Determination of the Complex Dielectric Permittivity Industrial Materials of the Adhesive Products for the Modeling of an Electromagnetic Field at the Level of a Glue Joint

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Abstract

To achieve out this work we were interested in the study of microwaves techniques and also of the measurement of complex relative dielectric permittivity. It is important to measure this dielectric permittivity for the used adhesive before subjecting it to electromagnetic energy.

This prediction enables us to avoid an exothermic phenomenon due to the brutal rise in the temperature in the joint of adhesive. However, these results are used calculations program, to trace cartography of the electric field and of a temperature gradient in standardized test-tubes. At the end of this step, we have physical and experimental tools that can be used in the study of an optimized process using the microwaves. We check also the strong absorption of energy on the level of joint of adhesive (attenuation electric field), that the microwaves make it possible to well polymerize the adhesives with less times and low energy consumption without rise in prejudicial temperature of the parts to be stucked.

Keywords: *Microwave, Coaxial line, dielectric, permittivity, glue, adhesive.*

1. Introduction

The dielectric heating concerns dielectric body, the body that is bad electrically conductive is generally bad driver of heat. In general, such a body contains molecules or groups polar. These charges tend to align with the electric field within the material. In the case where an electric field at low frequency is imposed, alignment can occur with a lag which is a loss of electromagnetic energy and thus heating of the material. The choice of the working frequency is regulated to avoid interfaces with telecommunications; some bands are released for industrial, scientific and medical use (ISM). The interaction of electromagnetic waves and materials transforms electromagnetic energy into thermal energy which is reflected in both the ionic conductivity and dielectric relaxation. Therefore, the dissipative properties and the complex properties of the materials are determined by the conductivity dielectric permittivity. Depending on their values, these factors characterize the absorbency of the product subjected to radiation.

When an electromagnetic wave comes into contact with a dielectric, a part of the wave is reflected and a part enters the material. The energy of transmission, in the sample to be treated, decreases exponentially transforming itself into heat. The attenuation factor depends on the physical characteristics of the local environment and the frequency and it is represented in the following equation [1].

$$E = E_0 e^{-\alpha x} \quad (1)$$

E_0 represents the amplitude of the field at the internal surface of the dielectric environment, the attenuation coefficient is given by [2, 3]:

$$\alpha = \frac{c}{2\pi\sqrt{\frac{\varepsilon_r'}{2}\left(-1+\sqrt{1+tg^2\Delta}\right)}} \quad (2)$$

α depends on the physical characteristics of the local environment and the frequency. Δ is the angle losses and it is given by:

$$tg\,\Delta = \frac{\varepsilon_r''}{\varepsilon_r'}, \quad (3)$$

C is the speed of the electromagnetic wave in vacuum; (C $=3x10^8 ms^{-1}$), $\varepsilon_r^{'}$ and $\varepsilon_r^{''}$ are the real and imaginary parts of the complex relative permittivity.

2. Technical Results of Measurement

The automotive industry introduces more and more plastic in these fabrications. This material replaces the metal, due to its low density, its chemical qualities of neutrality with respect to a wide range of corrosive agents and ways to implement it in simple process for some manufacturing. The addition of the reinforcing fibers can obtain parts whose mechanical properties are comparably seen superior to those of metals. We are also interested in the timber industry where we have made standard specimens exhibiting remarkable mechanical properties, after the treatment by microwave energy. The operation of traditional collage, produced with the help of a conformer metal movement of warm air when heated by resistance, lasts at least 3 minutes, the time required for the rise in temperature of the glue, because this should be restricted to avoid the distortion of parts to be assembled. Today, the demands of the production rates of the automobile industry need to realize this bonding time to less than one minute. In recent years, the use of microwaves in the collage of wood and in the automotive industry was growing significantly, but many principles were still poorly understood, which justifies our work. This work is to study the behavior of industrial adhesives during the cross linking reaction, polymerization is activated by an electromagnetic wave. In order to achieve this work, it is necessary to know in advance the dielectric behavior as a function of frequency and temperature of the various used glues. Unexpected reactions may occur such as shifting towards maximum absorption frequencies or thermal caused by a sudden increase in permittivity as soon as the temperature rises.

The measurement technique is to use a coaxial standard radius cell from a section of coaxial guide 50 Ω and exterior radius b (Fig. 1). This cell is terminated by driver infinity and must be immersed in the product. The network analyzer is used to measure the coefficient of reflection module and phase which is linked complex dielectric permittivity ($\varepsilon_r^{'}$ and $\varepsilon_r^{''}$) [5].

