SGL GROUP
THE CARBON COMPANY

Powerful Automation and Optimization Methods for Material and Process Analysis with Comsol Multiphysics and Matlab

BROAD BASE. BEST SOLUTIONS.

Dr. Thomas Frommelt

Comsol Conference, Paris, 17th-19th November 2010

Outline

- Background
- Matlab-based Automation
- Controlling with Comsol Global Equations
- Reverse Engineering of Transient Problems
- Summary and Outlook

Outline

Background

Matlab-based Automation

Controlling with Comsol Global Equations

Reverse Engineering of Transient Problems

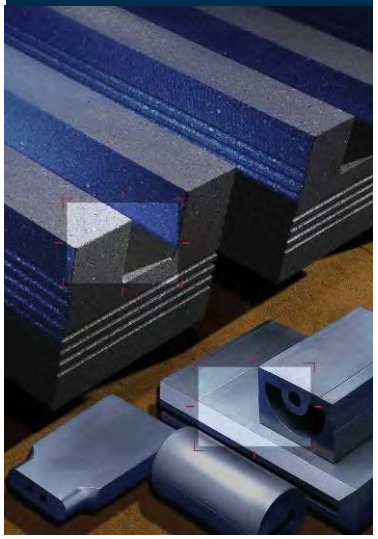
Summary and Outlook

SGL Group
Best Solutions for our Customers

Iron and Steel

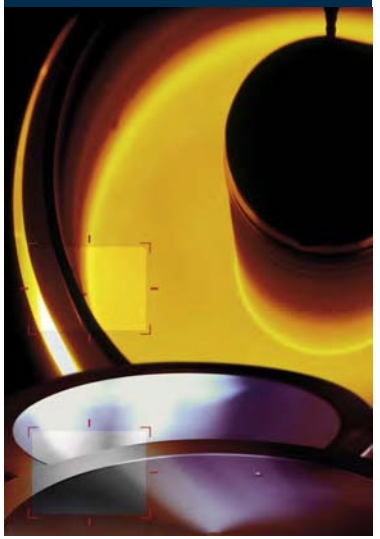
- High-performance graphite electrodes
- Carbon and graphite lining materials for blast furnaces

Non-Ferrous Metal



- Carbon and graphite cathodes in customized designs
- Fine-grain graphite for continuous casting

Semiconductor



- High-purity fine-grain graphite for Si monocrystal-growing
- Coated graphite susceptors

Best in Class Products, Services and Ideas to satisfy current and future Needs of our Customers

SGL Group
Best Solutions for our Customers

Automotive

- Cylinder head gaskets
- Carbon ceramic brake discs
- Pump components made of carbon and graphite

Mechanical Engineering

- CFRP light weight components
- Fine-grain graphite for electrical discharge machining

High Temperature Technology

- Graphite heaters and insulation material
- C/C charging systems

Chemicals

- Sealing material
- Thermal decom-position units
- Multi-tube heat exchangers

Best in Class Products, Services and Ideas to satisfy current and future Needs of our Customers

SGL Group
Modeling

- Leading manufacturer of carbon-based products with approx. 6.000 employees worldwide
- Centralized research and development:
  Technology & Innovation (T&I)
- Modeling group:
  - Material modeling
  - Product simulation
  - High-temperature processes
    - Heat and mass transport
  - Chemical conversion
  - High-temperature applications
    - Electro-thermo-mechanics
    - Induction heating


