Presented at the COMSOL Conference 2009 Boston and Milan

Research & Development, FEA, CFD,
Material Selection, Testing & Assessment

Multiphase, Dual Polymer Injection Molding & Cooling of Open Cavity

to form both distinct & graduated material properties within a complex body

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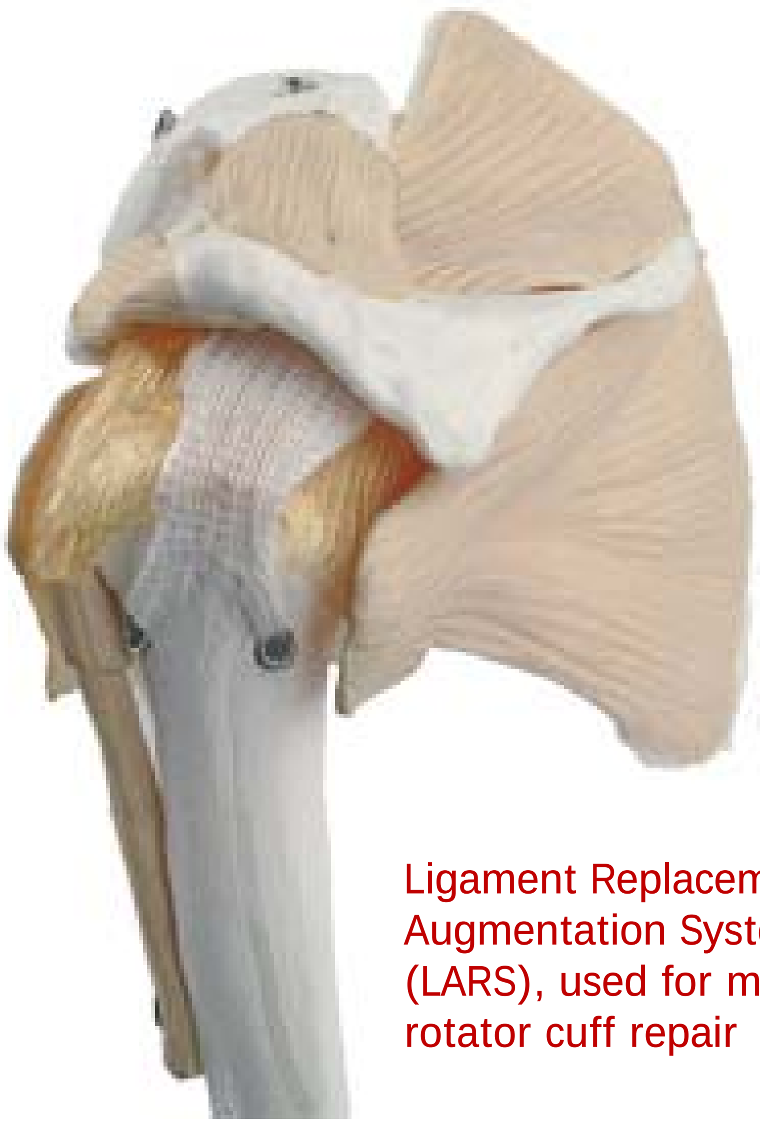
technology development

Implant Design



Ligament Replacement & Augmentation System (LARS), used for massive rotator cuff repair

General Soft Tissue Mechanics

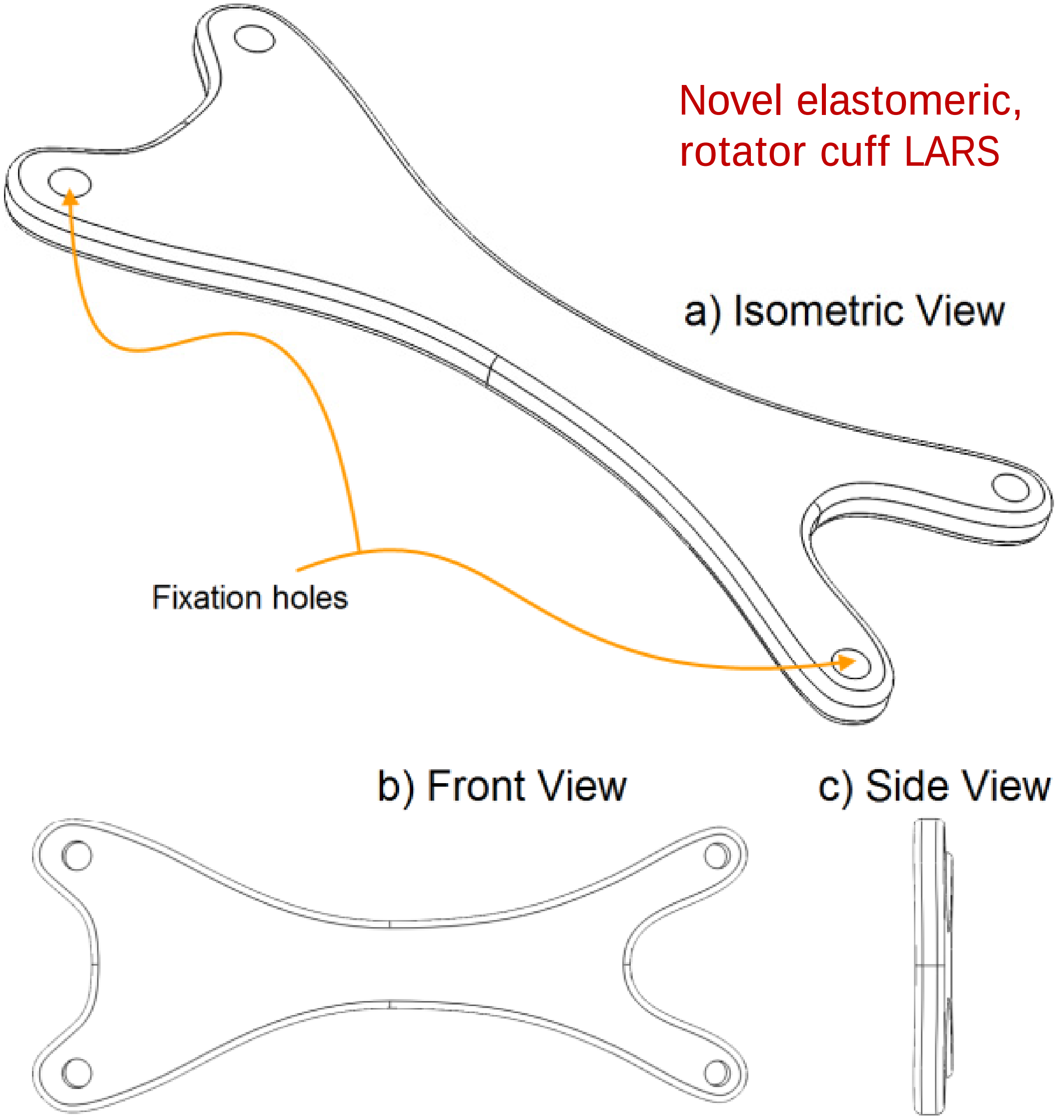
- Nonlinear, Hyper-elastic
- Anisotropic/Orthotropic
- Viscoelastic