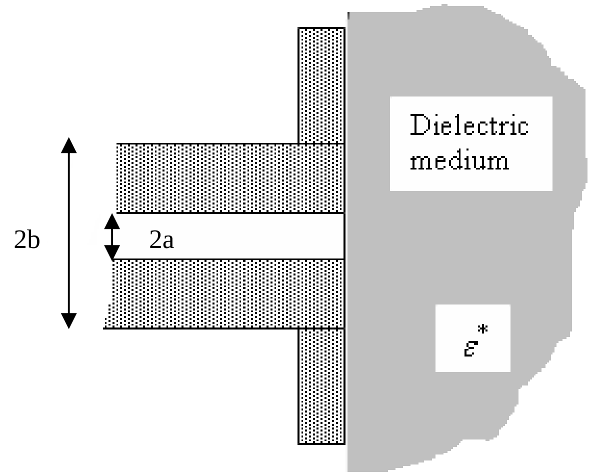

Fig 1: Coaxial Cell 50Ω

The main considered adhesives are: ALFO vinyl, epoxy glue FIX TOP 62 NA polyurethane varnish and glue XPU 4727 AC / BC, which have been developed and marketed by the company ELF ATOCHEM-France. For example, we present the results of measuring the dielectric permittivity of a polyurethane adhesive (XPU 4727 AC / BC). This is adhesive glue that can be used cold or hot. It is ideally suited for the assembly of structural composite materials made from polyester resins reinforced fiberglass, with thermoplastics. It is glue for the automobile industry, for a collage of body parts in SMC, BMC or pack. Figure 2 and Figure 3 show the curve of the glue XPU 4727 AC / BC according to the frequency and the temperature. We notice that the effect of temperature is dominant in high frequencies.

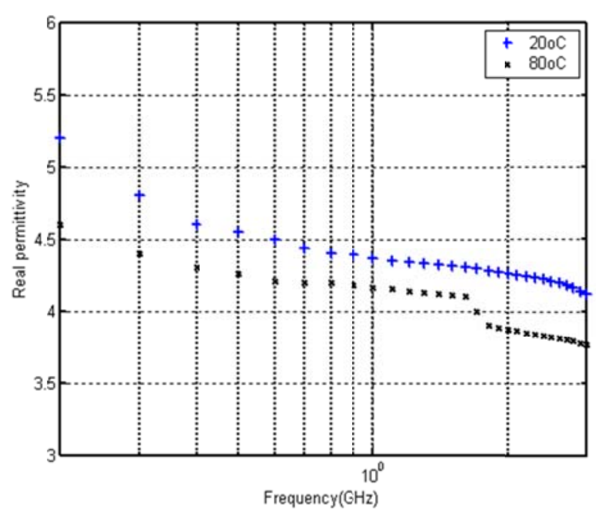

Fig 2: Real permittivity versus the frequency and the temperature

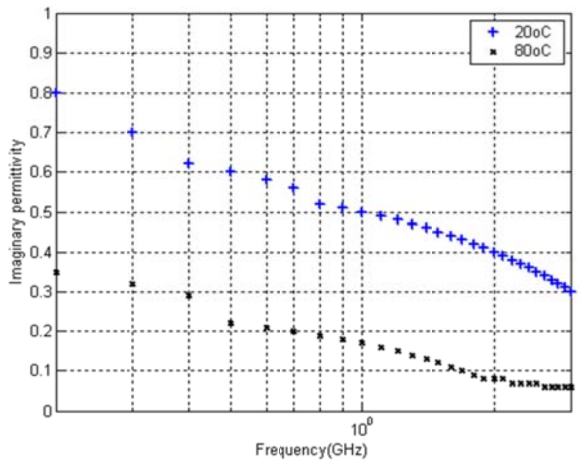

Fig 3: Imaginary permittivity versus the frequency and the temperature

The adhesive is fabricated using a mixture of equal volume of two components A and B, which results in a permittivity of 4.08- j0.30 at 2.45 GHz frequency. The permittivity of BMC, for example, at the same frequency is 4.3 - j 0.01. Figure 4 shows the temperature rise through the joint in terms of time. It has reached 150 ° C in less than 40 seconds. The measured temperatures in the socket BMC and glue highlights is one of the advantages of microwave, the maximum difference in temperature between the adhesive and support is 110 ° C at time t = 35 seconds [9]. These results are obtained from a test microwave containing:

- Power generator that can be adjusted from 0 to 1.2 kW, f = 2450 MHz.
- A pump for measuring the reflected power and protecting the generator reflected wave.
- An applicator consisting of a portion of a rectangular waveguide.

