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Electrical Study of Maritime Pine Wood in Relation to Blue Stain

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Abstract

Maritime pine (*Pinuspinaster var. atlantica*) wood (MPW) of western Mamora forest was characterized by electrical impedance spectroscopy (EIS) measurements at room temperature (20 ± 2 °C) and under frequency interval of 40 Hz - 100 KHz. One of the main applications of the Electrical Impedance Spectroscopy (EIS) is the study of the fundamental electrical properties of materials in order to correlate them with the intrinsic characteristics of the latter. This work consists on testing the proficiency of the EIS to examine the effect of blue stain on the electrical impedance parameters at low frequency. The double-DCE (ZARC) model was used as equivalent circuit for the MPW. The electrical impedance parameters of this model such as intracellular resistance (R_i), extracellular resistances (R_{e1} and R_{e2}), relaxation time (τ_1 and τ_2) and the distributed coefficient of the relaxation time (Ψ_1 and Ψ_2) for the sound and the blued MPW specimens were determined and compared. The effect of blue stain on the electrical impedance parameters indicated that their values were less than those of sound wood. The results obtained indicated also that the changes observed in electrical properties due to blue stain effect disappear after drying. Electrical properties were sufficient to distinguish between the samples from sound and blued MPW.

Keywords: Wood, *Pinuspinaster*, Blue stain, Electrical Impedance Spectroscopy (EIS), Double-DCE (ZARC) model.

INTRODUCTION

The forest area in Morocco is estimated at 5.8 Mha 12,000 ha is for pine trees (*pinuspinaster*) [1]. The maritime pine is a species of the western Mediterranean with an Atlantic affinity. It is predominantly widespread in the western basin of the Mediterranean. He spontaneously grows in Morocco, Algeria, Corsica, France and Tunisia. Outside these areas, maritime pin is also found in Italy, Portugal and south-western Spain [2]. Usually if the maritime pine logs have been left lying about in the forest or in storage for any length of time they are very liable to develop fungal stain unless they are sawed soon after felling and may arrive in market in a badly stained condition and even contain incipient decay.Blue stain, because of its occurrence in the sap wood of logs and lumber, has been the subject of numerous investigations to determine its effect on the sapwood [3-8]. Findlay and Pettifor [3] studied the effect of sap-stain on the strength of Scots pine sapwood and had found that the presence of the stained fungi had no appreciable effect on his compressive strength, or the bending strength, but that it caused a marked reduction in toughness and also slight reduction in hardness. Another work by Findlay and Pettifor [4] has shown that blue stain caused by Ophiostoma (Ceratostomella) sp. brings about an appreciable reduction in toughness, but scarcely affects the other strength properties of pine sapwood. Reference to Chapman [5] shows that the different species of blue stain fungi did not affect the wood with equal severity, nor was their relative order of superiority in this respect entirely the same for all properties tested. From initial observations of Ballard et al., [6] it was apparent that fungal hyphae were fairly widespread in sapwood tracheids in late stages of the blue-stain disease cycle. Ballard et al.,[7] had studied the penetration and growth of blue-stain fungi in the sapwood of lodgepole pine attacked by mountain pine beetle. The results on properties of blue-stained wood by Humaret al., [8] showed that blue stain fungi, besides considerable discoloration, do not cause any significant damage to wood.

On the other hand Electrical impedance spectroscopy (EIS) is one of the potential methods for non-destructive analysis for assessment of wood moisture content [9, 10], moisture gradient [11],mould development [12], effect of cold acclimation [13] and evaluation of the Interfacial Compatibility in Wood Flour/Polypropylene Composites [14]. This method is known by its simplicity, rapidity and efficiency. This technique generally makes it possible to connect the results of the electrical measurements with the physical and chemical properties of the material through the frequency response modelling of the studied samples by an equivalent circuit [15]. EIS has been used to study stress