Ideal Implant Mechanics

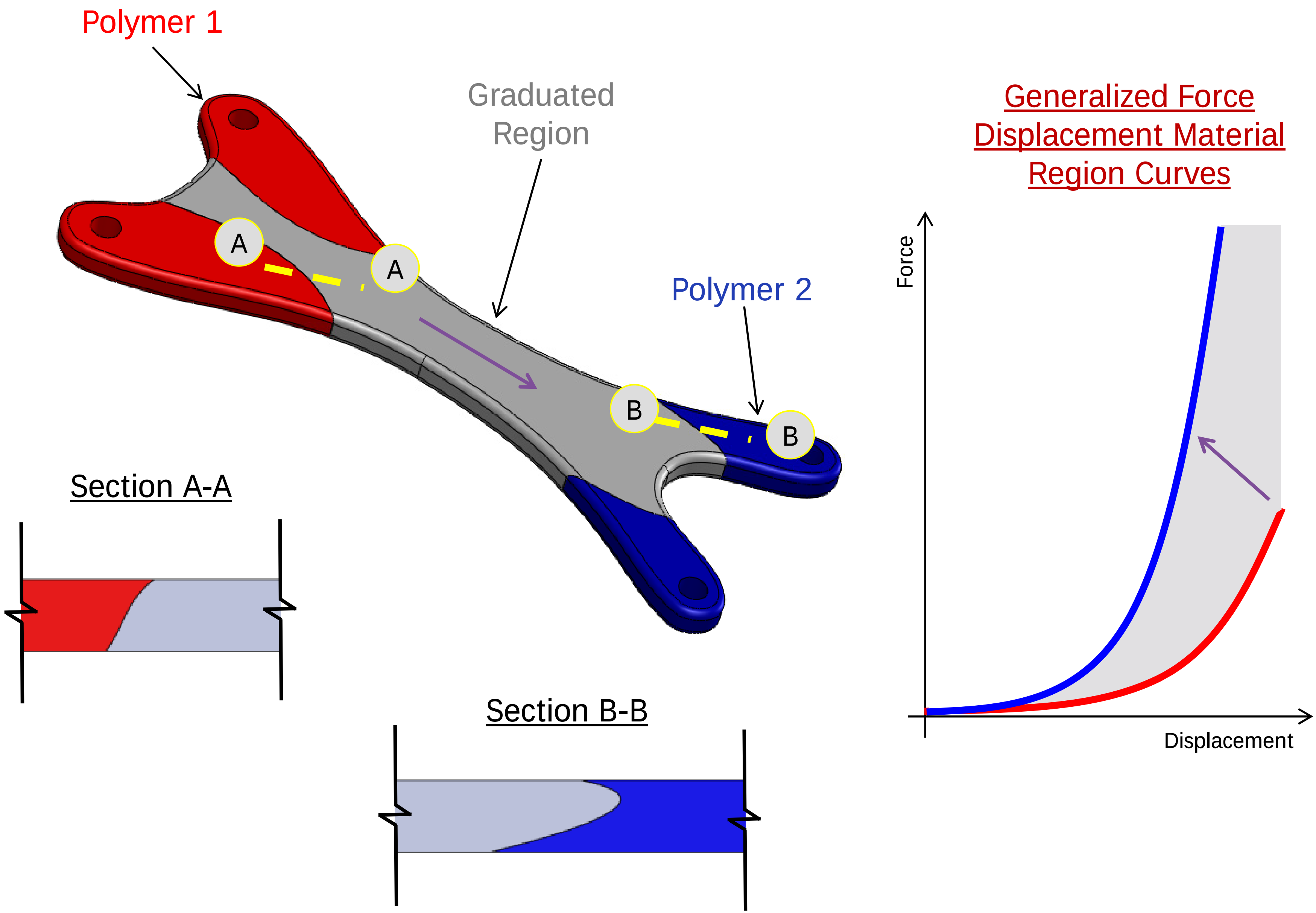
- Duplicate or augment the natural response of body tissue/ physiological function

