SIMULATION OF DUAL-PHASE FLOW IN POROUS MEDIA USING THE LATTICE BOLTZMANN METHOD

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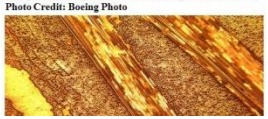
BACKGROUND

Reinforcements
- good structural properties
- strength
- stiffness
- low density

Composite materials

Matrix
- impact resistance
- protection against corrosion
- malleability
- toughness

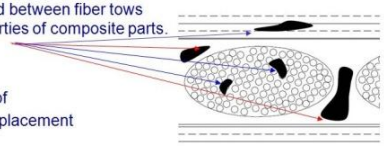
Composite fuselage section of the Boeing 787 Dreamliner. Photo Credit: Boeing Photo



BUT:
Coupling of the two "ingredients" is key

MOTIVATION

FACT: Voids between fibers and between fiber tows diminish the structural properties of composite parts.



NEED: A better understanding of
- Micro-void formation and displacement
- Role of capillarity

GOAL:
- Manufacture better parts through Liquid Composite Molding processes

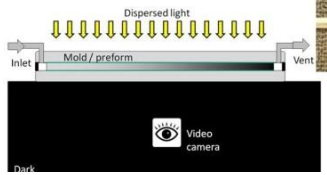
APPROACH:
- Analytical model to account for capillarity and air displacement
- **Experimental investigation**
- **Numerical approach** using the Lattice Boltzmann Method (LBM)

EXPERIMENTAL: ONLINE MONITORING OF PREFORM SATURATION

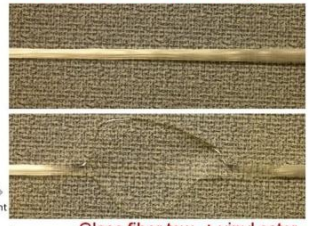
Observation: Vinyl ester and glass have similar refractive indexes

Consequence: Saturated fiber tows "disappear"

Application: Visualization of saturation status during an RTM injection in transparent mold



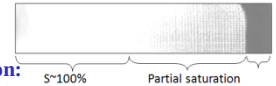
Glass fiber tow – before impregnation



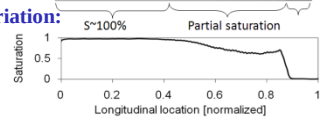
Glass fiber tow + vinyl ester

POTENTIAL OF TECHNIQUE

At mold level: Saturation = brightness

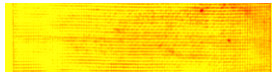


Void content variation:
- In time
- During process

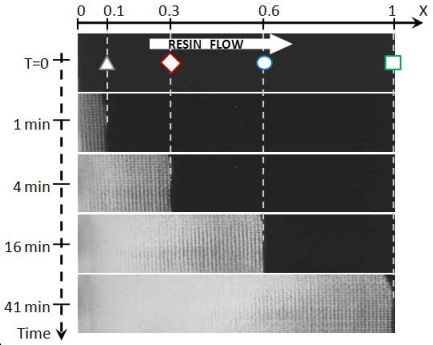


Previously used: C-scan

But, it shows void distribution:
- After injection
- After cure



RESULTS – TOW SATURATION VS. TIME



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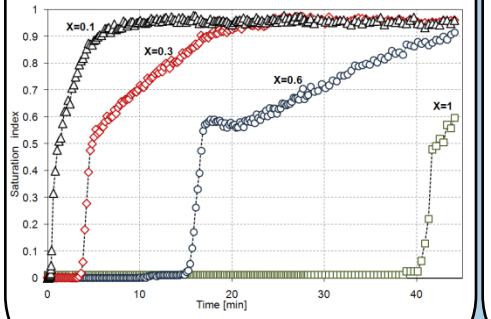
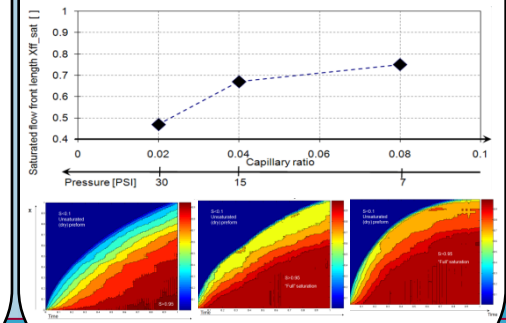