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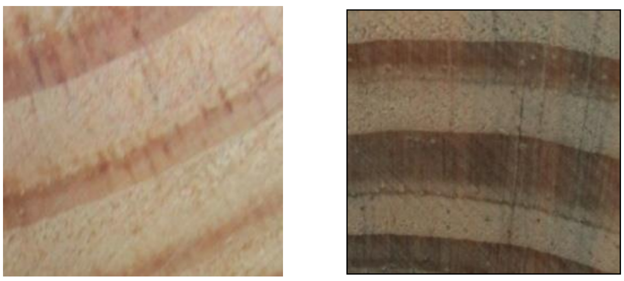
reaction in plants [13, 16 and 17). The method provides information about the physicochemical properties of cellular structure. According to [12, 18], EIS might be a useful technique to distinguish decayed and sound wood. A significant relation between density and electrical properties, as well as the specimen thickness impact on the electrical properties within a group of heartwood specimens had been reported. The observed changes in dielectric properties of Atlas Cedar Wood at its early stage of decay [18] indicated that at a constant temperature and 12% moisture content, both the dielectric constant (ε') and the loss factor (ε") decreased with increase in the frequency, and with the decay induced density loss. The characterization of MPW in relation to blue stain, with a low frequency electrical field has not yet been studied. It may provide a valuable basis for determining defects in this wood non-destructively.

MATERIALS AND METHODS

Materials

Wood samples were obtained from Forestry Research Center (CRF), Rabat (Morocco).The study was carried out on mature maritime pine trees of 45 years oldat western Mamora forest (6°45'O, 34°2'N, 30m of altitude), Rabat, Morocco. From the felled tree a log at 3m stem height was sawed into planks of 60 mm thickness. The wood drying caused a blue stain of some planks. From sound and blued planks, specimens for the electrical measurements were cut into square pieces of 40 mm and 2 to 4 mm of thickness in longitudinal direction to the growth ring, and gently smoothed by sanding (Figure 1). For physical measurements (moisture content and density) specimens were cut into cubic pieces of 20 mm. In study sapwood samples were analyzed under normal laboratory conditions.The physical parameters of the MPW specimens are gathered in Table 1.



a b

Figure 1: Contact surfaces of sound sample (a) and blue-stained sample (b)

Table 1: Number of specimens, density and moisture content of specimens in eachtreatment

Speciment	**Number of specimens**	**Densitymean/s.d**	**Moisture content % mean/s.d**
Control	4	650 / 0	15.4 / 0.1
Blued	8	652 / 3	15.7 / 0.7

There was no significant difference in moisture content and density between controls and decayed. Before the impedance measurements the samples were weighed and the dimensions were measured. After the impedance measurements, the specimens were dried at 103 ±3°C for 24 h and weighed. The dimensions, moisture content and densities were measured with 0.1 mg accuracy in weight, and 0.02 mm for dimensions. All specimens were kept in the same chamber at the same ambient conditions. The moisture content (MC) of specimen was calculated with:

$$MC = \frac{100 \times (M_H - M_0)}{M_0}$$

Where, M_H is air-dry mass before the impedance measurements and M_0 is the oven-dry mass after drying at 103 ±3°C for 24 h.

Impedance measurements

Indeed, relaxation and / or polarization of the excited materials is caused by the alternating current. The physical parameter varies with the frequency of the applied voltage; this may be due either to the physical structure of the materials or to the chemical and physical processes which occur within the subjected material. Thus, an impedance measurement over an appropriate frequency range offers the possibility of relating the measured electrical parameters to the physical and chemical properties of the materials. The EIS measurements on the MPW samples were carried out at ambient temperature with two copper circular electrodes placed directly in contact with the material without the use of conductive gel. The two electrodes were connected directly to the impedance measuring device (HP LCZ-meter 3330), with frequencies ranging from 40Hz to 100 kHz.

Electrical modelling

It has been proved in several previous studies that the frequency response of biological tissues ([11,12,17,18] such as wood cannot be adjusted using simple elements such as resistances (R), capacitances (C), inductances (L) or diffusion impedances. This frequency dispersion is often described as a change in capacitance and is expressed in terms of constant phase elements (Constant Phase Element: CPE):

$$Z_{CPE} = \frac{1}{(i\omega C)^{\psi}} \quad (1)$$

Where C is the capacity, ω the angular frequency, Ψ the distribution coefficient of the relaxation time and **i** the imaginary unit. In this study, the double-DCE mathematical model (ZARC) [19] which is illustrated by an equivalent scheme was fitted to the data. The DCE dual model (ZARC) comprises two distributed circuit elements (DCE) in series with a resistance (R∞ = very high frequency resistance) (Figure 2). The DCE element includes a constant phase element (CPE) in parallel with a resistor (R):

