Gas Transport and Void Formation
in Out-of-autoclave Prepregs

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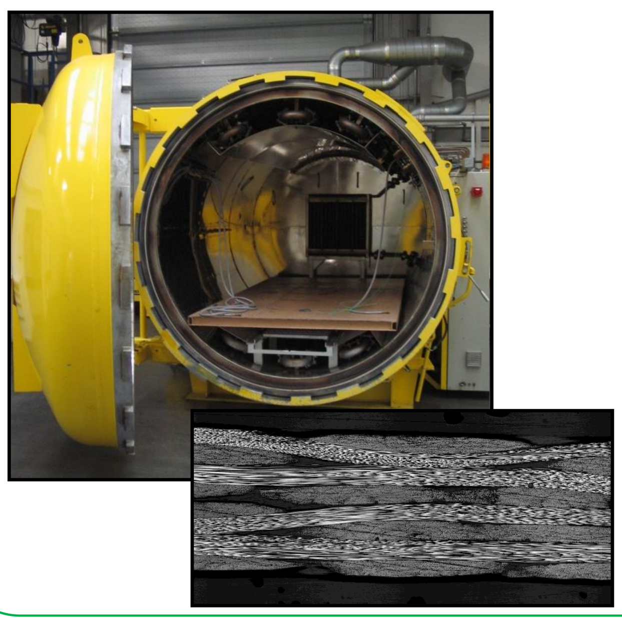
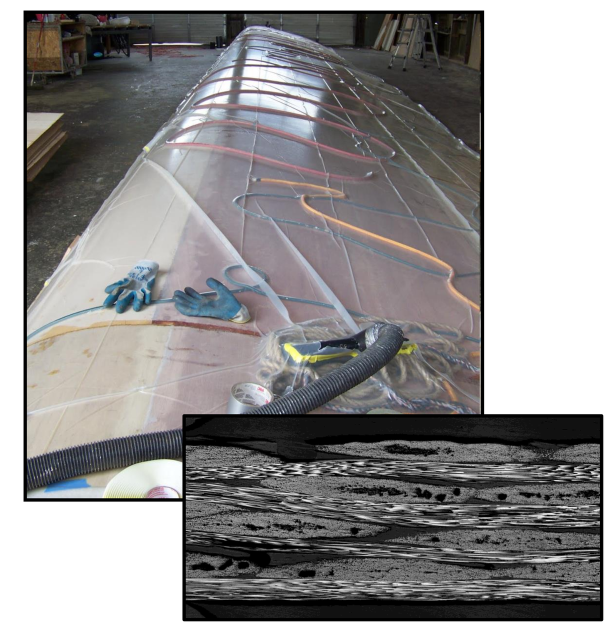
Autoclave versus Out-of-autoclave
1



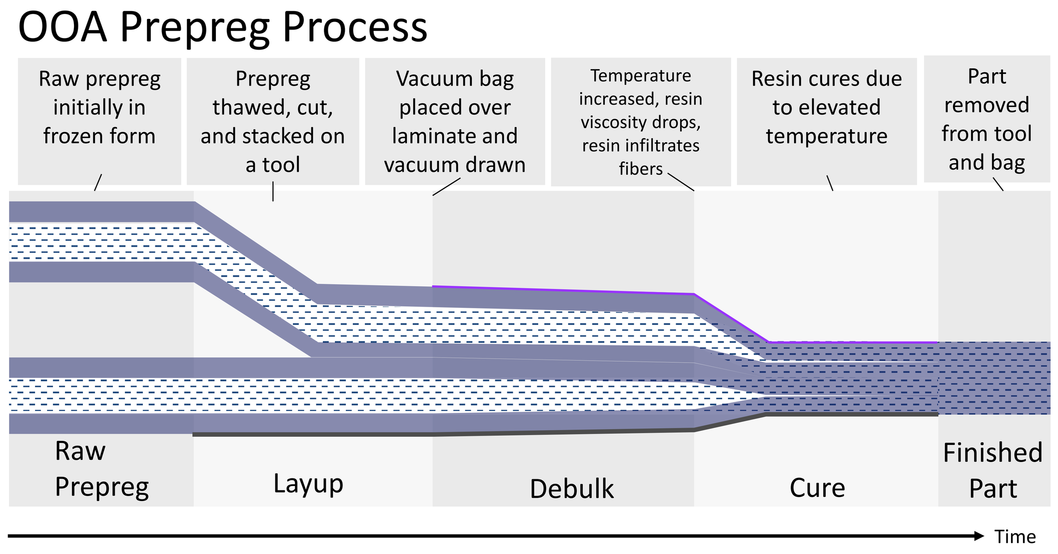
Autoclave Process
- Parts are cured at elevated temperature and pressure
- High pressure compresses voids, forces gas into solution, and helps keep volatiles dissolved in the resin
- Easier to produce low porosity parts
- Relatively high cost associated with purchasing and operating autoclave



