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Research Article

Dielectric Properties of Atlas Cedar Wood at its Early Stage of Decay

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ABSTRACT
The dielectric constant (ε') and dielectric loss factor (ε'') were measured for sound and decayed heartwood specimens of Atlas cedar (*Cedrus atlantica* Manetti) wood (ACW) at its early stage of decay in longitudinal direction using frequencies between 10 Hz and 1 MHz at 12% moisture content and room temperature (22 - 24 °C). The changes observed in dielectric properties due to brown-rot decay of ACW showed loss in wood density (the mean densities of the sound and decayed heartwood specimens of 12% moisture content were 595 and 531 $kg.cm^{-3}$, respectively). The results obtained indicated a direct relationship between dielectric constants decrease and density loss over the whole frequency range. The effect of thickness is also observed. The dielectric constant and the dielectric loss factor showed an important increase with the increase of the thickness, especially at low frequencies. Therefore the decrease in the values of the dielectric constants could be used as a good indicator of early wood decay. The changes in the dielectric properties were significant enough to distinguish between the samples from sound and decayed ACW.

Keywords: Atlas cedar wood, *Cedrus atlantica*, brown-rot decay, dielectric properties.

INTRODUCTION

The ACW is a native wood species of Morocco, valued for its economic and biogeographic importance. The Cedar stands cover an area of 130,000 ha, and occupy a privileged place in the Moroccan forest landscape. Unfortunately, the Cedar stands are greatly susceptible to attack by fungi[1]. The fungus considered as responsible for the decay is either *Phellinus chrysoloma* or *P. pini*[2,3]. The biodegradation of the heartwood takes place when the wood has high moisture content and access to air. The fungi attack the cell walls, consume the carbohydrates and leave a brown residue of condensed lignin. In an advanced stage the wood becomes discoloured, and suffers a considerable loss in weight and reduction in strength properties.

On the other hand, dielectric method is one of the potential methods for non-destructive analysis for assessment of wood moisture content, moisture gradient, decay, density and extractives analyses. It measures the dielectric properties of a medium as a function of frequencies[4]. According to Tiitta[5,6], dielectric method 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.

There are numerous publications on the dielectric properties of wood and their importance in studying the behavior of wood under different conditions. The effect of wood anisotropy on the dielectric constants of wood was largely studied by Norimoto and his co-workers[7,8,9,1011]. This research indicated that the relative dielectric constant was higher for the polarization parallel to the grain than across the grain. This behaviour was expected from the fact that the hydroxyl groups of the cellulose should have more freedom of rotation in the longitudinal direction than in radial and tangential direction[11,12]. The effect of density on the dielectric properties of wood was extensively studied by Skaar[13], Rafalski[14], Lin[15] and Vermaas[16]. Vermaas concluded that the dielectric constant ε' for all directions increased with the increase of density and moisture content, and decreased with the increased frequency.

The results of Karppanen et al.[17] demonstrated that the chemical composition of heartwood was changed radically by the fungus: the concentration of stilbenes, resin acids and free fatty acids decreased, while the concentration of soluble sugars increased as a result of decay. In addition, fungal sugars were found in the decayed samples. The concentration of total phenolics was increased, which obviously reflected chemical changes in cell wall constituents other than extractives (lignin). Bouslimi et al.[18] reported that brown-rot decay

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a


b

Figure 1: Contact surfaces of the altered samples (a) and sound samples (b).

