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STUDY OF DIELECTRIC BEHAVIOUR OF A FABRIC COATED WITH NANOCOMPOSITES POLYACRYLATE/CLAY

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ABSTRACT

Our aim in this paper is to study the dielectric properties of fabrics when we apply a nanocomposite coating (polyacrylate/clay). The used clay for manufacturing of the nanocomposites is a cheap natural Tunisian product. It is composed of different kinds of clays, more precisely dolomite, kaolinite, illite, calcite, and quartz. This clay is prepared through the following process: cleaning, purification, and drying. Then a polyacrylate resin (also used in the textile industry for many applications) has been added. Several clay/resin mixtures have been used to coat a pure cotton fabric. We then measured the electric capacitances of these coated fabrics using a domestically assembled capacitor instrument. This showed a variation in the electric permittivity of the differently coated samples. The main finding was that the more nanocomposites deposited the more important is the electrical insulation.

KEY WORDS

Nanocomposite; Clay; Coating; Modelling; Relative permittivity.

1. INTRODUCTION

Nanotechnology for the modern textile materials is used in several technical applications. One of the perspective areas is the dielectric applications, in which the new hybrid material will be more resistant to the electrical current flow or to operate as a part of an electric capacitor.
One of the crucial parameters is the electrical conductivity σ, which is generally deduced from the electrical resistivity ρ and as an outcome from sheet resistance R (Jihu et al., 2013). The most important parameter of the textile materials is its dielectric resistivity. It can be declined by using conductive composites (Gaurav et al., 2013) or enhanced by adding a non conductive coating. This last is a mixture of ceramic nanoadditives

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and organic resin, and subsequently the woven fabric will have hybrid dielectric characteristics: one of the fabric and the other of the constant thin film.
Electrical conductivity is the reciprocal of electrical resistivity. The characteristic of resistivity and dielectric constant is the important thing for investigating the dielectric properties of the nanocomposite system. The impedance of such systems has resistance, inductance and capacitance components. Resistance and capacitance depend on resistivity and permittivity. The characteristic variation of resistivity and permittivity depend on many parameters linked to the composition of the nanocomposites and the environment conditions. Some other researchers have investigated in the surface resistivity confirming that currents do not bore into the bulk of material (IEC 61340-5-1 Standard. Electrostatics; ESD STM 11.11-2001 Standard. Surface resistance measurement of static dissipative planar materials; Hemati et al., 2012; ASTM Standard D 257-99. Standard test methods for D-C resistance or conductance of insulating materials) because these researches have been done for the coated textile with a conductive polymer, and as a result, it is possible to evaluate the conductivity by DC methods (Pimpatima et al. 2013).
Recently, some electro-physical properties of textile fabrics having different forms and raw material compositions were studied by many researchers (Asanovic et al., 2013; Arous et al., 2007).
The aim of this work is to study the effect of nanocomposites on the dielectric properties of the fabric and to prove that the resulting resistivity can only be increased in comparing with the fabric resistivity.
In the first part of this work, we used capacitance measurements to determine the electric permittivity. A new measuring device has been developed for the purpose.
In the second part a dielectric impedance spectrometer was used in order to determine the electric resistance.

2. EXPERIMENTAL

The ultrasonication of 10 g of cleaned and purified Tunisian clay and 100 mL of dichloromethane (CH_2Cl_2) for 2h at 25°C (freq. = 28KHz) resulted in an even dispersion of clay grains, various amounts of which (3%, 5%, 8% and 10%) were then added successively to resin (Jagannathan et al., 2014; Hyoung et al., 2001; Wei et al., 2008; ashok et al., 2008).
The samples were submitted to regular coating. A pressure-controlled rake was used for this purpose. The nanocomposite formation was confirmed in our previous work (Abid et al., 2010). After a 5 min drying operation permitting for water and CH_2Cl_2 to evaporate, the polymerisation of these fabric coatings was done at 150°C for a period of 5 min (Hyoung et al., 2001).
All the samples were kept in a homogeneous atmosphere (HR=65%, T=25°C) for 48h.
The relative permittivity of the hybrid materials was determined by measuring the capacitance using a hand-made condenser (figure 1). This condenser is composed of two plates with the same thickness (1mm) and shape (rectangle: 10x15 cm).