T&I Center

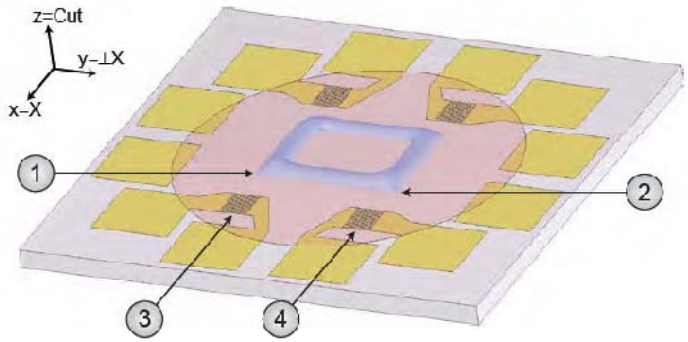

Electrode manufacturing

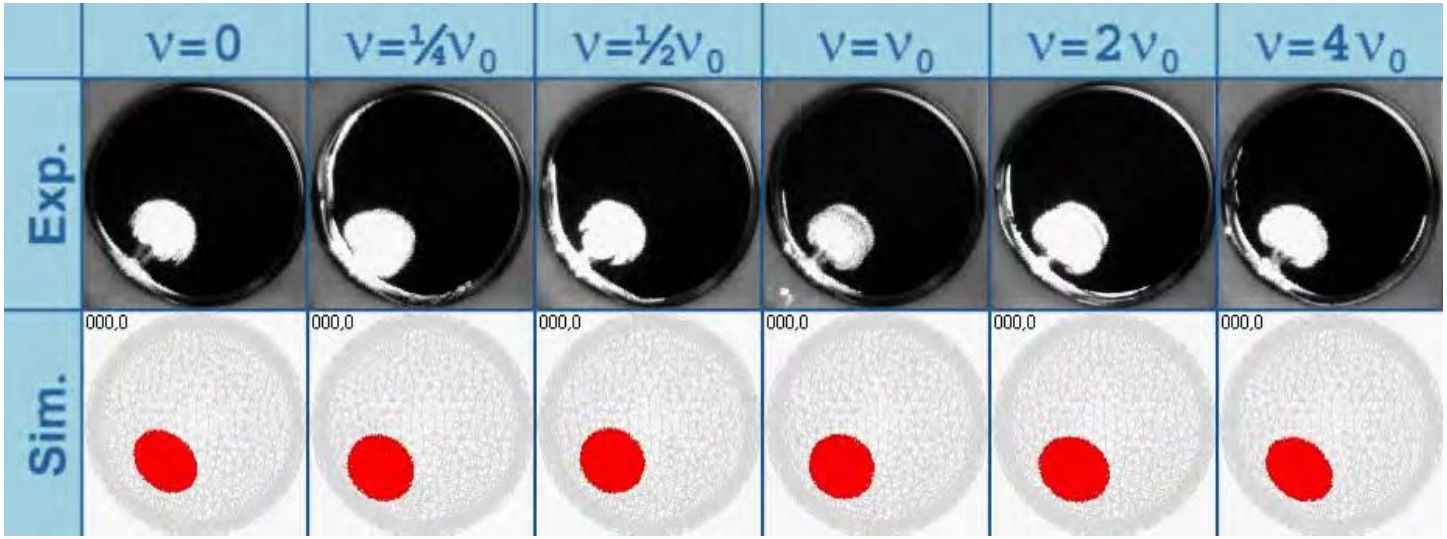

Brake discs


Graphite electrodes in arc furnace

Professional Background
T. Frommelt

- Experimental Physics
  - PhD thesis on microfluidics at University of Augsburg in 2007
  - Acoustically driven flow (3, 4) in free-surface fluid circuits (1, 2)
  - Script-driven mixing optimization of highly laminar flow





750µm

Outline

Background

Matlab-based Automation

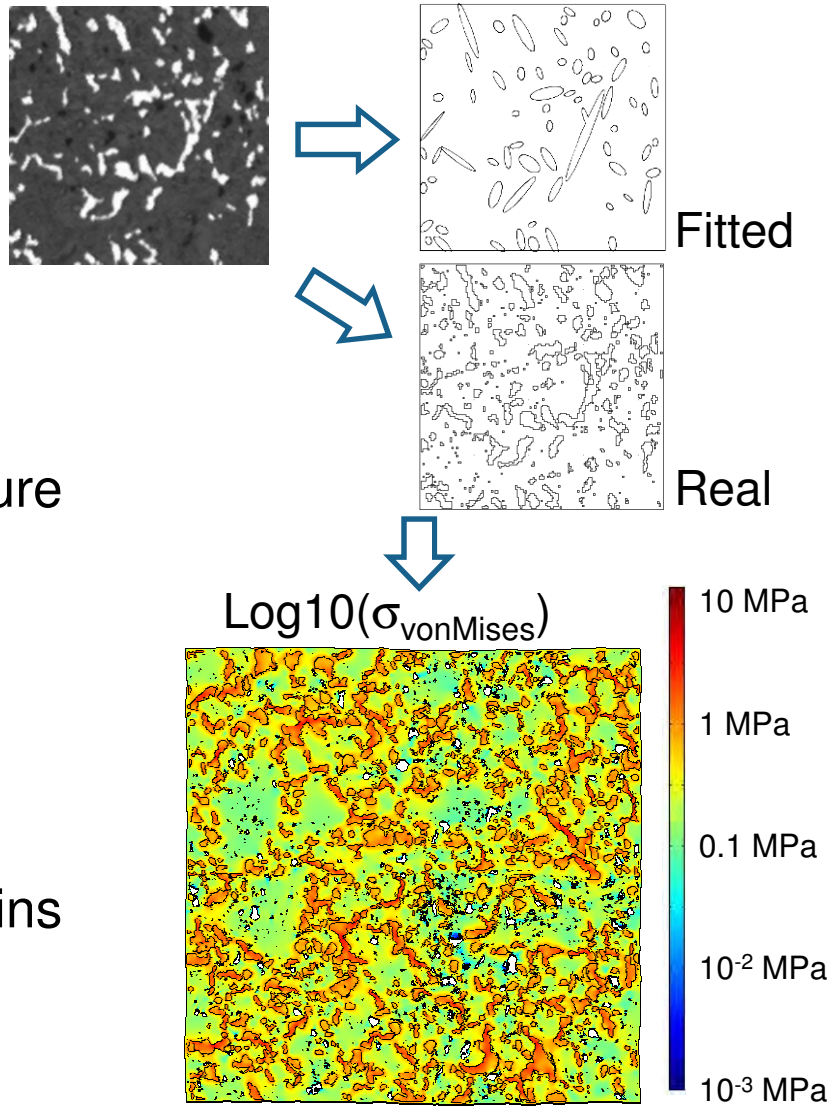
Controlling with Comsol Global Equations

Reverse Engineering of Transient Problems

Summary and Outlook

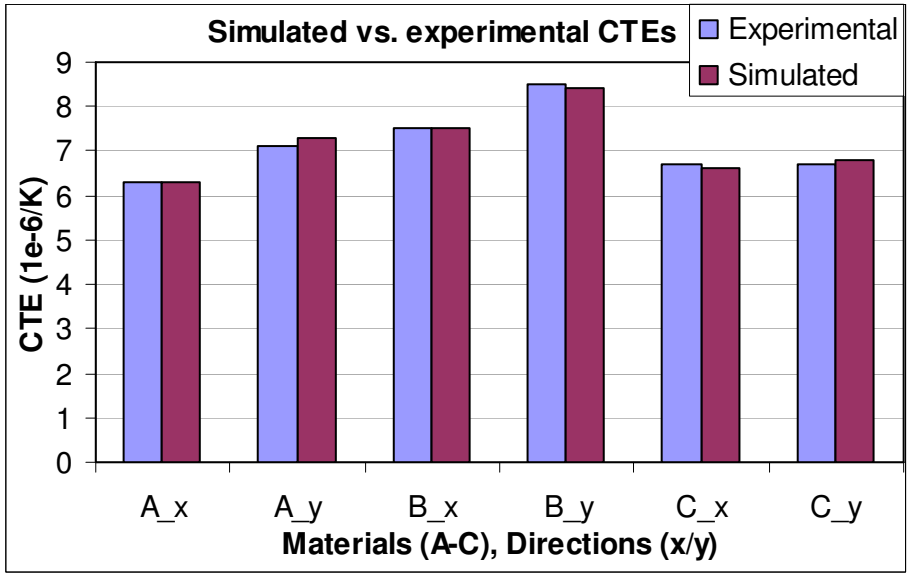
Metal Matrix Composite: Al–Infiltrated Graphite
Task and Solution

