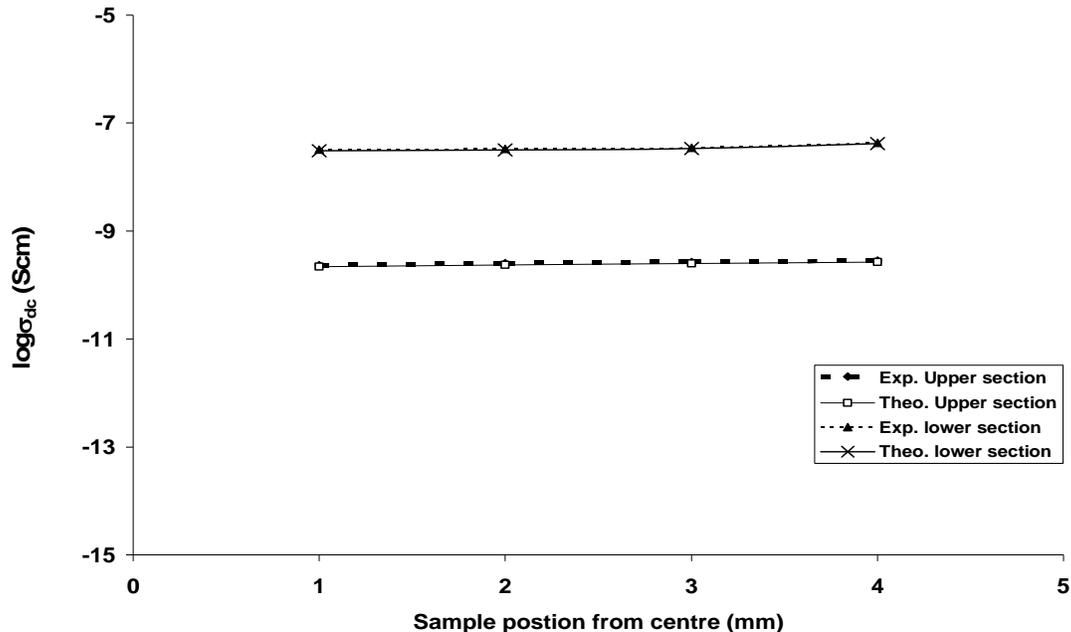


Fig. 4. Experimental and theoretical results for DC conductivity (σ_{dc}) of upper and of lower portion of bamboo fibres (Sample 1 centre to sample 4 periphery)

In contrast, in the lower section fiber density was greater, hence the moisture content was higher and the variation in conductivity was also higher.

CONCLUSIONS

1. The DC conductivity for a lower section of bamboo stem was greater than that of an upper section from the same stem.
2. DC conductivity decreased from the periphery to the centre, which was consistent with a trend that the fiber density was greater at the periphery as compared to the centre.
3. A model has been proposed for the dependence of density on radial position.

APPENDIX

e	is the charge on ion
D	is the diffusion coefficient
k	is the Boltzmann constant
T	is absolute temperature
P_0	is a proportionality constant.
n_m	is the moisture content in samples,
n_l	is the lignin concentration in bamboo
d	is the density of samples,
l	is the thickness of the samples,
w	is the mass of the sample,
x	is the distance of sample from center
σ_{dc}	is dc conductivity

REFERENCES CITED:

- Alekseeva, L. V. (2007). "Theoretical aspects of predicting the electrostatic properties of textile materials," *Fibre Chemistry* 39, 1-3.
- Barton, F. E., Akin, D. E., Morriso, W. H., Ulrich, A., and Archibald, D. D. (2002). "Analysis of fiber content in flax stems by near-infrared spectroscopy," *Journal of Agricultural and Food Chemistry* 50(26), 7576-7580.
- Chand, N., Jain, D., and Nigrawal, A. (2006a). "Investigation on gradient dielectric characteristics of bamboo (*Dentoclamus strictus*)," *J. Applied Polymer Science* 102, 380-386.
- Chand, N. (1982). "Free volume and ionic DC conductivity in polymers," *J. Applied Polymer Science* 27, 4889-4891.
- Chand, N., Sharma, M. K., and Shukla, M. (2006b). "Tensile strength of bamboo across the radial direction," *International Journal of Bamboo and Rattan* 5(1-2), 67-72,
- Datta, A. K., Mukherjee, P. S., and Mitra, G. B. (1980). "A dielectric study of cellulose fibres," *Journal of Materials Science* 15, 1856-1860.
- Jain, S., Jindal, U. C., and Kumar, R. (1993). "Development and fracture mechanism of the bamboo/polyester resin composite," *J. Mat. Sci. Letters* 12, 558-560.
- Kubisz, L., and Ehrlich, H. (2007). "Temperature dependence of electric conductivity of bamboo coral skeleton and glass sponge spicules, the marine origin biomaterials," *Journal of Non-Crystalline Solids* 353(47-51), 4497-4500.
- Kulkarni, A. G., Satyanatayana, K. G., and Rohatgi, P. K. (1981). "Electrical resistivity and dielectric strength of some plant fibers," *Journal of Materials Science* 16, 1719-1726.
- Mwaikambo, L. Y. (2006). "Review of the history, properties and applications of plant fibers," *African Journal of Science and Technology (AJST)*, Science and Engineering Series 7(2), 120-133.
- Ray, A. K., Das, S. K., Mondal, S., and Ramachandrarao, P. (2004). "Microstructural characterization of bamboo," *Journal of Materials Science* 39(3), 1055-1060.

- Titok, V., Leontiev, V., Shostak, L., and Khotyleva, L., (2006), "Thermogravimetric analysis of the flax bast fibre bundle," *J. Natural Fibers* 3(1), 35-41.
- Van de Velde, K., and Kiekens, P. (2002), "Thermal degradation of flax: The determination of kinetic parameters with thermogravimetric analysis," *Journal of Applied Polymer Science* 83(12), 2634-2643.
- Walter, L. (1992), "The Structure of Bamboo in relation to its properties and utilization," In: *Bamboo and its Uses - International Symposium on Industrial Use of Bamboo*, Beijing, China, Intern. Trop. Timber Organization, Chinese Academy of Forestry, 7-11, December.

Article submitted: Feb. 8, 2010; Peer review completed: March 18, 2010; Revised article received: March 31, 2010; Tentative acceptance: June 22, 2010; Further minor corrections: June 29, 2010; Published: July 13, 2010.