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ABSTRACT (ENGLISH VERSION)

Tesi di Dottorato

Electromagnetic Characterization and Modeling of CNT-based Composites for Industrial Applications

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In several applications for the aeronautic, automotive and electronic industries, there is an increasing demand of structural nanocomposites exhibiting remarkable thermal and mechanical properties and, at the same time, tailored and controlled electromagnetic (EM) performances.

The interest and the scientific importance of the topic is justified by the fact that the conventional materials do not have the suitable properties to satisfy the specific requirements for modern applications. Instead, two or more distinct materials may be combined to form a material which possesses superior properties, with respect to those of individual components.

Thus the individuation and preparation of advanced composites with best features respect to the traditional materials is currently required in several industrial sectors.

Since CNTs can be exploited with varying structural and physical properties, geometry and functionality, that result in a different dispersion and adhesion with the polymer matrix, the possible range of composite material properties can be very large.

For these reasons the experimental work of electromagnetic characterization and numerical modeling of such innovative composites are currently object of a fervent interest in science and technology.

The research activity has been focused on experimental and modeling aspects in order to attain the optimization of the analyzed nanocomposites by means of the correlation among the electromagnetic characteristics and morphological properties.

The experimental efforts have been done on bi-phase composites (epoxy resin/CNT) and on multi-phase ones (epoxy resin/CNT/clay). Indeed, it can be conjectured that the presence of an insulating lamellar phase (clay) yields to a CNT agglomeration and entanglement more difficult. So, epoxy resin samples with different MWCNTs and an additional filler (HT, Hydrotalcite) concentrations were analyzed.

Due to these possible different amounts of HT or CNT the composites can exhibit different performance based on these values.

Therefore, we have tried, with this activity, to improve the properties of the composites. In particular, the objective is to find the right combination of these parameters to achieve the enhancement of the electrical conductivity of such multi-phase systems.

This problem is classically tackled by means of a “trial and error” approach that requires a large number of produced samples, increasing so the costs and the material deployment time. Instead, goal of this work is to propose a theoretical approach to face this problem, leading to the individuation of the most influencing parameters and their best combination for optimizing the electrical conductivity. The approach of Design of Experiments (DoE) is adopted in order to reach this purpose.

The adoption of this approach, in the experimental field, aims to "ad hoc design" of the material. In fact, until now, the composite is first created and then characterized to determine its performance.

Instead the research efforts aim to predict the performance of the composite through an accurate theoretical study and subsequently to request the production of the composite, with the identified specifications, to have an experimental confirmation.

The results are really interesting because it is experimentally confirmed that there is a suitable concentration for the clay, as predicted, that must be used for the production of a composite so that it can presents the highest conductivity.

This can give the possibility of having a tailored material as well as build systems with controlled and reproducible properties.

In order to analyze such properties and design components based on nanocomposites with improved performances the experimental electromagnetic characterization of the composites has to be complemented with suitable models able to correlate structural and electrical characteristics.

In fact, a complete understanding of the relations linking the electrical properties with the geometrical and physical characteristics of the composite and the topological structures formed is still to be achieved.

Therefore, additional efforts aimed at providing further information on the dependencies among electrical characteristics and the above mentioned parameters seems valuable.

One possible approach to overcome such gap is trying to correlate the results of experimental investigations with predictions obtained by suitable numerical models.

For this reason, in this research activity, a structure mimicking a polymeric nanocomposite loaded with carbon nanotubes (CNTs) as conductive filler, is simulated by considering, in a three-dimensional space, a random distribution of impenetrable conducting cylinders inside an insulating cubic matrix.

The variation of the electrical conductivity of the obtained structure for different volume loadings of the conducting phase is estimated through a 3D resistor network.

The tunneling effect between conducting clusters which is deemed responsible of the global conductivity is taken into account. By using a Monte Carlo method, the electrical conductivity and the percolation thresholds of the obtained structures are analyzed as a function of geometrical and physical influencing parameters.

Unlike the models available in the literature, the proposed model allows to conduct studies in AC by means of an appropriate 3D network of capacitors. Therefore, by using the RC model is possible to have a wide range of information about the behavior of the system in the frequency domain.

The numerical analysis has been conducted to investigate the effects of processing parameters and material properties on the electromagnetic behavior of the CNT based-composite, deriving useful hints for their optimization.