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Advanced Computational & Engineering Services

Simulation of Manufacturing Process of Ceramic Matrix Composites

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ACES

Simulation of Manufacturing Process of CMCs

- Background
- Problem statement
- Analysis structure
- Validation studies

Ceramic Matrix Composites

- Ceramic matrix reinforced with continuous or discontinuous reinforcement

- Reinforcement:
  - Whiskers, particles, fibers
  - Oxide and Non-oxide CMC
    - Eg: SiC_w/Si_3N_4 , C/C, C/SiC, SiC/SiC, Al_2O_3

Motivation - CMCs

Demand

- Increased $T_{operation}$
- Eliminate cooling
- Decreased weight

Result

- ➢ Increase performance
- ➢ Improved fuel efficiency

adapted from GE

Option

- Ceramics
- Inherently brittle

Opportunity

- ➢ Ceramic Matrix Composites (CMCs)

CMC Applications

- Aerospace
  - *Rocket propulsion, Aeroengine*
- Defense
  - *Armor*
- Automotive
  - *Brakes*
- Industrial
  - *Tooling, Turbines*
- Nuclear
  - *Fusion, Fission*

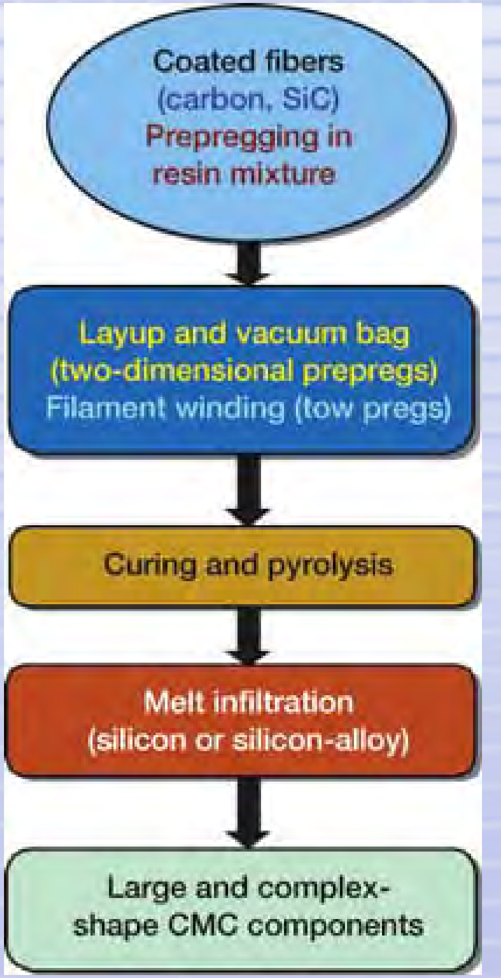
CMC Processing

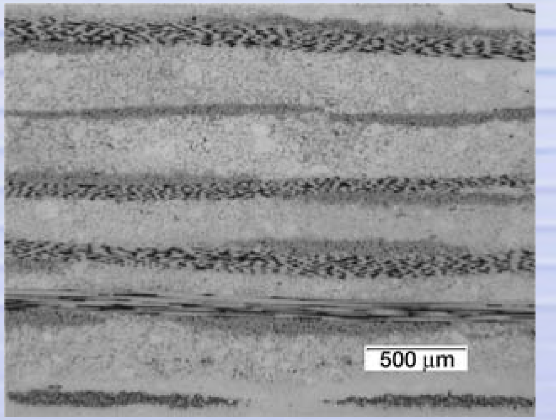
- Gas phase
  - *Chemical vapor infiltration (CVI)*
- Liquid phase
  - *Polymer impregnation and pyrolysis (PIP)*
  - *Reactive melt infiltration (RMI)*

CMC Processing: RMI

- RMI
  - *Liquid impregnation of porous preform*
  - *Quick*
  - *Low porosity*
  - *Thick sections*

