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Temperature, atomic oxygen and outgassing effects on dielectric parameters and electrical properties of nanostructured composite carbon-based materials

Davide Micheli, Carmelo Apollo*, Roberto Pastore, Ramon Bueno Morles, Plinio Coluzzi, Mario Marchetti

"Sapienza" University of Rome, Scuola di Ingegneria Aerospaziale, via Salaria 851, 00138 Roma, Italy

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ABSTRACT

This work deals with the dielectric properties of carbon-based nanostructured polymeric composite materials. A commercial epoxy matrix is currently filled with multiwalled carbon nanotubes in different percentages, and final composite material characterized in terms of microwave behavior by means of the waveguide method. By following the guidelines of previous studies, the attention is focused on the changes induced by hard environmental conditions (high temperature in ultra-high vacuum system) on the above mentioned properties. The results obtained in this preliminary research have outlined the intriguing properties of carbon nanostructures, establishing themselves as very promising materials for the future aerospace composite technology.

1. Introduction

In some current aerospace applications new nanostructured composite carbon-based materials are proposed in order to substitute traditional metal-based parts. Mainly due to their lightweight such composites are ultimately becoming more interesting as electric conductive polymers too. Electric conductive polymers have been receiving great attention upon comparison with conventional metal-based materials, because of their lightweight, resistance to corrosion, flexibility and processing advantages [1]. Some electric conductive polymer applications consist of potential discharge for systems, electrical grounding of systems and direct and indirect lightning strike protection. The introduction of carbon nanoparticles into Resin Transfer Molding (RTM) polymeric matrix for Carbon Fiber Reinforced Polymer (CFRP) components offers several specific improvements in terms composites electrical conductivity [2] and mechanical properties. Aim of the present work is to analyze the effect of the low orbit space environment on the electromagnetic properties of such nanostructured carbon-based composite materials.

In Low Earth Orbits (LEO), i.e. around 350–2000 km, the space environment is quite aggressive thus it can hardly affects the smooth functioning of materials and devices. In particular, temperature gradient between night and day, atomic oxygen, and outgassing phenomena are the main causes of materials degradation [3]. Electric conductive polymer conductivity and microwave absorbing properties are affected by space environment conditions too. This paper focuses on the dependence of carbon nanocomposite material relative permittivity on the space environment conditions [4].

Permittivity is a complex quantity describing the interaction between materials and electromagnetic fields.

* Corresponding author.
E-mail address: apollo.emanuele@gmail.com (C. Apollo).

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Accordingly, an increasing imaginary part of permittivity can be ascribed to the enhanced electrical conductivity of the composite, giving rise to electric losses too. In the present study, multi-walled carbon nanotubes (MWCNT) are employed as conductive fillers: they are first uniformly dispersed in an epoxy resin at different weight percentages by adopting improved mixing techniques, then transmission line measurement methods like waveguide measurements are performed to recover the dielectric properties of the carbon-based nanocomposite materials [5–7].

A commercial epoxy resin filled with MWCNT at 0.5, 2 and 2.5 wt% have been characterized in terms of dielectric permittivity and conductivity before and after a typical thermal–vacuum treatment: the results obtained are very interesting in the view of a possible wide employment of such materials in space and aerospace industry. Furthermore, all the samples have been analyzed in terms of erosion resistance after atomic oxygen treatment.

2. Experimental set-up

2.1. Microwave characterization

In our analysis the microwave lossy materials have been characterized in terms of the electrical permittivity, which describes the interaction of a material with an electric field and in general is a complex quantity ($e_r = e' - je''$). According to the theory of complex permittivity, when an electromagnetic field propagates within a dielectric material, the electric field induces two types of electrical effects, i.e. the conduction and the displacement currents. The effect arising from free electrons (conduction current) gives rise to power losses, which are related to the imaginary part of permittivity (e''); the interaction with bound charges (displacement current) induces polarization effects, which are described by the real part of permittivity (e'). Therefore, an increase of the real part of the complex permittivity can be mainly ascribed to dielectric relaxation and space charge polarization effects, whereas an increase of the imaginary part of the complex permittivity can be attributed to the enhanced electrical conductivity of the material [7].

In order to measure the microwave properties of the composite materials a Vector Network Analyzer (VNA) type-N5230C (Agilent PNA-L, 10 MHz–20 GHz, see Fig. 1) and the waveguide measurement method over the frequency band from 4 GHz up to 18 GHz (see Fig. 2) was adopted. First microwave scattering parameters (S_{ij}, i,j = 1,2) are measured: these quantities connect the circuit input and output by using the reflection and transmission parameters usually adopted in microwave analysis of devices. By means of such parameters it is possible to determine the real and the imaginary part of the electrical permittivity, which in turn can be used in order to compute the microwave electrical conductivity [7,8].

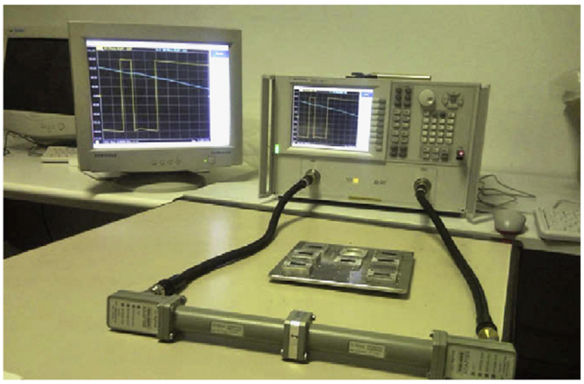

Fig. 1. The Agilent N5230C VNA and one of the microwave probes utilized for dielectric properties measurements.

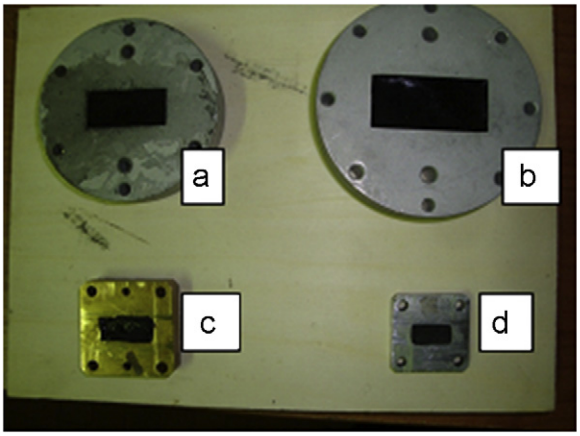

Fig. 2. Sample holders for microwave measurements over different frequency ranges: (a) 4 ÷ 6 GHz, (b) 6 ÷ 8 GHz, (c) 8 ÷ 12 GHz and (d) 12 ÷ 18 GHz.

Fig. 3. Outgassing Test Facility.