selectively removes structural carbohydrate components, increasing the lignin/carbohydrate ratio as decay progresses. The results demonstrated also a highly significant relationships between chemical composition, mechanical properties, and weight loss, with 15% weight loss leading to 40% loss in modulus of rupture (MOR) and 30% loss in bending modulus of elasticity (MOE). The concentration of individual resin acids and the equilibrium moisture content at a relative humidity of 100% were studied in brown-rot resistant and susceptible Scots pine (*Pinus sylvestris* L.) heartwood[19]. In this study the concentration of resin acids was higher in the decay-resistant heartwood than in the decay-susceptible heartwood. Resin acids are presumably in part responsible for the decay resistance of Scots pine heartwood. In the Scots pine heartwood of the resistant trees, the average total concentration of the stilbenes was 7.5 and 6.4 mg/g of dry weight, while in the susceptible trees the respective values were 5.0 and 4.7 mg/g[20]. The difference between the decay resistant and susceptible trees was statistically significant in both progeny tests. The results of Curling et al.[21] demonstrate a direct relationship between strength loss and weight loss suggesting a quantitative relationship between strength loss and chemical composition (hemicellulose sugars) during incipient decay of southern pine by basidiomycete fungi. Some properties of Moroccan wood species were reported earlier, but without mention of the dielectric properties of wood at low frequencies[22,23,24,25,26,27,28,29,30,31,32,33]. The purpose of the present study was to examine the effect of biodegradation by brown-rot on the dielectric constant (ε') and the loss factor (ε'') of ACW heartwood by means of dielectric method at low frequencies (10 Hz - 1 MHz) and to assess whether the changes in the dielectric constants could be used to detect the attack by fungi.

MATERIAL AND METHODS

Plant material

The wood specimens (*Cedrus atlantica* Manetti, heartwood) were obtained from Forest Research Center, Rabat (Morocco). Trees of 75 years-old ACW was selected and felled from the mature stands in the Azrou region in the Meknes province (33°26'N, 5°13'W, 1250 m asl.). A sub-sample of three trees (one sound and two decayed) from the original 18 ones was selected and six samples of each tree at average height of 1,3 m were cut for study. In study heartwood samples was analyzed under normal laboratory conditions. The specimens were cut into square pieces of 20 mm and of 2 to 6 mm in thickness in longitudinal direction to the growth ring, and gently smoothed by sanding (Figure 1).

Density

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 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.

Apparent (air-dry) density: (D_h) was determined as M_h/V_h, where M_h and V_h are air-dry mass and volume before drying.

Oven-dry (anhydrous) density (D_0) was determined as M_0/V_0, where M_0 and V_0 are mass and volume after drying.

Dielectric measurements

The dielectric constant ε' and dielectric loss factor ε'' of the sound and decayed heartwood ACW specimens were measured in the atmospheric conditions in the frequency range from 10 Hz to 1 MHz, at which the effect of the electrode type was negligible. These measurements were carried out using an LCZ meter HP 4192A and a pair of plates and circular metallic electrodes with a diameter of 20 mm for longitudinal direction at 12% moisture content of specimens and at a room temperature (20-22°C). No gel was used between the electrodes to avoid the absorption of the gel into the specimens.

RESULTS AND DISCUSSION

Density

The densities of sound and decayed ACW specimens are given in Table 1. The values obtained are in the medium range for commercially used wood and there is a very distinct indication of decrease in density with decay.

Electrical measurements

The dielectric constant of sound ACW decreases with the increase of the frequency of the applied electrical field. At low frequencies, complete orientation of the dipoles is possible leading to higher dielectric constant. However, at high frequencies the molecular vibrations are higher, the complete orientation of dipoles does not take place and then the dielectric constant decreases as the frequency increases. In Figure 2 dielectric constants (ε') of sound and decayed ACW in longitudinal direction are plotted as a function of frequency for specimen thicknesses (2mm and 4mm).

Biodegradation by brown-rot had an effect on the electrical properties over the whole frequency range. Dielectric loss factor ε'' of sound and decayed ACW in longitudinal direction as a function of frequency for two specimen thicknesses (2mm and 4mm) is shown in Figure 3.