- Target: Simulate material properties using the real microstructure
- Matlab image analysis:
  - Identify representative area
  - Segment into graphite, metal and voids
  - Transform into real or fitted microstructure
- Matlab-automated simulation
  - Rotate representative area
  - Setup microstructure
  - Thermo-mechanic application mode
  - Set properties of hundreds of subdomains
  - Generate periodic boundary conditions
  - Simulate thermal expansion

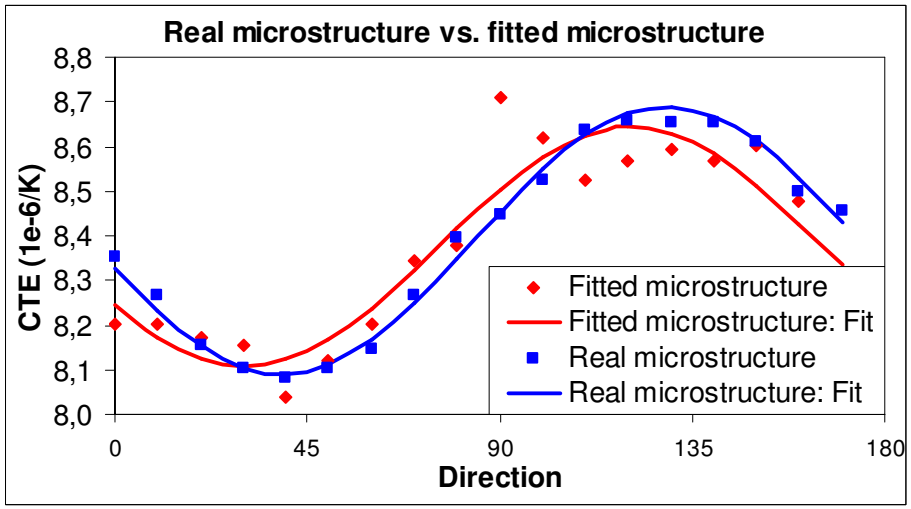


Metal Matrix Composite: Al–Infiltrated Graphite
Results

- Excellent agreement of anisotropic coefficients of thermal expansion (CTE)



- Simulations of real microstructure and fitted microstructure yield comparable results



Outline

Background

Matlab-based Automation

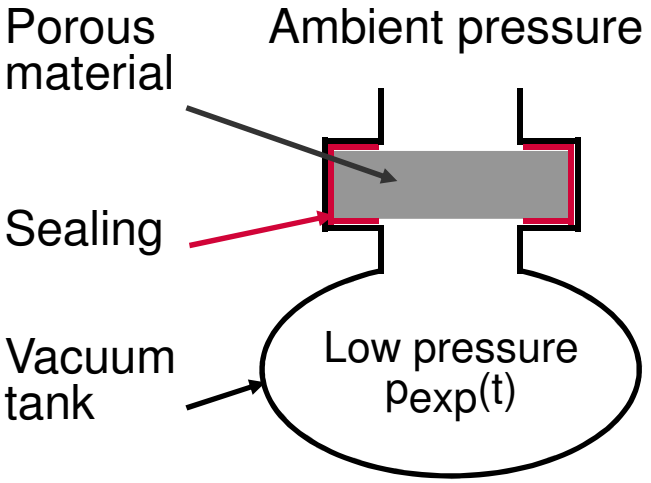
Controlling with Comsol Global Equations

Reverse Engineering of Transient Problems

Summary and Outlook

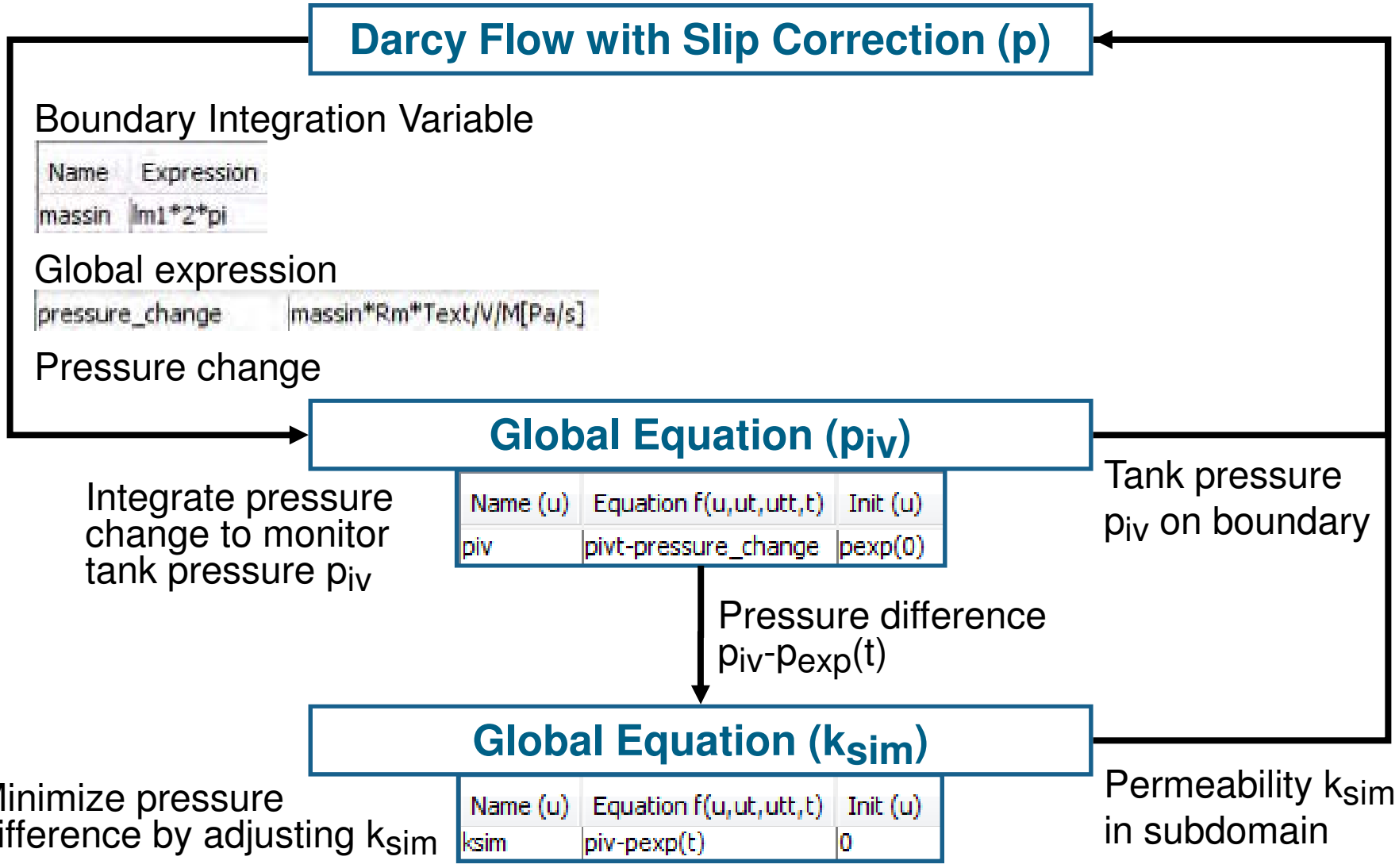
Permeability Measurement Setup Analysis
Task

