DIELECTRIC MODELING OF E-GLASS EPOXY COMPOSITE SYSTEM

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Abstract

Polymer matrix composite materials are excellent candidates for applications requiring exact dielectric properties, such as radio wave propagation and remote sensing applications. In this paper analytical method for material dielectric constant and loss tangent prediction is presented. Model is experimentally verified for E-glass fibers embedded in DER 324 epoxy matrix, for 100 KHz frequency.

Introduction

The complex permittivity, ε^*, can be considered as a fundamental parameter for the macroscopic description of a dielectric exposed to the alternating fields. The concept of the effective permittivity, or macroscopic dielectric constant, can be used to describe media that are homogeneous to the extent that scattering effects are insignificant as radio waves penetrate these materials. In radio wave propagation problems and remote sensing applications, the typical geophysical media is composed of materials with different dielectric properties. Using a theoretical approach to asses the effective permittivity of dielectric mixtures requires the calculation of the polarizabilities and dipole moments of the inclusions that compose the mixture. The dipole moments of simple discrete inclusions, like spheres and ellipsoids, can be expressed in closed form and the mixing formula for a two phase mixture can be derived. However, only for dilute suspensions is the mixing rule unique. Given the many degrees of freedom of a random medium for dense mixtures, it is plausible that many rivalling mixing formulas coexist.

Dielectric constant and loss tangent for composite system

A transversely isotropic fiber reinforced material has two principal dielectric constants: In fiber directions designated as εeff-a and normal to the fibers, designated as εeff-T. For fiber reinforced composite materials axial effective permittivity follows the rule of the mixtures and can be expressed as:

$$\varepsilon_{eff-a} = \varepsilon_{1a} \cdot f_1 + \varepsilon_{2a} \cdot f_2 \qquad (1)$$

In preceding equation effective permittivity (in fiber directions) is expressed as a function of axial dielectric properties of constituents which compose the mixture and their respected volume fractions in the composite. Using the composite cylinder assemblage scheme, Hashin [1] derived the formulation for the effective dielectric constant in the direction normal to the fibers. The equation given in the terms of the properties and volume fractions of the constituents is expressed as:

$$\varepsilon_{eff-T} = \varepsilon_1 + \frac{f_2}{\dfrac{1}{\varepsilon_2 - \varepsilon_1} + \dfrac{f_1}{2 \cdot \varepsilon_1}} \qquad (2)$$

Where, index ‘2’ refers to fiber properties and ‘1’ is matrix constituent. Absolute bounds for composite mixtures for statistically isotropic two phase material are given by Wiener [2]. The bounds for effective permittivity of two phase composite model are given as:

$$\frac{1}{\dfrac{f_1}{\varepsilon_1} + \dfrac{f_2}{\varepsilon_2}} \le \varepsilon_{eff} \le f_1 \cdot \varepsilon_1 + f_2 \cdot \varepsilon_2 \qquad (3)$$

Where the bounds for effective dielectric constant are expressed as functions of dielectric constants constituents and their respective volume fractions in composite material.

In order to characterize composite material as dielectric, predictions of the loss tangent are required. For most engineering materials, the loss per cycle is very small fraction of the total energy stored in the dielectric. Using this assumption the effective loss factor as can be as expressed linear combination of the loss factors of constituents that compose the composite material:

$$\varepsilon''_{eff} = \frac{\partial \varepsilon'_{eff}}{\partial \varepsilon'_1} \varepsilon_1 + \frac{\partial \varepsilon'_{eff}}{\partial \varepsilon'_2} \varepsilon_2 \qquad (4)$$

This approach is applicable to low loss materials, that is tan δ << 1. Prager [3] has derived bounds on the derivatives for two phase statistically homogenous and isotropic dielectrics. When applied to low loss dielectrics the bounds can be expressed as:

$$\frac{1}{f_2}\left(\frac{\varepsilon_{eff}-\varepsilon_1^{'}}{\varepsilon_2^{'}-\varepsilon_1^{'}}\right)\leq\frac{\partial\varepsilon_{eff}^{'}}{\partial\varepsilon_2^{'}}\leq\frac{\varepsilon_{eff}}{\varepsilon_2^{'}}-\frac{\varepsilon_1^{'}}{\varepsilon_2^{'}\cdot f_1}\left(\frac{\varepsilon_2^{'}-\varepsilon_{eff}}{\varepsilon_2^{'}-\varepsilon_1^{'}}\right)^2$$

$$\frac{1}{f_1}\left(\frac{\varepsilon_{eff}-\varepsilon_2^{'}}{\varepsilon_1^{'}-\varepsilon_2^{'}}\right)\leq\frac{\partial\varepsilon_{eff}^{'}}{\partial\varepsilon_1^{'}}\leq\frac{\varepsilon_{eff}}{\varepsilon_1^{'}}-\frac{\varepsilon_2^{'}}{\varepsilon_1^{'}\cdot f_2}\left(\frac{\varepsilon_1^{'}-\varepsilon_{eff}}{\varepsilon_1^{'}-\varepsilon_2^{'}}\right)^2 \quad (5)$$

With the bounds on derivatives and dielectric properties on constituents that compose the mixture, bounds on effective losses of composite material can be obtained.

