Study of thermo-mechanical characteristics of polymer composite materials with embedded optical fibre

D. Savastru, S. Miclos, R. Savastru, I.I. Lancranjan

PII: S0263-8223(16)32810-0
DOI: http://dx.doi.org/10.1016/j.compstruct.2017.09.042
Reference: COST 8905

To appear in: *Composite Structures*

Received Date: 9 December 2016
Revised Date: 14 September 2017
Accepted Date: 16 September 2017

Study of thermo-mechanical characteristics of polymer composite materials with embedded optical fibre

D. Savastru[a], S. Miclos[a], R. Savastru[a], I. I. Lancranjan[a,*]

[a]National Institute of R&D for Optoelectronics – INOE 2000, 409 Atomistilor Str., Magurele, Ilfov, RO-077125, Romania

Abstract

The purpose of the paper consists in presenting the simulation results obtained in analysing a major issue concerning the fabrication of smart composite materials (SCM) using fibre optic sensors, more exactly Long Period Grating Fibre Sensors (LPGFS) for the necessary feedback at environment inputs such as mechanical stress, strain, temperature or pressure. There is an increasing interest SCM regarding their various medical care, security, industry and aerospace applications. The major analysed issue of SCM using LPGFS fabrication and exploitation is how to investigate the mechanical characteristics of the optical fibre with grating (essential for its sensing capabilities) after embedding into the polymer matrix of a composite. One task to be accomplished by the performed analysis is to get accurate information about mechanical loads such as elongation, torsion and/or bending induced in the LPGFS by the composite polymer matrix in which it is embedded. For performing the proposed analysis of thermo-mechanical characteristics of composite polymer matrix having a LPGFS embedded inside it a simple FEM technique is used. The polymer and optical fibre thermal and mechanical characteristics are taken into account. The analysis is performed in order to design and manufacture smart polymer composite materials using fibre optics sensors.

Keywords: smart composite material, Long Period Grating Fibre Sensor, polymer matrix.

*Corresponding author at: National Institute of R&D for Optoelectronics – INOE 2000, 409 Atomistilor Str., Magurele, Ilfov, RO-077125, Romania. E-mail address: j_j_f_l@yahoo.com.

1. Introduction

The paper is an attempt in presenting the results obtained using a simple simulation software toolbox developed for analysing an important process of the fabrication of a smart polymer composite materials (SPCM) class, which is relying on the use of Long Period Grating Fibre Sensor (LPGFS) as the feedback element. The analysed process can be considered as a LPGFS calibration. It is necessary to consider few basic facts related to LPGFS sensing function: inducing grating into bare single mode optical fibre means to create mechanical strain into it besides creation of absorption bands into its transmission spectrum which are useful for sensing [1-16]. In addition, embedding a LPGFS into the polymer matrix means to micro-bend it or even to micro-twist it (much lower probability) [8-16]. The embedding induced micro-deformations have as a side effect that the induced absorption bands useful for LPGFS sensing function are shifted and broadened, before any mechanical or thermal load is applied on a SPCM [1-7]. In designing SPCM using LPGFS appears as useful a simple simulation software toolbox allowing the analysis of optic fibre micro-deformations in order to discriminate from that induced by external applied mechanical and/or thermal ones [1-20]. The analysed process of micro-deformation is performed by considering how a glass wire mechanically resembling single mode optical fibre is embedded into the matrix of a composite material, namely it is analysed how the thermo-mechanical characteristics of the glass wire are affected by embedding into the polymer matrix. Another issue of interest is how the optical fibre mechanically responds to vibration excitation applied to SCM part or during polymer curing. The presented simulation results are obtained using self-made software developed on the basis of MATLAB 8.7 commercial software package.

There are two main reasons for performing the analysis. The first one is a consequence of the increasing interest in composite materials and in their SPCM class for various applications in medicine, industry, defence and in aerospace [1-7]. Among the SPCM types, the ones using fibre optic sensors are relatively new, not older than four-five years. The majority of the studies realised in this field are experimental and refers to the grating fibre sensor type. The grating fibre sensor type includes the single mode optical fibres ("standard" dimensions: cladding of 125 μm diameter and core of 5-10 μm) characterised by a spatial modulation of the core refractive index inscribed in the fibre by various fabrication techniques [8-16]. The grating is inscribed in the single mode optical fibre in order to enlarge its sensing capabilities by variations of grating period and of the refractive index modulation amplitude [16-21]. There are two main types of grating fibre sensors: those using short period grating (500 – 1000 nm, grating length of 1-5 mm), denoted as Fibre Bragg Grating (FBG) and those relying on long period grating (10 – 1000 μm, grating length of 10 – 50 mm) which are denoted as Long Period Grating (LPG) [8 -12]. FBG are manufactured by inscribing grating pits in the core of the single mode fibre using UV lasers and can be operated by recording the reflection or the transmission spectrum of the fibre. In the LPG case, there are two possible manufacturing procedures: using UV lasers illumination for inscribing the LPG pits into the core of the optical fibre or modifying the optical fibre geometry by CO_2 laser or electric arc thermal induced deformations, small amplitude tapers. LPG are operated by observing the absorption bands appeared in the optic fibre transmission spectrum because of light propagating through the core as guided mode coupling to the possible cladding propagation modes [17-23]. These technological details of fibre grating manufacturing have certain significance regarding the main object of the performed analysis. Use of UV laser illumination means colour centres formation into the core of the optical fibre, a fact implying a not so great thermal stability over 300°C while thermal processing small amplitude tapering of optic fibre signifies a reduced elongation or twist mechanical strength [16-23].

The second reason for performing the analysis is related to the LPGFS characteristics. There is an important difference between FBG and LPG: in FBG, the sensing process is taking place only in the core while for LPG the sensing process includes the cladding a fact, which means interaction of the optical fibre with environment [16,19-21, 24-26]. LPGFS, besides the grating thermal and mechanical sensing characteristics, common to those of FBG, present the capacity of detecting even 10^{-4} relative modification of refractive index of the optic fibre environment [14-16, 19]. This means extended LPGFS capacities as chemical and biochemical sensors. It is worth to underline that LPGFS embedded in the polymer matrix of a composite material is used as thermal, mechanical and chemical sensor providing feedback for any modification, including chemical ones, such as fluid infiltration of the polymer matrix [13-14,16,27-32]. In other words: LPGFS can be used, for example, to detect humidity of the matrix polymer of a composite material. It becomes interesting to investigate the possibility to manufacture SPCM which uses LPGFS embedded in polymer matrix as its feedback element. A particular constructive detail of LPGFS becomes important versus SPCM manufacture, namely the fact that the acrylate buffer layer is removed along the optical fibre zone containing the LPG. It is necessary to remind that optical wires even thinner than LPGFS 125 μm "standard" diameter are embedded in polymer matrix in order to reinforce the composite material [1-4]. Concerning LPGFS embedment in polymer matrix there are several technical issues to be underlined. First of all, inscribing a