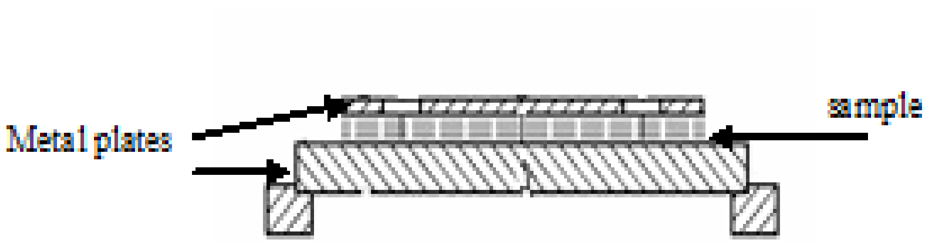


Figure 1: Condenser: two metal plates and the fabric inside.

The used electric circuit for measuring the capacitance of the fabrics is shown in figure 2, and the used resistance = 47KΩ.

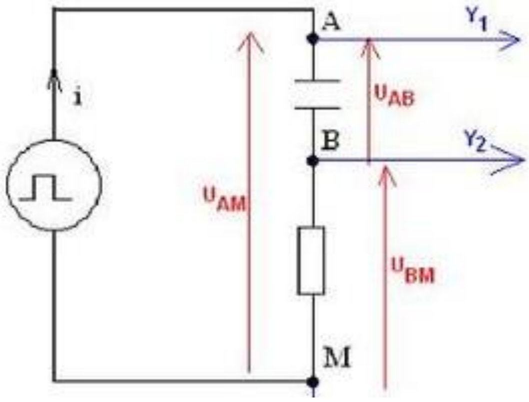


Figure 2: Measurement of the capacitance.

Where:

- Y_1 : channel 1 to oscilloscope
- Y_2 : channel 2 to oscilloscope
- U_{BM} : Resistance voltage
- U_{AM} : Generator voltage
- U_{AB} : Condenser voltage
- I : current

3. RESULTS

3-1 Electric resistance measurement

The charge and the discharge of the condenser can be seen in the two channels of the numerical oscilloscope as shown below (figure 3):

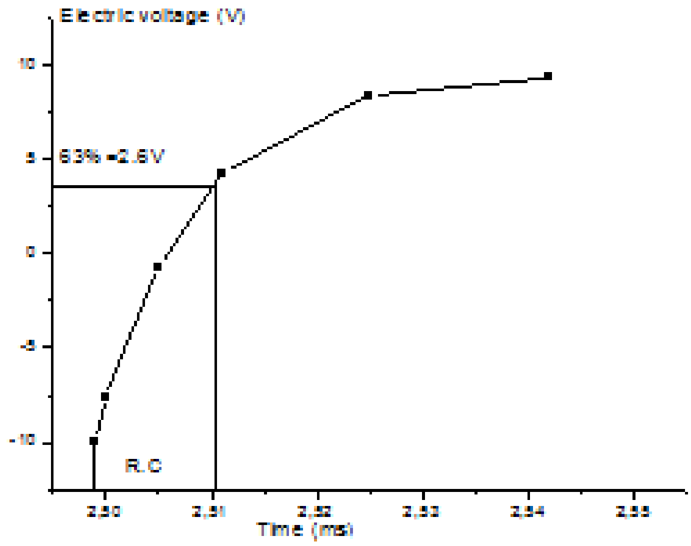


Figure 3: Determination of the time constant ζ= RC for the sample N°1.

The dropped quantity of nanocomposites on the fabric (Qc), the clay filling, and the electric capacitance are shown in table 1.

Table 1: Electric capacitances in conjunction with the clay percentages and the deposited quantities.

