THE EFFECTS OF IN-TOOL RESIN DELIVERY PORTS ON PROCESS CONTROL AND MOLDED PART QUALITY FOR VACUUM-BASED COMPOSITE MANUFACTURING

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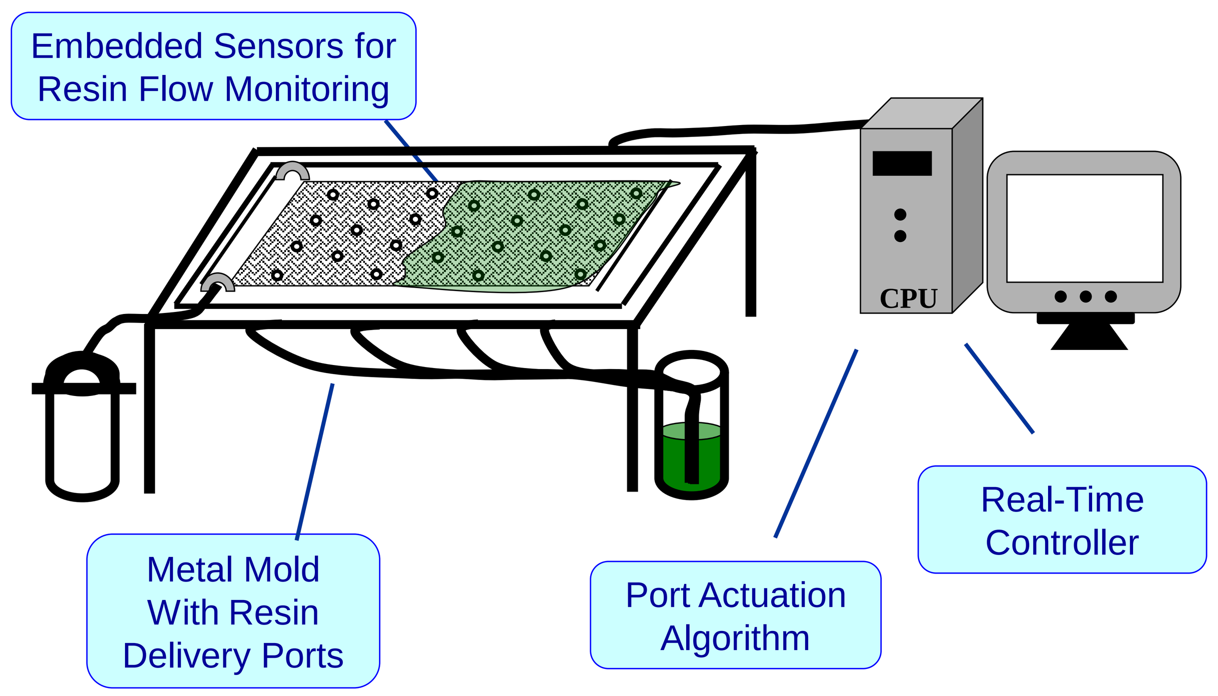
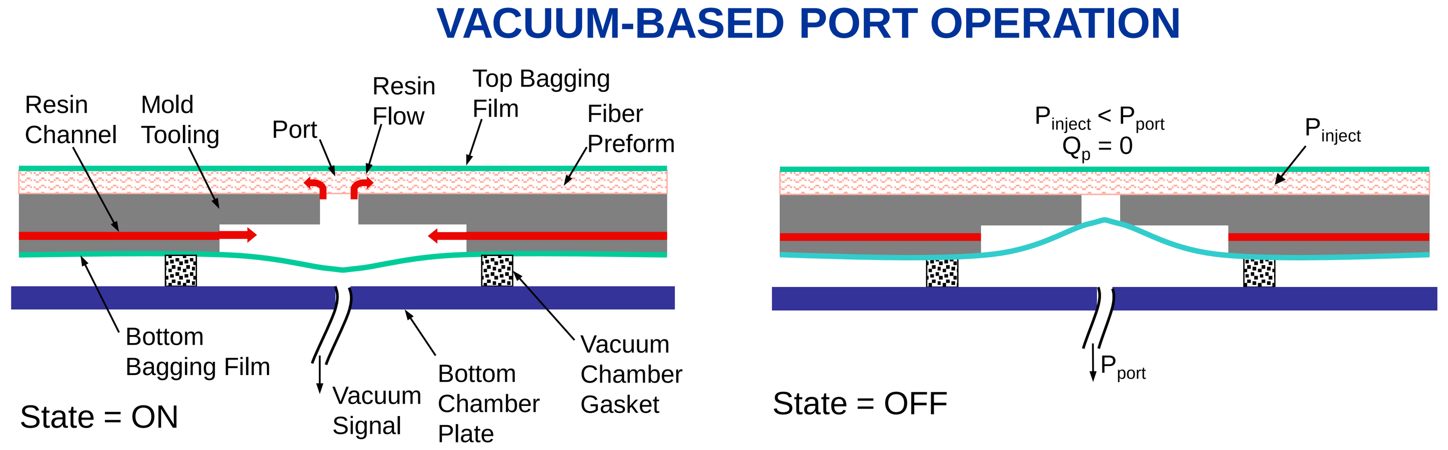
DEVELOPMENT OF A PORT-BASED RESIN DELIVERY SYSTEM