Novel LARS Implant

Novel elastomeric, rotator cuff LARS



Material Regions



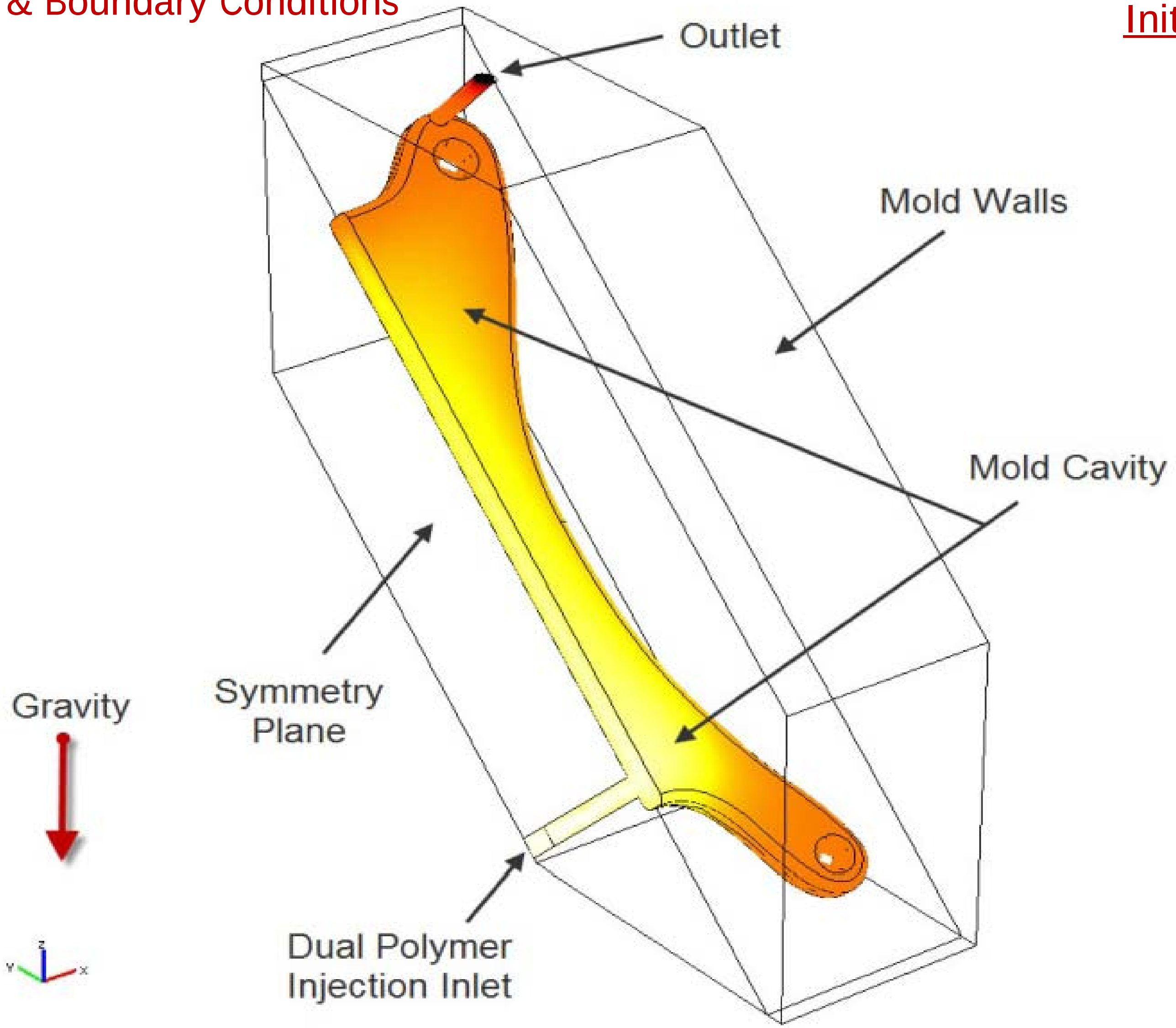
Manufacture Process

Aim is to find the production & process parameters required to produce the elastomeric implant, using a single injection mold process.

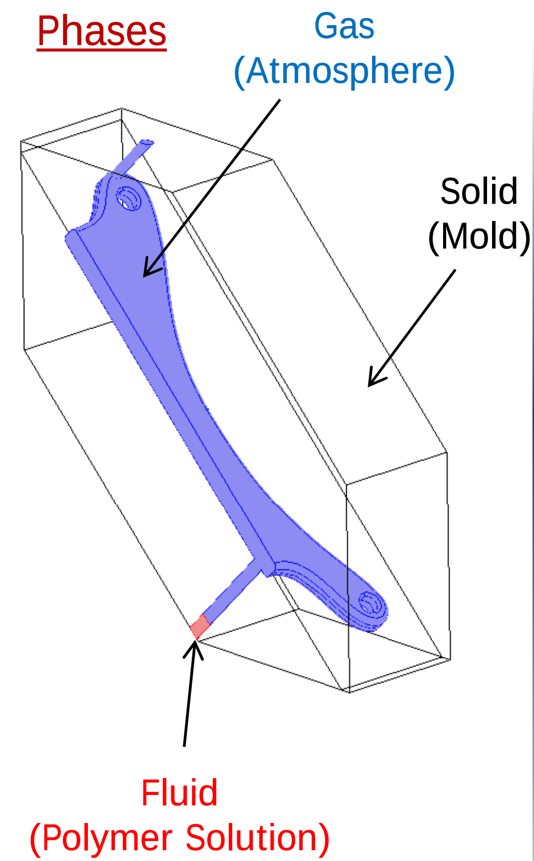
- Reduce production costs
  - Single process
  - Reduce physical handing
  - Increased production yields
  - Reduce QC steps
- Increase integrity & homogeneity of implant
  - Reduces the delaminating & bonding issues found in layered production process