Sample N°	Description	Coated fabric thickness (mm)	Deposited quantity (g/m²)	RC (ms)	C(pF)
0	Reference	0,533	0	0,02923	622
1	Clay 0%	0,552	26,0	0,01161	247
2	Clay 3%	0,553	29,2	0,01775	378
3	Clay 3%	0,573	106,2	0,01174	250
4	Clay 3%	0,603	120	0,01046	223
5	Clay 3%	0,623	130,8	0,01036	220
6	Clay 3%	0,657	140,8	0,00947	201
7	Clay 5%	0,547	23,1	0,01488	317
8	Clay 5%	0,557	43,8	0,01194	254
9	Clay 5%	0,567	46,2	0,01037	221
10	Clay 5%	0,587	88,5	0,00880	187
11	Clay 5%	0,590	96,2	0,00873	186
12	Clay 8%	0,547	31,5	0,01116	237
13	Clay 8%	0,590	76,9	0,01097	233
14	Clay 8%	0,610	96,2	0,00989	210
15	Clay 8%	0,653	112,3	0,00923	196
16	Clay 8%	0,677	148,5	0,00900	191
17	Clay 10%	0,557	25,4	0,01190	253
18	Clay 10%	0,587	67,7	0,01132	241
19	Clay 10%	0,620	113,1	0,01053	224
20	Clay 10%	0,630	135,4	0,01023	218
21	Clay 10%	0,647	193,1	0,00787	167

It can be noticed that the capacitance values for all samples are below that of the reference (622pF), which means that the coated fabrics become more resistant to the electric current. However, they all have a limit which is the vacuum or the air relative permittivity (=1). Besides, concerning sample N°1 which represents the fabric coated only with resin, it was impossible to go over 26g/m² for the deposited quantity. And it was also impossible to put less than this quantity because the fabric is very hydrophilic and using little quantities of resin can contribute to have a non-uniform layer on it.
According to table 1, capacitance values of all fabrics increase in conjunction with the clay percentage and they range from 167 to 378 pF. It is also noted that the capacitance values increase with an increased deposited quantity, though the clay percentage remains constant.
The reference fabric's capacitance (C = 622 pF) is higher than that of the coated samples which is also the case for the sample without applied clay. This is due to the presence of moisture in the interyarn and intrayarn pores since the HR% = 65% (Chanselme et al., 2006). This can be explained by the fact that the resin replaces the humidity, thus giving the fabric a higher electrostatic field resistance. We can therefore deduce that nanocomposites could be a good solution for stabilisation of the fabric hygrometric characteristics which makes the fabric less influenced by the climactic conditions.
When the clay percentage exceeds a specific value (ex. 3 % for the deposited quantity = 110 g/m²), the nanocomposites (resin/clay)-coated fabric's capacitance becomes lower than that of the resin-coated fabric with the same deposited quantity.
We have noted an exponential decay tendency in the nanocomposites-coated samples' capacitances. As a matter of fact, from about 50g/m² upwards, their capacitances become significantly lower than the resin-coated fabric, This is probably due to the non-influence of little clay percentages on the coated fabric behaviour in term of capacitance.

3-2 Permittivity measurement

In this section, we want to determine the relative permittivities of these fabrics which will allow us to make a comparison between their electrical resistances.

The relative permittivity ε_r can be determined by using this formula:

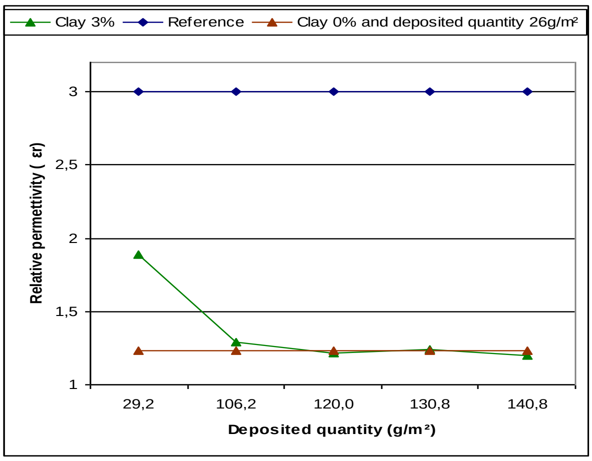
$$(1) \quad \_ = \varepsilon_0 \varepsilon_r \frac{S}{d}$$

Where:

