SOLEGEAR

Bioplastic Technologies Inc.

Michel Labonté Ph.D.
CTO

Study of Different Plug Geometries and Optimization of Wall Thickness Distribution of a Typical 16-Once Container made in PET

Presentation

1. Project description
   - Some previous works done on different products
2. How and why that project did start ?
3. Basic theory behind the simulations
4. Inputs required
5. End results of 8 different simulations
6. Benefits of using dedicated software to simulate process and get adequate WTD

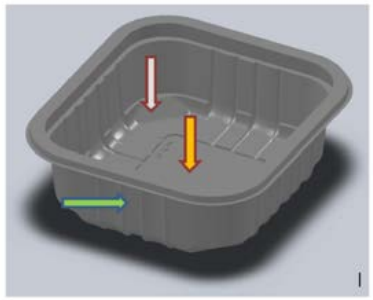
1. Project description

- Main objectives:
  - Obtain an *optimized and adequate* wall thickness distribution (WTD) at specific sections of the container

  +

  - Use *lowest sheet gage possible* and still meet customers *QC requirements* to reduce raw material costs

  - And validate if a *dedicated software* can be of a certain help

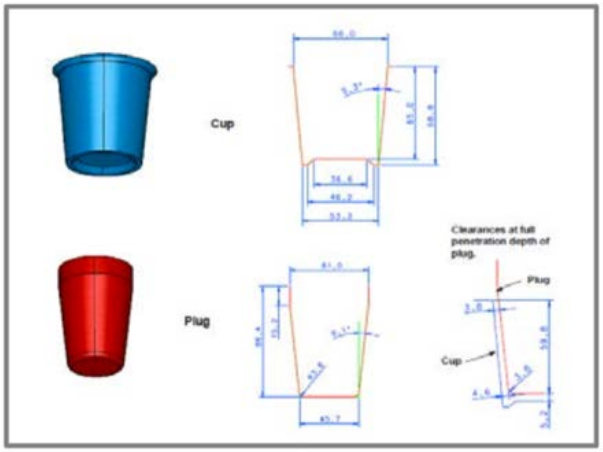


The Product and the process info

- Container size:
  - 16 on. for Guacamole (5.5" X 5.5" X 1.5") (13.5 g / 0.48 oz.)
- Material :
  - Thin gage aPET sheet 23 mils (585 mm) + tie layer and 1 mil PE

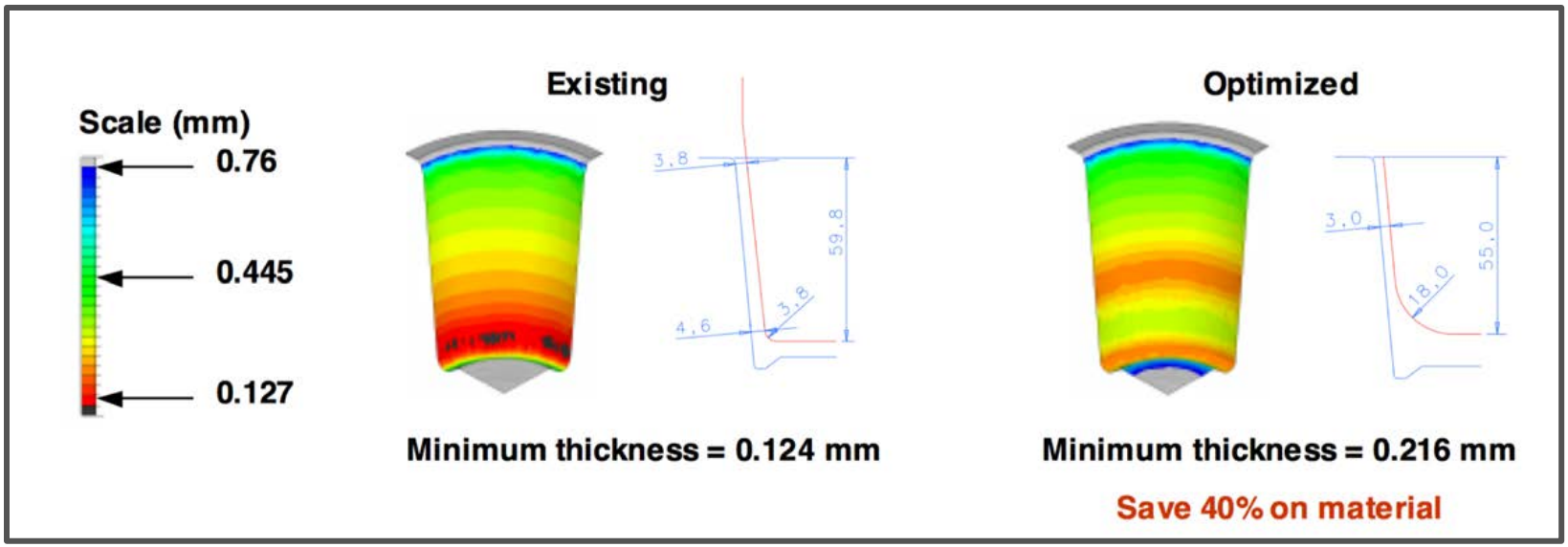
- Mold : Machined Aluminum, 6 cavities
- Plug assisted system (syntactic foam)
- Thermoforming machine used: GN 1914DM
- Cycle time : approx. 2.1 sec (28 cycles per minute)
- Molder : Inopak, Division of Cascades LLC., QC, Canada

