A Modeling Study of the Pin-Assisted Resin Infiltration of Porous Substrates

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We investigate numerically the process of flow-induced and pin-assisted resin infiltration of porous substrates, with applications in the pultrusion process for the production of continuous fiber reinforced composites. In such a process a glass roving is pulled over and around a stationary pin, resulting in the formation of a wedge-shaped fluid region between the pin and the (moving) roving surfaces [1,2,3]. The pressure build-up in this wedge-shaped flow is causing the fluid to infiltrate the porous substrate and sequential passing over several such pins allows the desired degree of infiltration to be achieved. This process is underlined by its high complexity and may be characterized as a sensitive operation which can be influenced by several parameters at the same time. In the past, the current authors [4] and for the first time, carried out two-dimensional simulations based on the OpenFOAM software and the Brinkman equation to account for the flow within the porous medium for a single-pin process and gave an in-depth view of the process fluid mechanics as well as a qualitative trend for the effect of the several parameters on the protrusion depth (L_f) (i.e. the distance the fluid penetrates into the porous substrate). This depth was determined through successive 2D simulations and imposition of a free surface condition at the air/porous medium interface. For a single-pin process (L_f) was found to depend on the permeability (K) of the porous material as well as the diameter of the pin (D) and to a lesser extent on the gap (δ_o) between the porous and the pin. The effect of the porous substrate pulling speed (V) (i.e. the production rate) and the thickness of the porous substrate L_o were also investigated. The above-mentioned parameters were studied separately each time. However, in reality it is very difficult and tedious to select the optimum operating conditions by changing all the parameters independently. For this reason, with the present approach we present an analysis in which all the data points obtained at different operational conditions, fall onto a single line showing a pressure-velocity-permeability-viscosity and geometric characteristics superposition expressed through a dimensionless group, namely $\frac{\mu V L_o}{PK}\frac{\delta_o}{R}$. Such an analysis not only provides a fundamental qualitative and quantitative understanding of the fluid penetration into the porous medium, but also gives the flexibility to carry out estimations of the penetration depth in the porous substrate for a sequential pin arrangement system often encountered in the pin-assisted impregnation technical literature. Different conditions were examined in the study, indicatively, pin number range N=3~10, R=3~20 mm, V=0.1~0.3 m/s, $K=10^{-7}\sim10^{-10}$ m^2 and L_o=100μm~2mm. As it will be presented, the behavior of the obtained results was compared with experimental results from relevant studies [2,3] and showed good qualitative and quantitative agreement.

References

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