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Monitoring changes in CFRP laminates microstructure during oven and autoclave curing using electrical impedancemetry

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In order to meet the conceptual requirements of structural relief but also to ensure health monitoring, the use of functionalized or smart materials is becoming widespread, particularly in the transport sector. Concerning carbon fibre composites (CFRP) strongly used in the aeronautical and space sector, it is possible to take advantage of the electrical conduction of the reinforcement. If CFRP structures are designed to be mechanically optimized the growing need for functionalization remains limited by potential internal damage. In this context, the demand of manufacturers is moving in the medium and long term towards an in-situ and real-time control of the life cycle of materials and structures, from development to service behaviour until the end of life. To answer this aim, electrodes can be introduced during manufacturing. The mastery of the curing step and the knowledge of the in situ changes of the physicochemical properties of the thermosetting matrix directly condition the long-term behaviour of the composite material. It is therefore essential to ensure that not only the material is optimized during its production but also the manufacturing process itself. This is precisely the objective of this study: to design a robust and non-intrusive electrical instrumentation able to monitor in situ the curing cycle of composites made of T700/M21 aerospace prepregs using electrical impedance measurements.

The study presented here is part of a more comprehensive work on structural health monitoring (SHM) of composite structures produced in and out of autoclave. The material is used as a sensor but can also serve as an actuator (functionalization of the material) and the used instrumentation (thin copper electrodes embedded in the laminate) will remain thereafter to monitor the health of the material in service (SHM) [1-7].

In this paper we focus on unidirectional CFRP made of T700 / M21 prepregs. In this type of conductive fibre composite, the measured impedance will be limited in particular by the inter-fibres conduction. In the ply, the fibre density favours longitudinal conduction and, to a lesser extent, intra-ply transverse conduction is carried out via the percolation network. With regard to the inter-ply conduction, the area between two layers has a low fibre density and an excess of resin inducing brake to the through-the-thickness conduction. A specific experimental bench has been thus developed to correlate the 3D electrical information with the evolutions of the electrode/plies electrical contact and rheological parameters of the material during in- and out-of-autoclave curing.

The first part of this work focusses on the implemented experimental approach and bench as well as the modelling assumption used to define 3D electrical conduction within the materials considered for the study and the parasitic elements linked to the electrical bench. A frequency study optimization is proposed to improve impedance (Z) measurements accuracy during oven and autoclave curing. Furthermore the interest of using the modulus $|Z|$ and argument of the electrical impedance rather than resistance (R) and/or capacities (C) alone was studied (see Fig.1).

The second part focuses on preliminary electrical characterization undergone to define electrical parameters in longitudinal and transverse intra-ply conduction using a specific single-ply platform and in through-the-thickness conduction using 8-ply UD samples with embedded electrodes. This section aims to highlight that it is not only possible to monitor the curing key parameters (rheology of the thermosetting resin) but also to define the quality of contact with the embedded electrodes. Electrical signatures during and at the end of cure can thus be defined to highlight optimal cures or manufacturing defaults as illustrated by Fig. 2 which shows how a vacuum defect can easily be detected. The final part of our work is devoted to settling a 3D modelling on the basis of experimental results leading to the complete electrical characterization of the studied composite laminates highlighting electrical conduction zones and process effects.

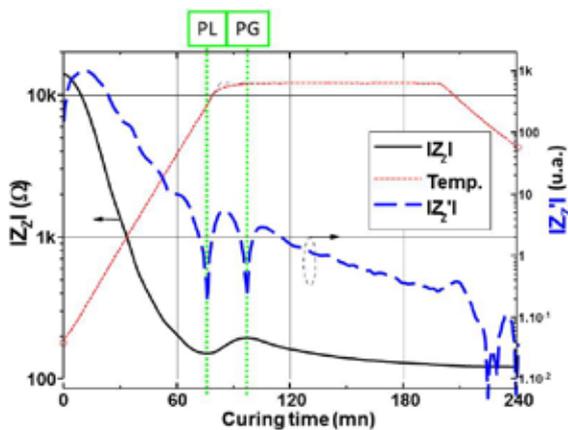


Fig. 1 Changes in $|Z_L|$ and its first time derivative $|Z'_L|$ (arbitrary units) during oven-curing of an $[0^\circ_8]$ sample. PL=minimum viscosity point, PG=gel point.

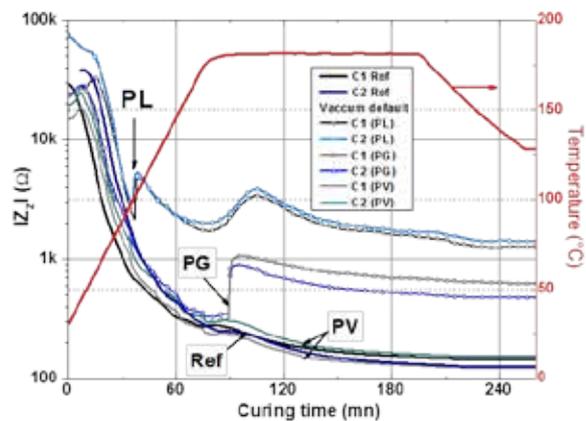


Fig. 2 Vacuum defect effect on the through-the-thickness impedance $|Z_T|$ ($f = 10$ kHz) during oven curing of $[0^\circ_8]$ laminates.

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