Similar works done by others #1



Optimizing Plug Assist Geometry Using Simulations

Jerry Dees
Engineering Simulations LLC



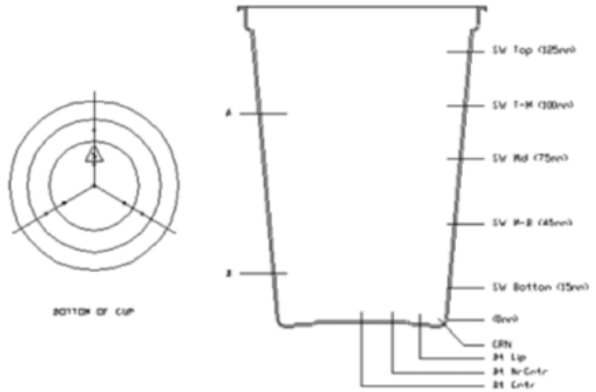
Similar works done by others #2

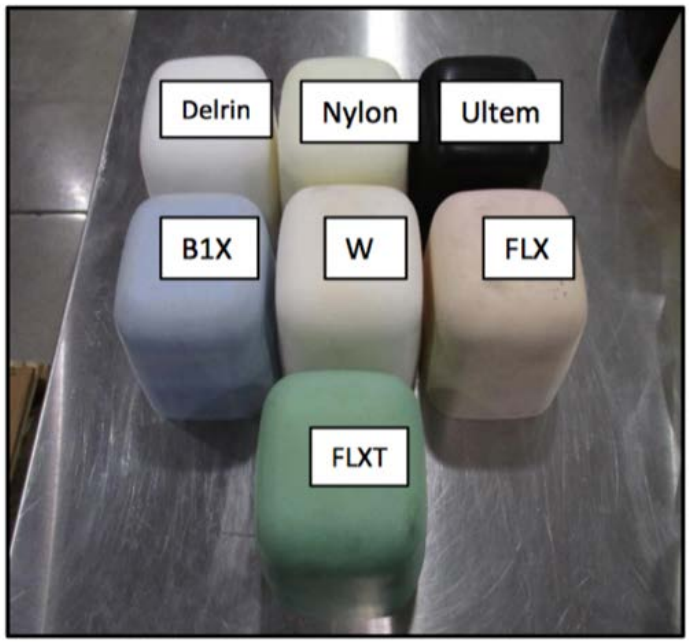
Managing Wall Thickness Variation in Thermoformed Parts

By Kathleen Boivin, Sr. Materials Engineer & Conor Carlin, Sales & Marketing Manager, CMT Materials, Inc. Attleboro, MA