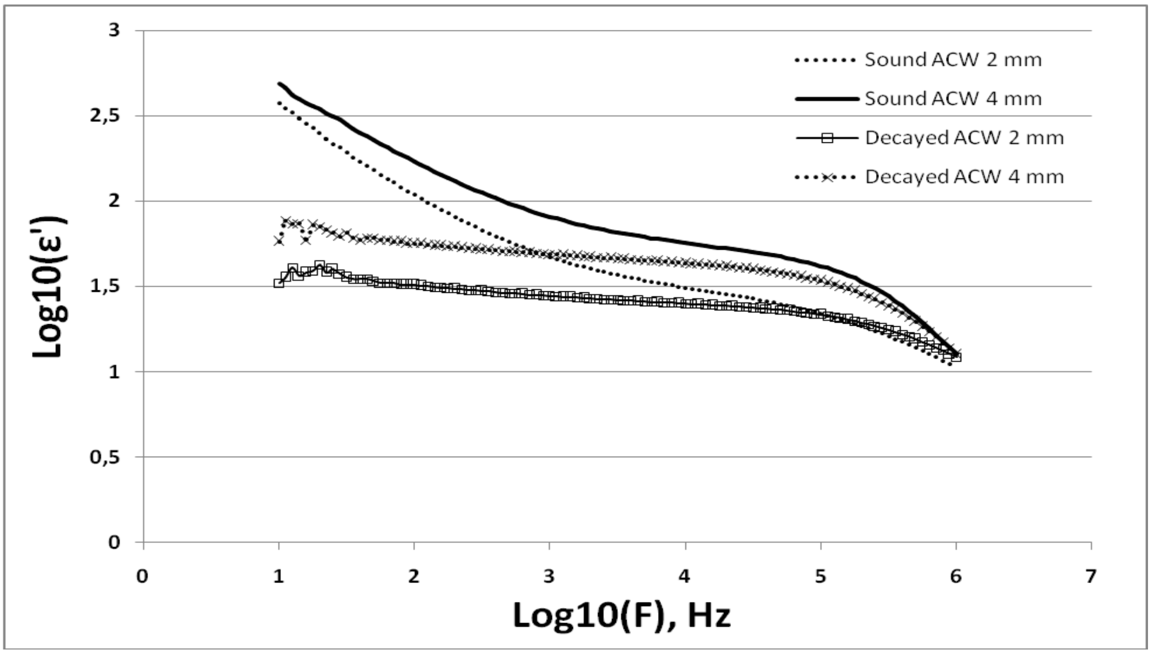

Figure 2: Logarithmic dielectric constant (ε') of sound and decayed ACW in longitudinal direction as a function of logarithmic frequency for two specimen thicknesses (2mm and 4mm).

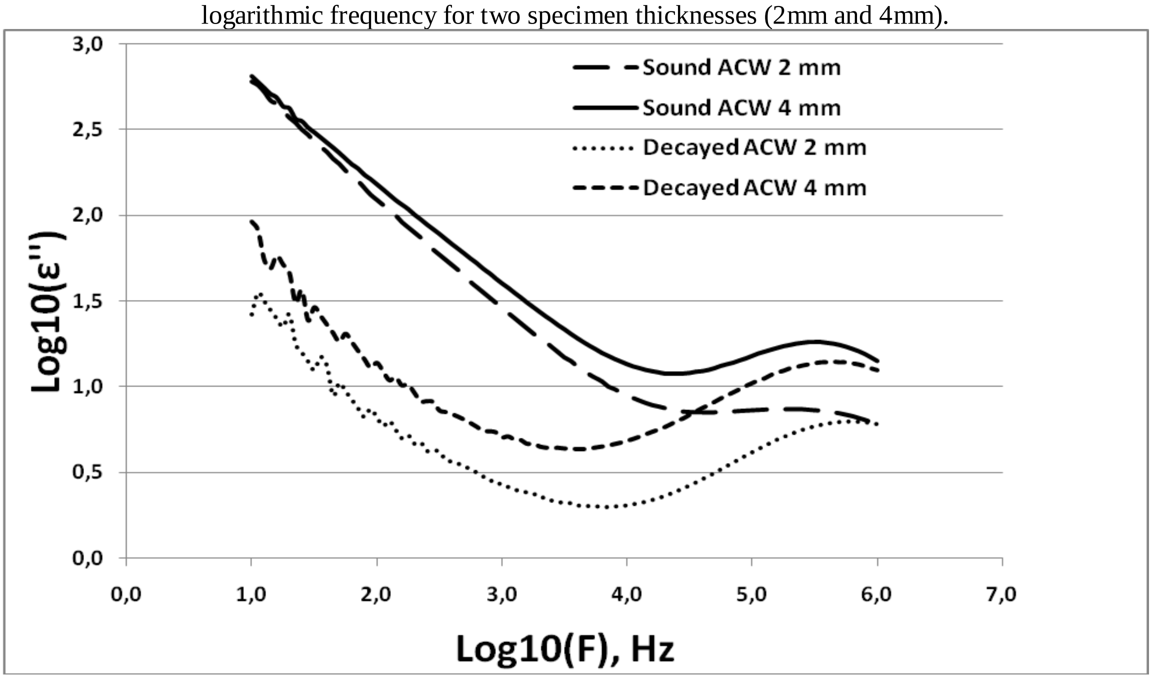

Figure 3: Logarithmic dielectric loss factor (ε'') of sound and decayed ACW in longitudinal direction as a function of logarithmic frequency for specimen thicknesses (2mm and 4mm).

