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Plaster Glue Complex Permittivity Response in the Microwave Range

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This paper describes a complementary method for determining dielectric properties of granular materials using the Transmission/Reflection Method in order to estimate their moisture content. The Newton's Complex Interactive Method is used here as a numerical tool to calculate the complex permittivity of the plaster glue material. Results for samples with moisture contents of 35%, 40% and 45% in the range of 100 MHz to 3 GHz are presented.

Keywords: *property studied: dielectric properties, electrical properties, dielectric, microwave, powder*

1. Introduction

The knowledge of complex permittivity of materials has been frequently used to manufacture sensors in the industrial sector designed to evaluate moisture content in the products of food processing industries. The dielectric properties of materials may be expressed by complex permittivity, $\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$. Here ε_r' is the dielectric constant associated to the energy storage capacity. ε_r'' is the loss factor that represents the loss of electric energy associated to the electric field inside the material. The specialized literature offers many ways for measuring ε_r. The Transmission/Reflection Method (T/R Method) has been often used by metrologists due to the easy way of measuring the scattering parameters of a sample with a vectorial network analyser. The use of coaxial line favours the sample characterization because of its broad operating band. The T/R Method uses the measured parameter S_{21} for high loss materials where samples have length that allows tests within the dynamic range of the network analyser. For low loss materials, only the parameter S_{11} is exploited. In this way, Nicholson and Ross[1] have been referred quite often by many authors because of their simple expression for S_{11} and S_{21} as functions of ε_r' and ε_r''. However, that method presents difficulties for being unstable at frequencies for which the sample length is a multiple of a half wavelength.

This instability is resolved when the Newton's Interactive Complex Method is used. In order to work with this method conveniently, initial guess for certain parameters are required.

This initial estimation is treated by two of the authors[2] and has to do with the ambiguity presented in the determination of the phase of S_{21}. This ambiguity arises because the sample length may contain an integer of wavelengths. In order to eliminate it, James Ball and Horsfield[3] obtained a transcendental equation system involving the measurement of S_{21} for three distinct frequencies. Similar procedure was followed by Wier[4] and Ness[5]. Trabelsi *et al.*[6], in order to tackle the ambiguity, have carried out some measurements with many samples at the same frequencies. All these procedures and others described in the specialized literature require additional effort to produce the first estimation for the Newton's interactive process.

This work exploits the Newton's Iterative Complex Method together with the Transmission/Reflection Method to measure the dielectric constant of a gypsum sample with 45% moisture on the L and C microwave ranges. The initial estimation to calculate the dielectric constant is different from the usual one described in the recent literature. This procedure was mentioned in a recent work by the authors of reference[6]. The technique applied is presented in the next section.

Plaster is a white paste made from gypsum (hydrated calcium sulphate, $CaSO_4{\cdot}2H_2O$), which is a common sulphate mineral of great commercial importance. Among the natural resources of the Northeast of Brazil, the gypsum zone is one of the largest exploitable deposits of gypsum in the American Continent. The installed capacity of 2,6 mil-

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lions ton per year represents 95% of Brazilian gypsum production, generating 12,000 direct and 60,000 indirect jobs.

The moisture content is an important parameter in the process of production that is related to the kind of commercialised plaster. Characterizing this material by microwave technique reveals a promising quality control technique for its internal and either external trading market. It includes the building industry, arts, some medicine sectors, agriculture industry etc.

The knowledge of complex permittivity of plaster on microwave frequencies is not reported on the specialized literature, as far as the authors know. However, plaster material deserves closer attention in the local context, as long as Pernambuco (a Brazilian state) is the greatest plaster producer all over the country.

Plaster glue is a product developed for the collage of pre-formed plaster moulds, such as, sheets for lowering ceilings, plaster blocks for internal wall dividers and decorative pieces. It is produced from Beta plaster of high quality, purity and fineness.

2. Theory

Figure 1 describes a coaxial structure with a length d containing plaster sample. A section of length d_1 is filled up with a material of low permittivity and low loss when compared with the material of the sample.

