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Unambiguous Assessment of Solid Materials Dielectric Constant at Microwave Frequencies

D. Faktorová, K. Isteníková
Department of Measurement and Applied Electrical Engineering, Faculty of Electrical Engineering, ŽU, Žilina, Univerzitná 1, Žilina
E-mail : faktor@fel.uniza.sk, istenikova@fel.uniza.sk

Abstract:
The paper presents the effect of carbon powder admixture added to the volume of dielectric slab at its absorbing properties. A practical method for dielectric constant determination with fully unknown dielectric properties of new material formed from basic dielectric material and carbon admixture is given. Very simple and well – known theoretical formulae are used for unambiguous determination at the complex permittivity calculation. Experimental results are presented, too.

INTRODUCTION

The production of microwaves absorbing material is directly related to the development of new materials for providing several applications involving tight requirements in the microwave reflection suppression. The electromagnetic pollution increase promoted by the rapid development of electronic and telecommunication systems has expanded in the form of electromagnetic interference [1], resulting in various studies involving the radar absorbing material technology. Aiming at controlling the problems created by electromagnetic interference, the electromagnetic wave absorbing technology is an important topic to be considered for fulfilling civil and military purposes. Usually, in the military area the studies involve development of radar absorbing materials for the frequency range of 8 to 12 GHz. For this purpose, the role of microwave absorbing materials is to reduce target detection by the radar, i.e., to reduce its signature for radar detection (to reduce its eco-radar) [2]. For this, microwave absorbing material is used to fill the building slabs. In the microwave absorbing material the processing of several parameters have to be taken into account. Among them, weight, thickness, microwave absorption, environmental resistance and mechanical strength are of major importance [3, 4].It is a known fact that the adequate combination of components and experimental conditions may produce materials with specific requirements. The paper responds to technological practice needs, when the knowledge of complex permittivity is required, e.g. at manufacturing building slabs which are to safeguard buildings or their critical parts against microwave signal penetration [5], when the accurate estimation of crack dimensions in metal and dielectric sample in the case when the investigated crack is filled with dielectrics with unknown dielectric parameters is needed and when the crack presence and its dimensions assessment in dielectric sample is needed to estimateThe instructions for manuscript layout and submission procedure are as follows.

COMPLEX PERMITTIVITY OF DIELECTRIC SAMPLE WITH ADMIXTURES

Since the building materials are mostly of dielectric character, it is possible to influence this required property by suitable admixtures. In spite of the fact that the dielectric properties of suitable admixtures being well known, their inclusion with the suspension material can results in dielectric with unexpected properties. Permittivity of mixtures of dielectrics has been a subject of extensive study from the time of Maxwell and Wagner The measurement of complex permittivity is the subject of many technical and scientific areas and an unambiguous determination of its value often runs into difficulties. Particularly in technical applications it is possible to notice a situation when e.g. two specimens of nominally the same material may have significantly different complex permittivity as a consequence of different manufacturing processes, different amount of oxidation and different inclusions.

In dielectric materials, the main properties that enable them to be applicable as microwave absorber are the dielectric constant and the dissipation factor of energy. Usually, the dielectric microwave absorbers change their dielectric properties. This is achieved by the distribution of fillers that alters the electrical properties of the material [6].

From the microwaves absorption’s point of view [7] the mean quantity is the loss factor, which is connected with the real part of complex permittivity. The problem comes down to the determination of relative permittivity of the building material with the suitable admixture providing the required absorption of microwave signal.

Our method utilizes the microwave waveguide techniques and so it is based on rectifying medium for electromagnetic wave. As it is case of sinusoidal wave, we can use, for the *E*-component of electromagnetic field with the angular frequency *ω*, the wave equation

$$\frac{\partial^2 \dot{E}}{\partial x^2}+\frac{\partial^2 \dot{E}}{\partial y^2}+\frac{\partial^2 \dot{E}}{\partial z^2}+\frac{\omega^2}{c^2}\dot{E}=0\,, \qquad (1)$$

where *c* is the speed of light in vacuum. The waveguide is filled with the measured sample and our approach provides a technique for obtaining the wavelength directly in the investigated sample. The sample is gradually shortened and for every measured sample length (*d*) SWR can be calculated [8]

$$\mathrm{SWR}=\frac{\left|\dot{E}_{\mathrm{min}}\right|}{\left|\dot{E}_{\mathrm{max}}\right|}\,, \qquad (2)$$

where the function $\mathrm{SWR}=f(d)$ is plotted in a graph and this dependence displays minima and maxima of standing wave in the rectangular waveguide. The distance between them gives the wavelength in the dielectric sample (λ_{gd}) after taking all circumstances relating to the electromagnetic waves in waveguides propagation we can obtain