SYSTEM-LEVEL CONCEPTUAL VIEW



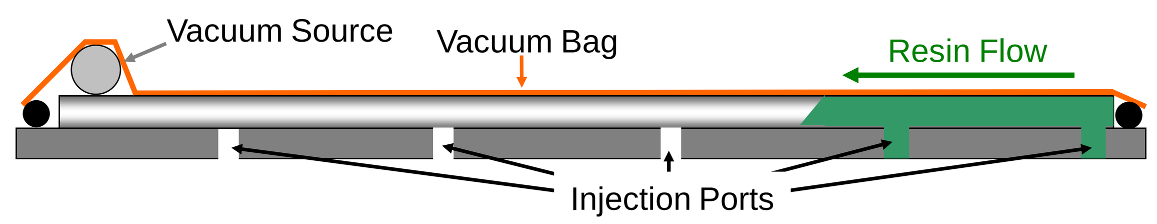
A modified VARTM manufacturing station that integrates computer controlled ports into the mold for resin transfer and preform filling.

VACUUM-BASED PORT OPERATION

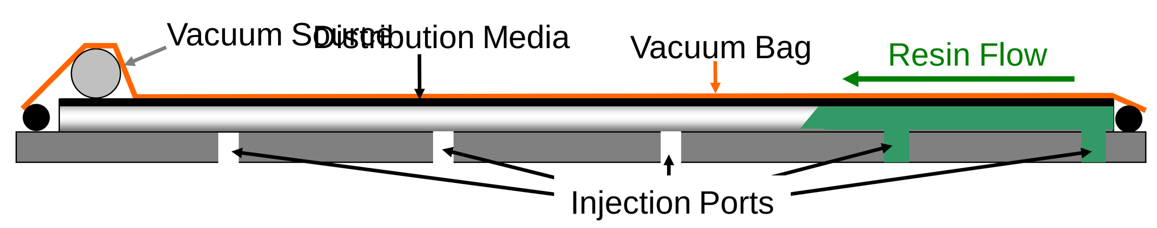


Cross-section of a typical port in the ON and OFF operating conditions.

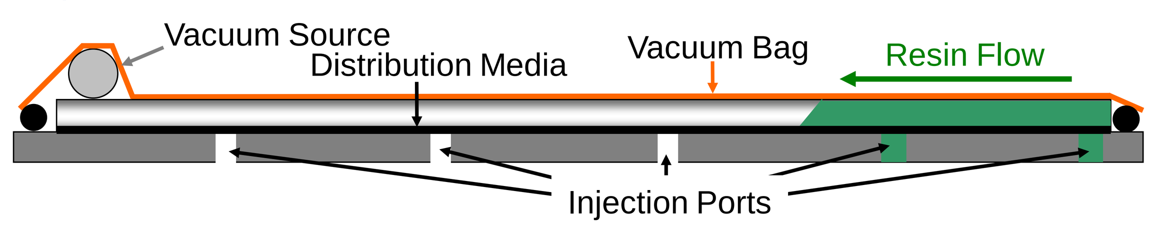
POTENTIAL PORT-BASED LAY-UPS FOR VACUUM MOLDING



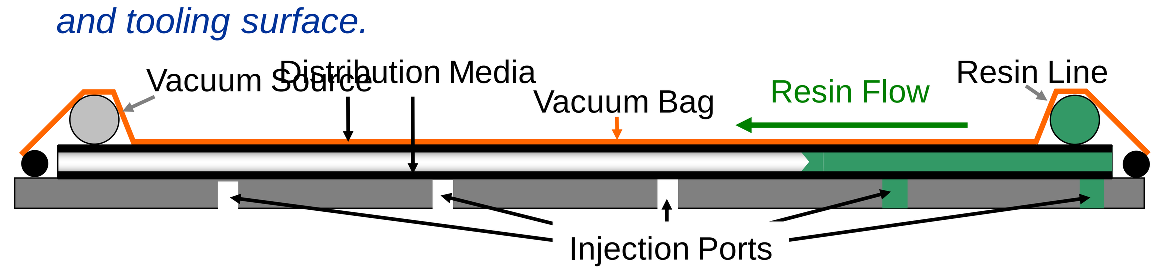
Setup 1: VARTM lay-up with tooling ports and no resin line.