Using the fields matching method at the dielectric and air interface and after some manipulations one has the following expressions for S_{21} and S_{11}:

$$S_{21} = e^{-j\beta_0 d_1} \frac{\left(1-\Gamma^2\right)\Omega}{1-\Gamma^2\Omega^2} \quad (1)$$

$$S_{11} = e^{-j2\beta_0 d_1} \frac{\left(1-\Omega^2\right)\Gamma}{1-\Gamma^2\Omega^2} \quad (2)$$

where, $\Omega = e^{-\gamma_s d}$, $\gamma_s = \alpha + j\beta_s$ and $\Gamma = \frac{Z-Z_0}{Z+Z_0}$

where Z and Z_0 are the intrinsic impedances of plaster and air, respectively. Inside the sample, the electromagnetic fields dependence with the longitudinal coordinate *z* is given by $e^{-j\beta z} = e^{-\gamma_s d}$ where $\beta = \omega\sqrt{\mu\varepsilon}$ Letting ε = ε' - jε'' (still not normalized to ε_0), one gets the following expressions for ε' and ε'' (already normalized to ε_0) in terms of α_s and β_s:

$$\varepsilon_r' = \left(\frac{c}{2\pi f}\right)^2 \left(\beta_s^{\,2} - \alpha_s^{\,2}\right) \quad (3)$$

$$\varepsilon_r'' = 2\alpha_s\beta_s \left(\frac{c}{2\pi f}\right)^2 \quad (4)$$

where *c* is the speed of light in free space. For the application of the Iterative Method, an initial estimation is necessary for α_5 and β_5. It is obtained by doing Γ = 0 in (1), resulting:

$$\alpha_s = -\frac{ln\left|s_{21}\right|}{d} \quad (5)$$

and

$$\beta_s = -\frac{\varphi + 2n\pi + \beta_0 d_1}{d} \quad (6)$$

where φ is the phase of S_{21}. After choosing the first pair of parameters α_s and β_s, they are then substituted back into expression (1) to give S_{21}.

For the same frequency the calculated value can be compared with the measured one, where the difference value is checked with respect to the established limit error. If a new interaction is necessary, another value for S_{21} is calculated from the new values of α_s and β_s, as the error limit is checked again, and so on. The whole process has to continue to achieve the desired limit error. The Method yields fast convergence. The success of this method depends on the right prediction of the initial values of α_s and β_s. The latter depends on the correct choice of the parameter *n* in Eq. 6. If the initial estimation for α_s and β_s is correct at the first frequency of the range, the last values calculated for α_s and β_s at that frequency are taken as the initial guess for the next frequency, and so on.

2.1. Technique for selecting n

The Eqs. 1 and 2 are the basic ones for determining the integer *n*. If we now take a complex permittivity ε_r at a certain frequency, under the same conditions of the experiment, we will be able to generate S_{11} and S_{21}, in accordance with Eqs. 1 and 2. Once we know S_{21}, it is possible to begin the iterative process using Eqs. 5 and 6. The value of ε_r will be the proper one if the chosen value for *n* is the correct one. This correct value for *n* is easily found if its variation is set starting from 0. Once this value is chosen, it is taken as the parameter that must initiate the iterative process, at this time with S_{21} measured. The measured value of S_{21} and the calculated value of *n* are taken into Eqs. 5 and 6 respectively, in order to estimate the first values of α_s and β_s to initiate the iterative process. An error can occur during the measurement of S_{21}, that would bring about the wrong determination of *n*. As a result, we will get a false start for the determination of sample's complex permittivity. Then, S_{21} measured and *n* calculated are taken to Eqs. 5 and 6 respectively, for the purpose of estimating the first and to initiate the iterative process. An error can occur during measurement of S_{21}, that implies a mistaken determination of *n*. As a result, we will get a false ε_r value. In this case, adding or subtracting a unit to *n* would yield an acceptable value for ε_r. This will be the correct one.

It is important to notice that, at the same frequency and under the same experimental conditions, n will depend on the value of the complex permittivity to be measured. Consequently, when a known permittivity is taken for the determination of n, which must go in the iterative process from the measured data, it is necessary to have a vague idea of the material under test.

