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On the choice of the dielectric characterization method for foam composite absorber material

Laura Pometcu[a], Chloé Méjean[a], Ratiba Benzerga[a,*], Ala Sharaiha[a], Philippe Pouliguen[b], Claire Le Paven[a]

[a] Institut d'Electronique et de Télécommunications de Rennes, Université de Rennes 1, 22004 Saint-Brieuc, France
[b] Research and Scientific Innovation Department of DGA, 92221 Bagneux, France

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ABSTRACT

This paper presents the characterization by three different techniques of a new lossy material made of carbon fibers loaded epoxy foam that can be used as an absorber in anechoic-chambers. The composite was characterized using free space, waveguide and coaxial probe techniques. Dielectric characteristics obtained from the three techniques are different and this is explained by the required dimensions of measured samples, not always representative of the porous form of the composites loaded with long fibers. Our study points out that the free space technique is the most appropriate to measure such composite samples with porosities and load having millimeter dimensions. Dielectric probe and waveguide are not suitable due to a small volume of measure which is not representative of the entire composite. The achieved prototype confirmed this result with a measured reflection coefficient very close to the simulation achieved with the dielectric characteristics obtained by the free space technique.

1. Introduction

Microwave absorber materials are used extensively in anechoic chambers (AC) to emulate free-space conditions and to suppress unintended radiations of the in-situ electronic equipment [1]. The choice of an absorber material for an AC use is based on its absorption performance, as well as its density and also its cost since a significant amount of materials is necessary to cover the entire surface of the AC. Different associations «polymer» + «carbon filler» are currently studied as absorbers, for example, resins loaded with carbon particles [2], resins loaded with carbon nanotubes [3], polymer foams loaded with carbon nanotubes [4] or resins loaded with carbon fibers [5]. The most used absorber material in AC is the polyurethane (PU) foam loaded with fine carbon particles [6]. Here, we propose to study the dielectric characteristics of an original composite which associates long carbon fibers with epoxy foam. Several studies have been carried out on carbon fibers mixed with epoxy resin [7,8], but, up to now, the density of the resin has limited its use as an absorber in AC. Then, the advantage of the epoxy foam compared to bulk resin is obviously the low density of the produced material, appropriate for its application in AC. In addition, another advantage of the epoxy foam, compared to the PU foam, lies in its high mechanical rigidity [9] which allows a machining under complex form to optimize the absorption performances [10,11].

The characterization of absorbing materials usually shows a decrease of the electromagnetic signal in certain frequency ranges depending on the composition as well as the overall geometry of the measured material. Moreover, available dielectric characterization techniques often present constraints, such as the size of samples needed for the characterization. For example, free space techniques require materials with large dimensions, contrary to coplanar techniques which need very thin samples. On the other hand, the waveguide technique requires samples with precise dimensions that will decrease as the measurement frequency increases. Another constraint is the frequency range of the measurement, sometimes limited, such as in the case of a resonant cavity for which only one frequency is explored, or in the case of a waveguide which works in a very short frequency range. The broadband techniques often need very large samples (several tens of cm^3) that cannot be obtained for all type of materials.

The purpose of the present article is to characterize by three different techniques an absorbing composite made of the association of epoxy foam and carbon fibers. The objective is to find the most suitable technique for this type of "heterogeneous" (i.e. composite) material. Free space, X-band waveguide and

* Corresponding author.
E-mail address: ratiba.benzerga@univ-rennes1.fr (R. Benzerga).

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dielectric probe measurement methods were used. The article is composed as follows: the first part briefly explains the elaboration of the composite samples, the second part details each of the three dielectric characterization techniques, the third part presents and discusses the results of the different measurements and the final part introduces the achievement and the measurement of a prototype, having a commercial geometry, in order to validate the dielectric properties obtained by one or more of the characterization methods.

2. Elaboration of carbon fibers loaded epoxy foams

The carbon fibers used in this study are 3 mm length and 7 μm diameter (provided by Apply Carbon SA). For the composite elaboration, we have used epoxy foam made from commercial epoxy resin and hardener from Sicomin [9]. The elaboration process of our material is described as follows. The chosen weight percentage of carbon fibers (here, between 0 wt.% and 1 wt.%) is added to the epoxy resin and mixed for a few minutes before the hardener agent is added. The latter induces the foaming process and the polymerization reaction of the resin (6 h step). At last, thermal treatment is achieved during 6 h at 60 °C in order to complete the polymerization reaction and to fix the mechanical properties of the foam composite. Finally, the samples are cut to the desired geometry required for the measurements. Here, three techniques, with samples having different sizes, have been used to determine the dielectric properties of the composites.