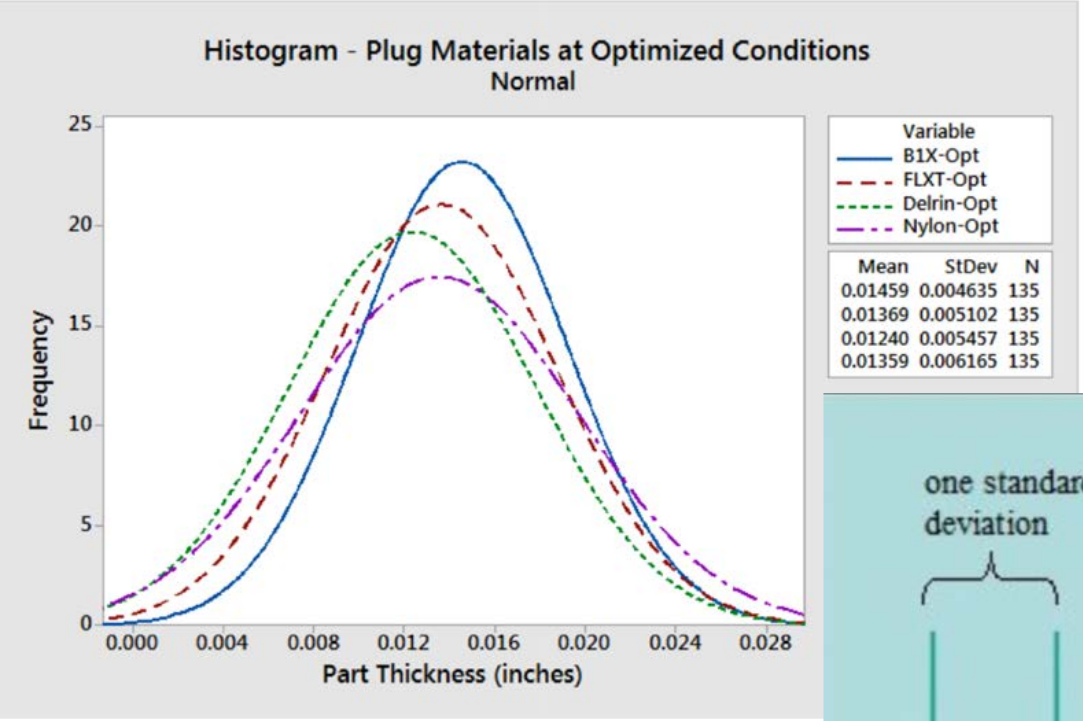
Illustrative Example: PP cup

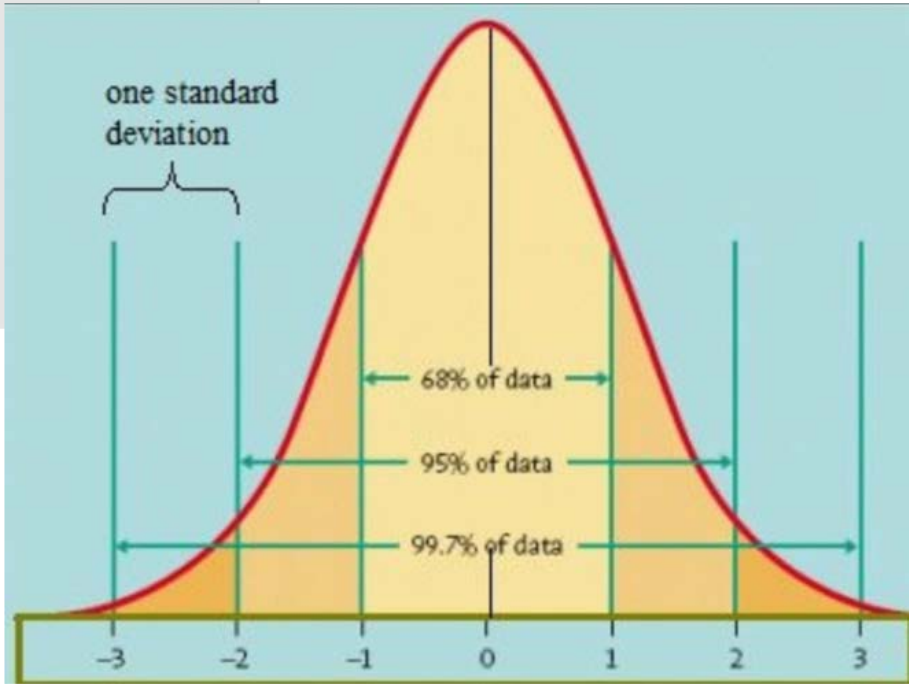
1. Plug material
2. Surface roughness
3. Plug diameter
4. Plug taper
5. Plug top radius
6. Plug depth
7. Sheet temperature