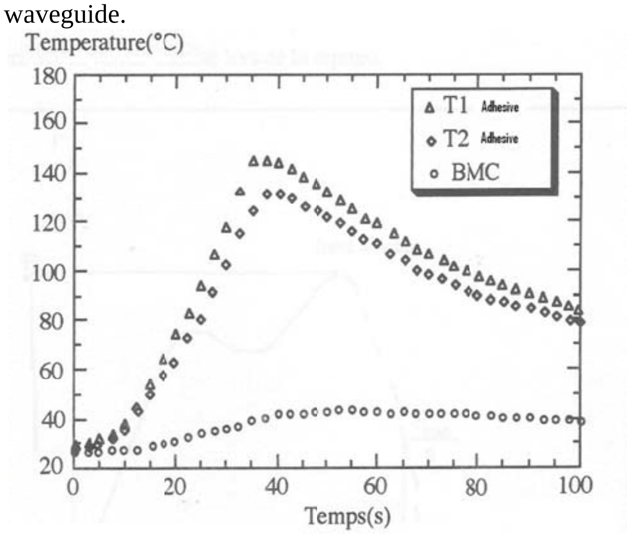

Fig 4: Evolution of the temperature through the joint glue and the BMC

Figure 4 shows, according to the curve of temperature mounted for different glued pieces that the warming of the joint adhesive is faster than the substrate. We can say that the parallel bonding field allows the reduction of processing time (electric field parallel to seal glue). This is an important point because production in a series, at a speed industry can be useful.

Tests of pure mechanical shearing, with a speed of 5 mm / min, depending on the extension, has been made on this standard test, 48 hours after bonding. The results are shown in the table below. By applying these tests, we noticed a breach of the bracket (BMC) with an average equal to 3.2 MPascal.

Table 1: Constraint observed on a series of tests of the adhesive polyurethane XPU 4727 AC/BC.

	Essay N°	Traction τ(MPascal)
	1	3,0
	2	3,1
Colle	3	3,0
polyurethane	4	2,6
ACBC 4727	5	3,0

3. Electromagnetic Field and Heat Modeling at Adhesive Joint [6, 7, 8]

It is often important to model the electric field and map temperature in the test tube before realizing an experimental microwave applicator. This allows us to optimize the energy absorbed by the sample. The development of a numerical model requires a physical analysis of the diffusion equation of heat and Maxwell's equations.

$$\vec{\nabla} \wedge \vec{E} = -\mu \frac{\partial \vec{H}}{\partial t} \qquad (4)$$

$$\vec{\nabla} \wedge \vec{H} = \varepsilon \frac{\partial \vec{E}}{\partial t} + \sigma \vec{E} + \vec{J}_{Source} \qquad (5)$$

$$\rho C_p \frac{\partial T}{\partial t} - div(\lambda \nabla T) = P_d \qquad (6)$$

σ: Electrical conductivity

ρ : bulk density of the material

Cp: Specific heat ($J.g^{-1}.K^{-1}$)

λ: thermal conductivity ($W.cm^{-1}.K^{-1}$)

Pd : Power absorbed by the material ($W.cm^{-3}$)

The energy is radiated by the antenna. We have a complex permittivity and a complex permeability. The source term is cos(ωt), ω = 2 πf (f = 2.45 GHz). This term source is placed at the ω π t, with two locations of the antenna magnetron. Therefore, thermal and electromagnetic phenomena are coupled, firstly by the density of power which is a function of H and E, and secondly, by electrical, which depend on the temperature. The modeling of these equations, using the finite volume, determines the distribution of the electric field and the temperature during the process of heating of materials. We give as an example, the distribution of electric field into a vacuum microwave cavity, Figure 5, shows the electric field on the propagation mode TE013. In figures 6 and 7, we present the results obtained by modeling glue XPU 4727 AC / BC. The simulation of this joint glue was conducted using samples from BMC used in the automotive industry. We note, however, a reduction in the field slightly stronger in the joint adhesive. This is normal because the angle of loss is slightly lower for the BMC than for the glue XPU 4727.

