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Smart coatings of epoxy based CNTs designed to meet practical expectations in aeronautics

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ABSTRACT

A smart coating exhibiting self-diagnostic capability is designed to meet industrial requirements in aeronautics. The coating made of epoxy-based carbon nanotubes (CNTs) has been applied on industrial Carbon Fiber Reinforced Plastics (CFRPs) currently employed in aeronautics. The correlations between mechanical strain and electrical properties of coated CFRPs highlights the feasibility in manufacturing CFRPs having integrated high sensitivity in providing an effective real-time structural health monitoring. The reliability of the developed CFRPs, in the normal operational temperature range of aircrafts, opens new perspectives in the field of self-responsive structures in aeronautics. Self-responsive panels can simultaneously act as sensor and structural element.

1. Introduction

Among the family of ultra-light structural materials, polymer-based composite materials have been introduced massively in the recent years in aeronautical applications and other fields like civil, automotive, aeolian engineering, etc. Recently, the two world leaders in the manufacture of aircraft, i.e. Boeing and Airbus, have placed on the market the 787 and A350 airbuses respectively, where the presence of composite material exceeds 50% of the airframe. An objective in technological innovations is the maintenance of highly reliable and safe transportation systems. Since the complexity of components and systems increases and the vulnerability of non-metallic materials to environmental hazards such as rain, storms, turbulence, icing, lightning, fog, volcanic ash, wind speed, wind direction, wind variation, or the like, needs of frequent time-consuming controls, the development of new advanced methodologies for real-time structural health monitoring is one of the hottest topics in the field of aircraft design. The development of innovative Non-Destructive Testing (NDT) techniques consisting in the appropriate design of self-responsive resin (and/or in coatings for airframe components) for the investigation of crack initiation, fatigue discontinuities, different types of defects etc. can provide a substantial breakthrough to the problem. Such self-responsive resin can simultaneously act as structural element and sensor. Recent developments in sensing technology have attractive potential for resolving numerous issues related to aircraft diagnostics in order to extend the life of structures with an overall safety improvement. The goals of any structural damage monitoring and assessment system are to ensure reliability and safety and to minimize life-cycle cost of the structures. Damage assessment has applications in the majority of engineering structures and mechanical systems ranging from aerospace systems to equipment manufacturing. As a result, a multitude of different approaches appears in the literature to address the problem of damage issues. Non-Destructive Testing (NDT) have been developed mainly for enhanced safety in the aeronautical industry for the detection, location and characterization of damage in composite materials. The state-of-the-art NDT techniques for composite materials can be found in Refs. [1,2] and the main ones are as follows: visual inspection, optical methods, eddy-current ultrasonic inspection, acoustic emission; vibration analysis, radiography and thermography. The design of a Structural Health Monitoring (SHM) systems implies the implementation of a damage detection strategy around a structure, i.e. a strategy whose main goal is to detect any changes in the geometrical or material properties of a structure or its boundary conditions. A new possible approach in order to have a SHM system consists in the development of polymeric materials filled with conductive nanofillers such as carbon nanotubes (CNTs) or other carbon nanostructured forms or magnetic

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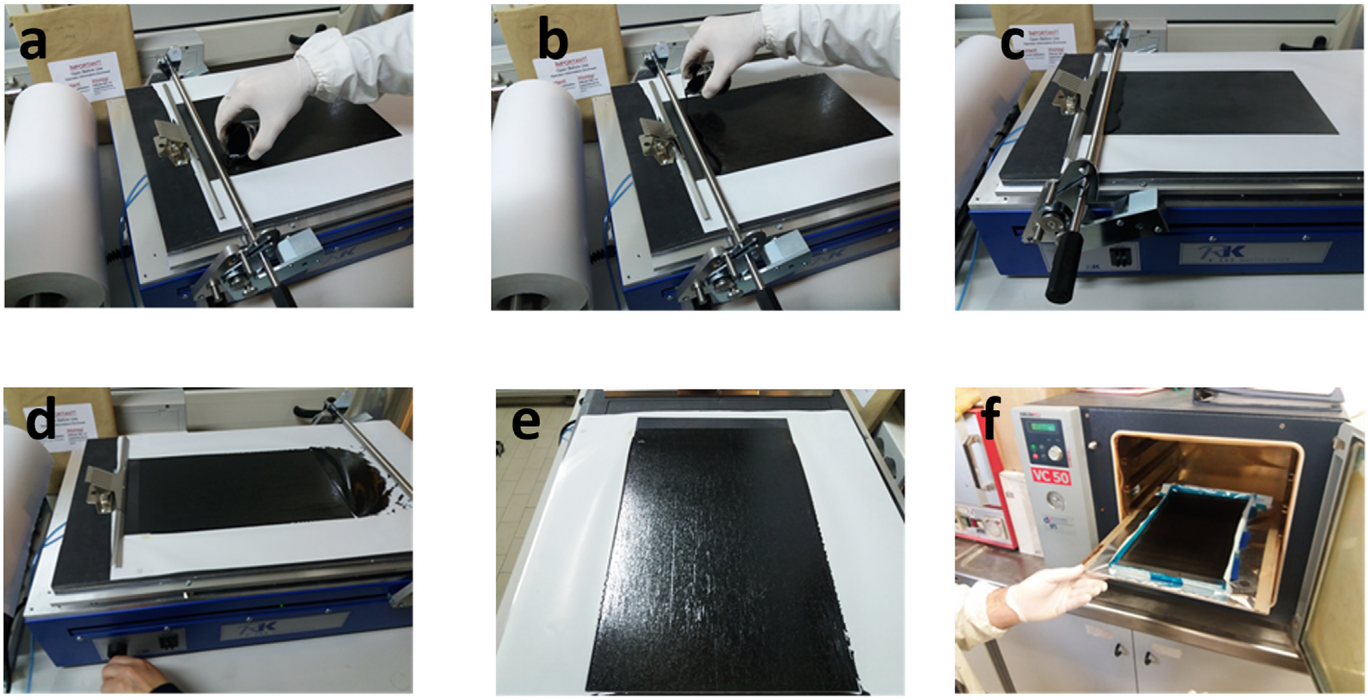