SATURATION VS. INJECTION PRESSURE (7,15,30psi)



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(Continued)

NUMERICAL: LATTICE BOLTZMANN METHOD (LBM)

Flow of multi-phase fluids through porous media is difficult to simulate using **computational fluid dynamics** because of:

- Complex geometry
- Surface tension effects
- Gas compressibility effects

Alternative: Lattice Boltzmann Methods, a class of techniques based on meso-scopic particles to simulate fluid flows.

Advantages:

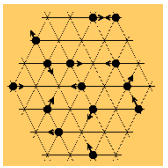
- LBM is suited to simulate flows around complex geometries
- Multi-phase flows
- Easily implemented on parallel machines

LBM - FEATURES

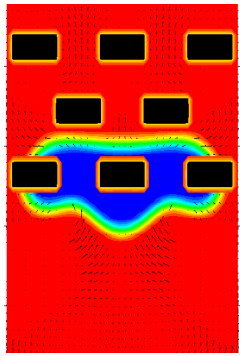
Flow is simulated through the collective behavior of a population of particles

Broad range of applications:

- Interface between phases
- Contact angles at a solid boundary
- Large density ratios between phases



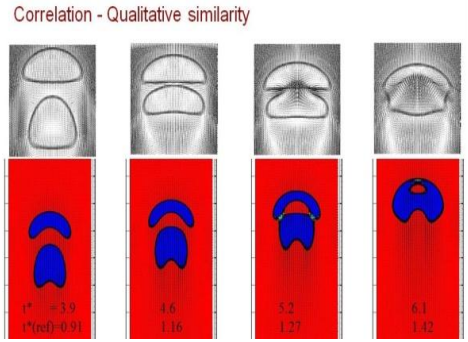
Collision / propagation of particles simulate flow



Gas pocket (void) moving through an array of obstacles (porous media)

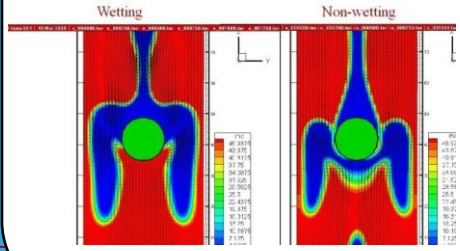
TEST CASE - TANDEM BUBBLES RAISING DUE TO BUOYANCY

- Qualitative validation – results compare well with literature



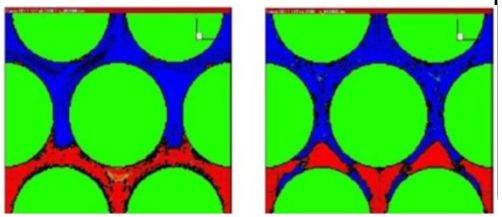
RESULTS – BUBBLE RAISING DUE TO BUOYANCY

The code simulates distinctly wetting and non-wetting behavior



RESULTS - RESIN IMPREGNATION OF FIBER TOWS

- Qualitative results seem reasonable
- Instabilities occur present at the solid / liquid/ gas contact line



Wetting Non-wetting

ROADMAP

LBM

- ✓ Gravity (buoyancy)
- ✓ Complex geometries
- ✓ Boundary conditions

Experimental

- ✓ RTM setup designed for online monitoring of tow saturation
- ✓ Technique established to determine variation of saturation with capillary effects

FUTURE WORK

LBM

- ➢ Contact angle between solid/ liquid / gas

Experimental

- ➢ Monitor saturation of one fabric layer
- ➢ Monitor saturation of individual tows

ACKNOWLEDGEMENTS

This work is supported by the Office of Naval Research through the Advanced Materials Intelligent Processing Center.

Assistance with the LBM approach:
Professor Lian-Ping Wang
(Department of Mechanical Engineering)

Collaboration on the experimental technique:
Dr. Jeffrey Lawrence
(VSC)