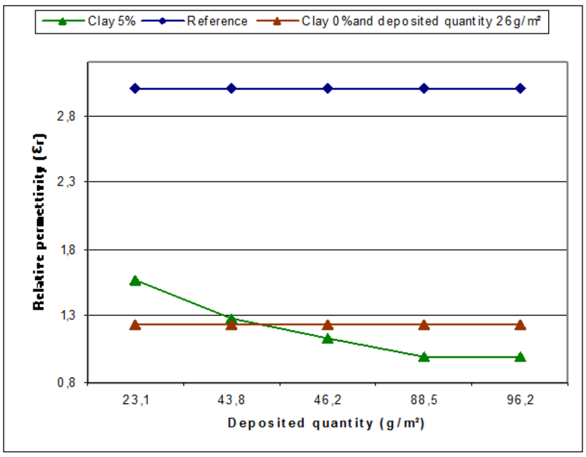
- ε_0 : vacuum relative permittivity:
- $\varepsilon_0 = \frac{1}{36\pi 10^9} = 8{,}85\,\mathrm{pF/m}$
- S : fabric surface = 0,0125m²,
- C: capacitance,
- d: fabric thickness measured in prolific thickness tester as shown in table 1.

The relative incertitude of relative permittivity $\Delta\varepsilon_r/\varepsilon_r < \Delta C/C + \Delta S/S + \Delta d/d = 2\%$.

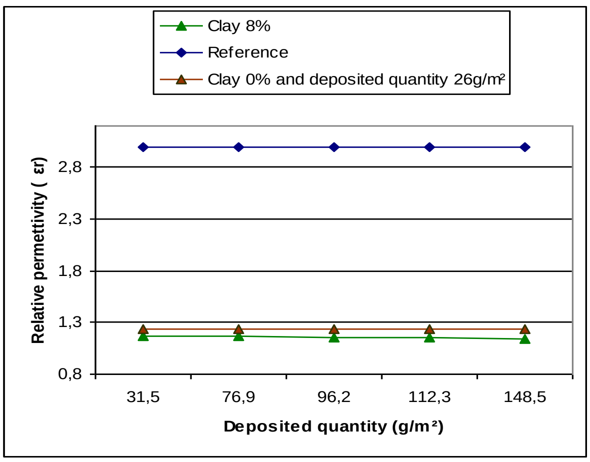
The results of these calculations are represented in figure 4(a-d) below:



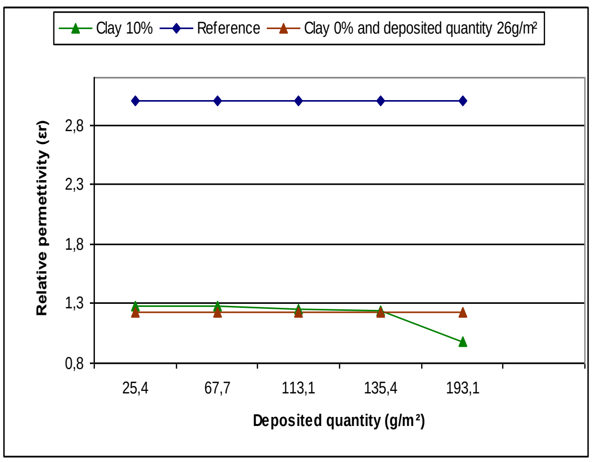
(a)



(b)



(b)



(d)

Figure 4 (a-d): Relative permittivity at different clay percentages and different deposited quantities.

4. DISCUSSION

The above experiments lead us to deduce:

- The coating operation had modified the material's electrical properties due to the fact that the fabric's pores are filled with resin instead of air bearing in mind the dielectric properties and the chemical nature of the latter.

- The samples with deposited quantities ranging from 20 g/m² to 200 g/m² displayed a significant increase in their relative permittivity. In fact, this enhancement of dielectric properties is very important, an average of almost 33% for all samples.

- Relative permittivity of all samples decreased in conjunction with the increased clay percentage. For 3% and 5% of clay loadings, the tendency of the relative permittivity is almost an exponential decrease, and for a precise deposited quantity (110g/m² and 45g/m² for a clay fillings 3% and 5% respectively), the relative permittivity becomes lower than that of the fabric coated with resin only. It continues to decrease until a very low relative permittivity (almost = 1 for the 5% clay filling). For higher clay adding, it can be noticed that the relative permittivities are almost constant and very close to the sample N°1's value (see figure 4(a-d)).