Model Geometry

Model Geometry, Domains & Boundary Conditions



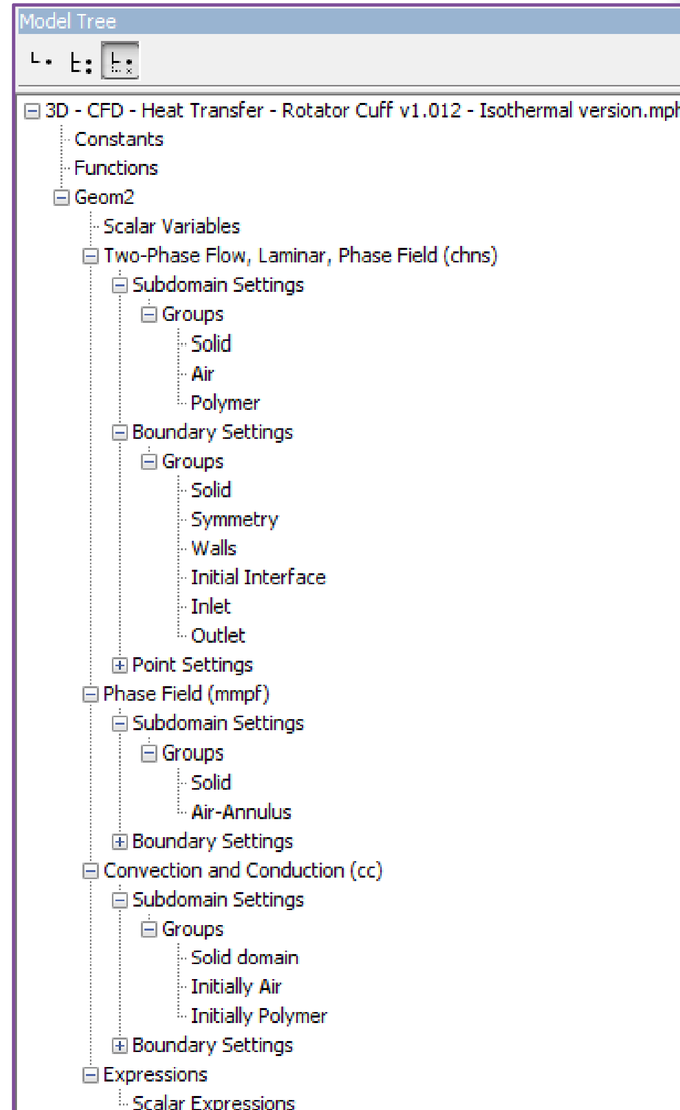
Initial Subdomain Phases



COMSOL Model Overview

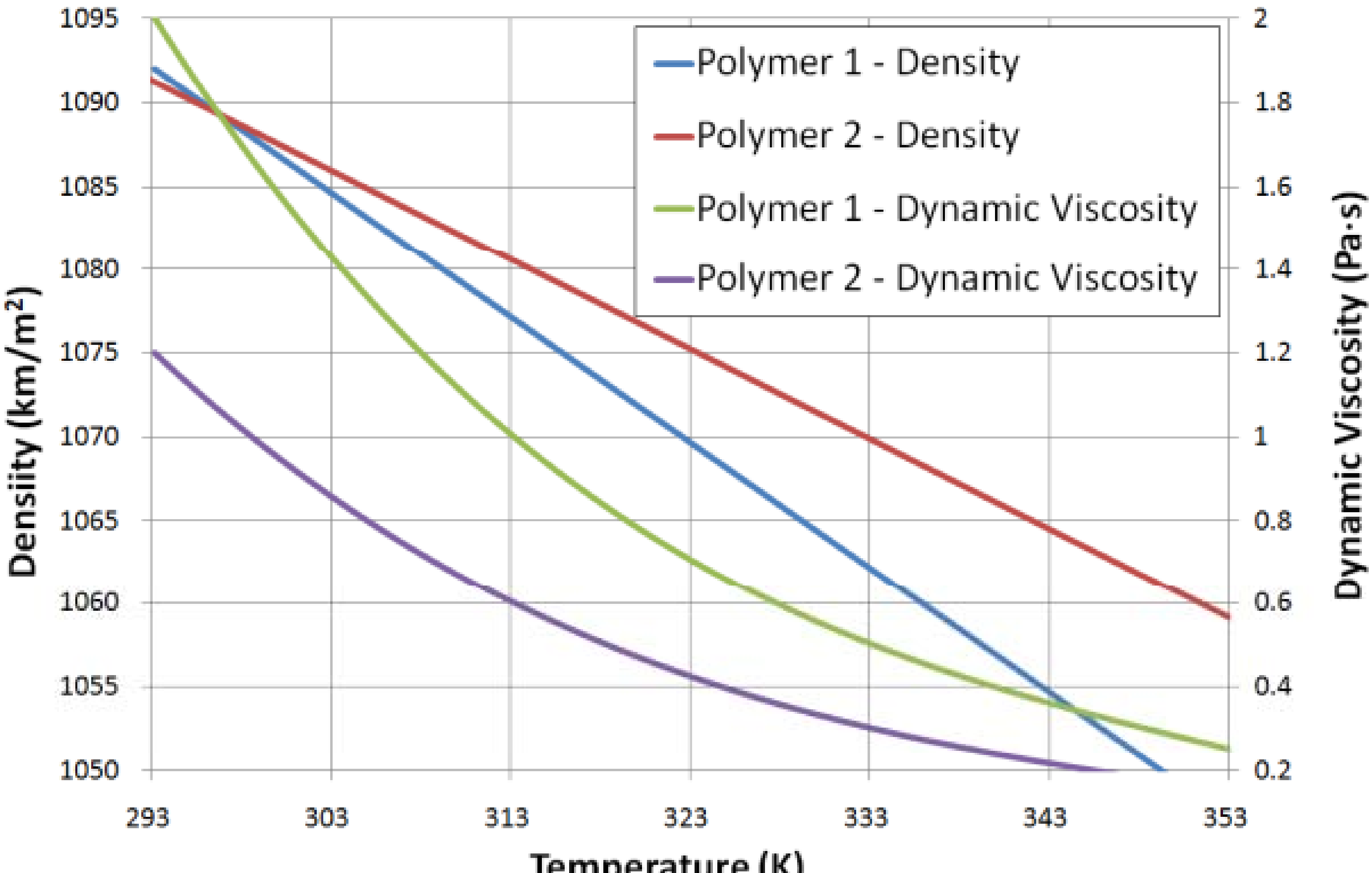
- 3 Transient Modules utilized:
  - Two-Phase Flow Laminar Phase Field (chns)
  - Phase Field (mmpf)
  - Convection & Conduction (cc)

- Two-Phase Flow Laminar Phase Field
  - Models Fluid-Air Boundary Flow
- Phase Field
  - Models 2 dual injected polymer solutions
- Convection & Conduction
  - Models thermal changes (Solid, Fluid & Gas)



