PROCESS MONITORING OF FIBRE REINFORCED COMPOSITES: A TRIBUTE

V.R. Machavaram[1], A.K. Nair[1], R.S. Mahendran[1], L. Wang[1], D. Harris[1], C. Paget[2], C. Barrow[3], B.D. Gupta[4] and G.F. Fernando[1]
[1]Sensors and Composites Group, University of Birmingham.
[2]Airbus, Filton, UK.
[3]Bruker UK Ltd, Coventry, UK.
[4]Department of Physics, IIT Delhi. India.

g.fernando@bham.ac.uk

1. Introduction

Advanced fibre reinforced composites (AFRCs) are used extensively in industrial sectors where weight is at a premium, for example, aerospace, automotive, marine and sport. AFRCs consist of three key components: (i) the reinforcement; (ii) the matrix; and (iii) the interface between the reinforcement and the matrix. The reinforcement can be in the form of continuous fibres or rovings, short-fibres, woven, knitted and stitched fabrics, braided preforms and prepregs. AFRCs can be manufactured using a number of techniques including the following: (i) filament winding; (ii) pultrusion; (iii) pull-winding, (iv) resin transfer moulding, (v) resin/film/vacuum infusion, (vi) autoclaving, (vii) out-of autoclave moulding, (viii) hand/spray layup, (ix) diaphragm forming, (x) reaction injection moulding and (xi) tape laying.

The manufacturing of AFRCs, using thermosetting matrices, starts with the impregnation of the reinforcement by the matrix; this is followed by consolidation (vacuum and external pressure) of the laminated preform, and cross-linking of the matrix, generally by the application of heat. The cross-linking reactions of certain classes of thermosetting resins can also be initiated by UV-visible light, electron-beam and microwaves.

The rate and extent of chemical conversion of the functional groups present in the matrix or resin system can be influenced by parameters such as: (i) the chemical integrity of the constituent components of the resin; (ii) the number of freeze/thaw cycles experienced (relevant to prepregs that are stored at sub-ambient temperatures; (iv) the moisture content on the surface or the fibres or binder; (v) the rate of heating and the heat-transfer efficiency in and out of the preform; and (vi) the surface chemistry of the reinforcing fibres (including the chemistry of the binder).

The chemical reactions involving the monomers in thermosetting resins result in shrinkage during cross-linking as new covalent bonds are formed. Furthermore, thermosetting reactions are exothermic and therefore, efficient thermal management is important especially for large and thick laminated preforms. Failure to control the temperature within the laminate can lead to an "exotherm" where the temperature released during the cross-linking reactions exceeds the desired processing (isothermal) temperature; this can lead to the thermo-oxidative degradation of the matrix. Under normal processing conditions, when the composite is cooled down from its processing temperature, residual stresses can develop in the material due to the thermal expansion mismatch between the fibres and the matrix, and other factors such as tool/preform interactions. The magnitude of the residual fabrication stresses can be large enough to cause warping of the composite; these stresses can also be high enough to initiate cracking and delamination.

2. Criteria for selecting sensor for process monitoring

The selection of the most appropriate sensor system for process monitoring of AFRCs is not straight forward as due consideration has to be given to a multitude of factors. With reference to process monitoring of AFRCs, Figure 1 presents a schematic illustration of possible sensing strategies.

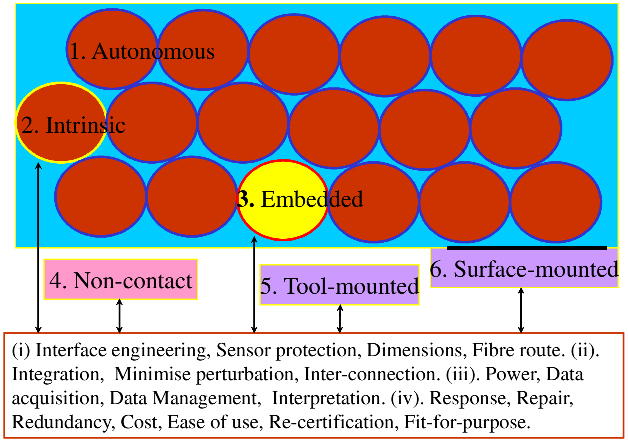


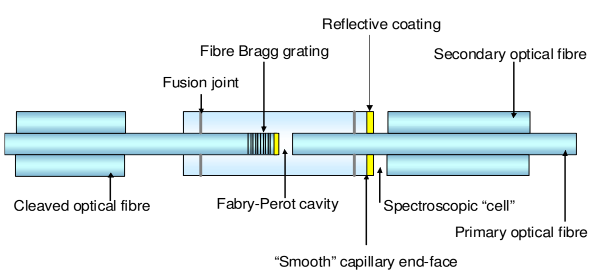
Figure 1 illustrates five sensing strategies for AFRCs. The first is referred to an autonomous composite which by definition is capable of sensing and responding to the stimuli/measurand without any human intervention. The second is the situation where the reinforcing fibres are used as the sensor (optical or electrical). In the optical case, the assumption is that the reinforcing fibre is capable of transmitting light; here the matrix acts as the cladding for the core of the "optical fibre". The third sensing strategy is where the sensor is embedded or integrated into the preform. The fourth approach is where the sensing system offers a non-contact route for process monitoring. Here the sensor system is position over the preform to facilitate process monitoring. The final sensing strategy considered here is surface-mounted sensor systems. The double-sided arrows indicate some of the key issues that need to be considered. A similar approach can be taken with regard to the integration of specified classes of sensor systems for specified classes of preforms, manufacturing process and end-use application.

In situations where quantitative information is required on the cross-linking kinetics of thermosetting resins, the only traceable option is to use spectral techniques where the depletion and formation of specified chemical functional groups in the resin system can be tracked in real-time. A primary perquisite for kinetic modelling is that information on the temperature of the resin system during cross-linking is also required. As indicated previously, it cannot be assumed that the set isothermal temperature is a true representation of the temperature within the resin system during cross-linking. The other complication is the spatial location of the sensor within the preform where the shrinkage of the resin can be influenced by the degree of "bonding" between the preform and the surface of the mould/substrate.

3. Overview of the Presentation

This talk will discuss briefly, the above-mentioned issues and proceed to give an overview of optical fibre-based sensor system that have been demonstrated in the Sensors and Composites Group including the following categories: (i) transmission; (ii) reflection; (iii) evanescent wave; (iv) Fresnel; (v) non-contact probes; (vi) self-sensing reinforcing fibre light guides; and (vii) multi-functional sensors.

To-date, majority of the fibre optic-based sensor systems have been single or at the most, dual-measurand systems. This paper presents an overview of the design and deployment of a multi-measurand optical fibre sensor (MMS). The MMS is capable of monitoring four independent measurands simultaneously: strain, temperature, relative concentration of specified functional groups in the resin system and refractive index. The sensor design is based on the extrinsic fibre Fabry-Perot interferometer. A unique feature of this design is that a conventional fibre-coupled near-infrared spectrometer is used to monitor the four independent parameters.



A schematic illustration of the multi-functional sensor is presented in Figure 2.