$$Z_{DCE} = \frac{R}{1+(i\omega\tau)^{\psi}} \quad (2)$$

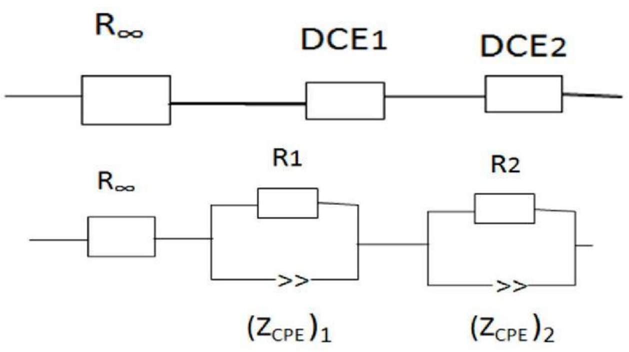


Figure 2: Equivalent circuit of the double-DCE model (ZARC)

Electrical parameters of this model were determined for sound and blued MPW: intracellular resistance (Ri = R∞), extracellular resistances ($Re_1 = R_1$ and $Re_2 = R_2$), relaxation times (τ_1 and τ_2) and coefficients of relaxation time distribution (Ψ_1 and Ψ_2).

The parameters of the model were estimated using the complex non-linear least squares (CNLS) curve fitting program LEVM version 8.13 (J.R. Macdonald, University of North Carolina, USA).

RESULTS AND DISCUSSION

Frequency Response

The electrical impedance spectra of the sound and blued MPW were measured in the laboratory in the way described above. The behaviour of the imaginary part of the impedance (Zi) as a function of the real part of the impedance (Zr) for the sound MPW at ambient temperature are exhibited in figures 3.

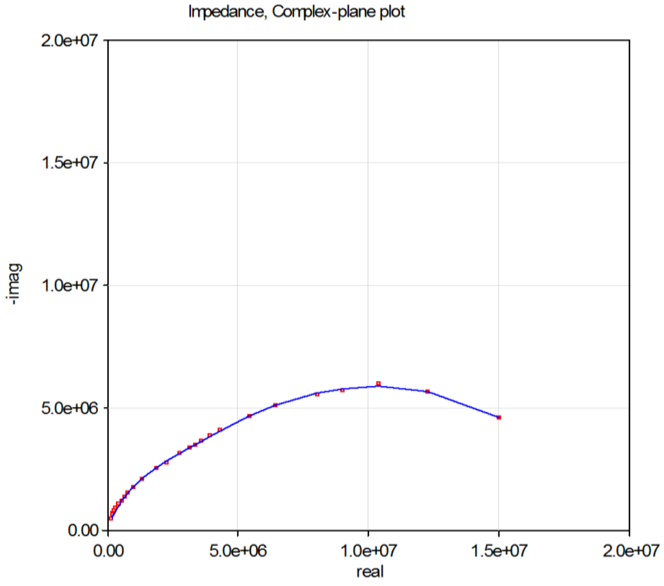


Figure 3: Imaginary component of the impedance (Zi) as a function of the real component (Zr) for sound MPW. Experimental (dashed) and theoretical (continuous lines) curves deduced from the double DCE model.

The graph representing Zi=f (Zr) in complex plane for bluing MPW are presented in figure 4.

