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Electromagnetic absorber composite made of carbon fibers loaded epoxy foam for anechoic chamber application

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ABSTRACT

This paper presents a new electromagnetic absorbing material developed from carbon fibers loaded epoxy foam for an application in anechoic chamber. The composite was developed in order to replace the currently used pyramidal absorbers made of carbon particles loaded polyurethane foam. Epoxy-composites filled with different weight percentages (from 0 wt.% to 4 wt.%) and length (1 and 3 mm) of carbon fibers were achieved. After an optimization of the dispersion of carbon fibers in composite materials, the dielectric properties of the composites were measured using a coaxial-probe in the frequency range 4–18 GHz. Results have shown that the complex permittivity of the composites increases with the amount of charge and also with the length of the carbon fibers. Absorption performance of a prototype prepared with a low concentration (0.5 wt.%) of carbon fibers was measured in an anechoic chamber: it shows a mean gain of 10 dB compared to a commercial absorber.

1. Introduction

Nowadays, the demand about electromagnetic (EM) wave absorbing materials is constantly growing to meet needs in various application areas such as electromagnetic compatibility (reduction of electromagnetic interference) [1–3], stealth technology [4–6] or anechoic chambers [7–9]. In the past decades, there has been tremendous interest in carbon based (graphite, graphene, nanotubes, particles...) absorbing composites thanks to the high electrical conductivity of carbon combined to a relatively low weight and low cost [10–12]. Magnetic based materials have also generated a lot of attention thanks to the combination of magnetic and dielectric losses and have shown good absorption performance at low frequencies (<10^9 Hz) [13] or at microwave frequencies [14,15]. However, magnetic materials are heavy and tend to oxidize, consequently hybrid materials combining magnetic particles and dielectric particles have been also studied [16,17]. To ensure the best electromagnetic absorption in anechoic chambers, pyramidal absorbers are currently made of flexible polyurethane (PU) foams loaded with nano or micrometric conductive carbon black particles [18]. These absorbers show good absorption performance for frequencies between 80 MHz and 40 GHz, depending on the size of the pyramids and carbon black concentration [19]. Their low reflection coefficient is partly due to their pyramidal shape which enables a gradual transition of impedance between the air and the absorber [20]. Furthermore, the polyurethane foam brings lightness to the absorber (for example, density is 66 kg/m^3 for SIEPEL APM12 [19]) which leads to an easy installation in anechoic chambers. The huge amount of air bubbles also leads to low values of the real permittivity (ε') which prevent from a high level of reflection [20]. However, the flexibility of the polyurethane foam doesn't allow the fabrication of complex shapes which are needed to enhance the absorption [21,22]. The process used to impregnate the foam also leads to an inhomogeneous distribution of the conductive particles. In addition, the use of nanoparticles remains today uncertain: these volatile dust particles can be hazardous regarding human health [23].

Here, we present a new absorbing material made of epoxy foam and long carbon fibers, the latter being less hazardous to the health and safety of users than nanoparticles. There has been a strong interest in carbon fibers composites for microwave applications thanks to their high dielectric losses obtained with low fiber concentrations [24]; epoxy resin has been also widely used for microwave absorbers [25–29] but not in the form of foam. Our original approach is to combine the epoxy foam and the carbon fibers to obtain new low weight absorbing composites. This association has several advantages, for example, it allows the addition of the

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carbon fibers to the epoxy foam before the foaming process in order to deeply integrate them into the composite. Being trapped inside the foam, the carbon fibers cannot escape and therefore, it avoids any potential health risk. It has to be noted that with this elaboration technique, the absorber material longevity is also improved. Another advantage of the epoxy foam is its good mechanical (rigidity) properties [30] which allow an easy and reproducible cut needed for the achievement of more complex shapes designed to improve the electromagnetic wave absorption [21,22].

This paper presents an overall study going from the elaboration of the absorbing materials to the achievement and characterization of a prototype. The latter has been machined with the same dimensions as a commercial pyramidal absorber in order to allow the comparison between them. This paper is organized as follows: the next part is devoted to the presentation of the materials and the characterization methods. Then, results concerning the dispersion of fibers in the composite and dielectric characterization are given. In the last part, the absorption performance of the prototype is presented and compared to the commercial absorber.

2. Materials and methods

2.1. Elaboration of composite samples

The composite absorber was elaborated with an epoxy foam made from the commercial PB170 epoxy resin and the DM02 hardener from Sicomin. Carbon fibers, of 7 μm diameter from Apply Carbon, were used as absorbing load. Two lengths of carbon fibers (1 mm and 3 mm) and different weight percentages (between 0 wt.% and 4 wt.% for 1 mm carbon fibers and between 0 wt.% and 1.5 wt.% for 3 mm carbon fibers) were used to achieve the composites. The elaboration process of the composite is simple; first, carbon fibers are mixed with the resin, by means of a helical agitator, for a few minutes before the hardener is added. The latter allows the mixture to warm up (exothermic reaction) which leads to a lower viscosity and a better distribution of the fibers thanks to the ease of mixing thus induced. The hardener allows both the foaming of the epoxy system and its polymerization. Once the foaming step is complete (it takes 5–6 h), the foam is cured in an oven at 60 °C for at least 6 h in order to complete the polymerization. The measured density of the different composites is 140 kg/m^3.