CMC Processing: RMI

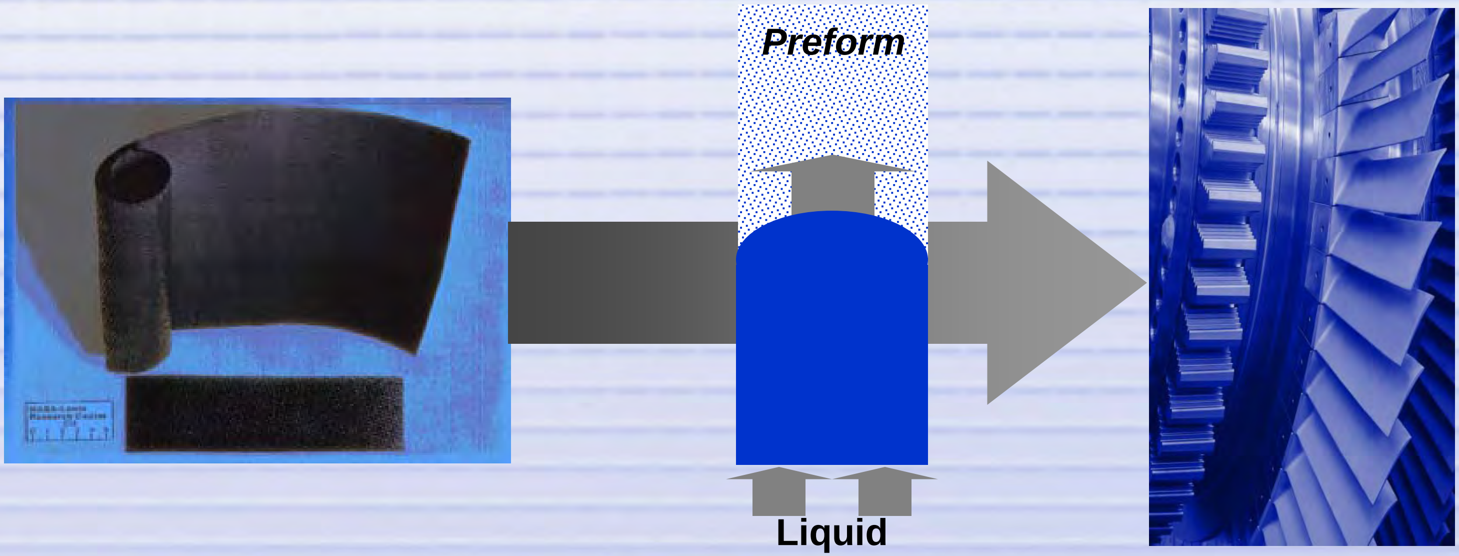




RMI Analysis

- Analytical tool to:
  - Incorporates interdependent multiphysics of RMI
  - Identify critical parameters
  - Optimize production process
  - Predict process parameters for complex geometries
  - Minimize process development time

RMI Problem Statement



Liquid flow
-Capillary flow
-Porous media

Thermal history
-***Applied***
-***Reaction***
-***Phase change***

Residual stress
-***Thermal***
-***Volumetric phase change***

Chemical reaction
-***Kinetics***
-***Thermal evolution***

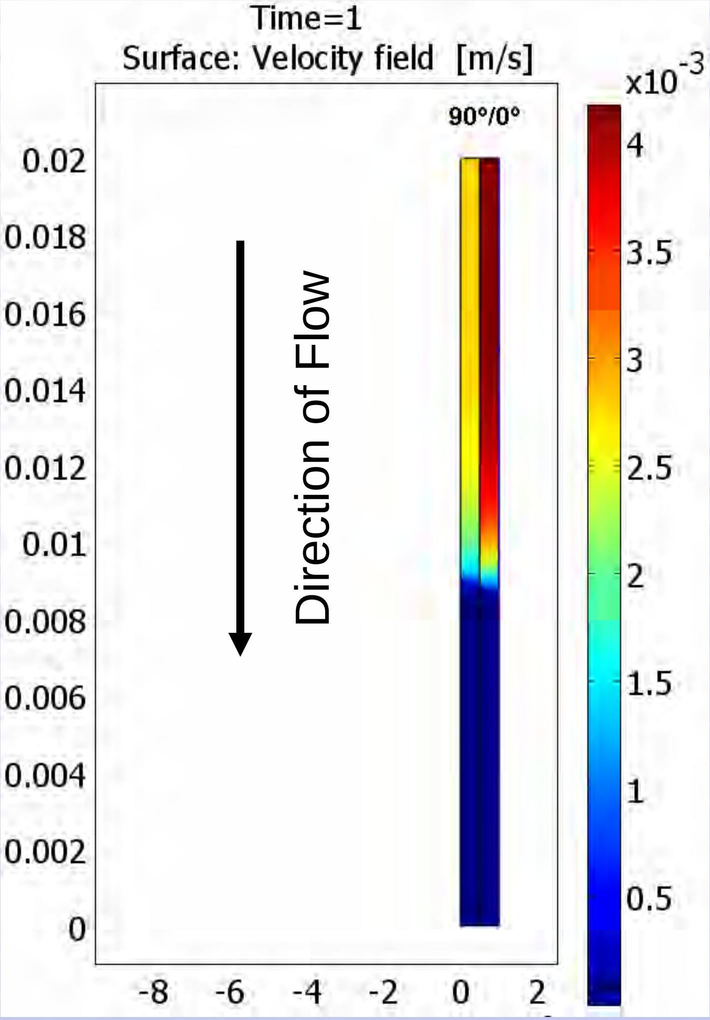
Microstructure
-***Excess material***
-***Unreacted matrix***