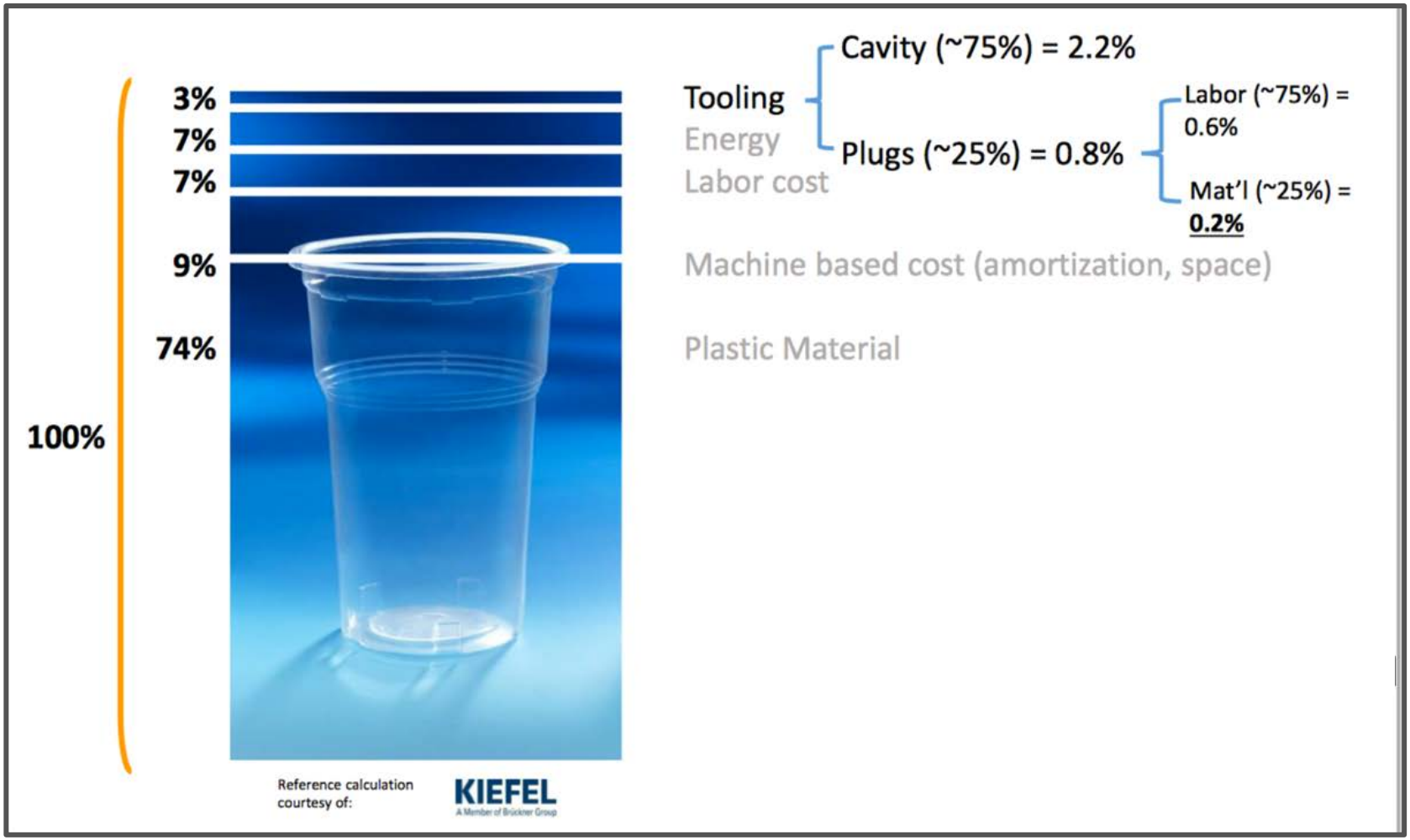


Similar works done by others and some statistical results





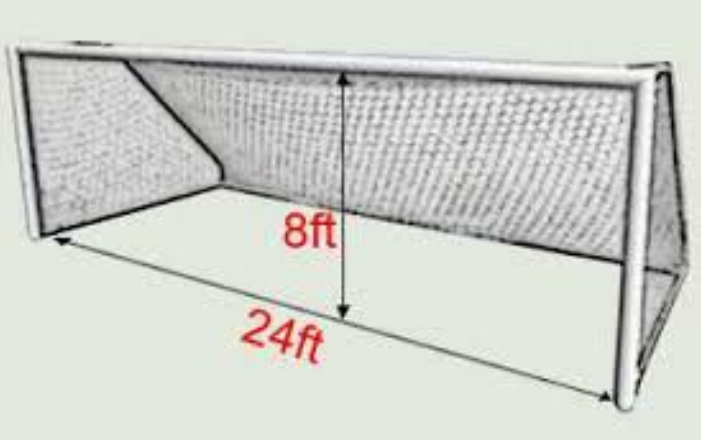
Similar works done by others and some costs perspective



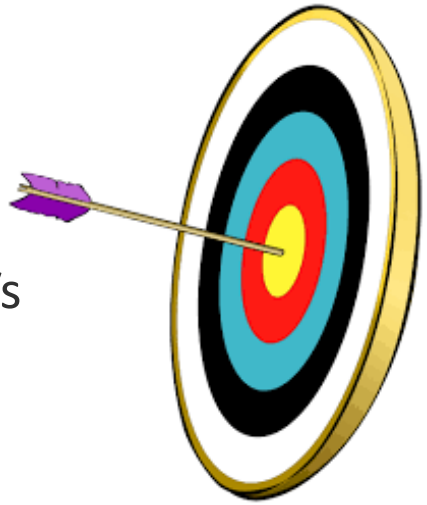
2. How and why such research project starts ?