- Permeability measurement by vacuum decay method
  - Slip flow of gas through porous material into an evacuated tank
  - Continuous pressure rise $p_{exp}(t)$ in tank
  - Experimental pressure change dp_{exp}/dt depends on material permeability



- Target: The model adjusts the material permeability k_{sim} such that model tank pressure p_{iv} follows experimental pressure $p_{exp}(t)$

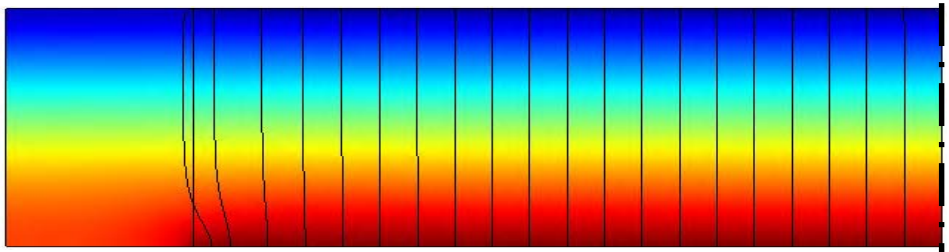
Permeability Measurement Setup Analysis
Solution



Permeability Measurement Setup Analysis
Results

- Determines permeability including all effects like slippage or local sealing of specimen

Pressure distribution and streamlines



Symmetry axis

- Results of vacuum decay method agree with reference method

Specimen	Vacuum decay method [mD]	Reference method [mD]	Deviation []
1	2,75E+00	2,84E+00	-3%
2	3,17E+00	3,06E+00	4%
3	5,74E-01	6,01E-01	-4%
4	7,20E-01	7,35E-01	-2%
5	1,70E-01	1,66E-01	3%
6	1,11E-01	1,08E-01	2%

$1\ D = 9.87 \cdot 10^{-13}\ m^2$

Outline

Background

Matlab-based Automation

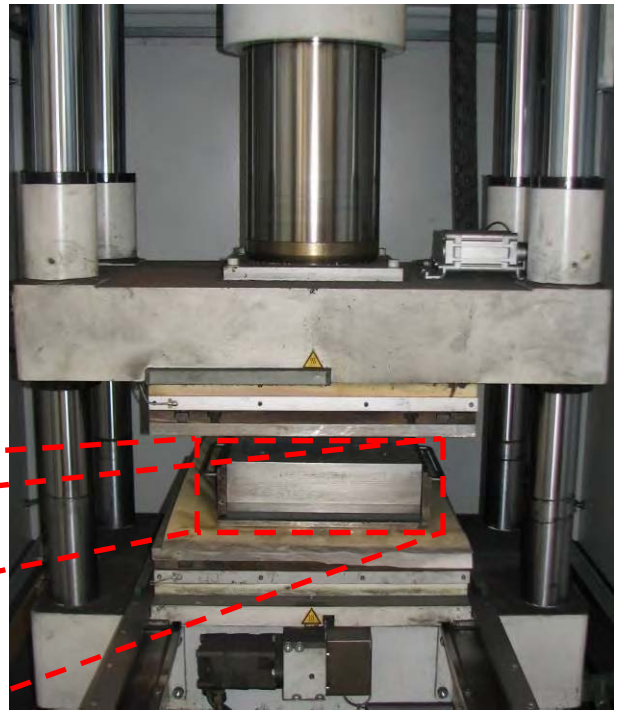
Controlling with Comsol Global Equations