- The clay loading had no influence on the fabric's dielectric behaviour if it exceeds 5% at the exception of samples with a deposited quantity of 20-30g/m². In other words, if we exceed 5% of clay filling, a minimum of deposited quantity (20-30g/m²) could lead to a maximum of dielectric performance.

- As a last remark, we exceptionally registered a very low relative permittivity (~1) for a deposited quantity of 193 g/m² and a clay percentage of 10%.

A comprehensive study of this fact is in progress to see if the superposition of several coated fabrics (20-30 g/m² as a deposited quantity of nanocomposite for each fabric) would provide a better dielectric insulation than putting the whole quantity of nanocomposite on one fabric layer.

5. ELECTRIC RESISTANCE MEASUREMENT

In this paragraph and in order to determine the influence of the amount of clay filling on these samples' resistances, we have chosen to apply equation 4 and determine the electrical resistances of these coated fabrics in conjunction with the frequency of an AC voltage (1V). For this reason, a dielectric impedance spectrometer device was used and, thanks to its impedance calculators, we determined the complex impedance $Z^*(\omega) = Z'(\omega) + jZ''(\omega)$ between electric ports of the tested sample (depending on the frequency $\omega/(2\pi)$) (figure 5).

Figure 5(a) represents the phase shift between the voltage and the current.
Figure 5(b) represents the schematic circuit composed by the capacitance (coated fabric), and a resistance.
Figure 5(c) represents the phase shift between the measured current and the current in the capacitor.

The dissipation factor is defined by the following relation:

$$\text{Tan}\ \delta = \varepsilon''/\varepsilon' \qquad (2)$$

And:

$$\varepsilon' = c\ e/s\ \varepsilon_0 \ \text{ and } \ \varepsilon'' = e/s\ r\ \omega\ \varepsilon_0 \qquad (3)$$

Where:

- c: Capacitance of the fabric,
- ε_0: Vacuum permittivity.

- e: Thickness of the fabric,
- s: Surface of the electrode = 3.14cm²,
- r: Resistance of the fabric,
- ω: Pulsation of the AC voltage,

It comes :

$$\text{Tan } \delta = 1/RC\omega \text{ and } R = 1/C\omega \text{ Tan } \delta \qquad (4)$$

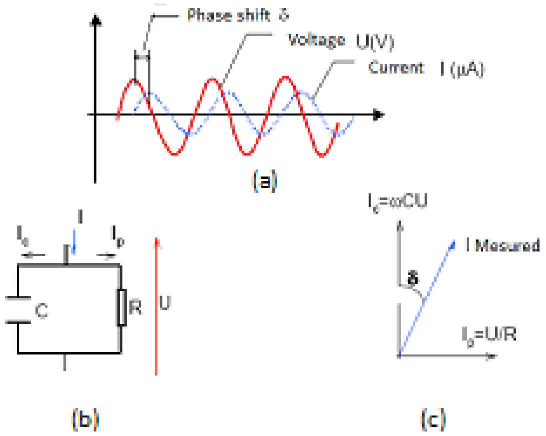
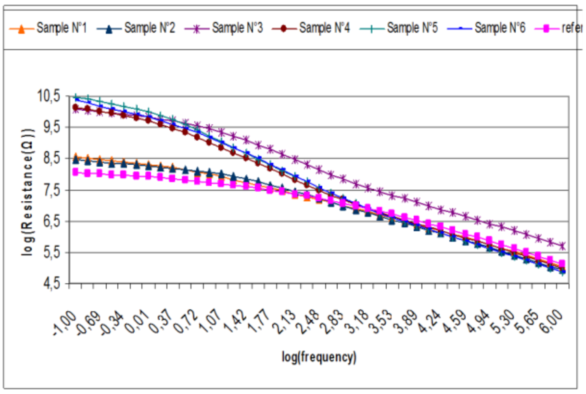
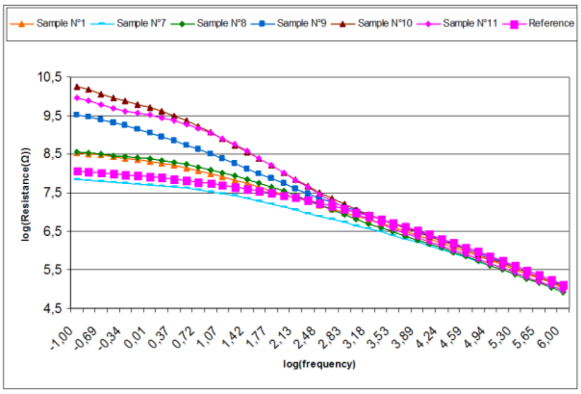


Figure 5: Dielectric respond.