From previous collaborations with this company

- After 2 Taguchi DoE
  - Taguchi is an old method to ***minimize loss*** due to not meeting specifications



Vs



- Identify which **process variables** are the most sensitive on '*wall thickness distribution*' (WTD) (the *loss*) and **how to improve output** ?
  - 1st : 7 variables, 2 conditions, **8 experiments**
  - 2nd : 4 variables, 3 conditions, **9 experiments**
    - Oven temp
    - Forming time
    - Plug lowering time
    - Plug velocity

2^7 = 128 exp.
3^4 = 81 exp.

- Result: potential gain of 0.1 sec on cycle time (5 % potential gain in production)

In fact, gains for the thermoformer were

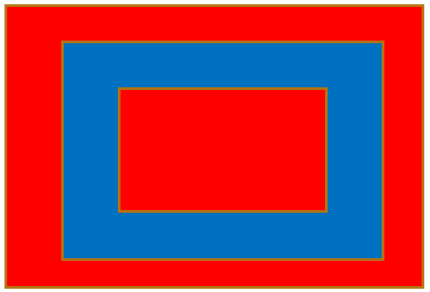
1. Better understanding on the sheet behavior during the pre-stretching due to:
   - The Plug displacement (approx. 2.5 in.)
   - Under a certain Plug velocity (in less than 0.1 sec)
2. Combined on SPC, a better control on the process and the AQL output
3. Opening to a greater technical (and scientific) collaboration

3. Basic theory around thermoforming

- Type of mold

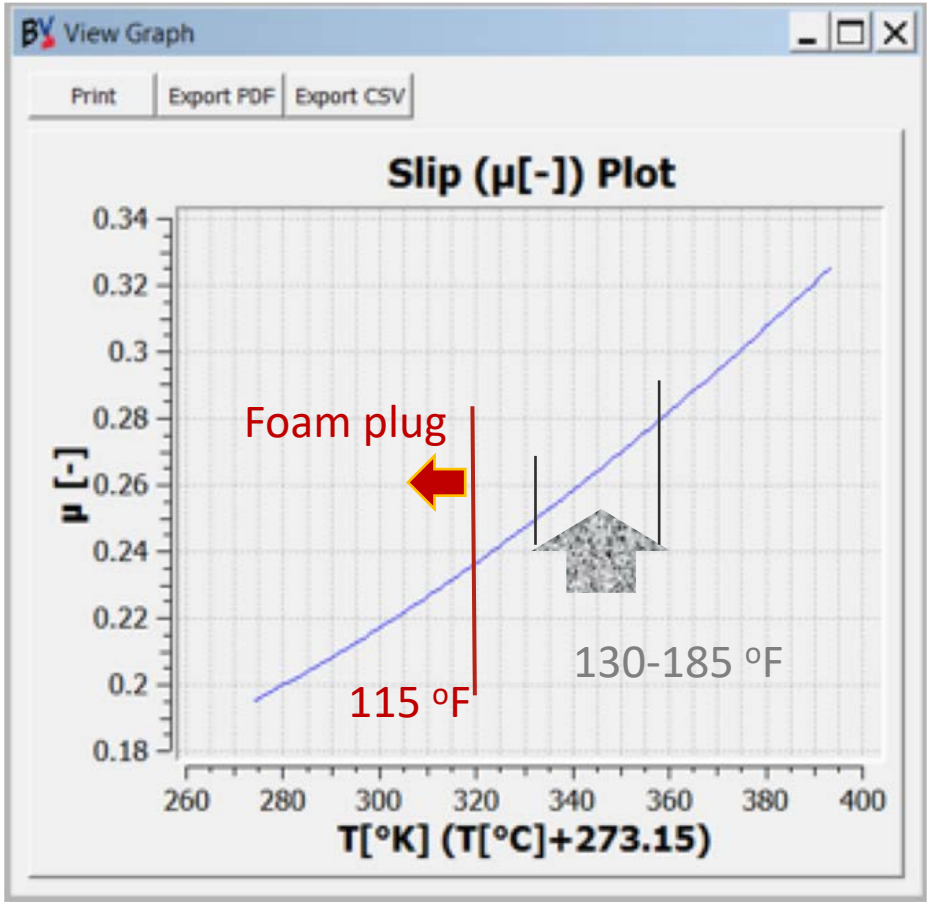
- Instant Heat transfer sheet and plug or mold
  - **Different material stretching rate as per temperature of sheet sections**

- Plug material (Al, Syntactic Foam, Nylons, Delrin, ….)
  - Operating *building up* temperature
  - Coefficient of friction (slip)
    very low slip → **low slip conditions**



The slip – low –no slip factor …

- From Coulomb's law, CoF varies with:
  - Material combination
  - Plug material
  - Temperature of plug and sheet
  - Nature of surface,
  - …