Setup 2: SCRIMP lay-up with distribution media above the preform.



Setup 3: SCRIMP lay-up with distribution media between the preform and tooling surface.



Setup 4: Combination of in-mold ports and a resin line on the top of the preform, with distribution media above and below the preform.

The four port-based lay-up configurations evaluated in this study.

MODELING AND SIMULATION

GOVERNING EQUATIONS

Darcy's Law: $\mathbf{v} = -\frac{\mathbf{K}}{\mu}\cdot\nabla P$

Continuity: $\nabla\cdot\mathbf{v} = 0$

Combination: $\nabla\cdot\left(-\frac{\mathbf{K}}{\mu}\cdot\nabla P\right) = 0$

where:

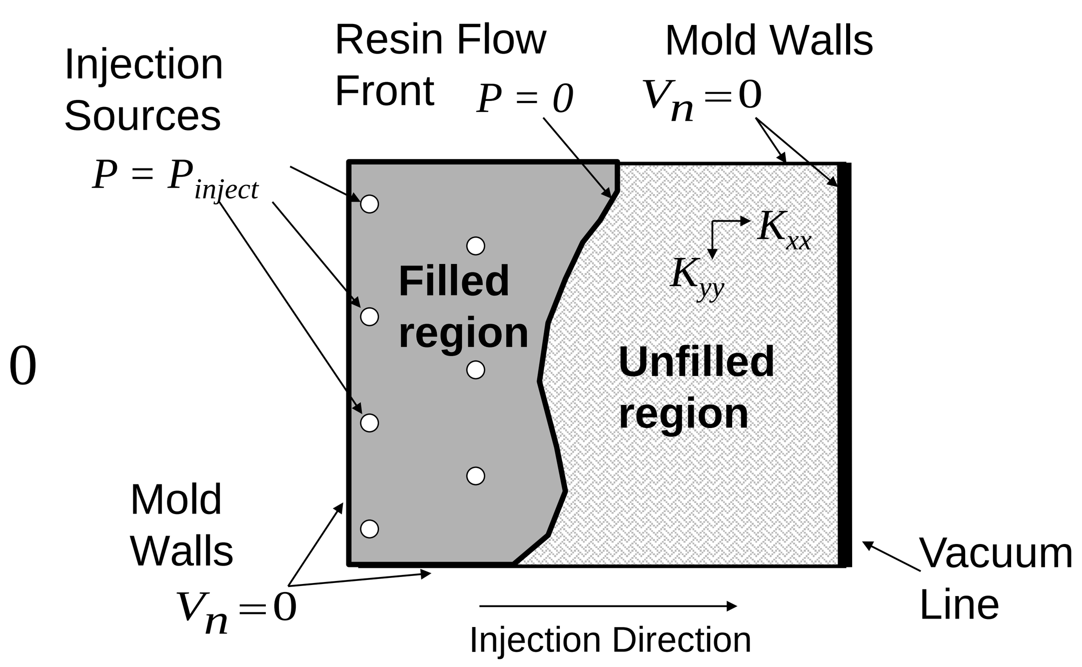
$\mathbf{v}$ = velocity vector,

$\mathbf{K}$ = permeability tensor,

μ = kinematic viscosity,

∇P = pressure gradient.

BOUNDARY CONDITIONS



This is a moving boundary condition problem in which the zero pressure contour (boundary) represents the resin flow front at any instant in time.

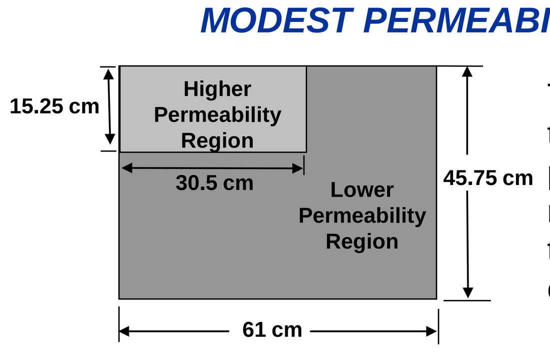
COMPUTER SIMULATIONS

The above expressions were solved numerically using the Liquid Injection Molding Software (LIMS) developed at the University of Delaware for simulating resin flow position over time within a mold.

