FAST ALGORITHMS FOR ACTIVE CONTROL OF MOULD FILLING IN RTM PROCESS WITH UNCERTAINTIES

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Introduction

A consistent and repeatable manufacturing process is seen by the composites industry as a key for reducing wastage and for obtaining repeatable mechanical properties of composite components. For the Resin Transfer Moulding (RTM) process, the quality is defined not only by the absence of incomplete mouldings but also by having a repeatable mould filling process with minimum deviations from the design. Such deviations, as result of irreducible uncertainties and variabilities of reinforcement and process parameters (see e.g. [1-3] and the references therein), can lead to dry spots and/or high micro-void content. The aim of this study is to implement an active control (AC) system aimed at reducing deviations from the designed process as well as estimating the permeability of the preform using a novel regularizing ensemble Kalman algorithm (REnKA) from [4].

There is a number of existing implementations of AC systems, see e.g. [5-7] and references therein. The system from [5] relied on using a surrogate model such as artificial neural network. Surrogate models are not physics-based and their performance can degrade when encountering a case which is significantly different from those used for the model training. This study aims to implement a physics-based model which can work online for a real mould filling process. In comparison with [6, 7], fast and efficient estimation of permeability using REnKA is incorporated in the proposed AC system to ensure more accurate control without any need to run a large number of simulation scenarios before the AC system is deployed. The AC system presented in this study is implemented into a numerical flow simulation package and validated for a case of a relatively simple resin flow problem. The numerical experiments made it possible to improve and tune the AC system before its implementation in a real setup.

Modelling flow through a fibre preform with no variability

A relatively simple tool design for resin injection was selected to demonstrate feasibility of the considered AC system. The tool is rectangular in shape with dimension of 115 mm × 270 mm. Three equally spaced injection gates are located on one short edge of the tool. The pressure at each of the injection gates can be controlled independently. One linear vent is placed on the short edge opposite the gates. The tool is fitted with two types of sensors – six pressure transducers and seven linear sensors for flow detection (see e.g. [8]). Fluid flow through a fibre preform in the tool with the geometry described above was simulated using Ansys Fluent®, where flow through the preform is described by Darcy's law. The design configuration of the experiment assumes that the reinforcement with the porosity of 0.45 has isotropic and uniform permeability at a value of 10^{-9} m^2, and that the pressure difference between the gates and the vent is 35 kPa. Owing to the simplicity of the design, this setup predicts no void formation and a filling time of approximately 600 s. The flow sensor history is recorded for the design configuration in order to use it as a reference in the AC system.

Preforms with uncertainty and design of active control system

Uncertainties considered in this study are both random material non-uniformity and additional defects such as localised but significant changes in fibre volume fraction (e.g. racetracking). These defects can be manufacturing defects such as over-compressed reinforcement or even holes in the reinforcement. In the virtual experiment, the material variability is modelled via a combination of two independent random fields which represent local variability of porosity and local geometrical variabilities. The resultant of this combination is a log-normal random field for permeability with a mean of 10^{-9} m^2 and a variance of 10^{-10} m^2. Additional defects are modelled as patches of a random size with permeability several times higher or lower than the mean permeability and are superimposed over the material variability.

The AC system was set up for real-time acquisition of results from simulations or experiments. The flow in simulations or in experiments is compared with the simulated flow in the reference configuration at given time intervals. Once the difference between the current flow front position and the reference position exceeds a selected tolerance level, the control algorithm is triggered, and the control parameters, i.e. the pressure values at each of the injection gates, are adjusted to minimise the difference for the next time interval. It is assumed that the flow front propagation over a small distance can be described using a pseudo-1D model. In this case, the pressure at a gate, p_I^{new}, at time t_i is estimated as:

$$p_I^{new} \approx p_o + \frac{\mu(x_{i+1} - x_i)\Phi(x_i)}{t_{i+1} - t_i} E\left[\int_0^{x_i} \frac{dz}{K(z)}\right], \tag{1}$$

where p_o is the pressure at the outlet, μ is the resin viscosity, x_i is the observed position of the pseudo-1D front at time t_i, x_{i+1} is the target position of the front at the time t_{i+1}, and $\Phi(x_i)$ is the porosity at position. The permeability $K(z)$ is estimated by REnKA from [4] which uses observations of the front positions and pressure at times $t_1, \ldots, t_i$ either from the simulations or from an experiment in a real setup. The outcome of REnKA is an approximation of the distribution of the random field $K(z)$ obtained using pressure and flow front data up to time t_i. The expectation, $E[\cdot]$, in (1) is taken with respect to the distribution of $K(z)$. The knowledge of the distribution also allows suitable intervals for the updated pressure values, p_I^{new}, to be found, which can be used to control the flow front within given error bounds. In the AC realisation, the new pressure on each of the gates is recorded in a file which is used by Ansys Fluent® via a user defined function. Once control is triggered, it is applied iteratively for the duration of the process.

Results and Conclusions

The presented AC system was shown to be suitable for flow control in a preform with local variability in permeability. It was observed that the efficient use of a pseudo-1D model requires adaptation of the pressure at the gates frequently after it was triggered. The AC system will be implemented in an experimental set-up in the future. Future work will include testing REnKA in the case of more complex geometries of preform.

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