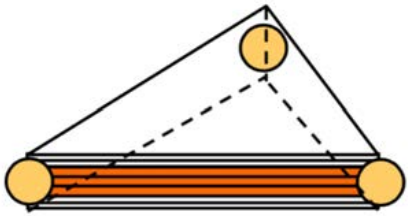


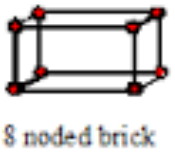
Steps in roll-feed thermoforming

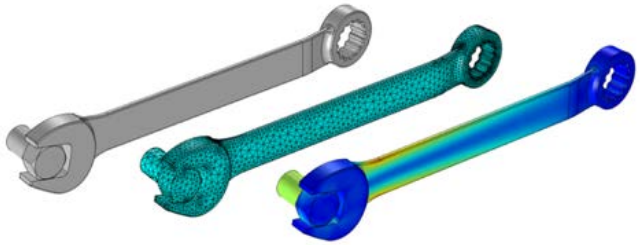
1. **Sheet reheating**
   - Sheet transport in oven by stroke (under a traveling speed)
   - Sheet transfer in ‘forming station’
2. **Pre-stretch**
   - Plug velocity and displacement
   - Mold displacement
3. **Stretch** (and forming)
   - By vacuum and/or pressure
4. **Cooling** (final forming)
   - In-Mold and Outside-Mold contact
5. Die-cutting

Process modelisation (use of a dedicated software)

- Process modelisation involves :
  1. Complicated mathematical equations
     - Thermal
     - Mechanical
     - Rheology
     - Thermo-mechanical behavior
     - …
  2. FEM methodology using different models:
     - 2D (triangular element : 3 nodes)
     - 2.5D (multiple 2D elements in inter-related layers)
     - 3D (block elements : 9 nodes)
  3. Mold and Plug geometries
  4. Parts dimensions (*shrinkage and deformation*)