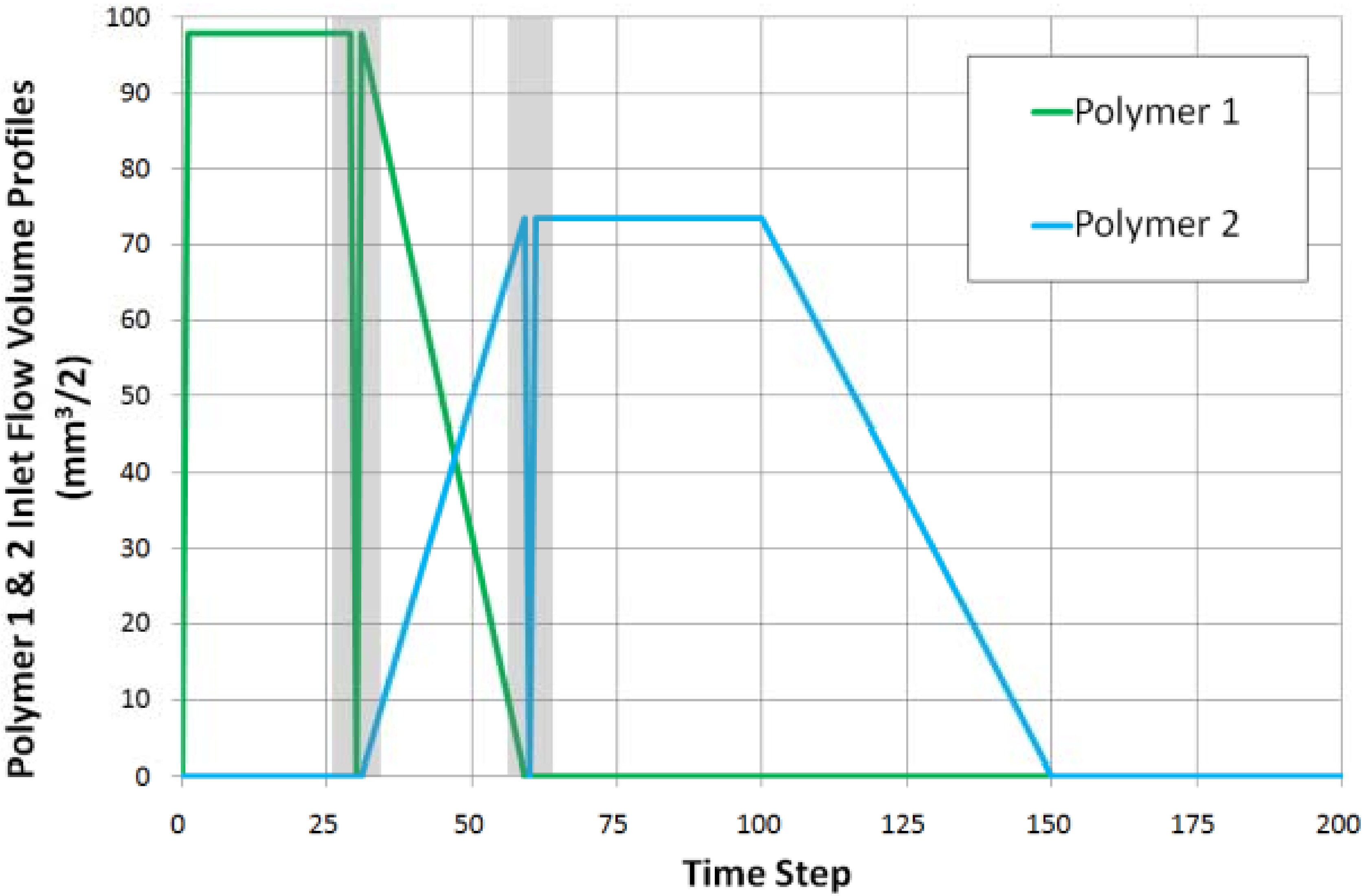
Density & Viscosity Functions

Change in dynamic viscosity & density vs. temperature for the two polymer solutions used in the injection mold process



Inlet Injection Process

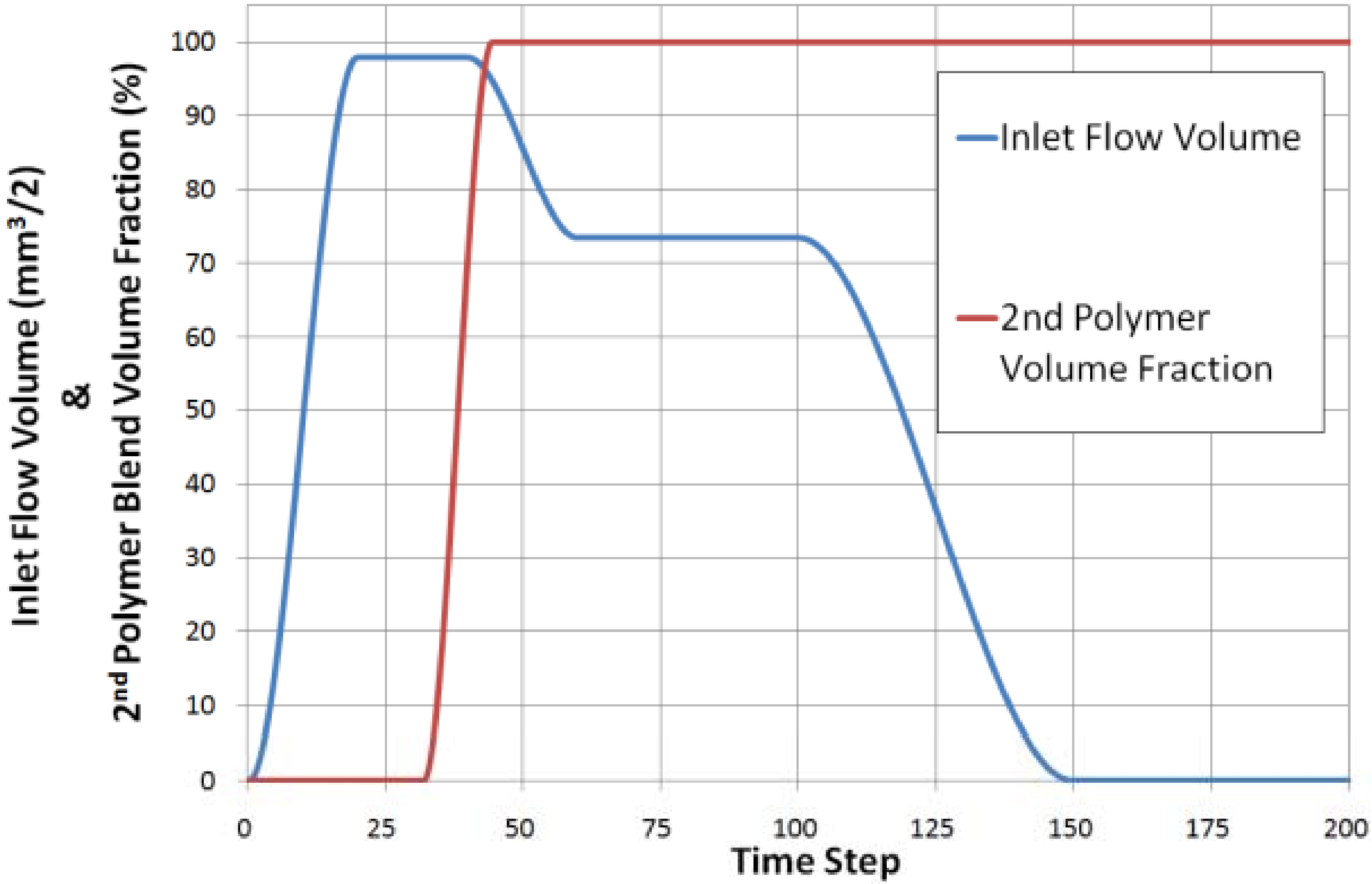
Mold machine polymer 1 & polymer 2 injection flow profiles vs. time.



