DISTRIBUTED FIBRE OPTIC SENSING FOR REAL-TIME MONITORING OF VARTM MANUFACTURING AND PROCESSING OF COMPOSITE LAMINATES

James R. Davidson[1*], Fayyaad Amod[2], Oliver M. Simpson[1], Hanisa Hasrin[2], Danijela Stankovic[2], Conchúr M. Ó Brádaigh[2], Samuel Furtado[1]

[1]Advanced Manufacturing Research Centre, University of Sheffield, Sheffield, S60 5TZ, UK.
Email: James.Davidson@amrc.co.uk, *Corresponding Author
[2]University of Sheffield, Department of Materials Science and Engineering, Sheffield, S1 3JD, UK.

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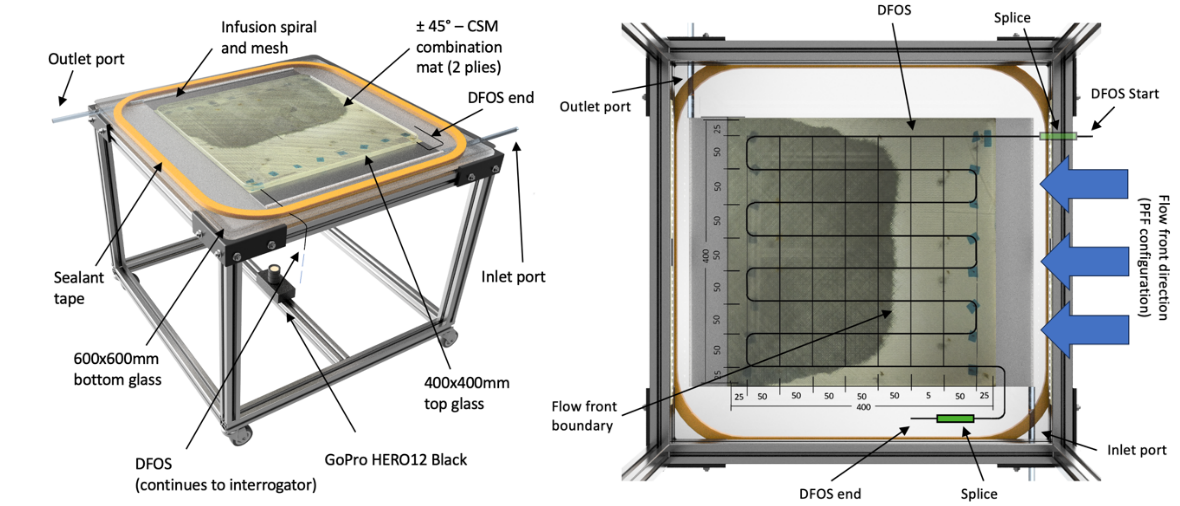
Abstract

The integration of fibre optic sensors within composite materials offers a potentially superior method for monitoring strains during processing and operational phases. Unlike more conventional sensors such as strain gauges and thermocouples, fibre optics offer distinct advantages. They remain unaffected by other monitoring techniques like dielectric analysis, are resistant to electromagnetic interference, and have minimal impact on the stiffness and physical form of the components. Technologies such as Fibre Bragg Gratings (FBGs) and Long Period Fibre Gratings (LPFGs) have become relatively well utilised in structural health monitoring for the purpose of identifying damage mechanisms such as transverse cracking, delamination, and impact damage. They enable detailed evaluation without significantly disrupting the mechanical integrity of parts, although some geometric discontinuities and induced defects can degrade performance under certain conditions. Distributed Fibre Optic Sensors (DFOS) offer extensive benefits for process monitoring by providing continuous strain measurements along the sensor length, as opposed to discrete points, which is crucial for detecting dynamic changes like crack formation in stressed composites or more broadly, in applications where strains increase or decrease quickly relative to spatial location. To date, DFOS have proven effective in tracking critical aspects of composite manufacture like resin flow and cure kinetics. Nonetheless, the induced strains from initial vacuum application and demoulding remains underexplored, with sensor orientation and layout playing crucial roles in data utility—an area which demands further investigation.

This study critically examines the effects of manufacturing stages from initial vacuum application to final laminate demoulding in Vacuum Assisted Resin Transfer Moulded (VARTM) panels, specifically assessing the impacts of fibre orientation relative to the flow front direction. A custom VARTM setup was employed, featuring a dual glass plate configuration to maintain consistent flow conditions across the reinforcing fabric—see Figure 1. The setup applied a linear infusion method, where small edge-chamfers in the upper glass plate promoted a U-shaped flow front, whilst still ensuring complete resin infusion without dry spots. Continuous flow monitoring was achieved using a high-resolution GoPro HERO12 camera positioned beneath the setup, where a custom Python script was utilised for analysing the video data to track the advancing resin front.

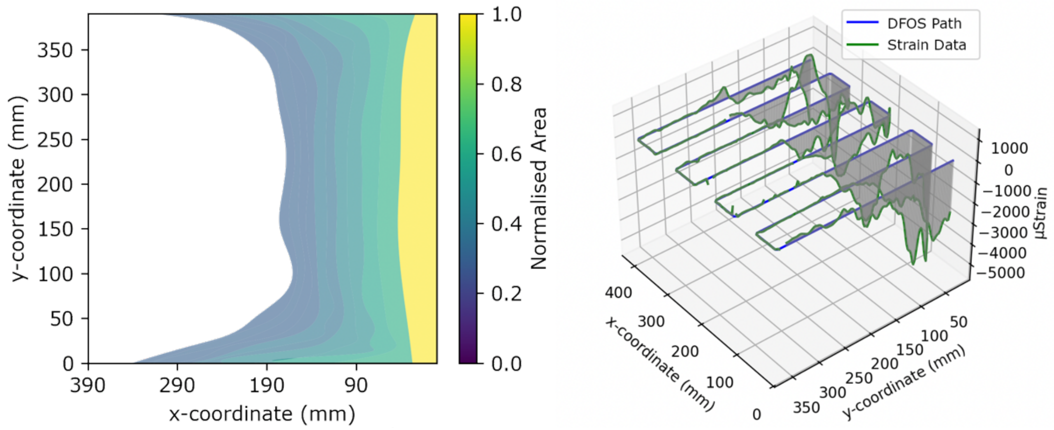


(a) Labelled diagram of infusion setup

(b) DFOS path and camera FOV (from beneath panel)

Figure 1. VARTM Infusion Schematics for PFF Configuration.

For the fabrication of all laminates, two plies of ±45° unidirectional (UD)/Chopped Strand Mat (CSM) combination mat were utilised. The interfacing fibres between the two plies were oriented in a ±45° configuration, with the DFOS—connected to a Luna ODiSI 6100 interrogator—placed between these plies as denoted in Figure 1b. For the configurations transverse to the flow front (TFF), the DFOS layout mirrored that of Figure 1b but with the flow front orientation rotated by 90°. Representative results from video-based and DFOS monitoring of the parallel to flow front (PFF) setup—captured at 11 minutes of elapsed time—are illustrated in Figures 2a and 2b. The findings highlight that the DFOS' constraining approach significantly impacts the induced strains during initial vacuum application. Both parallel and transverse DFOS orientations relative to the flow front direction are capable of determining the location of the flow front, each presenting unique challenges and advantages. Additionally, post-demoulding, the laminates exhibited straining and warping, where deformations were attributed to residual stresses accumulated during the curing process.



(a) Normalised infused area at t = 11 minutes, colour regions discretised per minute

(b) μstrain data along DFOS path at t = 11 minutes

Figure 2. Representative Results from a VARTM Infusion with PFF configuration.