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Strategies on implementing a potential self-healing functionality in a composite structure

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Abstract

Deteriorations generated in service can cause catastrophic failure at the specific properties of the polymer composite materials. In view of this, scientists have drawn inspirations by natural biological systems and their unique ability to heal an external wound, to develop a similar repair system within a material. Carbon and glass fiber reinforced polymers were manufactured following the wet lay up or the prepreg process. Microcapsules at contents, 5% or 10% by weight, vascular networks from wax and steel wires and finally reversible polymers were implemented within a composite as a potential self-healing system. Inspection techniques, including Ultrasonic C-Scan and Infrared Thermography, were applied, where possible. Optical microscopy revealed the disruption of the composite structural integrity, regarding the observed ply waviness and the resin reach zones around the vascular structures. Three point bending experiments determined the knock down factor, expressed as a decrease on flexural strength and modulus values, for each case, compared to the reference material. The reduction ranged from 12%-64% depending mainly not only to the selected manufacturing method but also to the different implemented healing system.

Keywords: Composites; self-healing functionality; implementation strategies; knock down factor.

1. Introduction

The use of composite materials has grown rapidly since their introduction in a variety of application fields, one of which is the aerospace industry. However, besides their exponential growth, polymer composites are susceptible to damage in the form of micro cracking and delamination generated mostly during their service. Regardless of the application, once cracks are developed, the overall mechanical performance of the composite structure is compromised and the damage evolution can be fatal. Riefsnider et al. [1] predicted the degradation in tensile strength and fatigue life of fiber reinforced composites due to the redistribution of loads caused by matrix damage. Chamis et al. [2] and Wilson et al. [3] worked in the same direction for defining how the matrix cracking affects the compressive strength of the composite structure. Jang et al. [4] and more extensively Morton et al. [5] studied the behavior of polymer composites and concluded that matrix cracking is responsible for the delamination and subsequent the fiber fracture. It is conceivable that degradation, damage and finally failure of the materials are natural consequences due to their exposure to harsh operation conditions. In light of the aforementioned issues, scientists developed several conventional techniques like welding [6], patching [7], and in situ curing of new resins [8], which were adopted by industries in order to repair visible or detectable damages in polymer matrix composite structures. However, these methods are applied once

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the damage has been detected either by the naked eye or other non-destructive techniques which are time consuming and quite costly processes. Additionally invisible micro cracks developed during service life are not taken into account as they are barely detected.

In view of this, researchers were inspired by the biological systems in nature, which are able to repair themselves and recover their functionality using their inherently available resources. This idea triggered an entire new field of research. Different techniques were developed according to the mechanism in which the healing system is implemented. In the case of extrinsic self-healing the healing agent is stored and incorporated within the material in advance. On the contrary, the intrinsic self-healing polymers are based on the specific molecular structures which under certain stimulation (mostly heating and pressure) enable crack healing. From the early 1990s Dry et al. [9] investigated the development of a smart polymer composite, which had the ability to self-repair internal micro cracks by a vascular type healing system. C.J Norris et al. [10] described very detailed the design considerations for a successful vascular network implementation in a carbon fiber reinforced laminate. Ideally this process could be achieved with the minimal disruption in the material structural integrity. Later, White et al. [11] further promoted the concept of extrinsic self-healing by introducing an autonomic healing in polymer composites. The study proposed a system in which the healing agent was encapsulated and incorporated within the material. Upon crack intrusion, the healing agent was released, triggered by the contact with an embedded catalyst, polymerized and finally healed the damaged area. Jud et al. [12] studied the copolymerization degree on the crack healing behavior of PolyMethylmethacrylate (PMMA). The healing time, temperature and the clamping pressure were investigated for better properties recovery.

The scope of the present work is the investigation of the handling and processing difficulties arising from the incorporation of the different self-healing technologies, during FRPs manufacturing (Table 1). Capsules and vascular network approached the extrinsic self-healing strategy. In case 1, PMMA microcapsules were used as potential self-healing carriers (Fig. 1a). Two different wire materials (wax and steel) were tested in case 2 (Fig. 1b), for their suitability for the vascular formation. Finally, the intrinsic self-healing technology was approached via the incorporation of reversible thermoplastic particles (Figure 1c). The current case was also investigated by combining modified Nylon with Multiwall Carbon Nanotubes (MWCNTs). The composite geometric distortion caused by the potential self-healing materials incorporation was considered. Furthermore, the knock down factor as a result of the healing system implementation was determined under three point bending loading conditions

2. Manufacturing

2.1. Materials selection

The primary materials used for the present study were SIGRAFIL unidirectional carbon fiber prepreg (150g/m^2), purchased from SGL group, Germany, and woven glass and carbon fabric (280g/m^2) supplied by R&G, Germany. Table 1 presents in details the manufacturing method for each case study (Fig. 1).

In wet layup technique, the matrix material was a two part epoxy system supplied by R&G consisting of an epoxy resin (L) and a hardener (EPH 161).

Empty microcapsules with an approximately diameter of 50 μm, provided by TECNALIA, Spain, were incorporated within the matrix material for case study 1 in contents of 5% and 10% by weight.

Vascular network in case 2 were formed from wax wires having diameters of 0.9 and 1.4 mm, supplied by Chryssotechniki, Greece and steel wires commercially available at 0.9 mm diameter size.

Two different thermoplastic materials were used for providing intrinsic healing functionality to the epoxy composites. Polyethylene Terephthalate (PET) was supplied by NGP, Greece, in pellet form. It was transformed to sub-micro-particles using a powdering machine into Nitrogen.

Doped nylon (Copolyamide) Griltex D 1330A, with 10% wt. Multi Walled Carbon Nanotubes (MWCNTs), was supplied by Nanocyl, Belgium, in the form of powder of sub-micron size.

2.2. Composite manufacture

Unidirectional carbon fiber composite plates (CFRP) $[0]_{22}$ were manufactured by prepreg process for case study 1.