A dielectric process could be clearly observed in the frequency region centered around 10^6 Hz (Figure 3) (In this frequency region only the half of the peak of dielectric process appear). Norimoto and Yamada[34] suggested that this relaxation process is caused by the reorientation of CH_2OH group in the amorphous region of wood cell wall. Zhao et al.[35], Cao and Zhao[36,37] observed the similar behaviour at studying the dielectric properties of wood in moisture equilibrium state. The effect of thickness is clearly observed in Figure 2 and 3 for thicknesses of 2 and 4 mm. The dielectric constant and the dielectric loss factor showed an important increase with the increase of the thickness, especially at low frequencies. The value of ε''of thicker (4mm) ACW was higher than that of 2mm ACW and the values for the sound ACW were higher than those of decayed ACW. Both dielectric constants and dielectric loss factors (Figure 2 and 3) increased with the increase in thickness at frequencies studied, at lower frequencies the effect was sometimes masked by noise. It is obvious that the effect of the specimen's thickness on dielectric constant (ε') or dielectric loss factor (ε'') was small compared to the effects of moisture content effect and frequency. The increase in the dielectric constant with thickness can be explained by the fact that increasing thickness leads to an increase in the number of polar groups inside the sample

Table 1: Densities of sound and decayed ACW.

	Density	Av.	Max	Min	CV (%)
Sound ACW	D_h	0,595	0,695	0,491	7,899
Decayed ACW	D_h	0,531	0,684	0,457	9,040
Sound ACW	D_0	0,460	0,530	0,386	7,391
Decayed ACW	D_0	0,476	0,620	0,420	8,824

Where, D_h is Apparent (air-dry) density and D_0 is Oven-dry (anhydrous) density. The mean densities of the sound and decayed heartwood specimens of 12% moisture content were 595 and 531 kg.cm^{-3}, respectively.

which leads to an increase in orientation of the polarization. As a result of such effects the dielectric constant increases with thickness at all frequencies. The dielectric loss factors obtained were of a minimal value, which was less pronounced for the sound ACW of lower thickness (2mm) (Figure 3). These minimal loss factors shifted towards lower frequencies with increases in thickness and shifted strongly towards lower frequencies for decayed wood in the longitudinal direction. The decrease of density should decrease the amount of bound water because less dense material cannot bind more water molecules into the wood fibers. A minimum value for the loss factor in the same frequency region (30 to 10^6 Hz) was also reported by Norimoto and Yamada[34] for kusunoki wood.

CONCLUSION

The purpose of the present study was to examine the effect of biodegradation by brown-rot on the dielectric constant (ε’) and the loss factor (ε’’) of ACW heartwood by means of dielectric method at low frequencies and to assess whether the changes in the dielectric constants could be used to detect the attack by fungi.

The effect of decay on wood density and dielectric properties of ACW at its early stage of degradation by fungi were investigated in longitudinal direction, by means of dielectric method. The dielectric constant and dielectric loss factor of ACW specimens were measured in atmospheric conditions at 20 - 22 ° C and 10 Hz to 1 MHz frequency range, in which the effect of the electrode was negligible.

The observed changes in dielectric properties of ACW due to brown-rot decay indicated that

at a constant temperature and 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 decrease in density leads to decrease in the amount of bound water, and therefore a decrease in the value of the dielectric constant.

The dielectric loss factor exhibited minimum values, which were shifted to the lower frequency with decreased thickness and with the brown-rot decay. The results obtained demonstrated that decayed ACW can be distinguished from sound wood by observing the variation in the impedance measurements. At the very early stages of decay of ACW by fungi, changes in the wood density cause measurable reductions in its dielectric constants which is a good indicator of early wood decay.

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