$$\lambda_{\mathrm{g}}=\frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{\lambda_{\mathrm{c}}}\right)^2}}\,, \qquad (3)$$

where λ_0 is the wavelength in free space, λ_{c} is critical wavelength and *ε* dielectric constant of the sample. As λ_0 and λ_{c} are known and our approach gives the way how to obtain λ_{gd} , *ε* can be unambiguously calculated from the formula

$$\varepsilon'=\left(\frac{x\lambda}{2\pi d}\right)^2+\left(\frac{\lambda}{\lambda_{\mathrm{c}}}\right)^2, \qquad (4)$$

which follows from Eq. (3). As λ_0 is known from the used frequency and λ_{c} depends on the waveguide dimensions, it remains to measure the wavelength of electromagnetic wave in investigated dielectric materials λ_{gd} . The whole procedure lies in the fact that through this method is unambiguously determined real part of complex permittivity *ε*, (in some cases loss factor , too) and on the basis of known *ε* it is possible to proceed to the choice to some of known methods enabling to obtain $\mathrm{tg}\delta$.

$$\mathrm{tg}\delta=\frac{\Delta x_{\mathrm{s}}-\Delta x}{\varepsilon' d}\left(\frac{\lambda}{\lambda_{\mathrm{g}}}\right)^2. \qquad (5)$$

The distance Δx using the "twice - minimum" method for high standing – wave ratio was measured, Fig. 1.

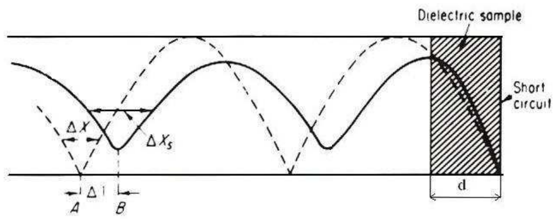

Fig. 1: Standing waves in the waveguide with (solid line) and without (dashed line) the sample

In this case (high SWR) the probe depth must be increased if a reading is to be obtained at a voltage minimum. This will, however, cause a) field deformation when the probe is at a voltage maximum and perhaps b) so much power on the crystal detector (CD) that it does not work in the square – low region. To avoid these problems we used this "twice – minimum" or "3 dB - method." In this method we measured the distance between the points where the crystal detector output voltage was double the minimum, Fig. 2.

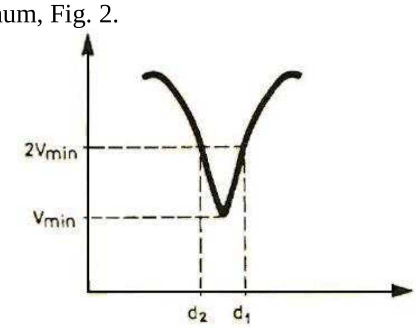

Fig. 2: The "3 dB - method"

MEASUREMENTS AND RESULTS

Microwave technique provides a great range of measuring methods [5], [7], [9] for the complex permittivity determination from gases via liquids, up to solid materials according to the dielectric in question. The measurement usually exploits an approximate knowledge of complex permittivity or some methods assuring its unambiguous determination is chosen (e.g. some of waveguide methods). In spite of that a considerable inhomogenity of prefabricated parts and also owing to a polysemy of results obtained from measurement (e.g. periodicity of functions used in computations) causes some uncertainty in determination of the complex permittivity of the final product.

For measurement we have chosen the waveguide Hippel's method which has proved successful for the measured material and it behaves to the most accurate methods for dielectric properties measurement. The measurements were carried out in X – band (frequencies from 8 to 12 GHz). The experimental set-up is in Fig. 3.

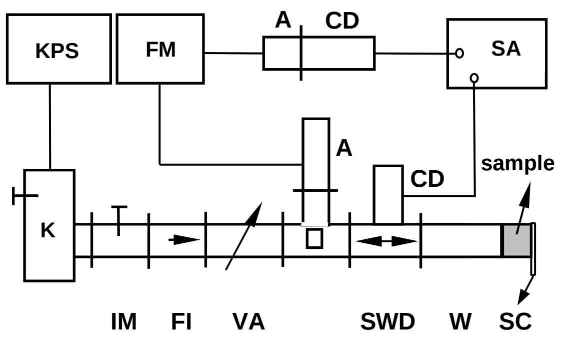

Fig. 3: Experimental set-up for complex permittivity measurement. K – klystron, KPS – klystron power supply, FM – frequency meter, SA – selective amplifier, IM – impedance match, FI – ferrite isolator, VA – variable attenuator, MT – magic T, SWD – slotted section, W – waveguide, SC – short circuit, A – adapter, CD – crystal detector

The samples were formed in such way to fit close to the waveguide walls (they were impressed into the waveguide).

