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Examination of Interfacial Compatibility Within WPC Panels Using Electrical Impedance Spectroscopy

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Abstract: Composite plates containing pine wood particulates and high density Polyethylene (PE) matrix were prepared using thermo-compression and characterized by Electrical Impedance Spectroscopy (EIS) measurements at room temperature and under frequency interval of 40-100 kHz for different wood contents ranging from 40-70%. The double-DCE (ZARC) Model was used as equivalent circuit for the obtained plates. The 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) were determined for the different specimens. Effects of pine powder concentration on interfacial compatibility within the composites were analyzed. The relaxation time increased with increasing wood contents up to 50% and decreased at higher rates. This finding suggests that the optimal interfacial compatibility in wood powder/polyethylene chips composites without additives is attributed at 50% wood contents.

Key words: Composite, polyethylene, interfacial compatibility, electrical impedance spectroscopy, double-DCE (ZARC) Model, relaxation time

INTRODUCTION

The forest area in Morocco is estimated at 5.8 mha wherein 12,000 ha is for pine trees *(Pinus pinaster)* (Hammouzaki, 2013). Most of the wood from these trees is used as fire wood. Moreover, Morocco consumes 10,525 tons of plastic bags a year. For this, each family throws up to 100 plastic bags per month. This waste is estimated at 220,000 tons per year that is not recycled (Bensaid, 2010). Plastic bags after use are exhibiting a real environmental hazard because they take about 450 years to degrade in nature. One of the solutions envisaged to upgrade plastic waste and maritime pine wood from fire wood is the manufacturing of Wood/Plastic Composites (WPC). Indeed, wood/plastic composites have been used in many applications such as packaging, automotive parts, construction, decoration materials, etc. However, much research have found that the properties of wood/plastic composites are highly dependent on the percentages of their constituents as well as on their interfacial compatibility (Woodhams *et al*., 1984; Bledzki and Gassan, 1999; George *et al*., 2001; Liao *et al*., 1997; Ghasemi and Kord, 2009; Kord, 2011). These investigations emphasized that there is an accurate percentage of wood to be incorporated in order to provide better mechanical performance to composites. Various methods in the literature have been applied to study the interfacial compatibility of wood/plastic composites. One of these methods is electrical impedance spectroscopy which uses a dielectric approach. This method is known by its simplicity, rapidity and efficiency (Zhu *et al*., 2013). This research consists on testing the proficiency of the (SIE) to study the compatibility of WPC plates. 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 modeling of the studied samples by an equivalent circuit.

MATERIALS AND METHODS

Materials and implementation: Maritime wood pine is cut into small pieces by sawing and then mixed with a crusher

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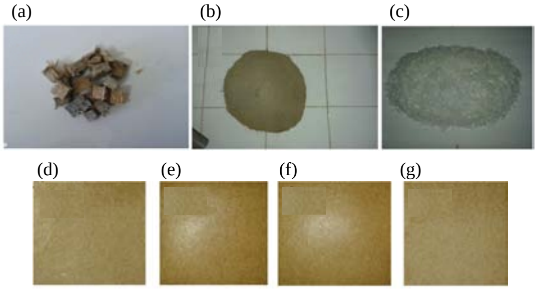

Fig. 1: Starting materials for the manufacture of WPC plates; a) Maritime pine wood; b) Marine pine wood powder; c) Polyethylene chips; d-g) Different spicimens for electrical measurements

Table 1: Manufacturing parameters for WPC plates

Samples	1	2	3	4
Wood/PE of (%)	40/60	50/50	60/40	70/30
Temperature (°C)	180	180	180	180
Pression (bar)	40	40	40	40
Duration (min)	8	8	8	8

equipped with a sieve of 0.5 mm diameter. The obtained fine powder of the maritime pine wood is mixed with polyethylene chips (Fig. 1). Pine wood powder/PE composite plates were performed by thermo compression at different wood contents of 40, 50, 60 and 70%. The manufacturing parameters of the WPC plates using a press of Italy Steton type are gathered in Table 1. Test pieces were prepared for the electrical measurements from the manufactured plates of surface of 4×4 cm^2 (Fig. 1d-g).