Reverse Engineering of Transient Problems

Summary and Outlook

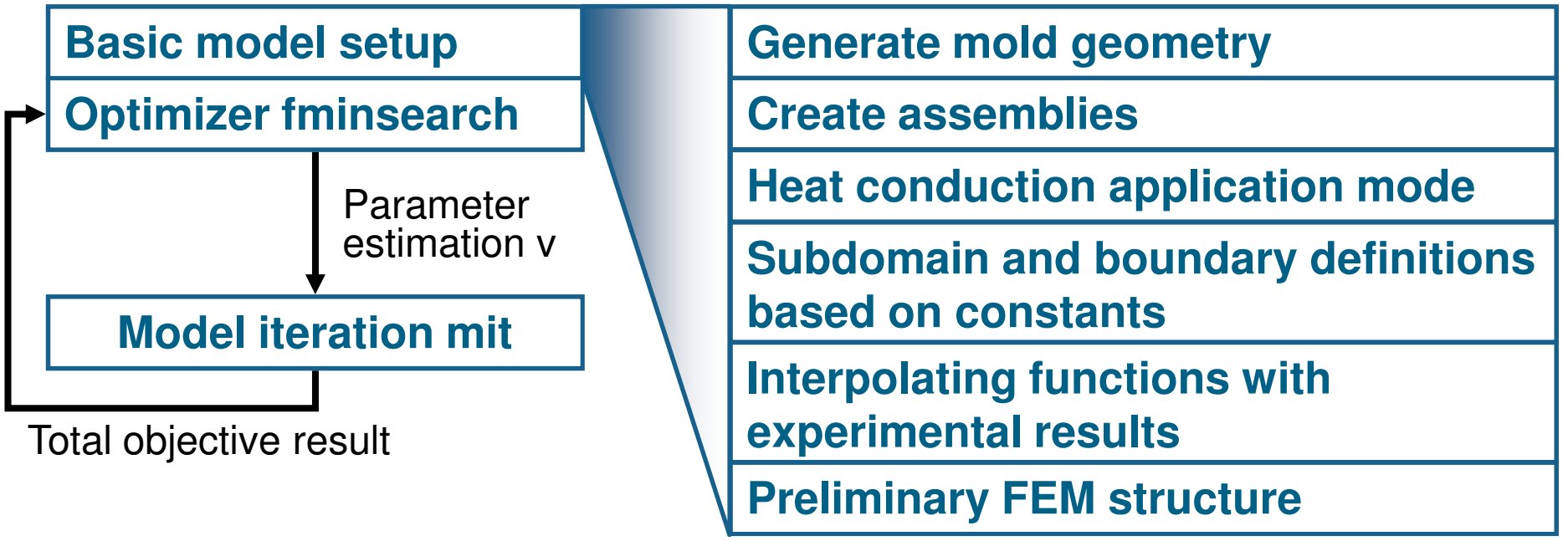
Molding of Composite Sheets
Task

- Molding of composite sheets
  - Fiber resin mixture in heated mold
  - Inhomogeneous curing is a relevant potential failure source:
    - Failure during further thermal processing
    - Bending of sheets



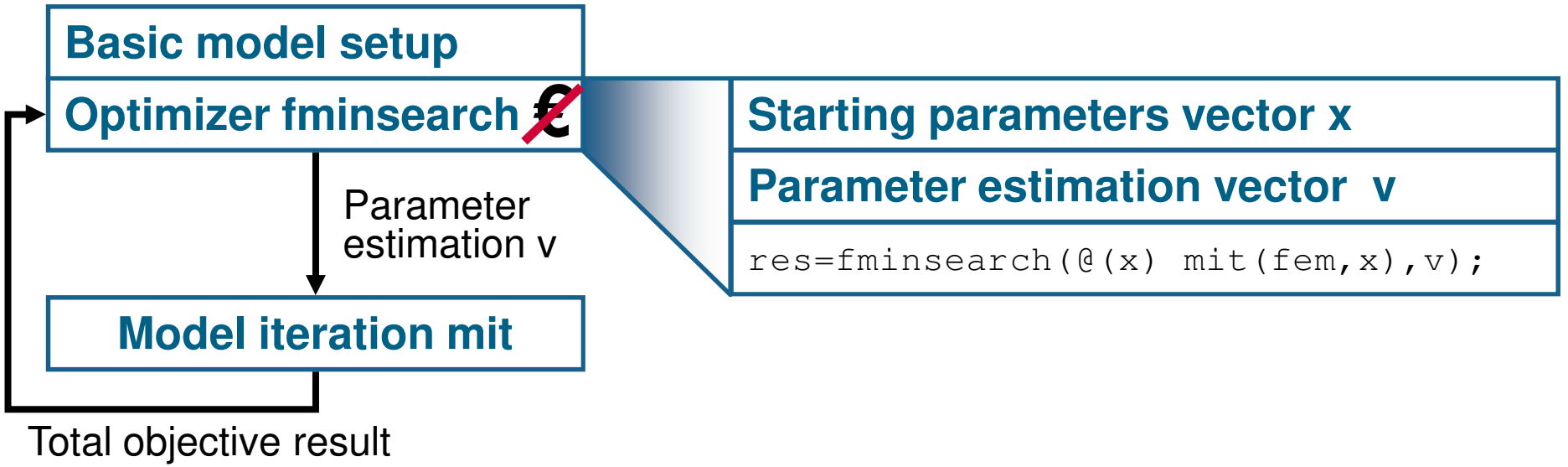
- Target: Develop temperature program for different sheet thicknesses
  - Homogeneous curing of resin
  - Minimum curing cycle time for high throughput

Molding of Composite Sheets
Solution



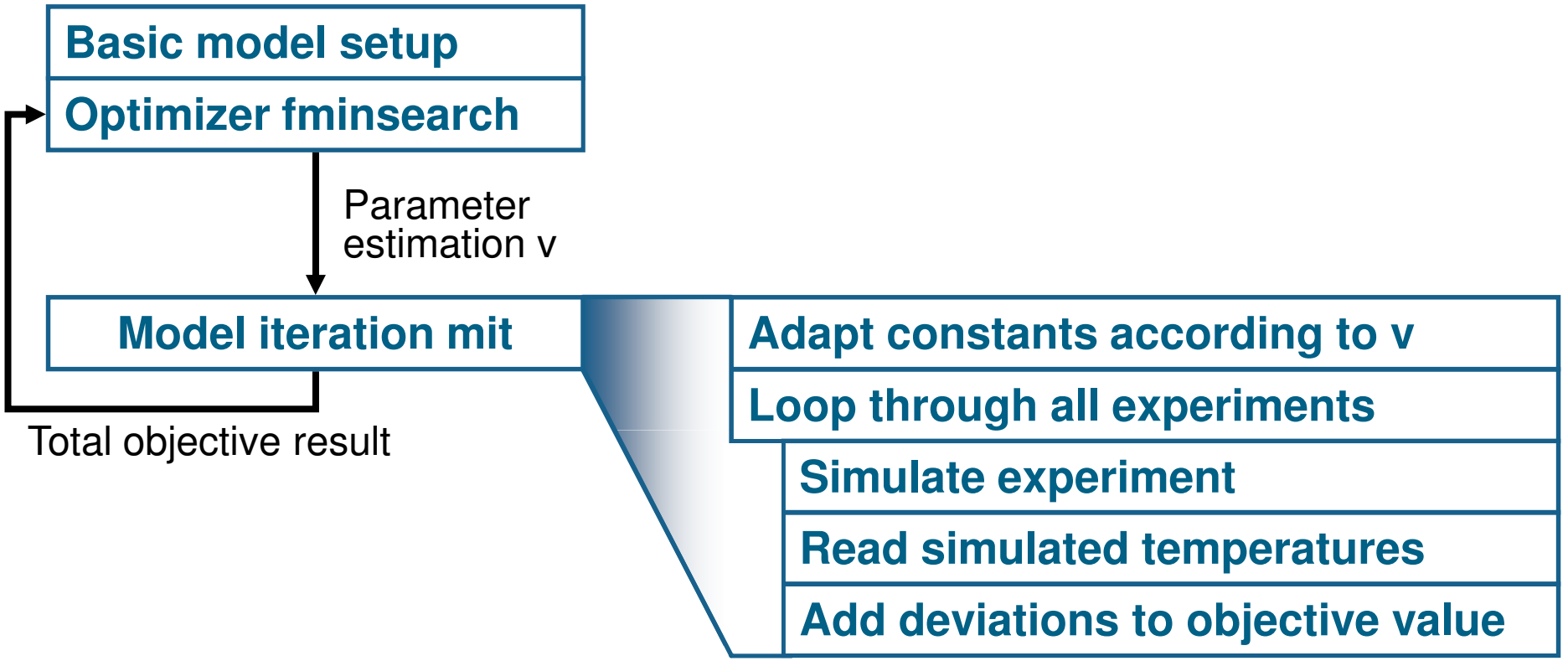
- 1st step: Reverse calibration of mold's thermal properties