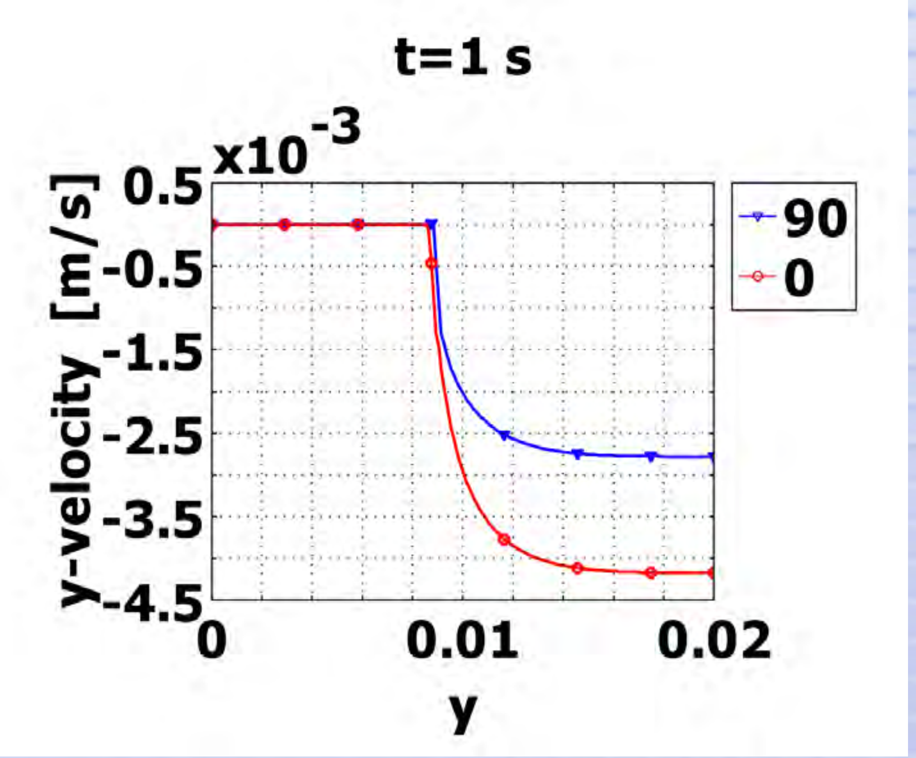
<u>Strongly coupled : Highly non-linear : Limited experimental data</u>