3. Basic concepts of the characterization methods

3.1. Free space technique

The free space method [12] is a nondestructive technique that can be used in a large frequency band. A schematic of the microwave measurement setup is given in Fig. 1. Two reflection coefficients (S_{11}) of the material are measured, respectively, with and without a metallic ground plane behind the sample. The complex permittivity of the characterized material is extracted from the two measured S_{11} coefficients using the method of *Fenner and al* [13].

For this technique, the dimensions of samples are $15 \times 15 \times 6.5$ cm^3. Two ultra-wideband (UWB) antennas (ETS-Lindgren's Model 3115 Double-ridged Waveguide Horn) of size 24.4 cm x 15.9 cm x 27.9 cm (length x width x depth) are used. The antennas are placed in front of the characterized sample (in order to have a normal incidence of the electromagnetic wave) and are coupled to a Vector Network Analyzer. The distance between sample and antennas is 113 cm. The latter is calculated considering far field (Fraunhofer) conditions (Eq. (1)–(3)) [14] at the lowest measured frequency.

$$R = \frac{2 * D^2}{\lambda} \quad (1)$$

$$R \gg D \quad (2)$$

$$R \gg \lambda \quad (3)$$

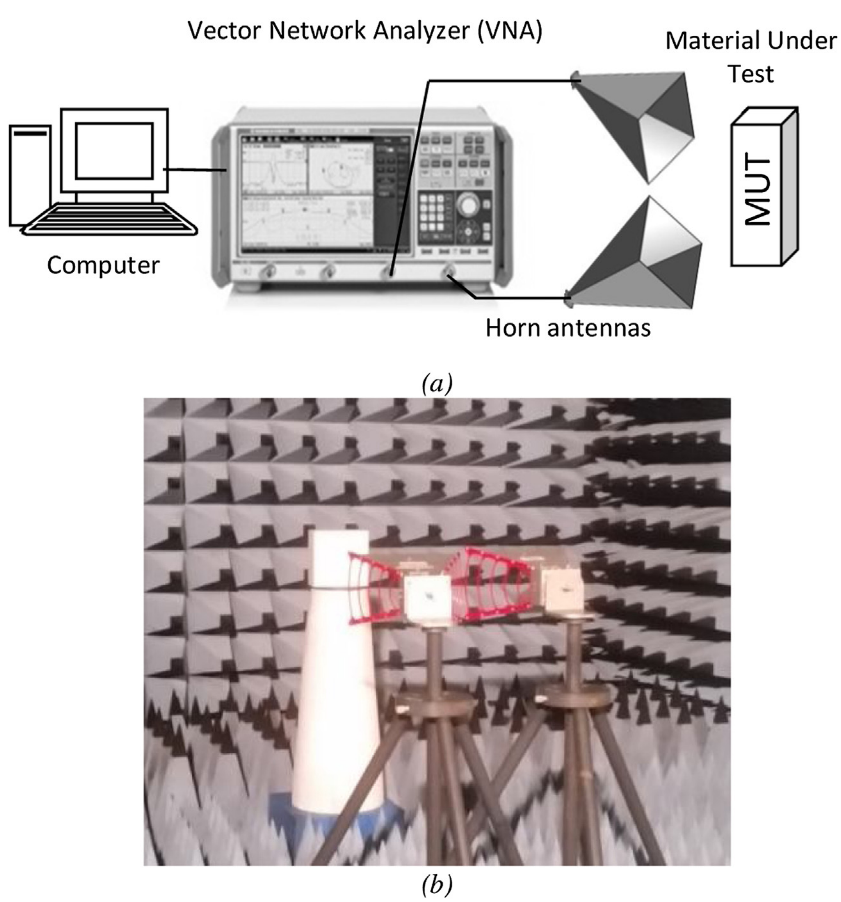

Fig. 1. (a) Schematic system of measurement and (b) Anechoic chamber of Institute of Electronics and Telecommunications of Rennes situated at INSA Rennes, France.