Molding of Composite Sheets
Solution



- Free optimizer fminsearch!
- 1st step: Reverse calibration of mold's thermal properties

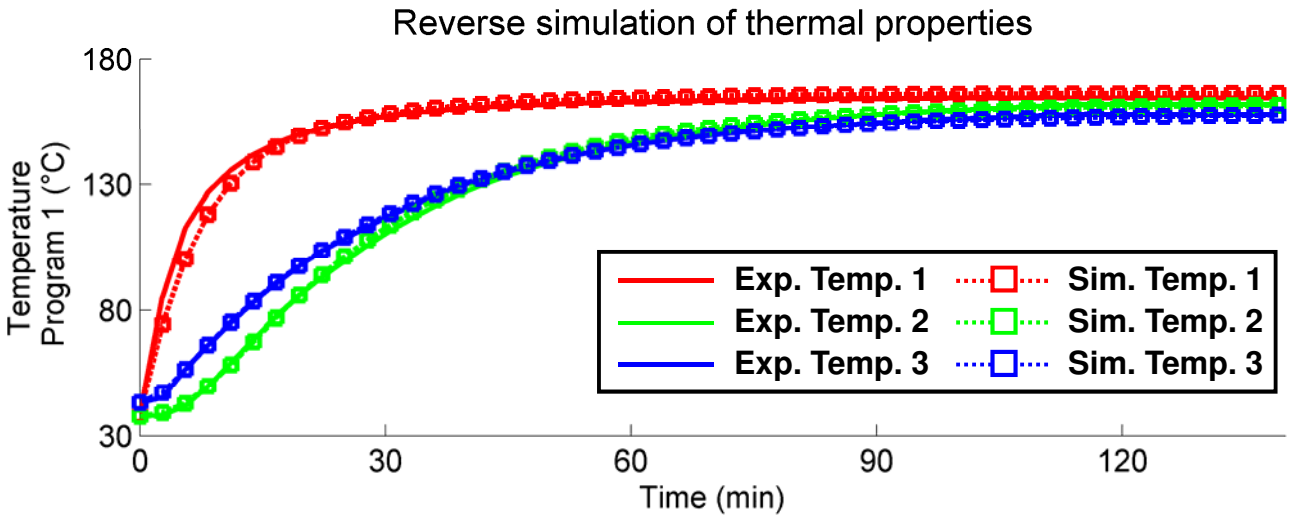
Molding of Composite Sheets
Solution



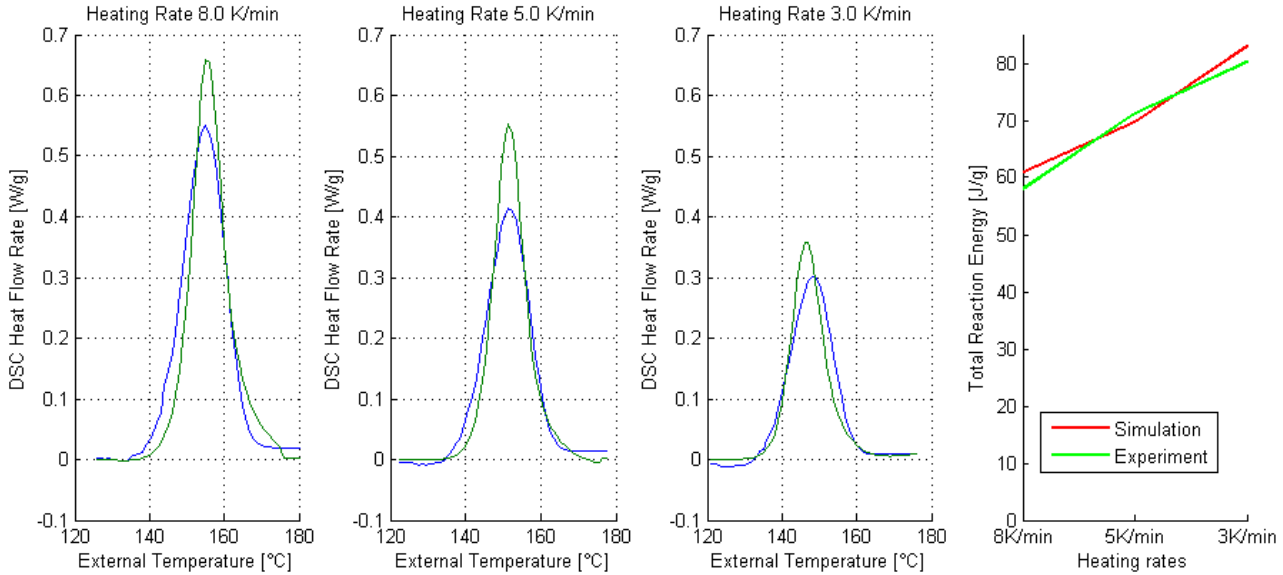
- 1st step: Reverse calibration of mold's thermal properties
- 2nd step accordingly: Reverse calibration of resin reaction model