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 SIE measurements on the WPC plates 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 (Hewlett-Packard LCZ-meter 3330) with a frequencies ranging from 40-100 kHz. One of the main applications of the SIE is the study of the fundamental electrical properties of materials in order to correlate them with the intrinsic characteristics of the latter.

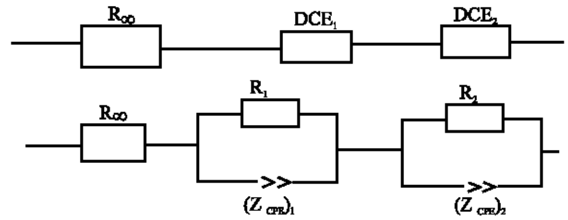

Fig. 2: Equivalent circuit of the double-DCE Model (ZARC)

Electrical modeling: It has been proved in several previous studies that the frequency response of biological tissues (Hakam *et al*., 2012a, b) such as wood can not 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 = The Capacity
ω = The angular frequency
Ψ = The distribution coefficient of the relaxation time
i = The imaginary unit

In this study, the double-DCE mathematical model (ZARC) (Barsoukov and Macdonald, 2005) 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) (Fig. 2). The DCE element includes a Constant Phase Element (CPE) in parallel with a Resistor (R):

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

Several electrical parameters of this model were determined for each wood content, intracellular resistance ($R_i = R_\infty$) extracellular resistances ($Re_1 = R_1$ and $Re_2 = R_2$), relaxation times (τ_1 and τ_2) and coefficients of relaxation time distribution (ψ1 and ψ2). Equivalent circuit parameters were estimated using Macdonald's adjustment program (LEVM, Version 8.13) (Macdonald, 1987).

RESULTS AND DISCUSSION

Frequency response: The knowledge of the experimental values for each frequency of the real part of the electrical impedance (Zr) and the imaginary part of the impedance (Zi) or the real part of the admittance (Yr) and the part (Yi) makes it possible to deduce the dielectric constant (ϵ) and the electrical Modulus (M) as a function of the frequency by a simple calculation, taking into account the geometrical parameters of the samples. Thus, the real part of the dielectric constant (ϵ') for the pine wood powder/PE composite plates as a function of the frequency at ambient temperature is shown in Fig. 3.

It's to be noted that (ϵ') of the specimen with a wood content of 50% remains low compared to the other studied specimens with wood contents of 40 and 70% over practically the entire range of frequency (Fig. 3). However, the (ϵ') describes the response of a given medium to an applied electric field. Therefore, the low value of (ϵ') observed is an indicator of enhanced interfacial compatibility of the wood powder/PE composite.

Frequency response modeling: The behavior of real part of the dielectric constant (ϵ') and the imaginary part of the dielectric constant (ϵ'') for the wood powder/polyethylene composite plates as a function of the frequency at ambient temperature are exhibited in Fig. 5ab, respectively. It is noteworthy that the experimental curves (in dotted lines) coincide perfectly with the curves (in solid lines) deduced from the double DCE Model (Fig. 4).

The curve shapes of (ϵ') as a function of (ϵ') (Fig. 5a) or (M'') as a function of (M') (Fig. 5b) are typical and exhibit two circular arcs. The comparison of the experimental curves (dashed lines) with the theoretical curves (in solid lines) (Fig. 4 and 5) is indicating that the experimental measurements are in good agreement with the values derived from the proposed double DCE Model.

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 performed plates were found to be strongly depending on the percentage of wood in the composites (Table 2). The effect of the mixture composition on the electrical parameters of the adopted model was clearly depicted in Table 2. According to this table, a maximum of τ_1 and τ_2 is obtained for the 50% wood percentage. This has spurred us thinking that for this percentage the compatibility is prominent.