If it is a case of ε measurement (for loss tangent tgδ determination can be used an another method, e.g. resonant method), λ_{gd} (respectively λ_{gd} /2) can be measured on the measuring line by simple monitoring of the standing wave ratio (SWR) minimum on the slotted line by successive shortening of the sample. Equation (3) gives unambiguous determination of ε and if the suitable technique is available for the sample length changing, such unambiguous determination of ε is very effective and reliable. If for individual lengths of the sample SWR is measured as well the results can be used for tgδ determination too, appropriately to determine the required thickness of the dielectric slab with carbon admixture.

First we have verified above mentioned method on Plexiglas as a material with the known dielectric constant (from literature: $\varepsilon = 2.2 \div 3.4$) and the obtained values are plotted in Fig. 4.

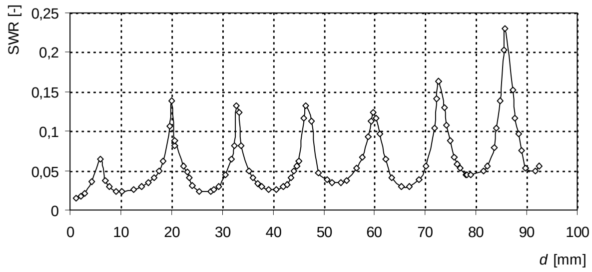

Fig. 4: Dependence of standing wave ratio (SWR) on the sample depth for Plexiglas

From Fig. 4 it is easy to get λ_{gd} and from Eq. (4) to calculate ε. For the measured Plexiglas sample the relative permittivity ε = 2.6.

In the same way chipboard samples with carbon powder admixture were measured at frequency f = 9.97 GHz too. In Fig. 5 there is plotted the dependence of SWR on the length of the sample manufactured from a chipboard containing 10% of carbon powder. From the measured values the wavelength in the sample for frequency 8200 MHz was found out: λ_{gd} = 16.4 mm (λ_0 = 36.6 mm, λ_c = 45 mm).

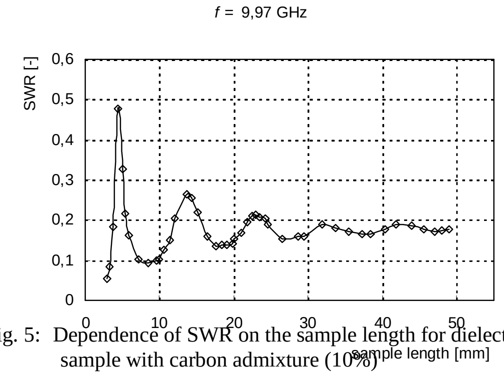

Fig. 5: Dependence of SWR on the sample length for dielectric sample with carbon admixture (10%)

The samples were prepared with different contents of carbon and the purpose of measurement was to find out dielectric constant of individual samples containing 0, 5, 10, 15 per cent of carbon. The measuring results were plotted in accordance with (2) in graphs, Fig. 6, from which λ_{gd} could be read.

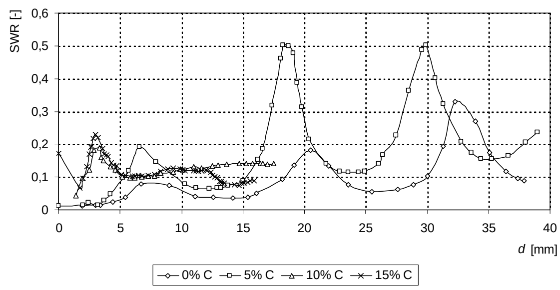

Fig. 6: Dependence of SWR on the sample depth for chipboard samples containing 0, 5, 10, 15 per cent of carbon

It is possible from the results plotted in Fig. 4, Fig. 5 and Fig. 6 to perform the following evaluations:

- the presented method is suitable for medium – loss materials dielectric properties measurement because at high – loss materials the determination of λ_{gd} is difficult,
- the method provides besides though not exact but unambiguous value of ε and if necessary to chose the exact value of ε from different values obtained with another method,
- the method can provide the reliable information about the microwave attenuation at utilization of carbon slabs against microwave signal penetration.

CONCLUSIONS

Practical use of the presented method applied on finding out of dielectric constant of chipboard samples with carbon admixture with the manufacturer intention to influence absorption properties of chipboards in microwave area.

The effect of carbon addition according to obtained results agrees with the chipboards producer conception that is an increase of microwave signal absorption.

This method proved to be reliable help for the first determination of dielectric constant in technical practice, especially for materials containing more admixtures and particularly in cases when other methods give ambiguous results.

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