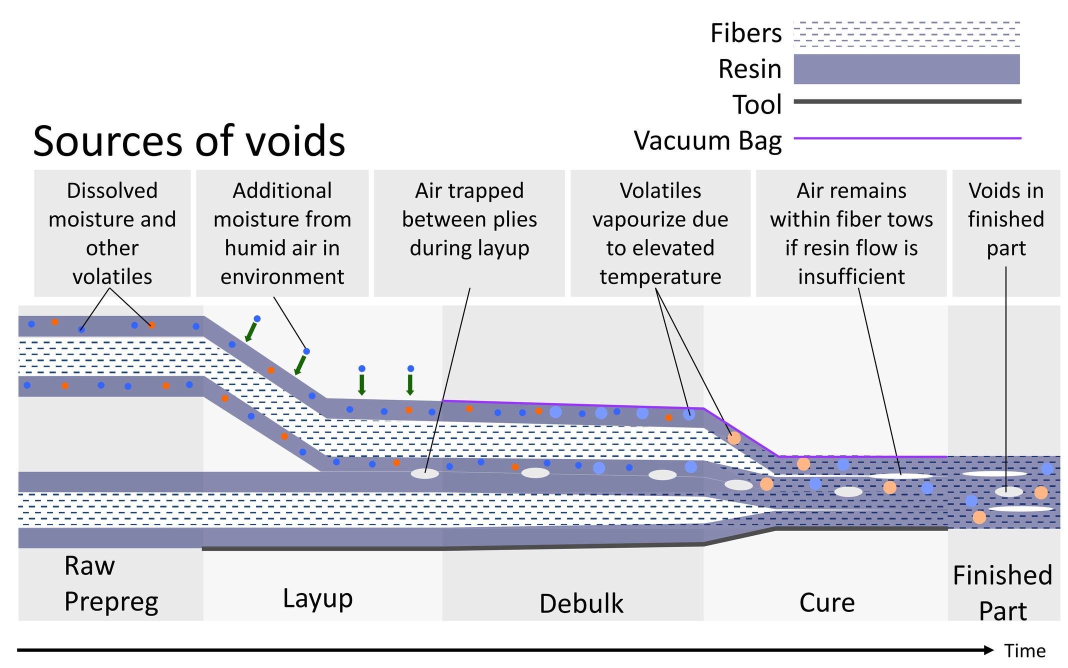
Out-of-autoclave (OOA) Process
- Parts are cured at elevated temperatures under a vacuum bag only, without additional pressure
- Lower pressures will lead to void formation if gas is not removed or if volatiles vaporize during cure
- Low porosity parts can be produced, but more knowledge is required to achieve this
- Low cost as only vacuum bag and an unpressurized oven are required

Void Sources in Prepreg Processing
2

OOA Prepreg Process



Sources of voids



Processing Parameters
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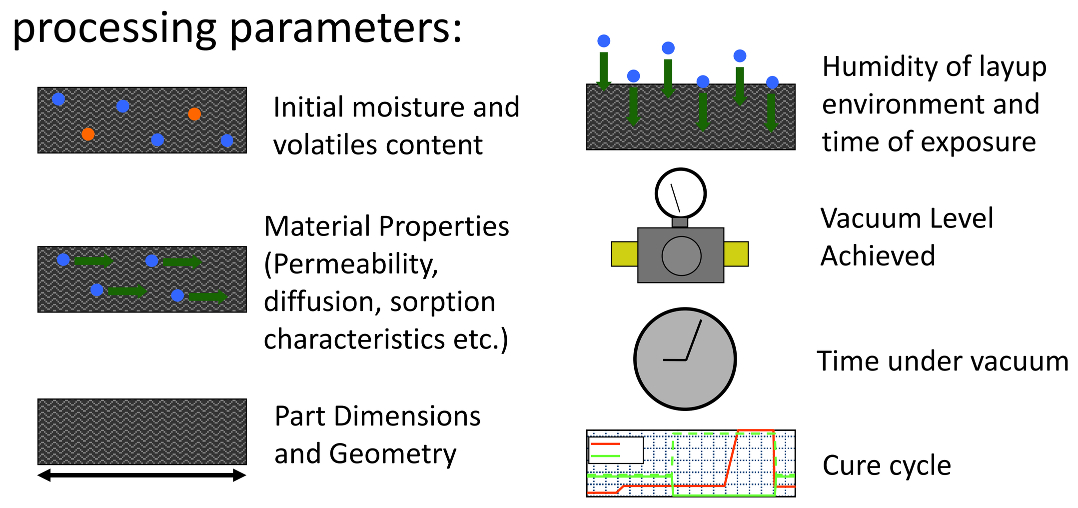
The porosity of a finished part will depend on the processing parameters:



Experimental Results[1]
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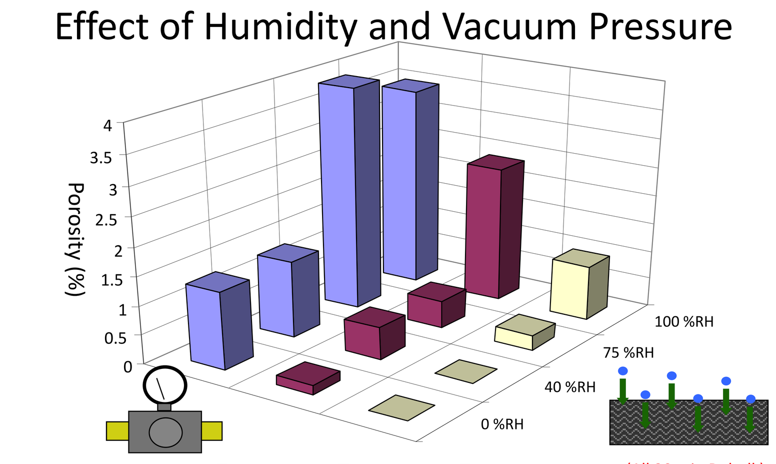
Small Parts (Length=64mm)
- Prepreg exposed to higher humidity levels produces parts with higher porosity
- Parts cured under full vacuum have lower porosity than parts under poor vacuum
- Low porosity parts can be made even under poor conditions if the parts are small enough (all parts are under 4% porosity, and most are under 2%)

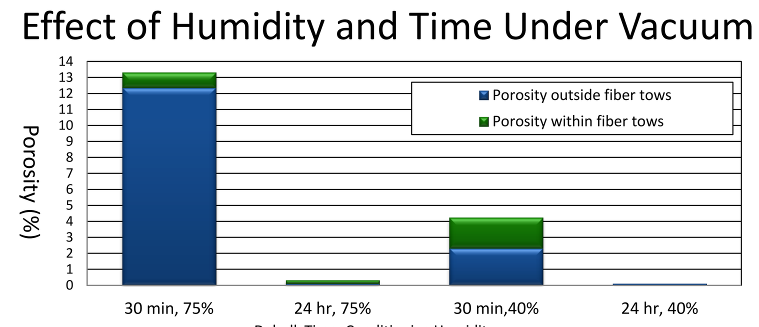
Large Parts (Length=1000mm)
- Pre-preg exposed to higher humidity levels produces parts with higher porosity
- Parts given a long debulk have very low porosity levels
- All else being equal, large parts have much more porosity than small parts

Porosity Gradients in Large Parts
- Large parts have lower porosity closer to the edge of the part that is exposed to the vacuum system
- Porosity increases with distance from this edge and eventually reaches a plateau