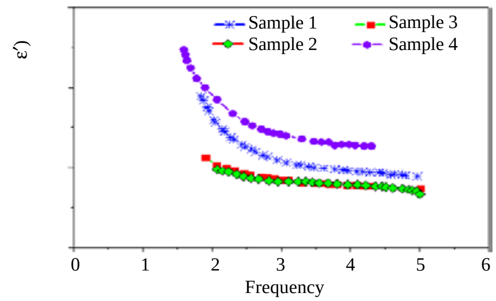

Fig. 3: Dielectric constant (ϵ') for the different wood levels in wood powder/PE composite plates as a function of frequency

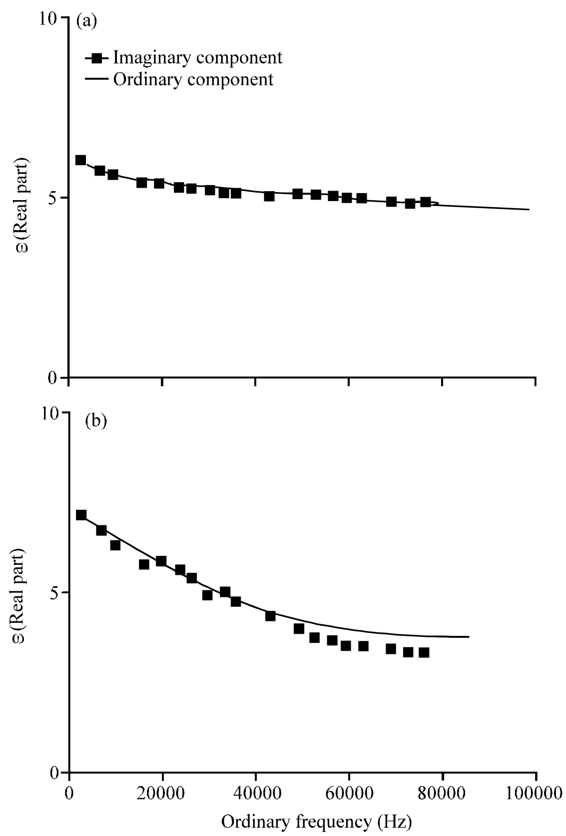

Fig. 4: a) Real component of dielectric constant (ϵ') for WPC composite plates versus frequency; b) Imaginary component of the dielectric constant (ϵ'') for WPC composite plates depending on frequency. Experimental (dashed) and theoretical (continuous lines) curves deduced from the double DCE Model

Table 2: Comparison of the electrical parameters of double-DCE (ZARC) Model for WPC

Samples	R∞ (KΩ)	R_1 (MΩ)	τ_1 (μ sec)	F (Hz)	ψ_1	R_2 (MΩ)	τ_2 (μ sec)	F (Hz)	ψ_2
1	1	17.40	455	350	0.932	437	6180	25	0.987
2	1	112.00	1710	90	0.963	4350	60199	2,5	0.986
3	1	15.30	893	180	0.941	654	16300	10	0.99
4	1	9.56	753	210	0.942	207	9390	17	0.988

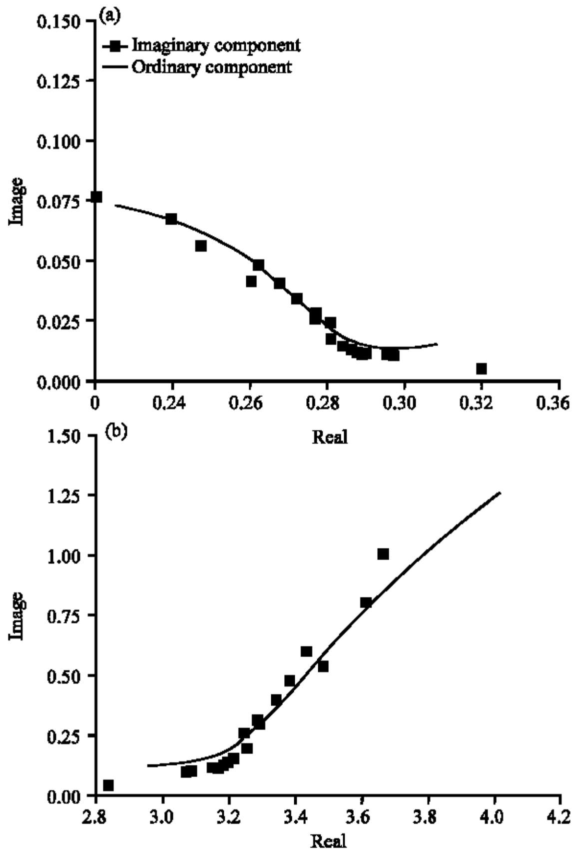

Fig. 5: a) Imaginary component of the dielectric constant (ϵ") as a function of the real component (ϵ'); b) Imaginary component of the modulus (M") as a function of the real component (M'), experimental (dashed) and theoretical (continuous lines) curves deduced from the double DCE Model