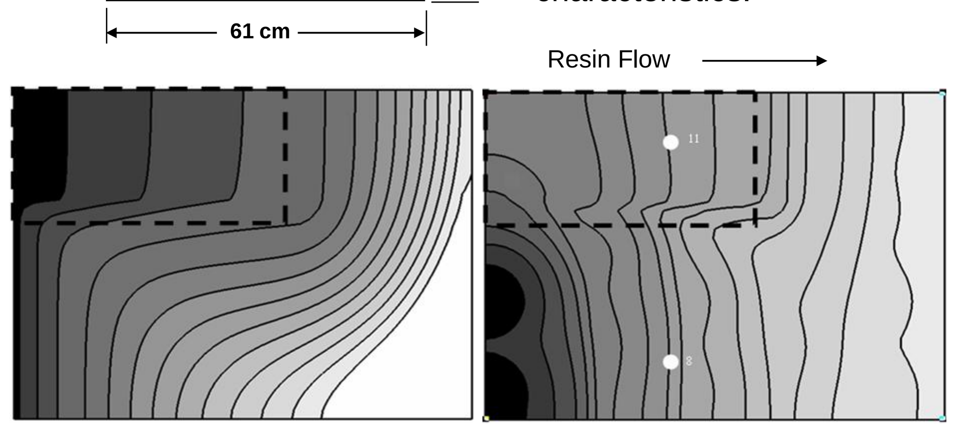
COMPUTER SIMULATIONS

SENERIO 1

MODEST PERMEABILITY VARIATION



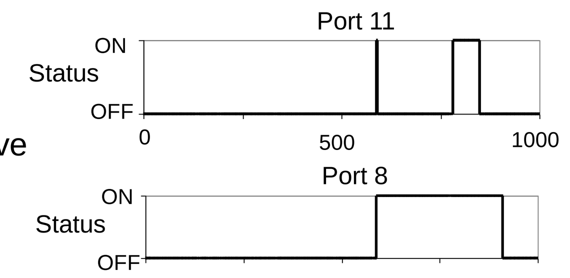
The heterogeneous mold to the left includes a *small* highly permeable region and a larger region with lower permeability, thus creating non-uniform flow characteristics.



Conventional VARTM Injection Line

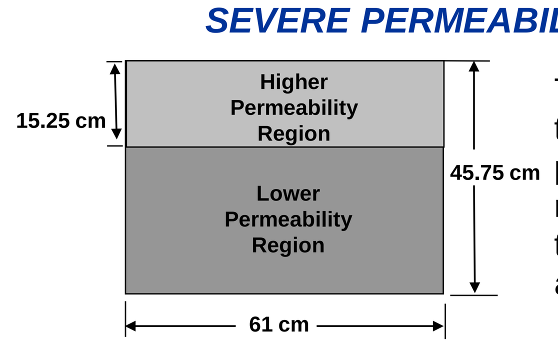
Setup 1 (shown above) with Control

Contour plots above show differences in the flow boundary over time. Complete filling was achieve due to the independent control of each port (right).