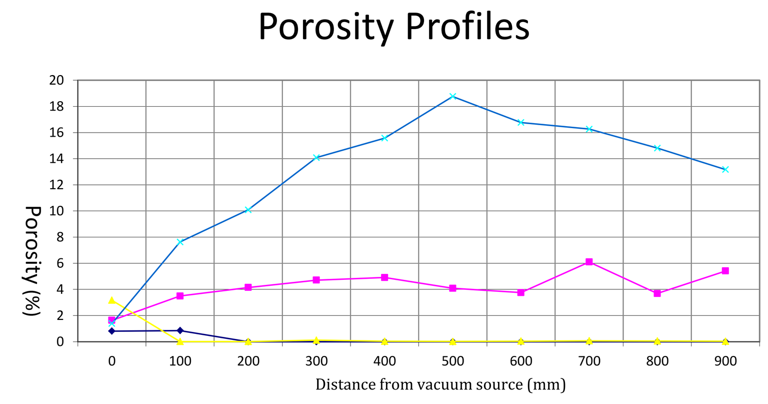
Effect of Humidity and Vacuum Pressure



Effect of Humidity and Time Under Vacuum



Porosity Profiles



Modelling
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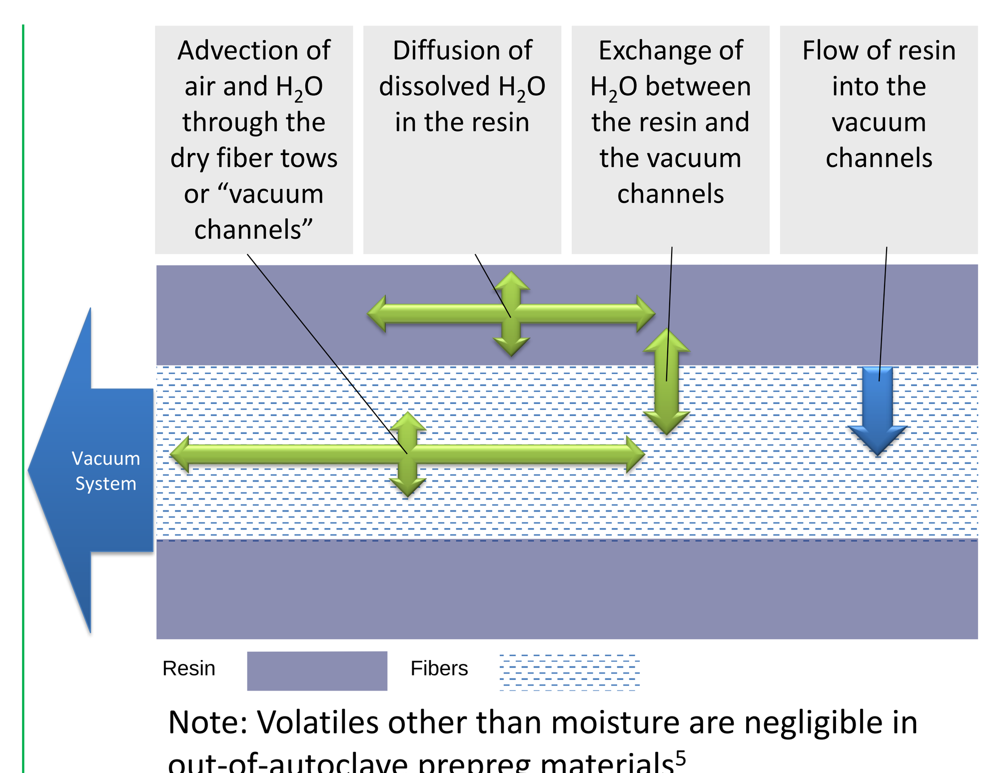
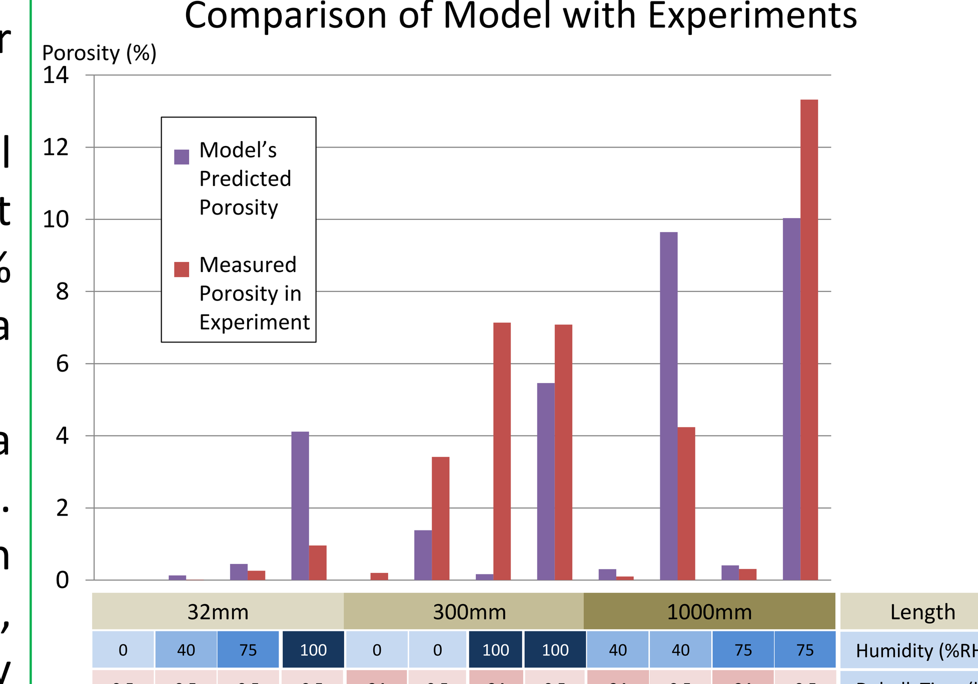
Transport Phenomena
- Void formation during prepreg processing is dependent on the movement of gas and resin
- The most important transport phenomena occurring are the flow of air and water vapour toward the vacuum system, the vapourization of dissolved moisture, and the flow of resin into the fibre tows
- These phenomena can be modelled using Darcy's law[3,4], Fick's law, and a parabolic sorption isotherm[2].