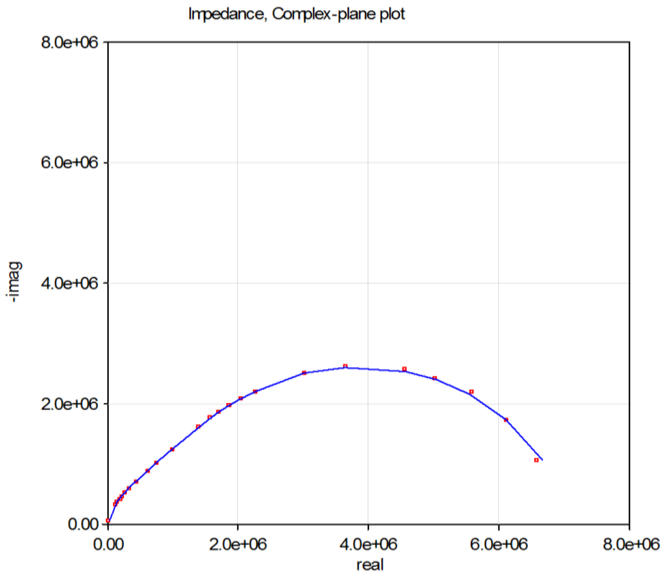


Figure 4: Imaginary component of the impedance (Zi) as a function of the real component (Zr) for blued MPW. Experimental (dashed) and theoretical (continuous lines) curves deduced from the double DCE model.

The graph representing Zi=f (Zr) in complex for bluing MPW after drying are presented in figure 5.

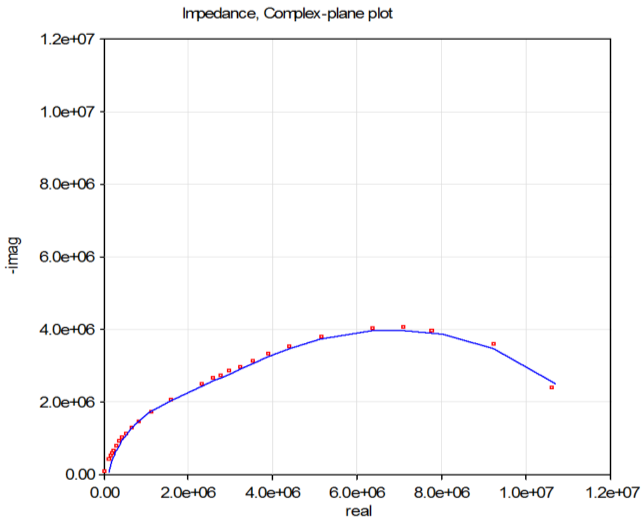


Figure 5: Imaginary component of the impedance (Zi) as a function of the real component (Zr) for blued MPW after drying. Experimental (dashed) and theoretical (continuous lines) curves deduced from the double DCE model.

The blue stain had an effect on electrical properties over the whole frequency range. It's to be noted that the experimental values for each frequency of the real part of the electrical impedance (Zr) of the blued specimen remains low compared to the sound specimens over practically the entire range of frequency and the experimental values for each frequency of the imaginary part of the electrical impedance (Zi) of the blued specimen remains low compared to the sound specimens over practically the entire range of frequency (Figure 3 and 4).

Frequency response Modelling

The impedance spectrum of every sample had a double arc in the form of parabola where the top corresponds to the frequency value characteristic of material f_c and the intersection of the parabola with the x axis gives R_∞ and the Re. The radius of the arc decreases with the onset of blueness. It is obvious that the effect of the specimen's blue stain had an effect on the electrical properties over the whole frequency range. The comparison of the experimental curves (dashed lines) with the theoretical curves (in solid lines) (Figures 3, 4, and 5) is indicating that the experimental measurements are in good agreement with the values derived from the proposed double DCE model.The satisfactory fit of the double DCE model strongly indicate the suitability of the model in the study of MPW.

Extraction of the electrical parameters from the Double-DCE (ZARC) model

In the physical sciences the characteristic features of commonly produced phenomenon by an excitation is known as relaxation time which usually means the return of a perturbed system into equilibrium. The relaxation times (τ_1 and τ_2) of the MPW were found to be strongly depending on the presence of blue stain (Table 2). The effect of the blue stain on the electrical parameters of the adopted model was clearly depicted in Table 2. According to this table, a minimum of τ_1 and τ_2 is obtained for the blue stained wood.

Table2: Parameter values (mean/s.d.) from double ZC – model (Fig.2) fits for specimens conditioned at RH 65±5%. Parameters R_1, τ_1 and Ψ_1 represent a higher frequency and arc R_2, τ_2 and Ψ_2 the low frequency arc of the spectrum

Sample	R_1 (MΩ)	τ_1 (µs)	ψ_1	R_2 (MΩ)	τ_2 (µs)	ψ_2
Sound MPW	2/0,8	80/20	0,95/0,02	20/10	1500/900	0,75/0,02
Blue-stained MPW	1/0,5	42/13	0,89/0,03	9,6/7	730/530	0,86/0,03

Reference to Table 2 shows that blue stain was accompanied by a decrease in the value of the relaxation times (τ_1 and τ_2) and the extracellular resistances (R_1 and R_2) of the MPW, and it was found that the decrease of 50 per cent in these properties. No change was observed in the intracellular resistance (R_i) (Table 2).