Experiment

Composite material under investigation, with constituent phases is presented in the following picture, Fig 1:

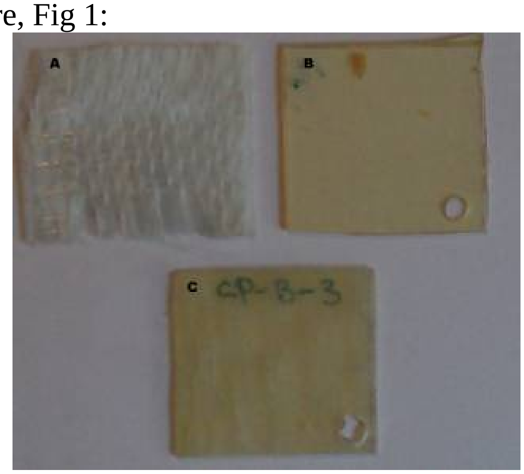

Fig. 1 DER 324/E-glass composite samples

The dimension of the E-glass/epoxy samples before dielectric measurement were 25 x 25 mm and 1.5 mm thick. These samples were subjected to dielectric tests at 100 kHz at room temperature and normal humidity, using the DEA 2970 dielectric analyzer. Dielectric data for constituents was initially obtained using same analyzer. The test results for composite system are presented in the following figure (Fig. 2).

Conclusion

Material dielectric properties can be successfully tailored using different materials having distinct dielectric values. New analytical model based on equations proposed by Prager and Wiener is formulated, and experimentally verified. Dielectric model proposed predicts lower values for dielectric material properties (loss tangent and dielectric constant) for higher fiber volume ratios. For lower fiber volume fractions (below 30% Vf) it is not conclusive which bound yields better results.

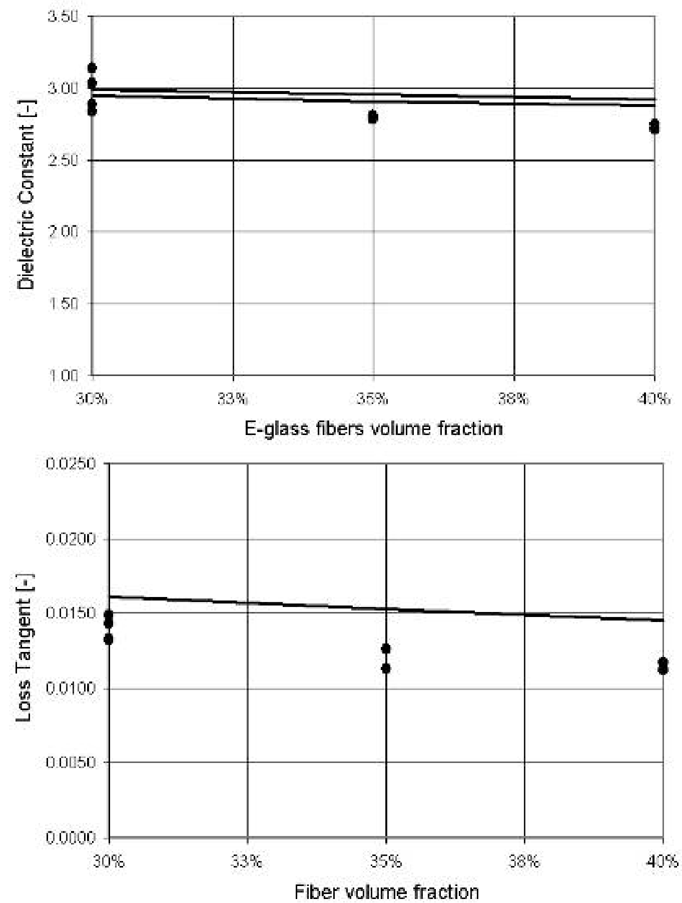

Fig 2. Effective dielectric constant and loss tangent for composite system at 100 KHz

Acknowledgement

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