CONCLUSION

Within this study, SIE method was used to examine the optimal interfacial compatibility of Wood Plastic Composites (WPC) without any other additives. The Double-DCE (ZARC) Model was used as an equivalent circuit. It has been shown that pine wood powder concentrations have great impact on electrical properties in the entire studied frequency range. The effect of the blend composition on interfacial compatibility of WPC plates was deduced from the dielectric relaxation process. A maximum of the relaxation constants (τ_1 and τ_2) of the studied plates is obtained at 50% of wood. This suggests that compatibility is better for this percentage. The impedance parameters were significantly sensitive to changes in wood content. According to this technique, the electrical parameters can be considered as an indicator of the degree of interfacial compatibility of the wood particulates/polyethylene composite plates.

REFERENCES

Barsoukov, E. and J.R. Macdonald, 2005. Impedance Spectroscopy: Theory, Experiment and Applications. 2nd Edn., John Wiley Sons, Hoboken, New Jersey, USA., Pages: 595.

Bensaid, S., 2010. Solid waste management in morocco institutional & policy issues. Ph.D Thesis, International Energy Agency, Paris, France.

Bledzki, A.K. and J. Gassan, 1999. Composites reinforced with cellulose based fibres. Prog. Polym. Sci., 24: 221-274.

George, J., M.S. Sreekala and S. Thomas, 2001. A review on interface modification and characterization of natural fiber reinforced plastic composites. Polym. Eng. Sci., 41: 1471-1485.

Ghasemi, I. and B. Kord, 2009. Long-term water absorption behaviour of polypropylene/wood flour/organoclay hybrid nanocomposite. Iran. Polym. J., 18: 683-691.

Hakam, A., M.M. Takam, M. Chokairi, E. Alami and A. Hamoutahra *et al*., 2012a. Bark stripping effect of Cork Oak (*Quercus Suber* L.) detected using moisture content measurements of leaves. Phys. Chem. News., 63: 73-77.

Hakam, A., M.M. Takam, M. Chokairi, N.A. Chantoufi and Z. Hamoutahra *et al*., 2012b. Effect of bark stripping on the electrical impedance of Quercus suber leaves. Maderas. Cienc. Tecnol., 14: 195-208.

Hammouzaki, Y., 2013. Desertification and its Control in Morocco. In: Combating Desertification in Asia, Africa and the Middle East, Heshmati, G. and V. Squires (Eds.). Springer, Netherlands, ISBN: 978-94-007-6651-8, pp: 91-111.

Kord, B., 2011. Effect of wood flour content on the hardness and water uptake of thermoplastic polymer composites. World Appl. Sci. J., 12: 1632-1634.

Liao, B., Y. Huang and G. Cong, 1997. Influence of modified wood fibers on the mechanical properties of wood fiber-reinforced polyethylene. J. Appl. Polym. Sci., 66: 1561-1568.

Macdonald, J.R. and W.R. Kenan, 1987. Impedance Spectroscopy: Emphasizing Solid Materials and Systems. Hoboken, New Jersey, USA., ISBN:9780471831228, Pages: 368.

Woodhams, R.T., G. Thomas and D.K. Rodgers, 1984. Wood fibers as reinforcing fillers for polyolefins. Polym. Eng. Sci., 24: 1166-1171.

Zhu, L., J. Cao and Y. Wang, 2013. Evaluation of the interfacial compatibility in wood flour/polypropylene composites with the dielectric approach. J. Appl. Polym. Sci., 129: 1520-1526.