Molding of Composite Sheets
Results

- Determined mold parameters fit heating experiments

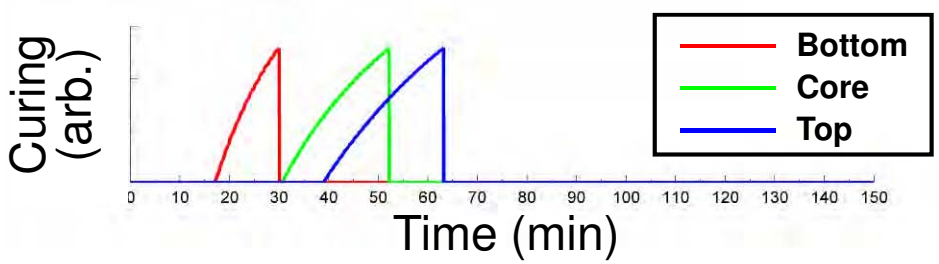


- Reaction model fits DSC experiments

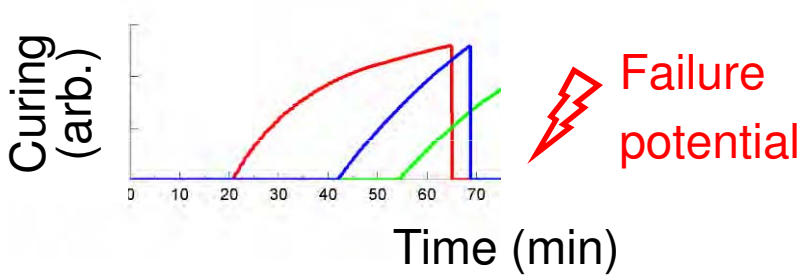


Molding of Composite Sheets
Results

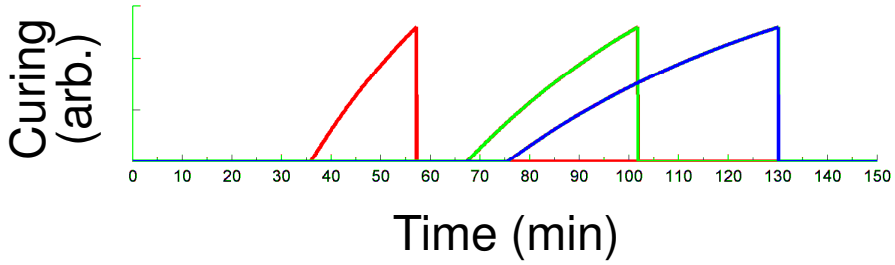
- Unidirectional curing of thin sheets (peaks indicate reaction progress)



- Standard curing parameters lead to cured skin (top, bottom) and uncured core in thick sheets



- New curing parameters allow for unidirectional curing of thick sheets



Outline

Background

Matlab-based Automation

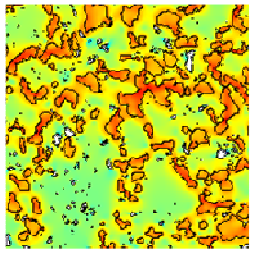
Controlling with Comsol Global Equations

Reverse Engineering of Transient Problems

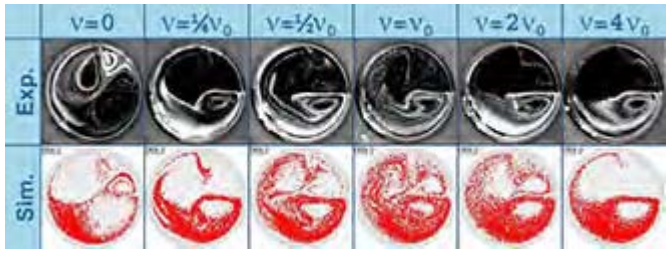
Summary and Outlook

Summary

- Powerful techniques using basic features of Matlab and Comsol
  - Automation with Matlab
    - MMC microstructure generation
    - Mixing simulation

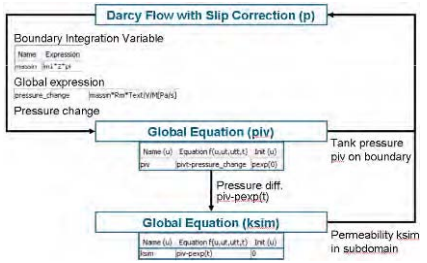


MMC



Mixing

  - Comsol global equations
    - Permeability parameter search



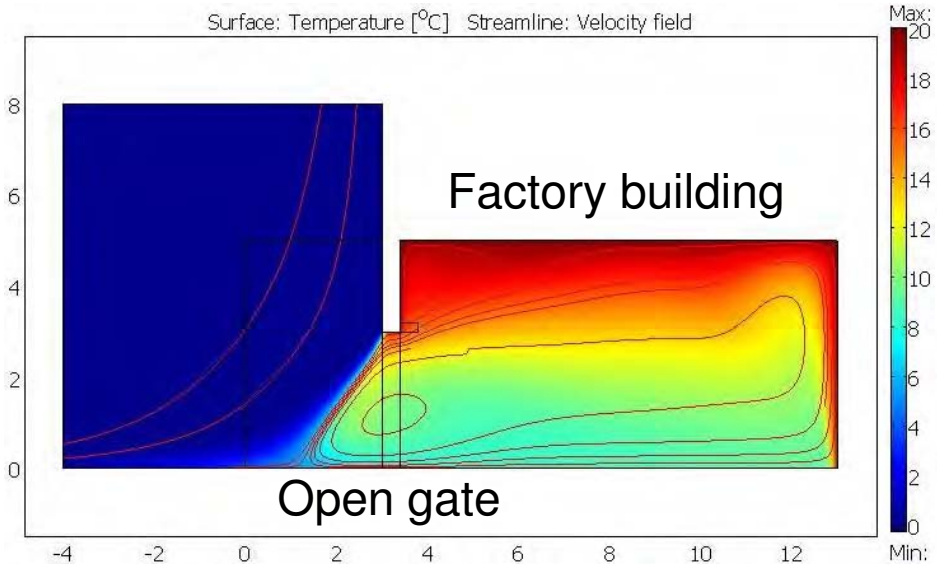
Permeability search

  - Optimization of transient tasks
    - Heat transfer in mold
    - Reaction model