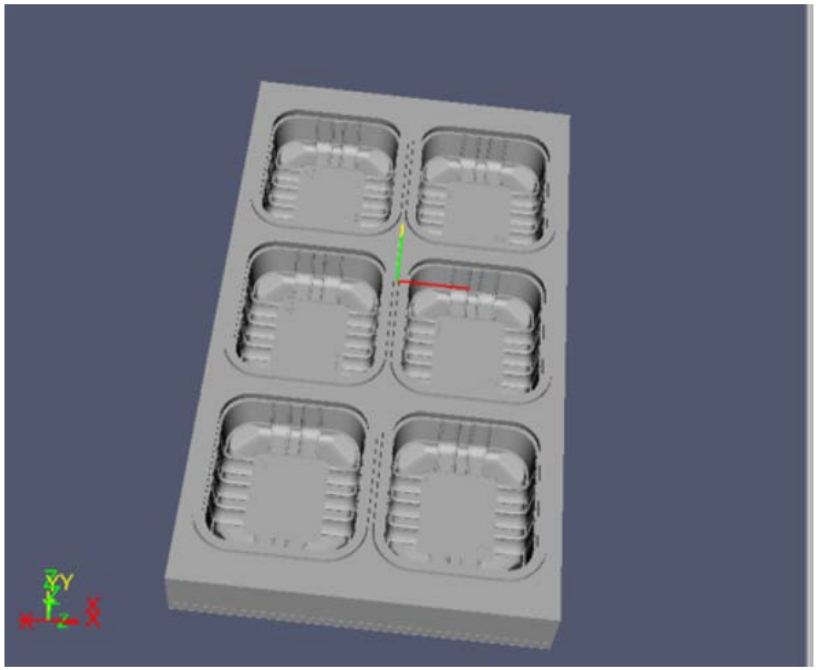




4. Inputs required (1 of 7)

1. Mold and plug geometries

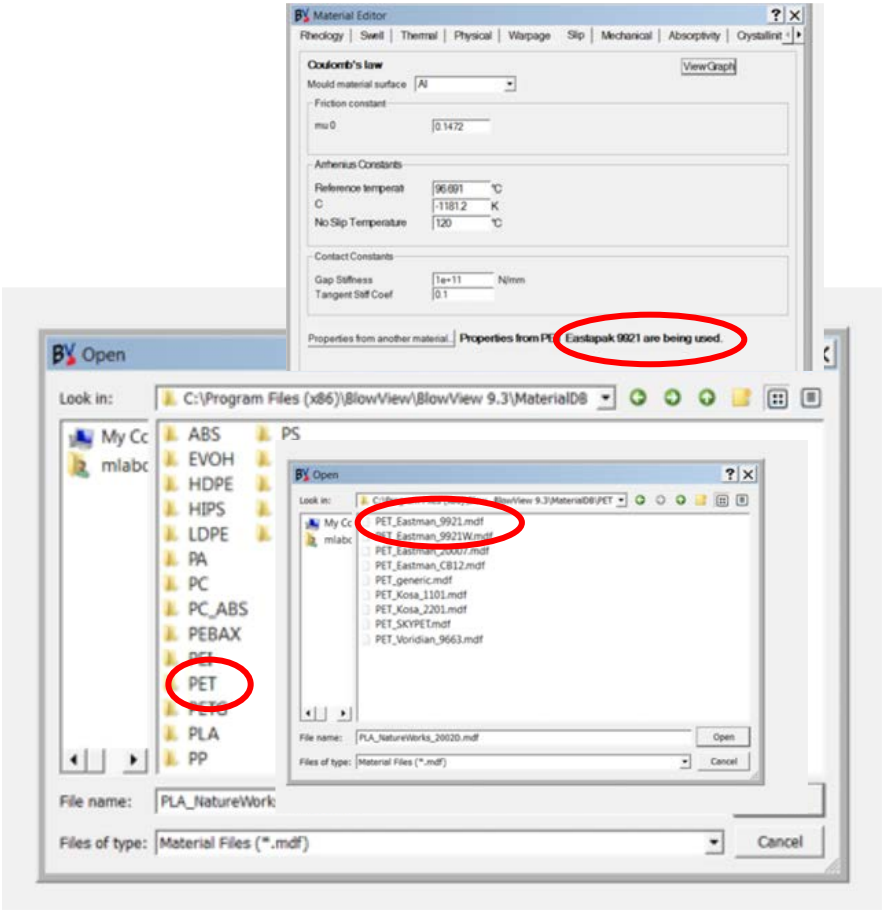
   - Temperature of mold and plug
   - Temperature *uniform* OR *variable (choice)*
   - Heat transfer coefficient for ALU or other material
   - …



Inputs required (2 of 7)

2. Material data: (*from database*)

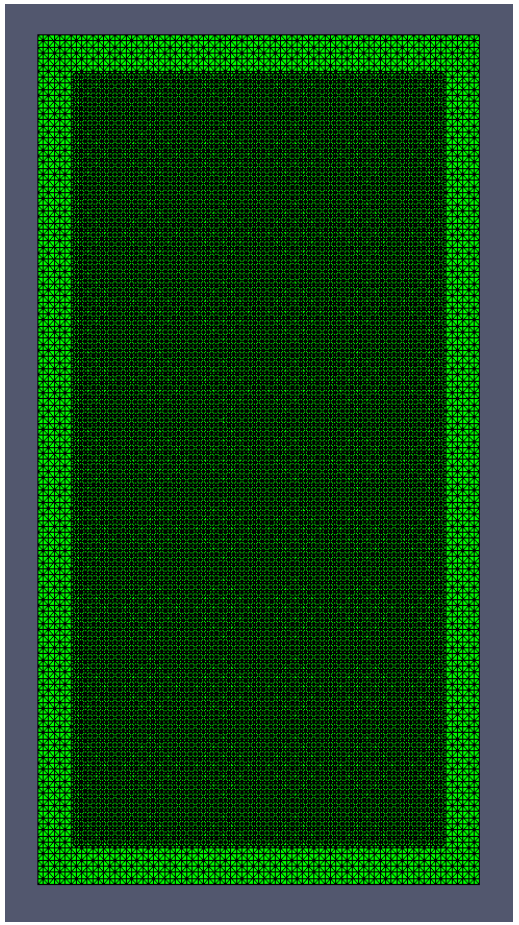
   - For **specific type of plastic**
   - From a **commercial formulation OR material characterization** *(as rheology model, specific heat, density, conductivity, absorption, crystallinity, molecular orientation, permeability, …)*
   - **Uniform OR multi-layer** (*option*)
   - …



Inputs required (3 of 7)