Analysis structure

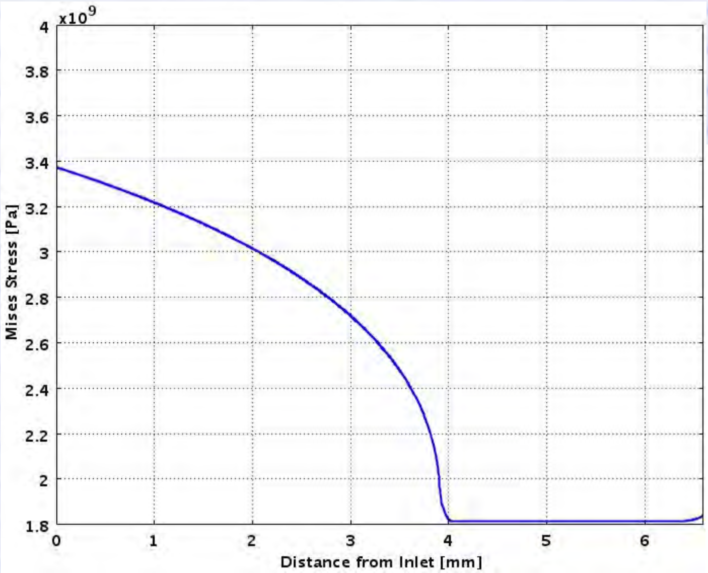
- Unsaturated flow of Si through porous C matrix:
  - *Richard's Equation*
  - *Darcy's Equation*
- Reaction kinetics for: $Si + C \rightarrow SiC$
- Volume change for: $Si + C \rightarrow SiC$
- Heat transfer
  - *Molten Si infiltrating porous C preform*
  - *Thermal evolution for: $Si + C \rightarrow SiC$*
- Stress analysis for residual stress/distortion
- All equations solved simultaneously using a concurrent multiphysics methodology