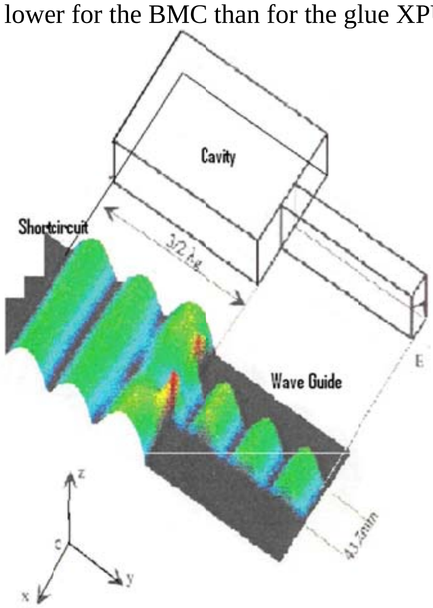

Fig 5: Cavity with vacuum, mode TE013, slice of the electric field in the yoz plan in 3D.

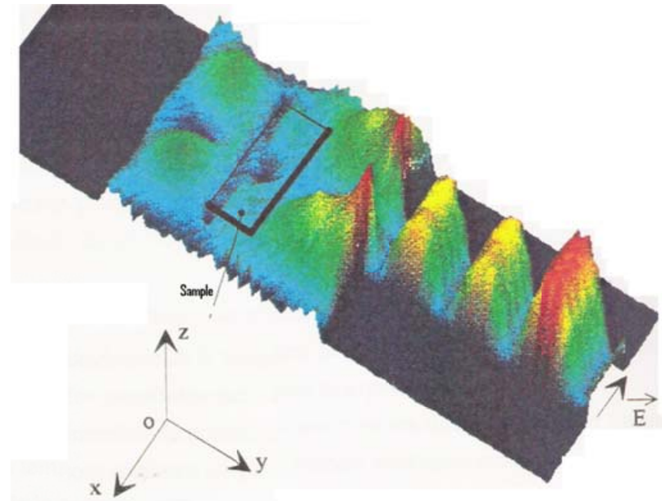

Fig 6: Cavity with sample, adhesive polyurethane XPU 4727 AC/BC, = 4, 08-j 0, 38 slice of the electric field in the xoy plan (in the joint of adhesive).

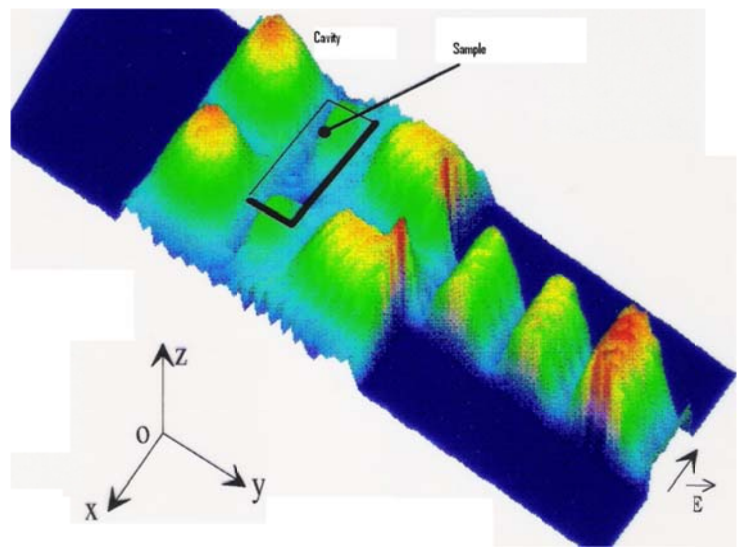

Fig 7: Cavity with sample, adhesive polyurethane XPU 4727AC/BC, slices electric field in the xoy plan (in the BMC).

4. Conclusion

By studying of the results produced through mechanical dimensioning of the applicator, we conclude that the couple modeling experimentation constitutes a solid basis and effective to apprehend the problems of bonding under microwave. We also check the strong absorption of energy at the level of glue seals (electric field attenuated) and the microwave can polymerize well the adhesives with reduced time and low energy consumption without fever parts pasting.

These results of measurement on the dielectric parameters will give us numerical data and give the thermal parameters using the Maxwell's equations and the equation of the conduction of heat. This is connected to model the distribution of electromagnetic field and the topography of the temperature in a joint of adhesive. Finally, these thermal and dielectric parameters of the adhesive products give us a quite precise idea on the choice of an applicator microwaves.

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