Note: Volatiles other than moisture are negligible in out-of-autoclave prepreg materials[5]

Predictive Power
- The model's predictions are poor for parts exposed to 100% humidity
- Excluding those parts, the model correctly predicted whether or not porosity would be below a 1% threshold in every case, and below a 2% threshold in every case but one
- Variability in the experimental data remains a challenge to modelling. Identically processed parts can often have very different porosity levels, and this may limit how well any model *can* predict part porosity

Comparison of Model with Experiments



Processing Parameters and Porosity
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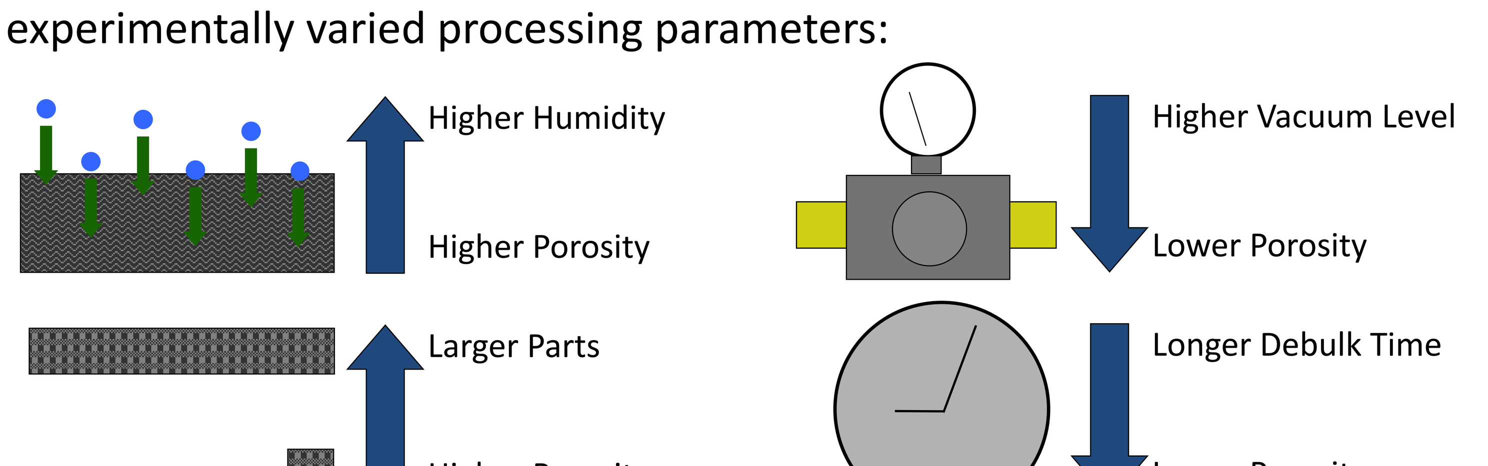
The experimental results show relationships between a part's porosity and the experimentally varied processing parameters:



Conclusions
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A relationship between processing parameters and part porosity in out-of-autoclave prepregs was experimentally demonstrated. We have begun to develop a mathematical model of this relationship. A simple implementation of this model shows some promise in its ability to make predictions of part porosity from the process parameters.

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