Dynamic performance of self-sensing epoxy resin for aerospace structures

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Abstract. To meet the demand, especially of the aerospace field, of more and more advanced materials, more intense studies are being carried out on carbon-fiber reinforced composite materials. CNTs reinforcements allow for modulating the characteristics of a polymer matrix composite making it also suitable for more extreme operating conditions and resistant to environmental damage. The advantages of carbon nanotube reinforcement are many. They allow to improve the mechanical characteristics of the composite. The most relevant aspect, however, lies in the electrical properties that make these composites suitable for the design of self-sensing materials. In other words, composite materials reinforced with CNTs are used as sensors as well as structural materials and this is a highly sought after goal in recent times. Electrical techniques are the non-destructive way to monitor damage in composites subjected to static and dynamic loads. However, this approach is not applicable to composites where the fibers are non-conductive, such as glass and aramid fibers. Damage detection through conductivity measurements offers many advantages when compared to traditional glass fiber optic sensors. In fact, because of their high cost, it is not possible to create a dense network of these fibers to inspect large parts of the composite and especially if the damage spreads in the material without crossing the fiber could also not be detected. Therefore, the reinforcement with carbon nanotubes is the best way to go under the many aspects described. As part of an intensive research activity aimed at studying the performance of innovative smart resins, the authors will show in this article the outcomes related to some of their dynamic properties.

Keywords: Aviation, Carbon nanotubes, Composite, Damping, Smart Structures.

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INTRODUCTION

During these years, the need for high-performance material properties, such as lightness, stiffness, damping and taking up a minimal amount of space, has greatly increased thanks to continuous technological research. Especially in the aerospace field, working with materials that are stiff, with high-damping capacity, anti-corrosive, sensorized and, above all, lightweight, is one of the most sought-after purpose. Therefore, this has led to investments in research of new generation materials, especially multi-layered and multifunctional composite materials, which, with the addition of nanoparticles in their composition, gain those sought-after capacities. So, "self-sensing" materials can be produced: the materials actually become sensors themselves without using external devices, embedded or attached. This work starts with a general study of these new generation materials, focusing on the applications in many work fields, such as aerospace engineering. The authors have investigated the piezoresistive capacities of nano-filled resins. The development of a multifunctional composite material represents both a scientific and technological challenge towards the realization of "intelligent" aeronautical structures, capable of detecting external variations, minimizing the invasiveness of the sensors. In this context, the possibility of extra-damping of vibrational energy is certainly another fundamental point for adaptive aerospace structures. Above all, since composite materials generally do not have high dissipative capacities. The damping of an innovative bi-phase resin has been therefore investigated in the present activity analyzing it at coupons level.

MATERIAL AND METHODS

Epoxy resins have been widely used for coatings, electronic materials, adhesives, and matrices for fiber-reinforced composites due to their outstanding mechanical properties ranging from extreme flexibility to high strength and hardness, high adhesion strength, good heat resistance, and high electrical resistance. The specimen used for our experimental tests consists of a composite material formed by an epoxy resin matrix and carbon nanotubes which play the reinforcement role and which, as mentioned above, are capable of modifying the insulating behavior of the resin once the electrical percolation threshold. We have made it clear that CNTs are materials with high electrical, thermal and mechanical characteristics due to their bonding structure. Epoxy resins are reactive monomers, which are generally mixed with amine in order to obtain thermosetting polymers. The result is a resin characterized by a relatively high rigidity and glass transition temperature (Tg). On the other hand, however, they are very fragile materials especially when compared to modern thermoplastics. Hence the need to modify the matrix through the insertion of an elastomeric phase. The effects of the inclusion of an elastomeric phase in the epoxy resin were evaluated by analyzing compositions with different concentrations of elastomers. In particular, the composite mixture consists of tetraglycidylmethylenedianiline (TGMDA), 1-4 epoxy butyedioldiglycidylether reactive monomer (BDE) acting as a reactive diluent, 4,4-diaminodifenilsulfone (DDS) which acts as a curing agent and butadiene acrylonitrile elastomeric copolymer at terminations. Carboxyl (CTBAC), to which multiple-wall carbon nanotubes have been added. The tests were performed on EPC samples, where EPC refers to the mixture of components: TGMDA, BDE, CTBAC and DDS, which have different concentrations of the elastomeric phase:

- 0 phr of CTBAC (EPC0 sample);
- 12.5 phr of CTBAC (EPC12.5 sample);
- 25 phr of CTBAC (EPC25 sample).

The data obtained from the shear strength test are shown below in figure 1. The figure shows an improvement in terms of shear strength with an increase in the amount of elastomers.