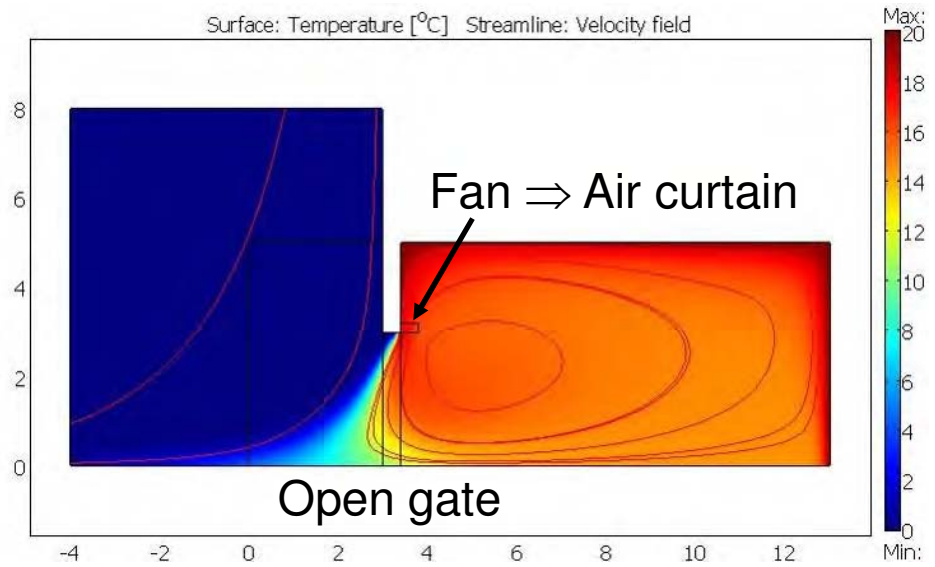
Mold

Outlook
More Tools

- Optimization with Comsol Optimization Module, e.g. optimized air curtain to screen factory building from chill through open gates



Heat loss to environment through open gate

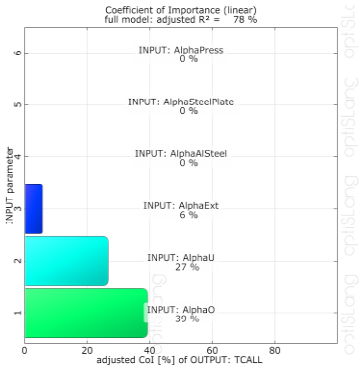


Screening effect of air curtain

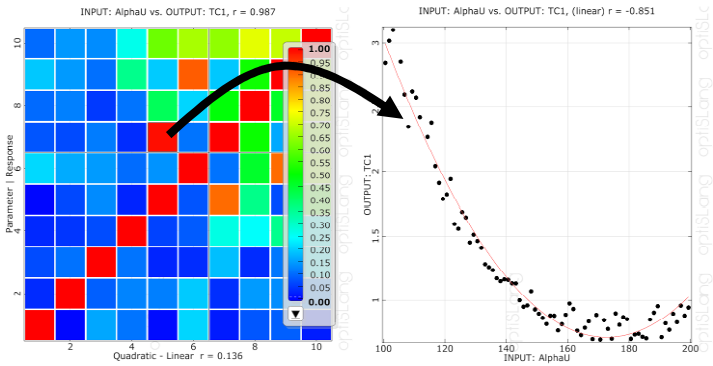
- Transient optimization with Comsol V4.x Optimization Lab

Outlook
More Tools

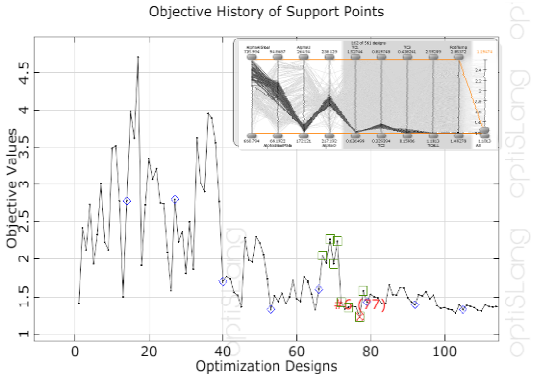
- Analysis and optimization with OptiSLang:



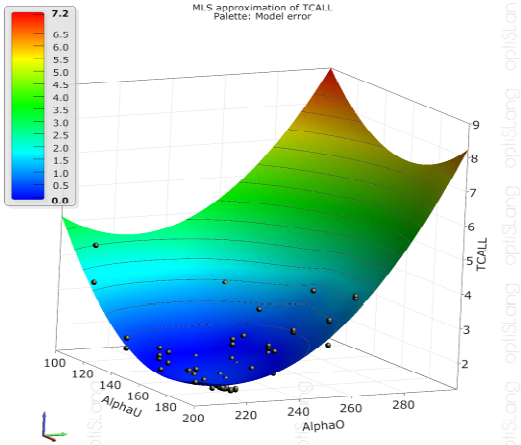
Significance and Importance



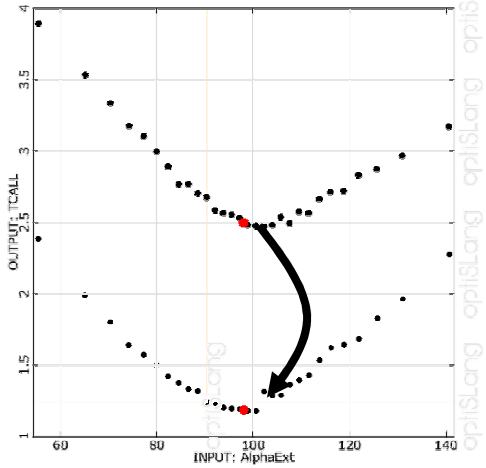
Correlations



Optimization



Meta Modeling



Robust Design

Sample data from composite sheet molding