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TITLE: MODELLING AND SIMULATING PARTICLE TRANSPORT IN LIQUID COMPOSITE MOULDING PROCESSES

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ABSTRACT:

Fibre Reinforced Polymers (FRP) have become a cornerstone in modern engineering materials due to their high strength-to-weight ratio, corrosion resistance and customisability [1]. Resin Transfer Moulding (RTM) is one of the most widely used methods of manufacturing FRPs, and falls under the broader category of Liquid Composite Moulding (LCM) techniques. In RTM, the reinforcement fabric is placed within a closed mould, and liquid resin is injected into the mould cavity, such that all the empty regions are saturated. Afterwards, the curing reaction occurs, and subsequently, the final part is demoulded. Nanofillers, which are physical entities which have at least one dimension in the nanometre scale [2], may be mixed with the polymer resin prior to injection. This can be done for several reasons, such as to improve the thermal and electrical properties of the FRP part [3][4], or to manufacture Functionally Graded Composites (FGC) [5]. Carbon-based nanofillers, particularly Graphene Nanoplatelets (GNP), are one of the commonly used such nanoparticle materials [6]. It has been experimentally observed that during the injection of polymer resins with suspended nanoparticles through reinforcement fabric, particle filtration occurs, which significantly influences the liquid flow and vice versa [7][8]. Particle filtration can either be cake filtration, where the particles are deposited on the surface of the fabric tows, or deep filtration, where the particles are deposited within the fibre tows [9]. This is shown schematically in Fig. 1.

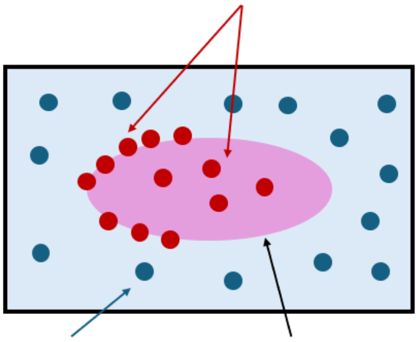

Figure 1: Classification of distinct particle species for the transport model

This overall process is modelled using Eqs. (1) and (2), which represent an Eulerian model of the particle transportation. Here, u is the velocity, C_1 is the concentration of particles in the resin, and C_2 is the concentration of particles deposited on the surface of and within a tow. Therefore, C_2 represents the combined concentration of cake and deep filtered nanoparticles. $S_{filtered}$ represents the rate of transfer of nanoparticles between the resin and tows.

$$\frac{\partial C_1}{\partial t} + \nabla \bullet \left(uC_1\right) = -\ S_{filtered} \qquad (1)$$

$$\frac{\partial C_2}{\partial t} = +\ S_{filtered} \qquad (2)$$

The flow velocity is calculated using LIMS (Liquid Injection Moulding Simulation) software, which is a commercial software for RTM mould filling simulations developed by the University of Delaware [10]. LIMS uses the mass conservation (Eq. 4) and Darcy (Eq. 5) equations to solve the pressure field and subsequently the flow velocities within the mould cavity.

$$\nabla \bullet u = 0 \qquad (1)$$

$$u = -\frac{K}{\mu}\nabla P \qquad (2)$$

Here, K is the reinforcement permeability, μ is the resin viscosity, and P is the pressure. Information between the flow variables obtained from LIMS and the particle distribution from the transport model is communicated using a Message Passing Interface (MPI) framework [11]. Initial simulations were carried out for a 1-dimensional flow under different resin inlet conditions. Figs. 2 and 3 show the results obtained from these simulations for the final distribution of particles, when $\left|S_{filtered}\right| = 0.0001$. Currently, work is being carried out to include the effects of particle distribution on reinforcement permeability and on determining the relationship between $S_{filtered}$ and process parameters. It is expected that the developed model could be used to determine the final distribution of nanoparticles under different injection conditions in 1-dimensional and 2-dimensional flow domains. Experimental work using GNP will also be carried out to validate the results

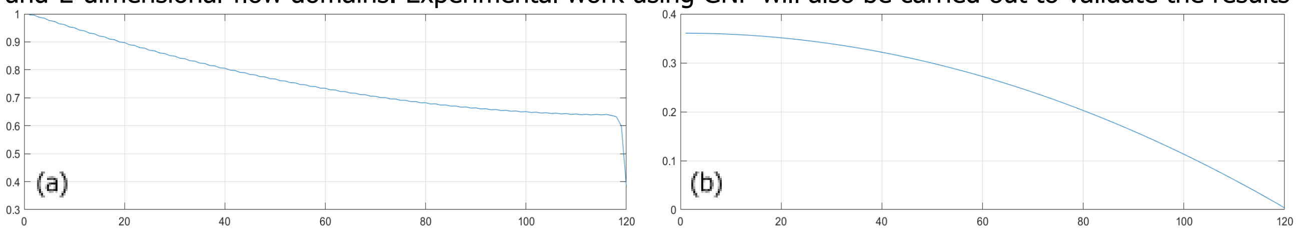

Figure 2: Distribution of particles along the length of the mould at the end of mould filling under constant pressure resin injection. (a) concentration of particles in the resin (b) concentration of particles on/ in the tows

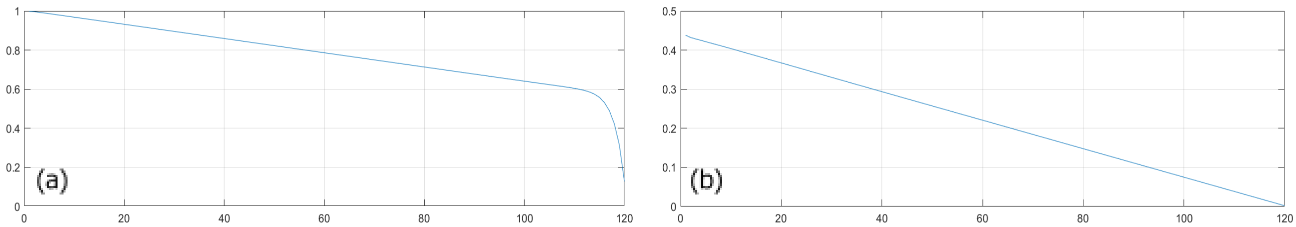

Figure 3: Distribution of particles along the length of the mould at the end of mould filling under constant flow rate resin injection. (a) concentration of particles in the resin (b) concentration of particles on/ in the tows

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