3. Results

For the measurement of S_{11} and S_{21} a vectorial network analyser model Agilent 8714ET operating in the Transmission/ Reflection mode with an output power level of 0dBm was used. The data were taken using a PC, Pentium IV, with a GPIB card installed. The device under test was a coaxial transmission line (LT) with outer radius of the inner conductor a = 2.2 mm, inner radius of the outer conductor b = 22 mm and length d = 128 mm. Region 2 of Fig.1 was filled up with powder of plaster glue. Region 1 was filled up with a piece of polystyrene. Using the numerical method described in Section 2, both amplitude and phase of S_{11} and S_{21} were measured. Figures 2, 3 and 4 show the frequency responses of ε_r', ε_r", and $|\varepsilon_r|$, respectively, for plaster glue samples with 35%, 40%, 45% and 0% of moisture content from 700 MHz to 3 GHz. From these figures one can see that moisture content is a suitable parameter for plaster characterization, since the responses are well defined and visibly apart.

Figure 1. Sketch of the coaxial line structure. Region 2 with length d (longitudinal section) contains the dielectric sample under investigation. Region 1 contains a dielectric material with lower permittivity and loss.

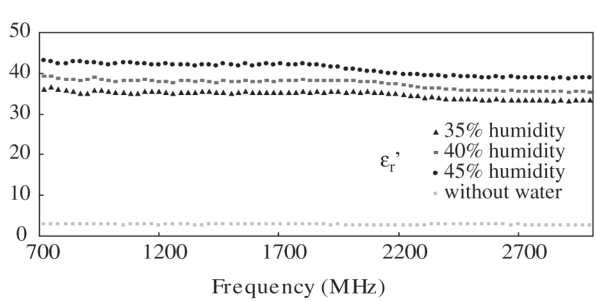

Figure 2. Frequency response of the real part of permittivity for plaster glue powder with some humidity contents.

4. Conclusions

The Newton's Complex Iterative Method in combination with the Transmission/Reflection Method avoids the frequency instability usually found in the process of determining the complex dielectric constant. This method requires the estimation of initial values for the real and imaginary parts of γ_s. We have shown how the parameter n could be estimated from a vague idea of ε_r. In many cases when the value of n is not correct the corresponding calculated value of ε_r have to be discarded. The regular behaviour of the plaster glue material that presents considerable moisture, as can be confirmed by Figs. 2, 3 and 4 shown, reveals that in the range from 700 to 3000 MHz it is possible to have clearly an estimation of water concentration in different samples of a material.

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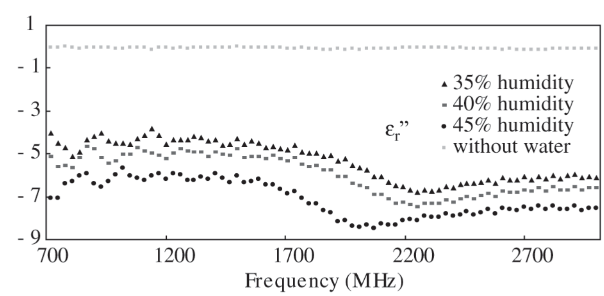

Figure 3. Frequency response of the imaginary part of permittivity for plaster glue powder with some humidity contents.

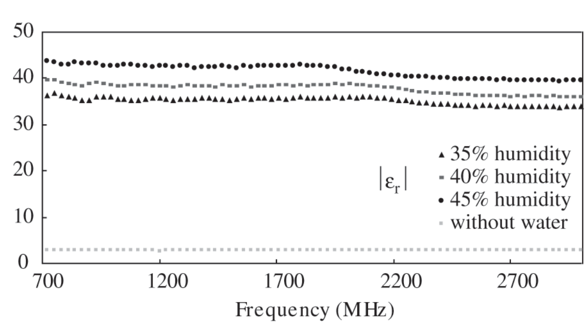

Figure 4. Frequency response of the magnitude of the permittivity for plaster glue powder with some humidity contents.

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