2.2. Dielectric and electromagnetic absorption characterization methods

Two technics were used to characterize the dielectric properties and absorption performance of the composite samples and the prototype. The complex permittivity, (ε^* (Eq. (1))) of samples was obtained between 4 and 18 GHz using an 85070E Agilent coaxial probe (Fig. 1a) linked to an 8510C Agilent vector network analyzer. The dielectric losses (tanδ) of the samples were calculated using the real and imaginary parts of the measured complex permittivity (Eqs. (1) and (2)). For this characterization, samples have to display a thickness of at least 2 cm and a surface having at least 2 × 2 cm^2 dimensions to be fully covered by the probe. The surface has to be as flat as possible to avoid any air gap between the probe and the sample which would underestimate the properties of the measured material. Eight measurements were run for each sample; the mean value is further presented in this paper.

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \quad (1)$$

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \quad (2)$$

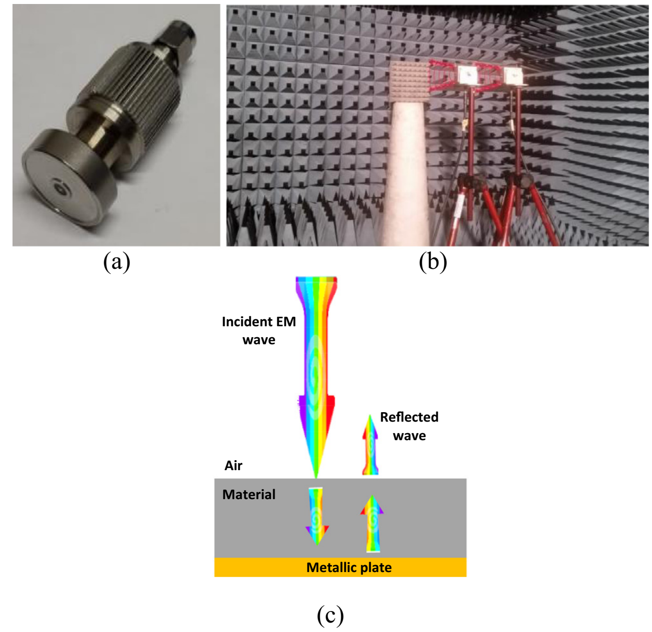

Fig. 1. The two used characterization methods: (a) coaxial probe, (b) photo of anechoic chamber and (c) reflection mode configuration for anechoic chamber measurement at normal incidence.

where ε' and ε'' are, respectively, the real and the imaginary parts of the complex permittivity ε^*, and tanδ, the dielectric losses of the material.

The reflection coefficient S_{11} (in decibel dB) was measured in an anechoic chamber (Fig. 1b) for the composite samples and the prototype, for frequencies varying from 4 GHz to 18 GHz. For this measurement, and as explained in [31], the sample is placed in front of two horn antennas linked to a 4 ports PNA-L Agilent vector network analyzer; the horn antennas are Q-par WBH2-18SHG Model. The calibration is carried out before the measurements of the prototypes in order to subtract all signals due to the chamber, antennas or other residual perturbations. The distance R between the sample and the antennas is calculated considering far field (Fraunhofer) conditions (Eq. (3)) [18] at the lowest measured frequency:

$$R = \frac{2^* D^2}{\lambda} \quad (3)$$

with $R \gg D$ and $R \gg \lambda$

where D is the antenna aperture and λ the highest measured wavelength.

For the anechoic chamber characterization, the composite sample (or the prototype) is measured in the same configuration as that used for the targeted application. In fact, all the pyramidal absorbers installed in an anechoic chamber are backed by a metallic plate so that the electromagnetic waves are not transmitted beyond the measuring chamber. For this reason, the measurement of the reflection coefficient S_{11} in the anechoic chamber was done on the composite or prototype backed by a metallic plate. The measured reflection parameter S_{11} is the result of the EM wave reflected at the interface air/material and also the EM wave transmitted through the material but reflected on the back metallic plate and therefore partially (because of the absorption of the material) transmitted again through the material towards the horn antennas (Fig. 1c). It should be noted here that for an optimal absorber material, both the reflection of the EM wave at the interface air/material and the transmission of the wave through the material have to be minimized, therefore the absorption inside the material has to be maximized.