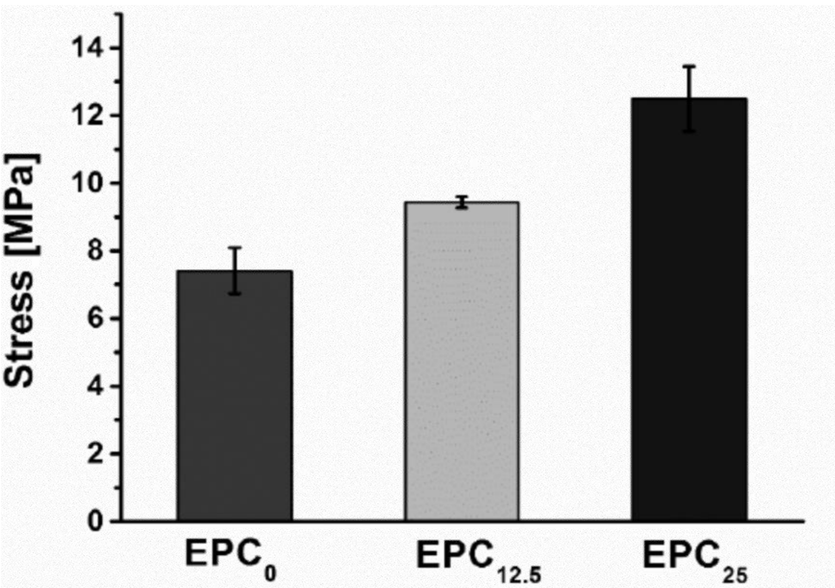


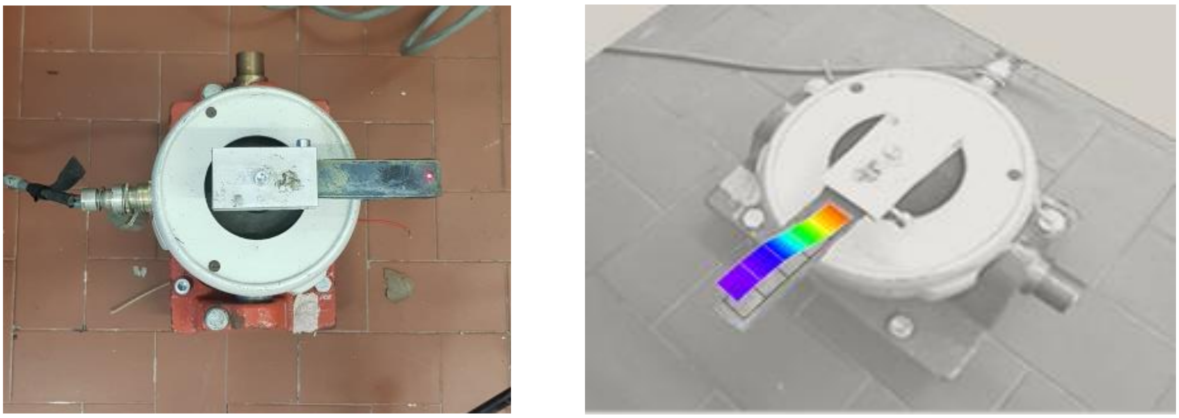
FIGURE 1. Shear resistance of the samples characterized by different CTBAC concentration.

TEST RESULTS

The test specimen used for the tests carried out in the laboratory and discussed below consists of an elastomeric composite material. The manufacturing result is an advanced material: resistant, flexible and with good electrical properties that can be suitably modulated by the concentration of MWNTs. A specimen with dimensions of 10 × 2.5 cm and a thickness of 2.5 mm was subjected to vibration tests to evaluate its behavior under various operating conditions. Damping the response of a structural component to dynamic actions is essential for optimal design that aims at reliability and reduction of management and production costs. The test instrumentation used in the laboratory is a PSV400 scanning laser vibrometer produced by the Polytec Company, which includes the following hardware elements:

- Unit of connection between all the systems that provides the interfaces for all the peripherals;
- Generator of an analogue voltage signal proportional to the measured speed;
- Optical head;

Furthermore, the use of a workstation for data acquisition, storage and analysis is essential. The damping values, measured both in the temporal and spectral domain, are close to 3%, therefore much higher than what is observed in traditional composite materials. The combination of the elastomeric phase with the addition of carbon nanotubes increases the dissipative phenomena within the resin, so that the damping of the material increases globally.



(a) Laser beam on the sample (b) First operating deflection shape

FIGURE 2. Dynamic test: set-up and results.

CONCLUSIONS AND FURTHER ACTIVITES

An adaptive structure is a system capable of perceiving changes in its own "state", in the environment in which it works. The frontiers in this sense are really wide and the scientific community is still involved in various problems aimed at improving their performance. Thinking of the aeronautics sector, there is more and more the need to meet different design requirements that regulate the life of each component. In this challenging context, the realization of innovative materials capable of being "multi-functional" is undoubtedly a viable cutting edge solution. The electrical properties that give carbon nanotubes to a composite material are very interesting and are used for structural health monitoring systems other than traditional ones. In order to investigate this concept, the piezoresisitive response of a MWCNTs epoxy resin has been already assessed by the authors. The sample was submitted to the tensile test to evaluate the variation of the electrical resistance according to the deformations that the material has undergone. Based on the satisfactory results obtained, a feasibility study aimed at introducing an elastomeric phase into the resin has been carried out and discussed in this paper. The properties of the resin are therefore improved by increasing the stiffness provided by the carbon nanotubes and by the flexibility linked to the elastomeric phase. Through the laser scanning vibrometry, the damping capacity of the specimen has been assessed following vibrational loads. The results, even in this case encouraging, motivates the research towards future developments aimed at characterizing the piezoresistive behavior with respect to the elastomer embedded in the epoxy matrix.

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