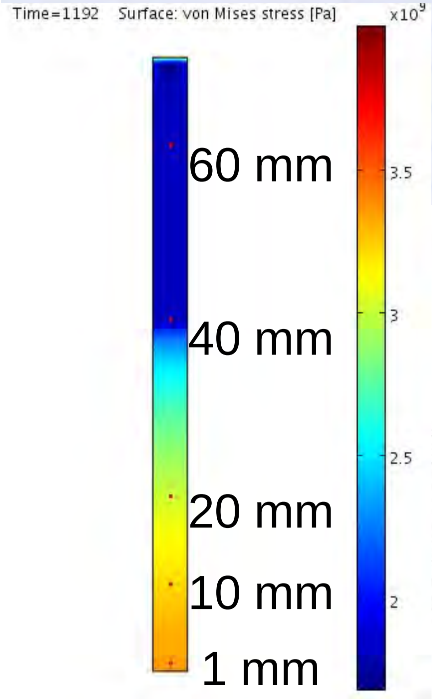
Unsaturated Flow - Velocity

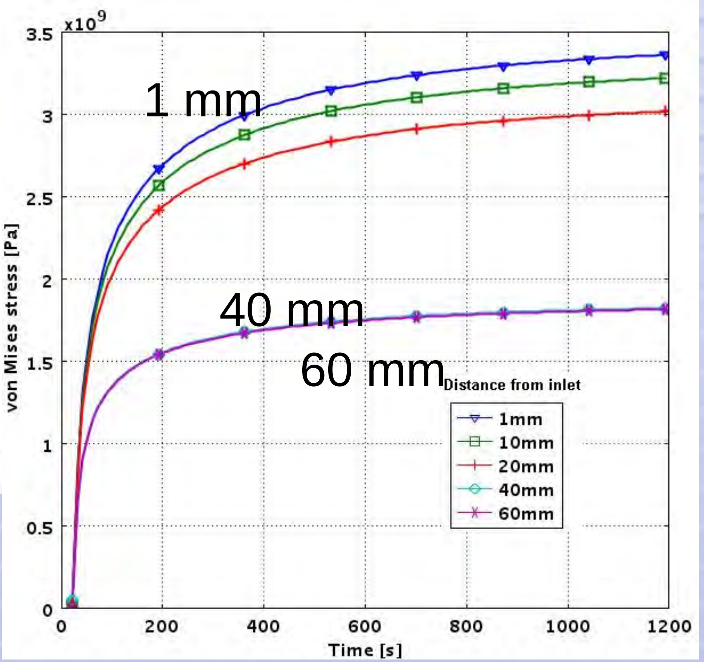




Residual Stress Distribution



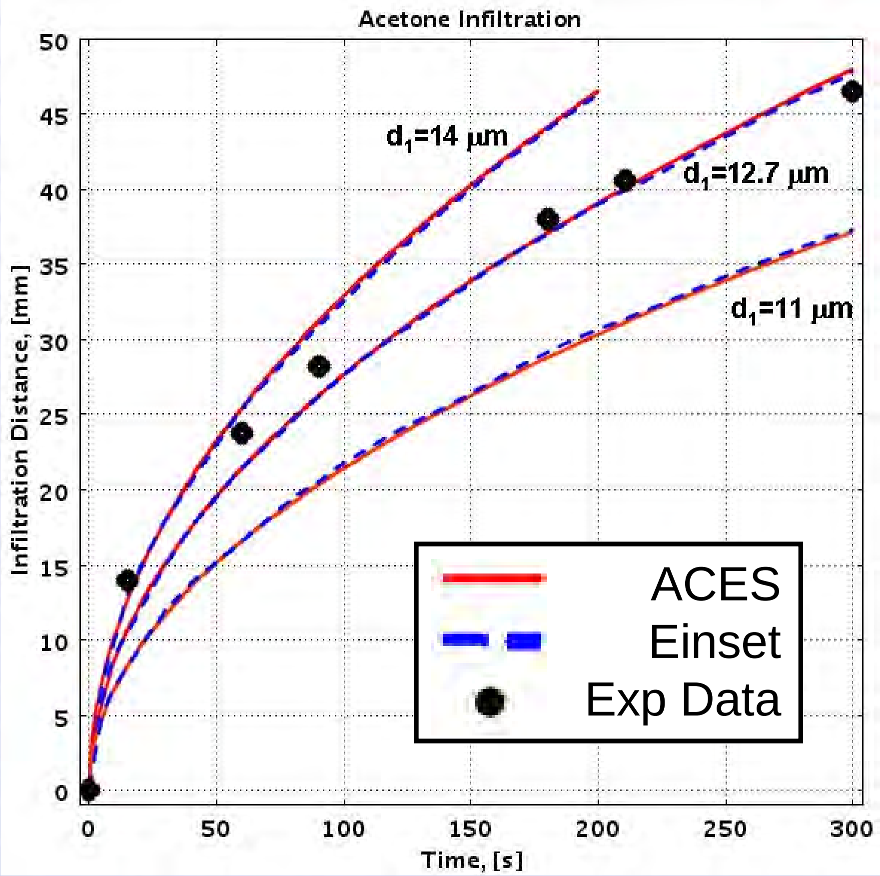