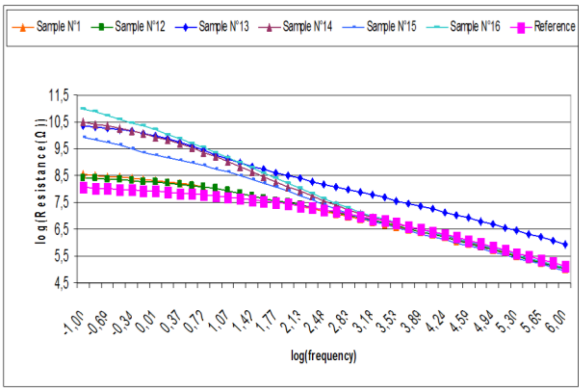
All the samples electric resistances were reached by measuring ε'' and ε', and represented in figure 6:



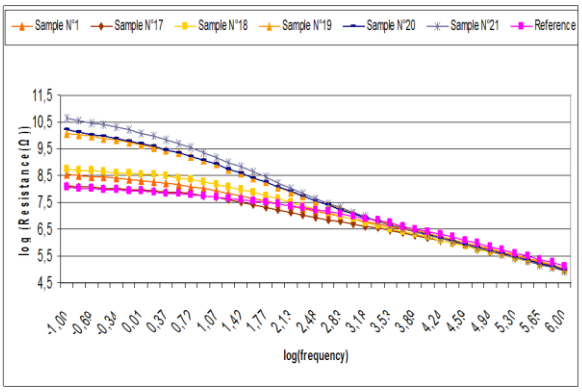
(a) 3% clay.



(b) 5% clay.



(c) 8% clay.



(d) 10% clay.

Figure 6 (a-d): Electric resistance at different clay percentages and different dropped quantities.   .

First of all, it can be noticed that the electric resistances of all samples decrease in relation with the AC voltage frequency. In fact, for frequencies less than 1 KHz, the resistances begin to increase considerably reaching values very close to 10GΩ for a frequency of 0.1 Hz. However, for high frequencies (1MHz), these resistances become low (1KΩ). On the other hand, we have noticed that for a constant clay percentage, the higher the deposited quantity the better the electric resistance. The more densely coated samples increased by about 10^3. This means that the electrical resistance could be enhanced from 10^8 Ω to 10^{11} Ω by adding a nanocomposite. Besides, as the fabric strongly depends on the relative humidity in term of electric resistance, adding a nanocomposites makes its behaviour strictly independent of the climatic conditions (this characteristic is very interesting for making protective clothes for electricians using high voltage).
Sample N°1, coated with resin only, presents a slightly higher resistance than the reference, but a lower one than the rest of the samples with nanocomposite fillings.
For the same deposited quantity of nanocomposite, any increase of the clay percentage leads to an enhancement of the electrical resistances. This is probably due to the high electric resistance of the ceramics such as clay in this study.

6. CONCLUSIONS

In this research, we have elaborated an approach to coated fabrics' dielectric impedance computing. The clay presence is a very important parameter since the higher the clay fillings in the nanocomposite the better dielectric performances.
The capacitances of these hybrid fabrics could be modified simply by varying the amount of added clay in the coating. The capacitance improvement can go as high as 30 % on average.
It would, therefore, be interesting to see if the superposition of several coated fabrics would enhance the dielectric characteristics than putting the whole quantity of nanocomposite on one fabric layer.
The validation of these results is only possible through direct resistivity measurements. Consequently, several parameters such as relative moisture, eliminating electromagnetic waves in the air (by a Faraday cage), choice of the electric cables and noise should be taken into consideration. We are currently working on the evaluation of the hybrid fabrics' electric characteristics.

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