Simplified Inlet Condition

Simplified inlet condition to equivalent condition:

- Smooth inlet flow function implemented
- Combined flow rate & volume fraction



Equations & Boundary Conditions

$$\rho(T_{cc})^{fluid}_{chns} = \rho(T_{cc})^{poly\,1} + \{[\rho(T_{cc})^{poly\,2} - \rho(T_{cc})^{poly\,1}] \times Vf^{poly\,2}_{mmpf}\}$$

$$\rho_{cc} = \rho_{chns}$$

$$\mu(T_{cc})^{fluid}_{chns} = \mu(T_{cc})^{poly\,1} + \{[\mu(T_{cc})^{poly\,2} - \mu(T_{cc})^{poly\,1}] \times Vf^{poly\,2}_{mmpf}\}$$

$$k_{cc} = A \times phi_{chns} + B$$

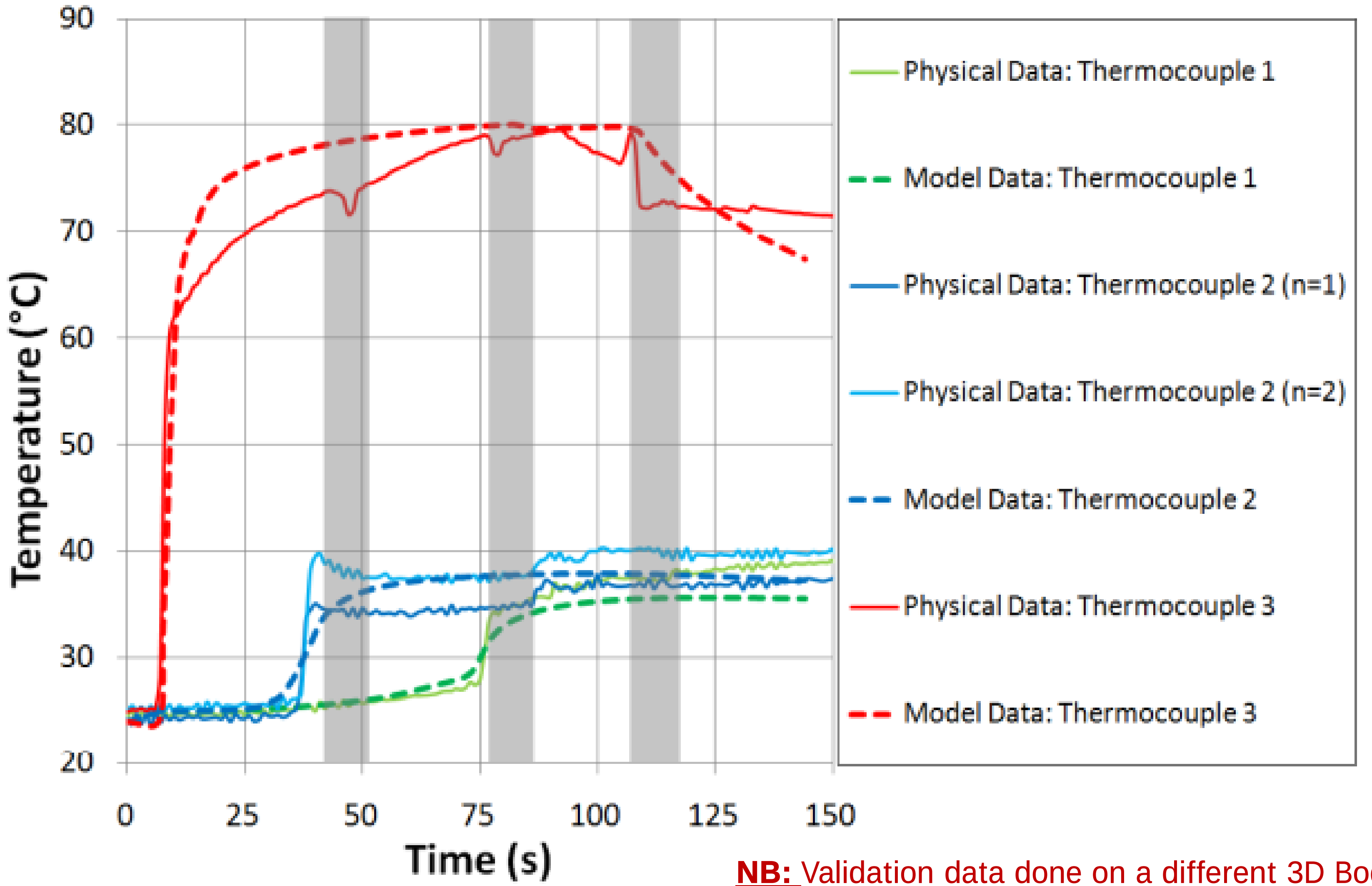
$$C_{p_{cc}} = D \times phi_{chns} + E$$

$$u_{cc} = u_{mmpf} = u_{chns}$$

Subscripts	=	COMSOL Multiphysics module
Superscripts	=	Material phase or state: solid, gas, fluid
Poly 1	=	1st Polymer material/solution
Poly 2	=	2nd Polymer material/solution
A, B, D & E	=	Various material dependent constants
k	=	Thermal Conductivity
C_p	=	Heat Capacity
u	=	Velocity Field

Validation (Thermal Data)

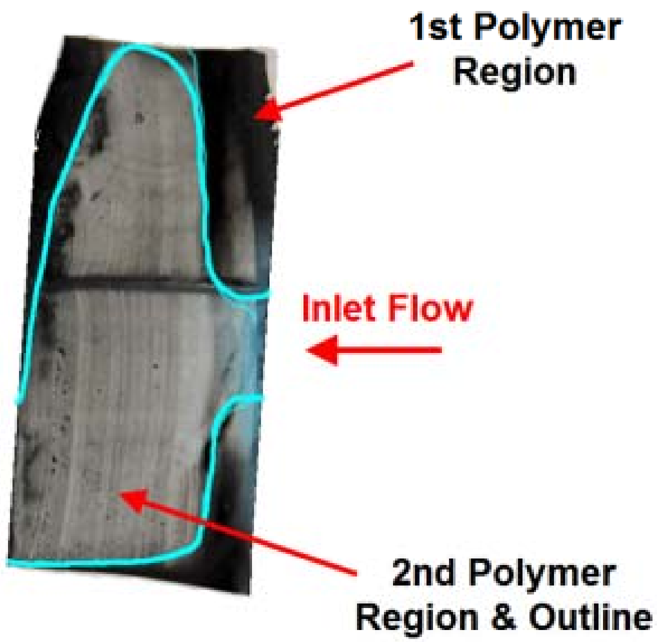
Time dependent thermal response curves of validation model vs. physical data at three different & distinct locations

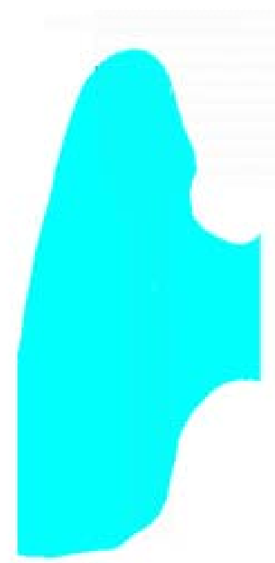


NB: Validation data done on a different 3D Body

Validation (Cured Sections Data)

Partial view of a cured section of a molded device, illustrating the distinct cured polymeric regions (1 & 2) and comparison to the equivalent COMSOL model.