Fig. 1. Illustration of the fabrication process of coated CFRP specimen.

nanoparticles characterized by interesting properties suitable in the field of sensing devices. Electrical techniques are non-invasive way to monitor damage in carbon-fiber-reinforced composites under static or dynamic loading conditions [3–6]. This approach is not applicable to composites where fibers are non-conducting (such as glass or aramid fibers). This problem has been overcome with the use of multi-walled nanotubes dispersed in the epoxy phase to design a distributed sensors able to evaluate the onset and evolution of damage in advanced fibrous composites [7]. The damage detection in composite parts by matrix conductivity measurements offers several advantages compared to traditional optical fibre sensors. For instance, due to their elevated cost it is not possible to apply a dense network of optical glass fibres to large composite components. Another reason is that if a crack is propagating without crossing one of the sensors, the damage would not be detected. Finally, in some cases, the optical fibres may also be a source of damage initiation when inserted in composite parts [8,9]. Thanks to their low density and their good adhesive and mechanical properties, epoxy resins are the most diffuse matrices for structural composites. In this work, starting from the optimized carbon-nanotubes-epoxy nanocomposite already developed by our group [10], the piezoresistive behaviour of an epoxy–CNT nanocomposite has been studied on its application as a strain sensor in a carbon fiber reinforced composite subjected to tensile loads. For this reason, the epoxy components mixture has been used as a conductive coating that can be easily poured and cured onto the surface of the composite for strain and damage sensing purposes. Subsequently, the electrical resistance change, due to the piezoresistive nature of the film coating, as a function of composite deformation has been studied.

2. Experimental

2.1. Materials

The epoxy resins diglycidyl ether of bisphenol A (DGEBA), the hardener 4,4 diaminodiphenylsulfone (DDS) were supplied by Aldrich Chemicals. Multi-walled carbon nanotubes, 3100 Grade, (MWCNTs) are been obtained from Nanocyl S.A. The morphological characterization of the MWCNTs has been carried out by high resolution transmission electron microscopy (HR-TEM). Most of MWCNTs show an outer diameter from 10 to 30 nm, but also an outer diameter lower than 10 nm or larger than 80 nm has been observed. Nanotubes length is from hundreds of nm to few mm. Number of walls, varies from 4 to 20 in most nanotubes [10]. The weight ratio between epoxy precursor and DDS was 10/2.85; they have been mixed at 120 °C and the MWCNTs filler (0.1% by weight) was added and dispersed with high power ultrasonic probe (Hielscher model UP200S-24 kHz) for 20 min.

2.2. Sample preparation and testing

The specimens analyzed in this work have been obtained following a well-defined procedure described in previous papers [11,12]. Fiber-reinforced composite parts have been cut into flat coupons 20 cm × 35 cm with a nominal thickness of 1.15 mm. A diamond tip water-cooled saw blade has been used. The surface of Carbon Fiber Reinforced Plastics (CFRP) parts has been treated by sandblasting in order to increase the roughness of the surface for a greater adhesion of the conductive coating to the laminate. Subsequently they have been cleaned and dried prior to coat them.

In order to obtain a uniform conductive resin coating on the panels produced, a “K303 MULTICOATER” of the RK Printcoat Instrument has been used, i.e. a surface coating applicator. The panel has been deposited on the multicoater and clamped by means of a vice (see Fig. 1a) in order to avoid movements during the covering. After the clamping, the appropriate head has been applied. Subsequently the mixture loaded with the carbon nanotubes has been deposited along the head and finally the movement of the head at programmed speed (1 mm/min) has been activated (see Fig. 1 b,c,d,e). Finally, the laminate, with the conductive coating, has undergone a curing cycle of 1 h at 150 °C and 3 h at 220 °C (see Fig. 1f). The carried-out process step allowed to have a coating thickness of about 150 μm. Different from conventional SHM systems, these multifunctional composites can be applied with successful on various surface giving rise to an innovative solution for monitoring structural deformation and damage directly measuring electrical resistance change, due to the piezoresistive properties of the developed coating, without require further additional sensors. For this purpose, suitable electrical contacts have been deposited on the panel