REAL TIME UNCERTAINTY ESTIMATION IN FLOW PROCESSES OF COMPOSITES MANUFACTURING

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Introduction

Composites manufacture involves several sources of uncertainties including environmental/boundary conditions (i.e. tool temperature, convection coefficient) variability and material properties variations [1]. Typically measurements of permeability have shown coefficients of variation up to 20% [2]. Application of stochastic simulation has shown that process uncertainty causes significant variations in manufacturing process outcomes such as process duration and defects formation affecting final part quality [3]. Flow process monitoring techniques have been developed to monitor critical parameters of such as flow front position and to identify potential defects. Lineal sensors have been used to monitor complex flow fields in liquid moulding as well race tracking effects based on strategic positioning [4]. Process monitoring can provide real time information to process modelling to improve its predictive capability.

The present study addresses the development of an inversion procedure based on Markov Chain Monte Carlo (MCMC) method integrating flow monitoring data with flow process modelling. This leads to on-line estimation of process outcomes and their uncertainty.

Methodology

Flow monitoring was utilised during RTM processing of a carbon fibre/epoxy composite panel with 3.3 mm thickness and the geometry illustrated in Figure 1b. The top plate of the RTM tool is transparent in order to allow acquisition of the actual flow front position during the process. The reinforcement material was Hexcel G0926 woven carbon fabric and the resin system was Hexcel RTM6 epoxy. The preform comprised 9 layers resulting in a volume fraction of 56.7%. The filling was carried out at a constant temperature of 120 °C under a pressure of 2 bar with the simultaneous application of vacuum applied at the inlet and outlet positions shown in Figure 1b. The geometry of the linear dielectric sensor is illustrated in Figure 1a [5]. It comprises two uniformly twisted solid copper wires covered by polyurethane enamel coating. The diameter of each wire is equal to 0.127 mm, whilst the twist length is 1 mm.

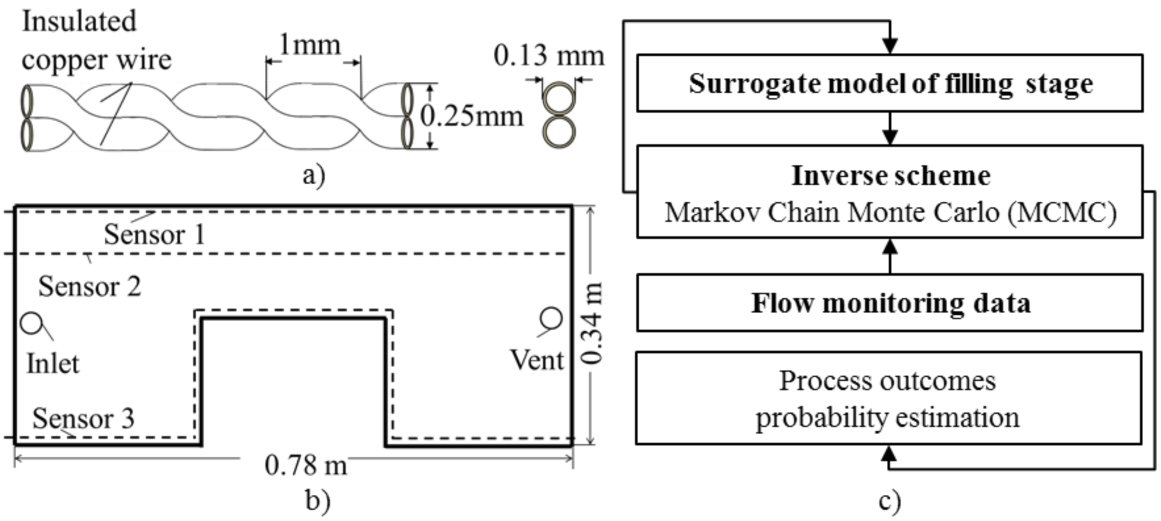

Figure 1 *a) Inversion procedure framework; b) dielectric sensor geometry [5]; c) composite part geometry and lineal sensor positions.*

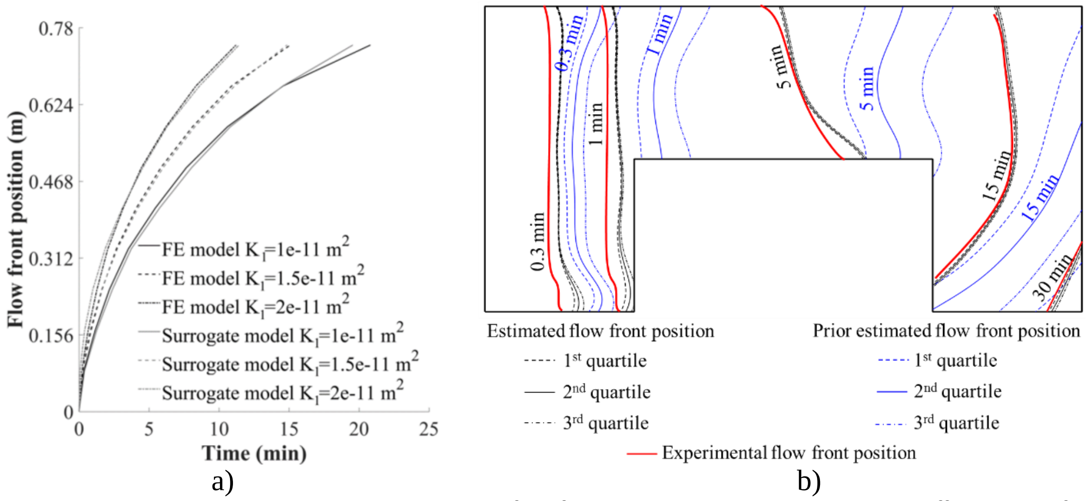

Figure 2 *a) Surrogate model validation; b) experimental flow front and iso-probability contours at different times for prior and posterior flow front estimates.*

Three lineal sensors were placed in strategic positions within the part aligned to the direction of resin flow to acquire information regarding the flow front evolution and the presence of edge effects (Figure 1c) during the impregnation. A computationally efficient surrogate model of the filling stage of RTM was developed based on Kriging applied to a set of results produced using Finite Element (FE) analysis. The inversion procedure presented schematically in Figure 1c is based on the Markov Chain Monte Carlo (MCMC) method and integrates flow monitoring data with the surrogate model. MCMC operates as a sampler drawing a series of realisations of unknown stochastic parameters (in this case principal permeabilities, edge permeability and initial resin viscosity) with a probability of acceptance proportional to the conditional incremental likelihood of process monitoring results. The accepted realisations constitute the solution of the inverse problem in the form of a probabilistic estimate of process outcomes.

Results

Figure 2a illustrates the efficiency of the surrogate model compared to FE simulation in three cases of different longitudinal permeability (K_1). The results of the inverse scheme are illustrated in Figure 2b. Prior stochastic model results include significant variations due to the initial uncertainty of the problem. The use of real time monitoring results reduces the uncertainty of the model prediction and improves its accuracy. The flow front predictions at specific times are in good agreement with the experimental flow front. The estimated and actual filling time is equal 32 min and 31.5 respectively. These results highlight the robustness of the MCMC algorithm and its efficiency in narrowing down the variability of unknown stochastic parameters as the flow stage progresses using flow monitoring data. The posterior model can estimate with higher probability not only the filling patterns but also the occurrence of potential defects such as dry spots and void formation during the process. The inverse scheme can be coupled with control. After the completion of the process, the result of the analysis can be used to drive targeted quality inspection based on the probability of defects formation at different locations in the produced component.

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