THE APPLICATION OF A NUMERICAL TOOL FOR SMART IN-SITU SENSING OF DEFECT FEATURES IN LARGE SCALE INFUSIONS

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Abstract

Recently, wind turbine blades have reached record breaking lengths with the innovative use of composite materials. The manufacturing of large scale composite parts increases the complexity, risk and the cost of errors. The vacuum infusion process is susceptible to defects such as voids, which compromise the part's structurally integrity. The remedial work required increases the production time and cost, as well as impeding the transition to net-zero.

Air entrapment can occur during the merging of resin flow fronts. The extent and location of air pockets can vary significantly from part to part, due to design features (presence of thickness changes, core, pre-cured components), process variations (compaction, ply/core placement tolerance and accumulation, vacuum level, ply shearing), and intrinsic material variability (yarn loss). The monitoring and prediction of air entrapment is challenging. In closed moulds and at blade-scales, the dense arrangements of sensors required is impractical. Process simulations require knowledge (or elimination) of the features and variations, and depend on the accuracy of the material characterisation, the modelling assumptions and simulation parameters set by the user. Therefore, industry practice is to detect and repair the defects after cure which is costly, wasteful and uncertain.

There is a growing demand for the use of in-line process monitoring and closed-loop control to mitigate defects in real-time. Accurate information is required across the entire part and the time for control decisions is limited by the process. The aim of the current work is to maximise the information obtained from a few sensors and then translate it into actionable control decisions.

An adaptive and efficient physics-based 1D numerical model is created based on Darcy's law and mass conservation to interrogate data obtained from sensors in the mould tool. The model pressures are matched to the sensor pressures by optimising the parameters in the governing equations. Latin Hypercube sampling and nonlinear least squares regression were used to obtain a balance between accurate and efficient predictions for real-time defect mitigation. In doing so, an in-situ calibration of material properties is performed, the size, position and magnitude of potential defects are identified, and the flow front progression is estimated.

Figure 1 shows the fitting of the modelled pressure against the sensor data and the convergence to an exact description of the defect. Figure 2 (a) shows that the simulation is able to recover accurate knowledge of defects present in an infusion, providing that there is a sensor upstream and within range of the simulated defect location. The sensing range is shown to be a trade-off between the sensor distance from the inlet and its measurement resolution. The effect of sensor placement on the efficiency of the defect characterisation is shown in Figure 2 (b). It is possible to make accurate predictions of defects that are several metres downstream from the sensor, yet a high sensor density is required to ensure that the predictions can be made quickly to enable real-time corrective actions to the process.

In summary, the research describes the development of an efficient framework for detecting flow features in real-time. It is numerically feasible to detect defects from limited pressure sensor data. The work will extend the discussion to the investigate the challenges of modelling the infusion process for wind turbine blade layups and the application of the developed framework to realistic part geometries. Enhanced sensing techniques are considered to further develop the numerical tool for increased real-time process understanding of multi-dimensional flows, with a view of establishing a pragmatic and efficient strategy for defect mitigation in the production of large composite structures.

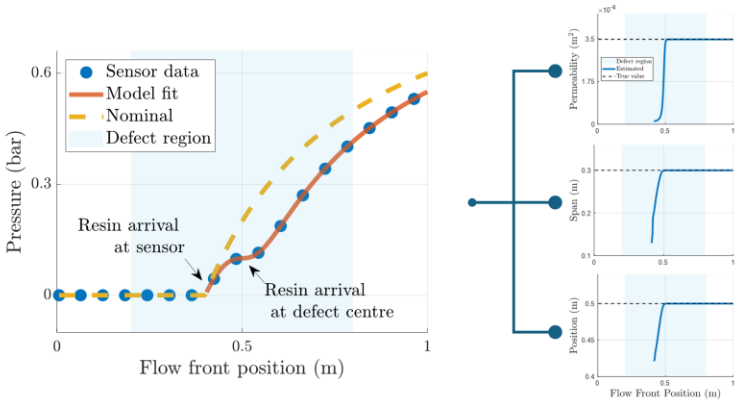
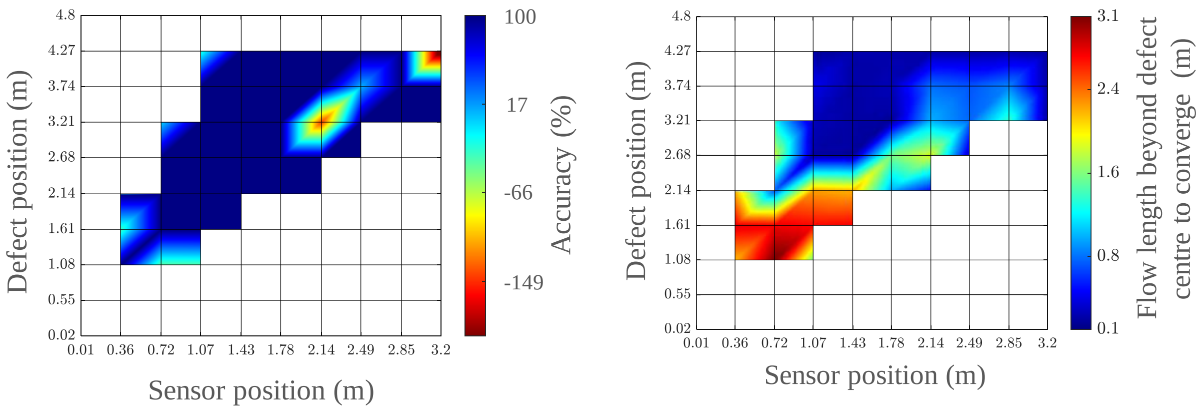


Figure 1. Fitting the modelled pressures to the sensor's pressures and convergence of defect parameters



(a) **(b)**

Figure 2. Defect prediction accuracy (a) and efficiency (b)