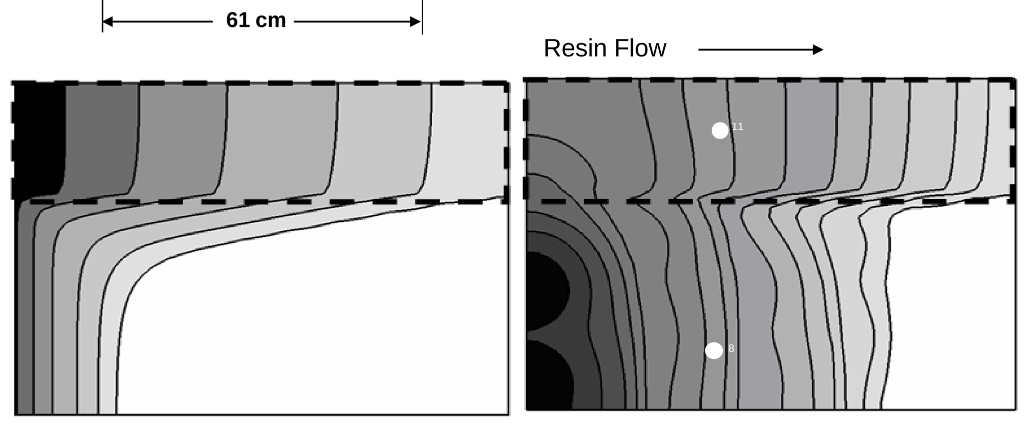


SENERIO 2

SEVERE PERMEABILITY VARIATION



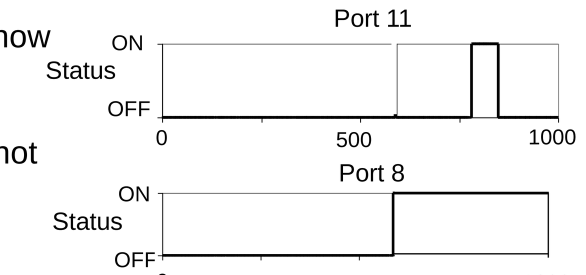
The heterogeneous mold to the left includes a *large* highly permeable region and a larger region with lower permeability, thus creating a large flow anomaly.



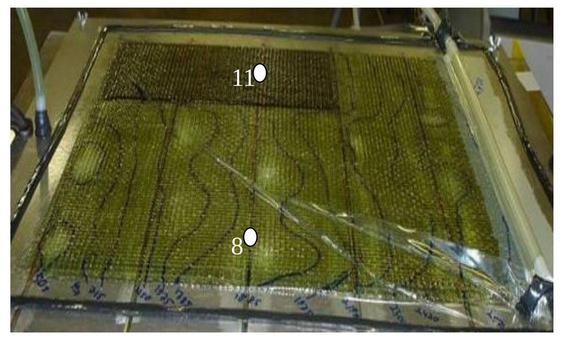
Conventional VARTM Injection Line

Setup 1 (shown above) with Control

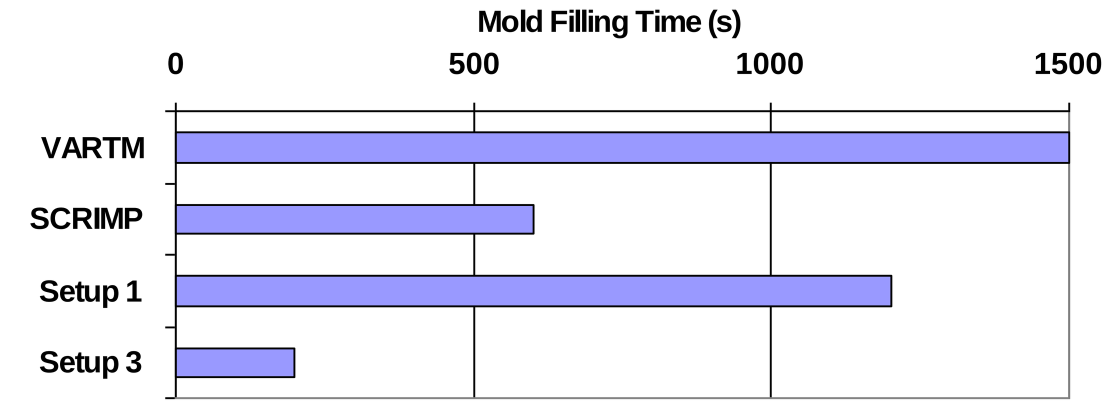
Contour plots above show differences in the flow boundary over time. Complete filling could not be achieved with the current port control algorithm.



EXPERIMENTAL VALIDATION



Lab-scale molds filled with a prototype port-based system confirm the filling characteristics predicted from the simulations (Scenario 1 is illustrated). Measurements of fiber volume fraction and flexural characteristics revealed no change in mechanical properties of parts infused using ports.



Experiments with homogeneous preforms were conducted to quantify time to fully infuse a part using various lay-ups. As evident with Setup 1, preforms placed directly over a port limit flow and extend fill time. The use of distribution media on the tooling surface significantly reduced filling time.

CONCLUSIONS

- Port-based injection is a viable resin delivery method for infusing composite preforms.
- Based on the FEA simulations and lab testing, this new technique can provide faster lay-up and injection times, as well as better resin control during infusion, thus insuring preforms are fully infused with resin.
- Resin flow velocities are limited by the local permeability above a port. As a result, Setup 3 and 4 provided the fastest filling times.
- Using a prototype intelligent computer controlled port injection system, significant void reduction was achieved for several (but not all) mold designs.

ACKNOWLEDGEMENTS

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