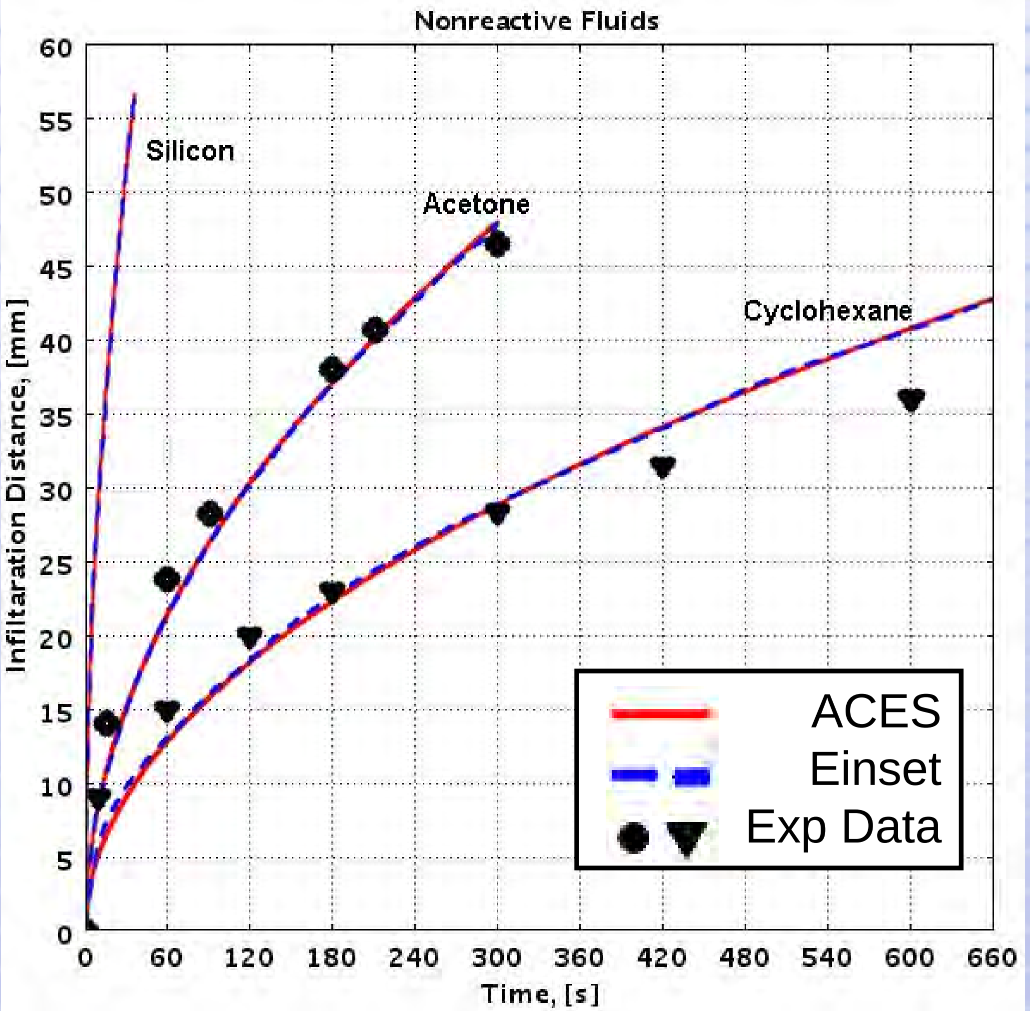
Validation studies

- Limited experimental data
- Previous analytical data
  - *Einset*
  - *Nelson*
- Validation parameters:
  - *Reactive flow*
  - *Non-reactive flow*