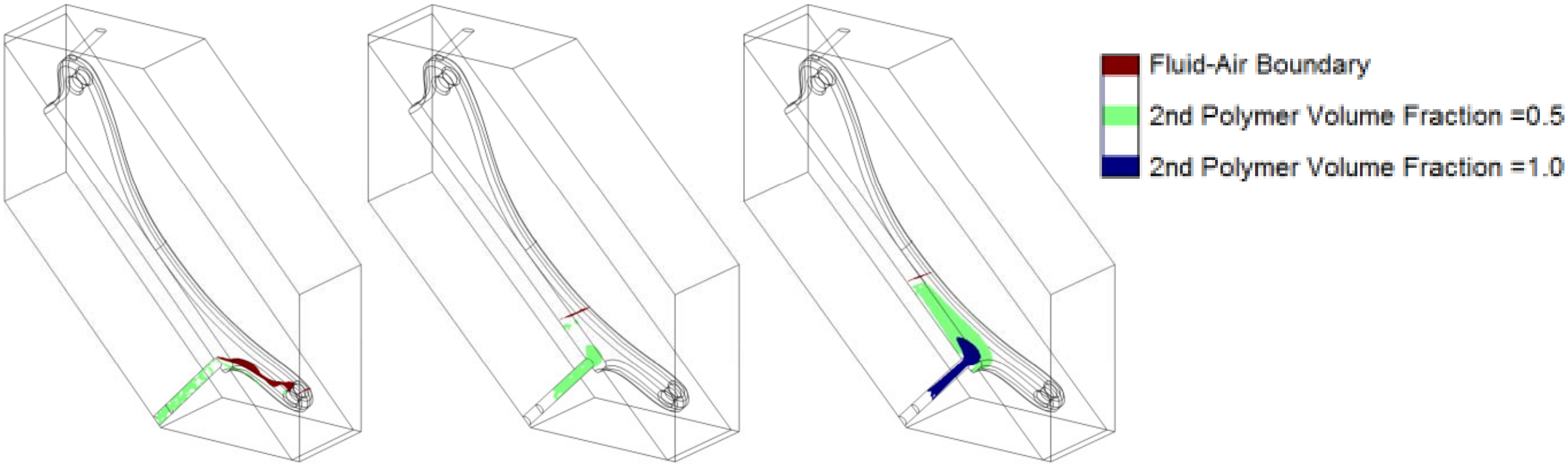


a) Validation Sample 2nd Polymer Outline

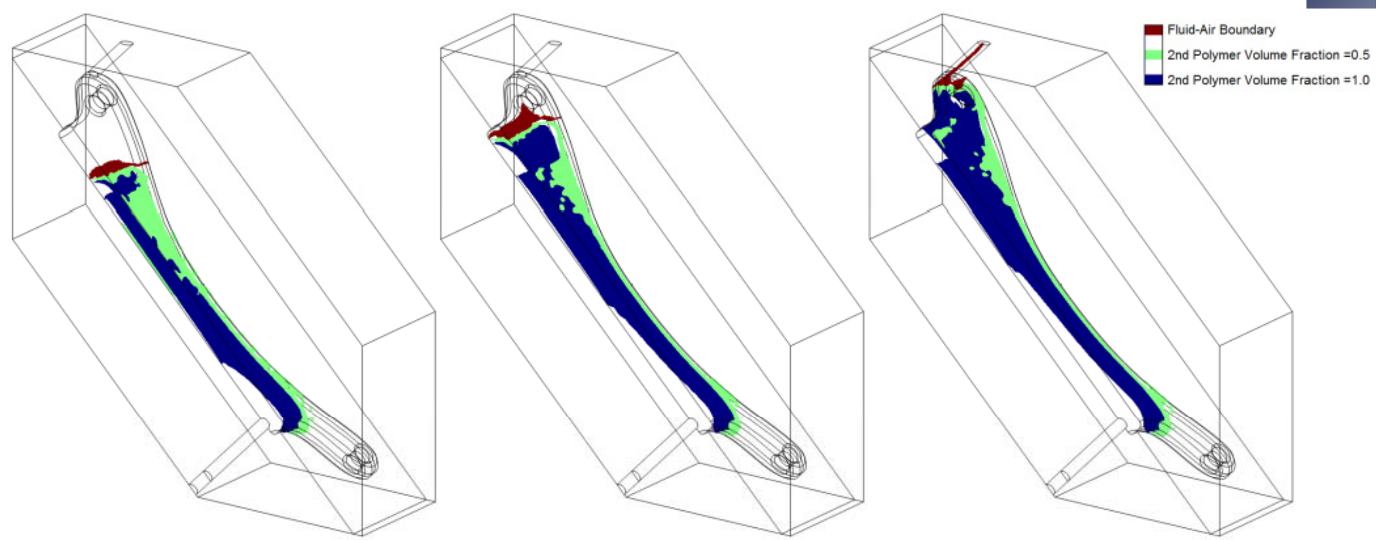
b) COMSOL Validation Model 2nd Polymer Outline