CONCLUSION

Within this study, EIS method was used to examine the effect of blue stain on electrical impedance of maritime pine (*Pinuspinaster* L.) wood at low frequency. In conclusion, this was the first time that EIS was applied to study the effect of blue stain on the electrical impedance of wood at low frequency and low moisture content. The effect of blue stain on wood density and electric properties of PMW at its early stage of bluing by fungi were investigated in longitudinal direction. The experimental value for each frequency of the real part (Zr) and the imaginary part (Zi) of the electrical impedance of sound and blued specimen were measured in atmospheric conditions at (20 ± 2 °C), and 10 Hz to 100 KHz frequency range, in which the effect of the electrode type was negligible. The Double-DCE (ZARC) model was used as an equivalent circuit. It has been shown that blue stain has great impact on electrical properties. The data presented here show that it is possible to detect the initiation of blue stain and to follow their growth by analysis of data obtained with electrochemical impedance spectroscopy. The blue stain had an effect on electrical properties over the whole frequency range. The observed changes in electric properties of PMW due to blue stain indicated that at a constant temperature and moisture content, both the relaxation times (τ_1 and τ_2) and the extracellular resistances (R_1 and R_2) decreased. The impedance parameters were significantly sensitive to blue stain. According to this technique, the electrical parameters can be considered as an indicator of the blue stain of the wood.

REFERENCES

[1] Blerot P, Mhirit O.Le grand livre de la forêt marocaine. Editions Mardaga1999,Brussels, 280p.

[2] Boudy P. Economie forestière nord-africaine, monographie et traitement des essences Forestière. Edition Larose1950, Paris, 505p.

[3] Findlay WPK, Pettifor CB. Forestry 1937; 11: 40-52.

[4] Findlay WPK, Pettifor CB. Empire Forestry Journal 1939; 18(2): 259-267.

[5] Chapman AD. Journal of Agricultural Research 1940;61(2): 125-133.

[6] Ballard RG, Walsh MA, Cole WE. Can. J. Bot. 1982; 60: 2334- 2341.

[7] Ballard RG, Walsh MA, Cole WE. Can. J. Bot. 1984; 62: 1724-1729.

[8] Humar M, Vek V, Bucar B. DrvnaIndustrija 2008; 59(2): 75-79.

[9] Zelinka SL, Stone DS, Rammer DR.Wood Fiber Sci. 2007; 39: 556-565.

[10] Zelinka SL, Douglas R, Rammer DR, Stone DS. Holzforschung 2008; 62: 737-744.

[11] Tiitta M, Savolainen T, Olkkonen H, Kanko T. Holzforschung 1999; 53: 68-76 .

[12] Tiitta M, Rero T, Viitanen H. Material und Organismen 1999; 33: 271-287.

[13] Repo T, Zhang G, Ryyppo A, Rikala R. Journal of Experimental Botany 2000; 51: 2095-2107.

[14] Zhu L, Cao J, Wang YJ.Appl. Polym. Sci. 2013;129(3): 1520-1626.

[15] Kremer F, Schonhals A, Lucky W. Broadband Dielectric Spectroscopy. Springer -Verlag2002.

[16] Väinölä A, Repo T.Annals of Botany 2000; 86: 799-805.

[17] Hakam A, MagneTakam M, Chokairi M, AlamiChantoufi N, Hamoutahra Z, El Alami A, Famiri A, Ziani M, Gril J. Maderas Ciencia y tecnología 2012; 14(2): 195- 208.

[18] Hakam A, Alami Chantoufi N, El Imame N, Guelzim M, Ziani M, Famiri A, Drissi Bakhkhat S, Ghailane F, Hachmi M, Sesbou A, Merlin A. International Journal ofPharmacognosy and Phytochemical Research 2017; 9(3): 444-448.

[19] MacDonald JR. ImpedanceSpectroscopy. John Wiley and Sons1987, New York, 368p.