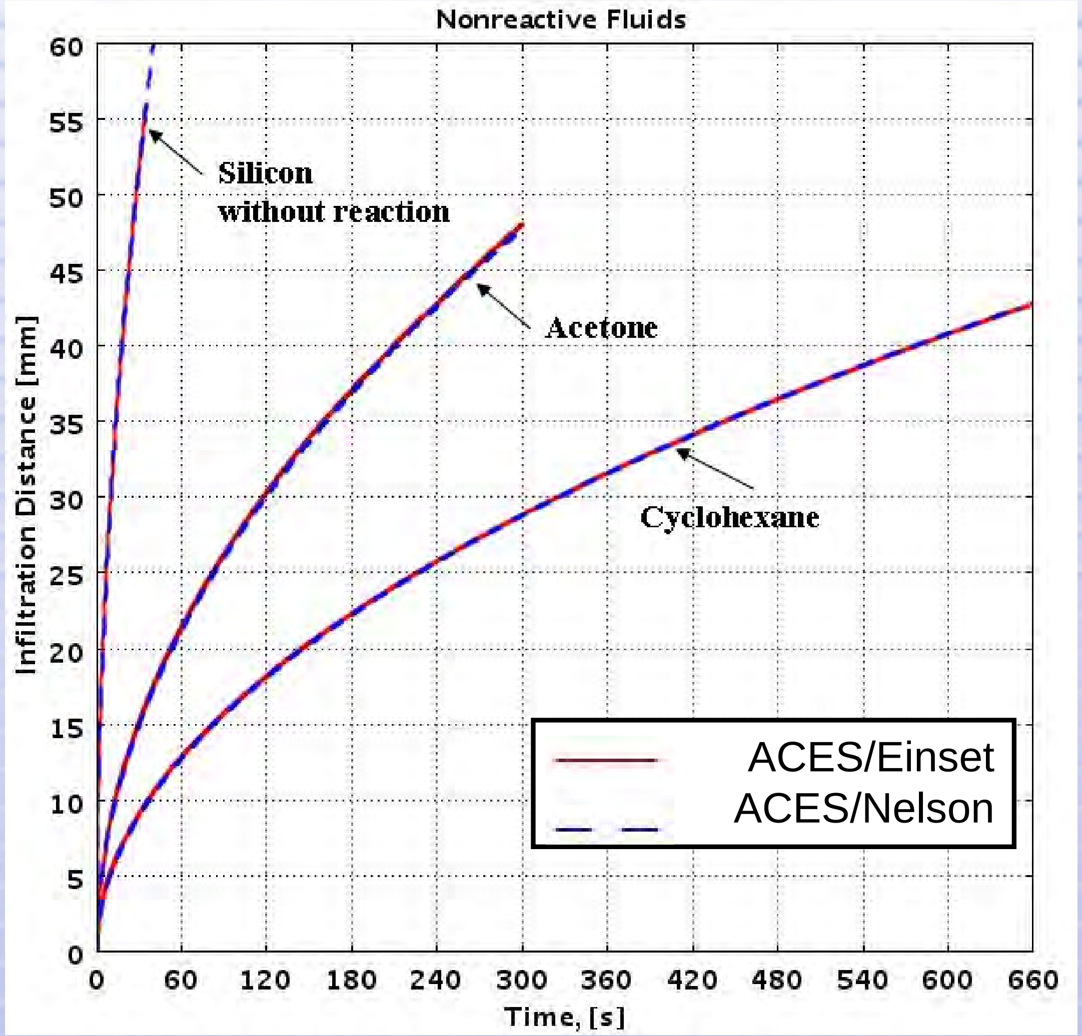
Validation – Nonreactive Flow



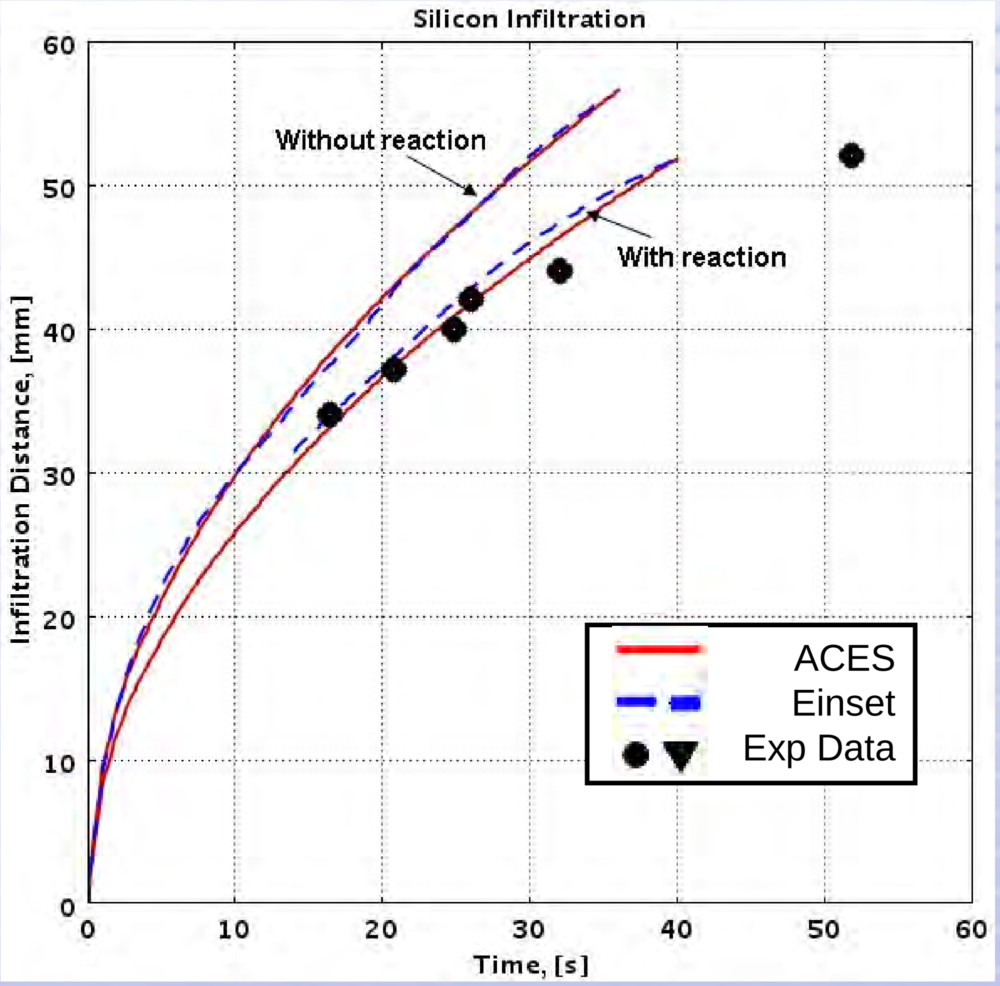
Validation – Nonreactive Flow



Validation - Analysis

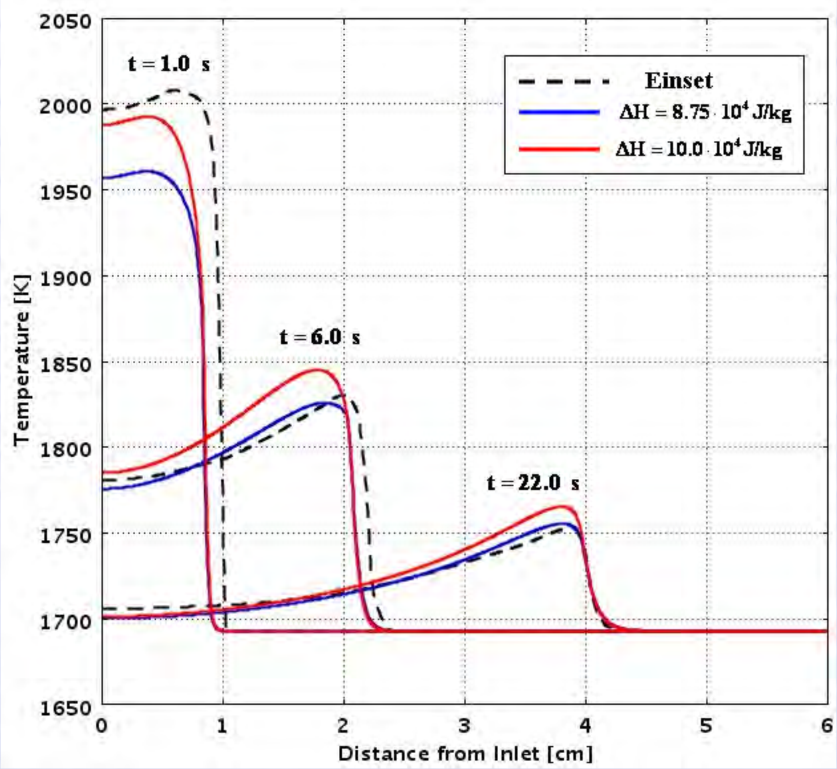


Validation – Reactive flow/reaction

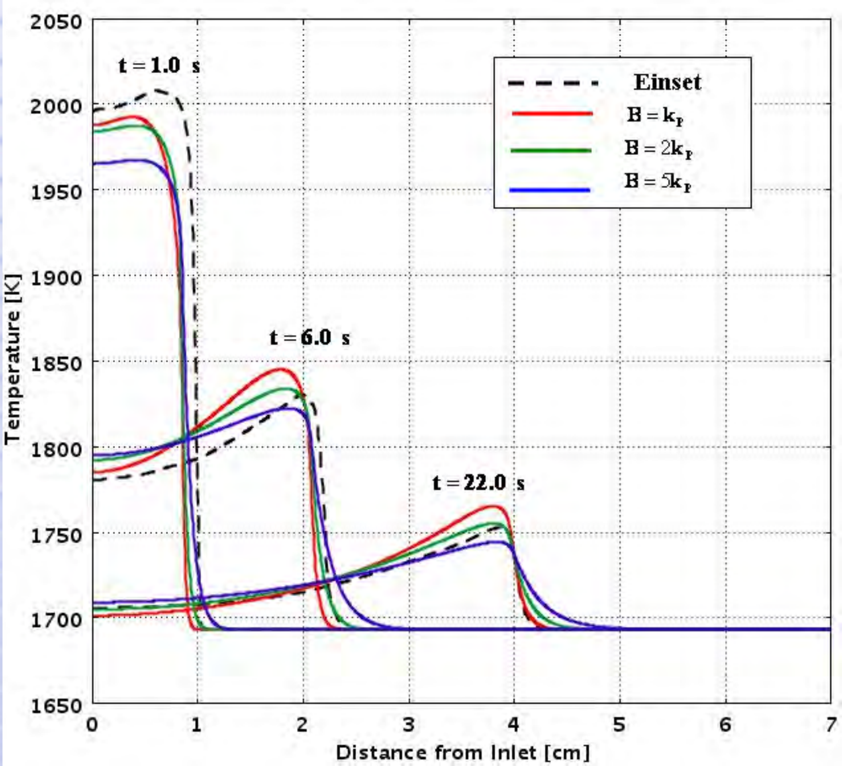


Validation - Temperature

Effect of Reaction Heat



Effect of Thermal Conductivity



Summary

- Concurrent multiphysics solution implemented in COMSOL Multiphysics
- Experimental and numerical data available for comparison for front position and temperature
- Results of current analysis compare favorably with previous work and experimental data
- Current analyses extend to include critical phenomena previously not included