<u>NB:</u> Validation data done on a different 3D Body

Fluid Fill & Polymer Regions

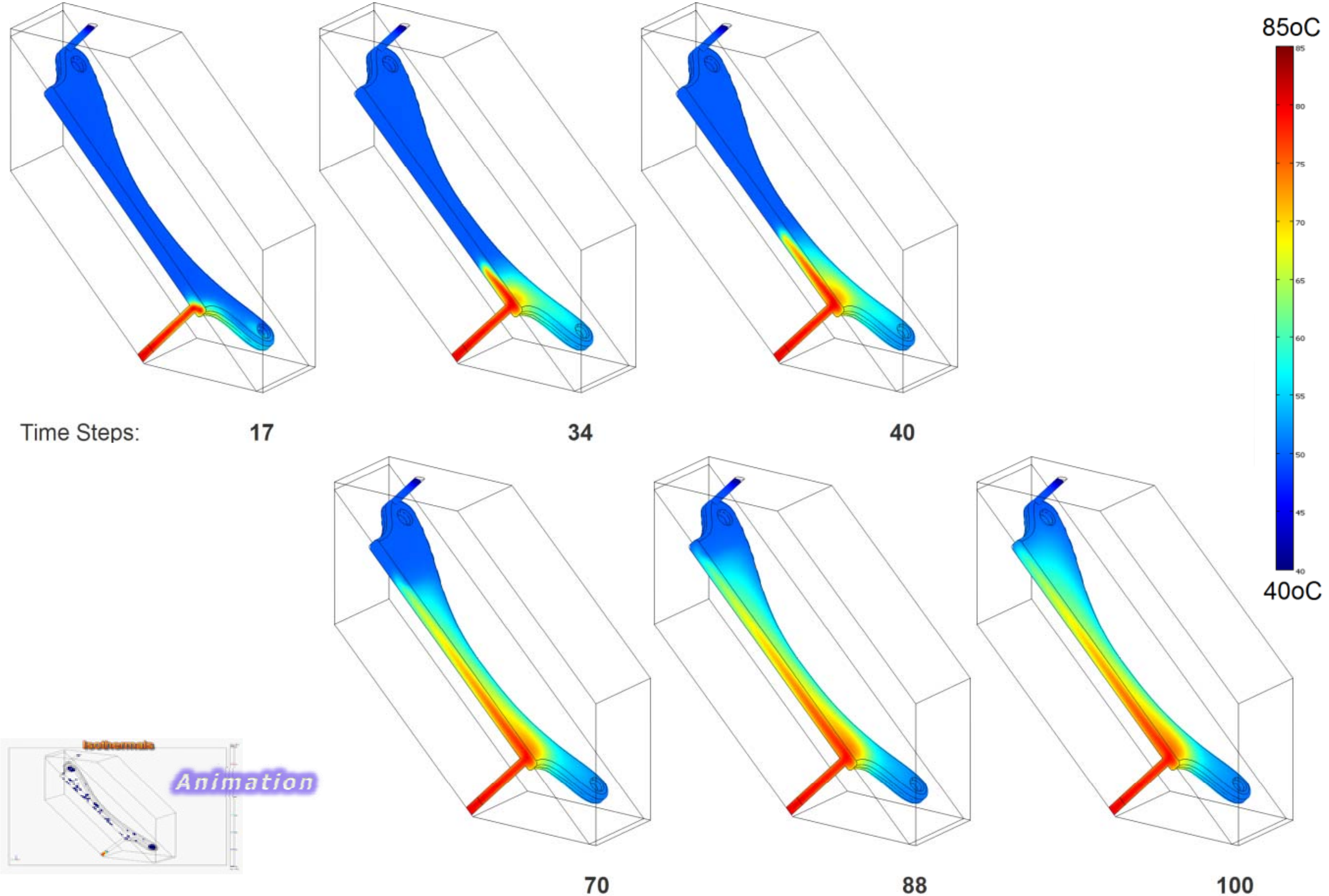


Time Steps: 17 34 40

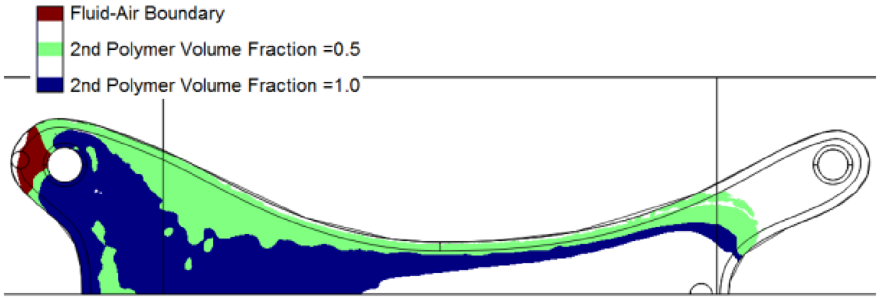


70 88 100

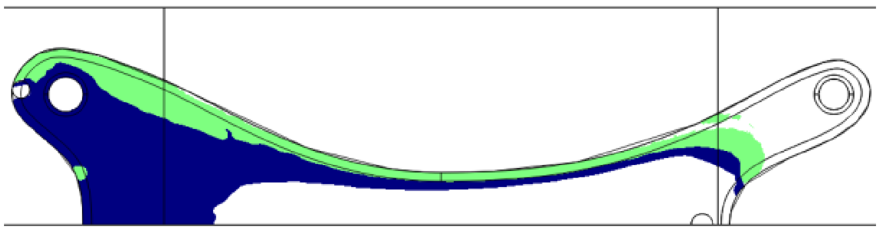
Thermal Effects During Filling



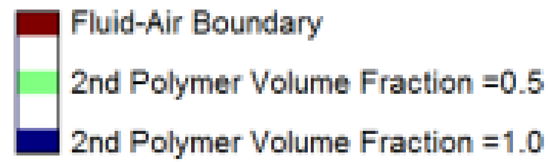
Continued Flow After Injection

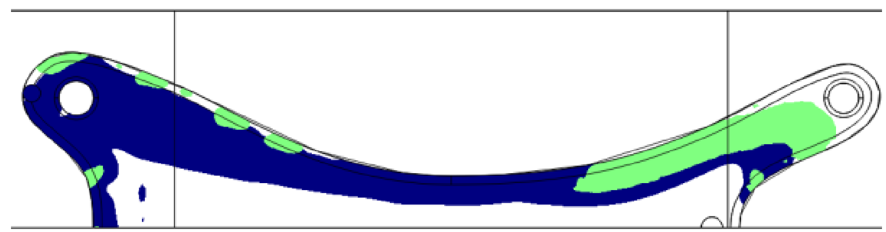


Time Step: 100

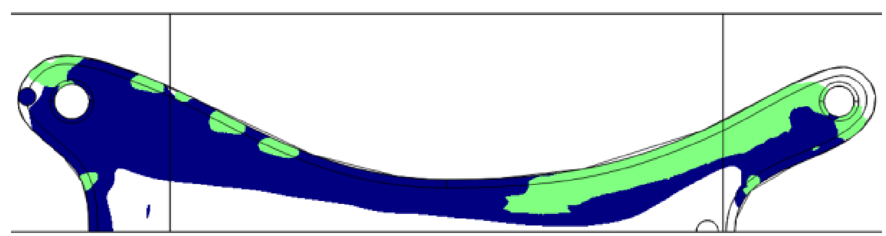


Time Step: 150
(End of Polymer Injection)





Time Step: 750



Time Step: 5000
(End of Polymer Flow)

Conclusions

- COMSOL Model successfully modeled the filling & curing of an open cavity mold with a combined polymer solution at an elevated temperature through a single port to produce vary graduated and distinct materials regions

- The COMSOL Model developed was validated against:
  - Quantitative thermal data
  - Quantitative cured sections
  - Qualitatively against captured video footage of filling process

NB: Validation data done on a different 3D Body

Future Developments

- Additional polymer solution (3rd polymer)
- Multiple inlet & outlet locations across the mold cavity
- Time dependent curing function (specifically required for 3rd polymer)
- Multi-parameter optimization of the injection flow inlet profiles, mold temperature & polymer inlet temperatures

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