3. Sheet dimensioning and frame

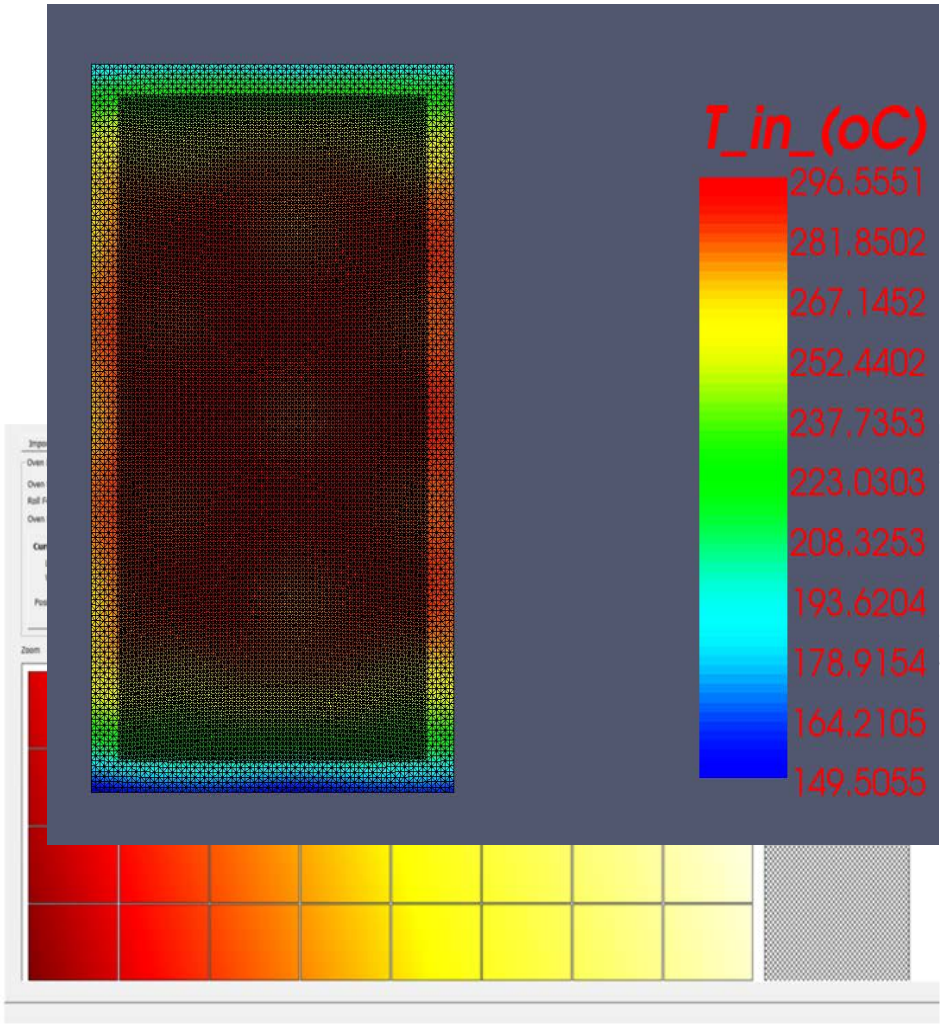
- Dimensions of sheet for molding station
- Sheet thickness
- Holding frame
- Mesh size to define (FEA) (# of nodes)
  - 37 913 nodes and 74 744 elements
- Others:
  - Air temperature, Coefficient of transfer, …



Inputs required (4 of. 7)

4. Sheet reheating

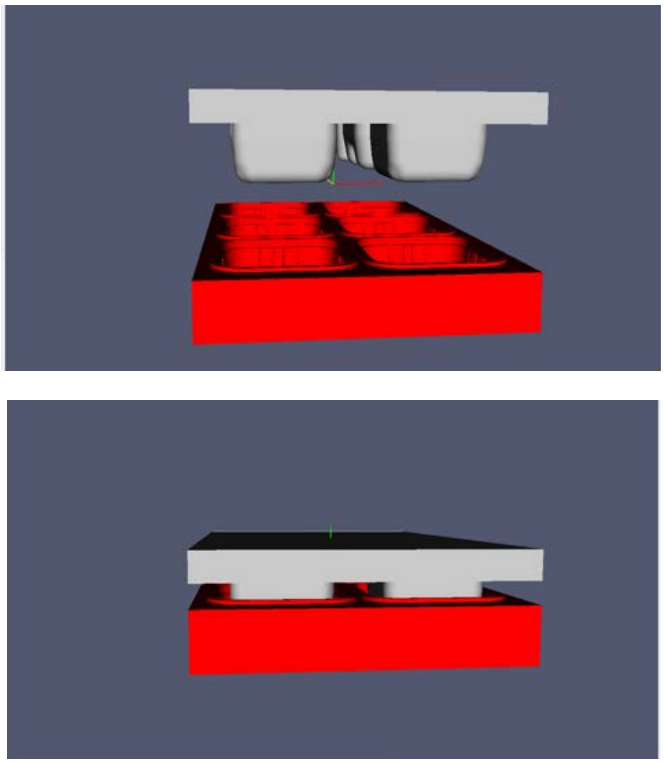
- Dimensions of oven *(length, width)*
- # of heating zones *(up and down)*
- Heaters distance *(up and down)* from sheet
- Temperature of each zone
- Emissivity of heaters, …
- Air properties in the oven
- …



Inputs required (5 of 7)

5. Mold and Plug displacements (**Pre-forming**)

- Initial Position
- Final Position
- Displacement under a specific time (i.e. velocity)
- …



Inputs required (6 of 7)

5. Vacuum and-or Pressure application **(forming)**

- Defined time of application
- Delay if any
- Pressure
- Air temperature, heat transfer, …
- …

Inputs required (7 of 7)

Processing Conditions (as per cycle time)

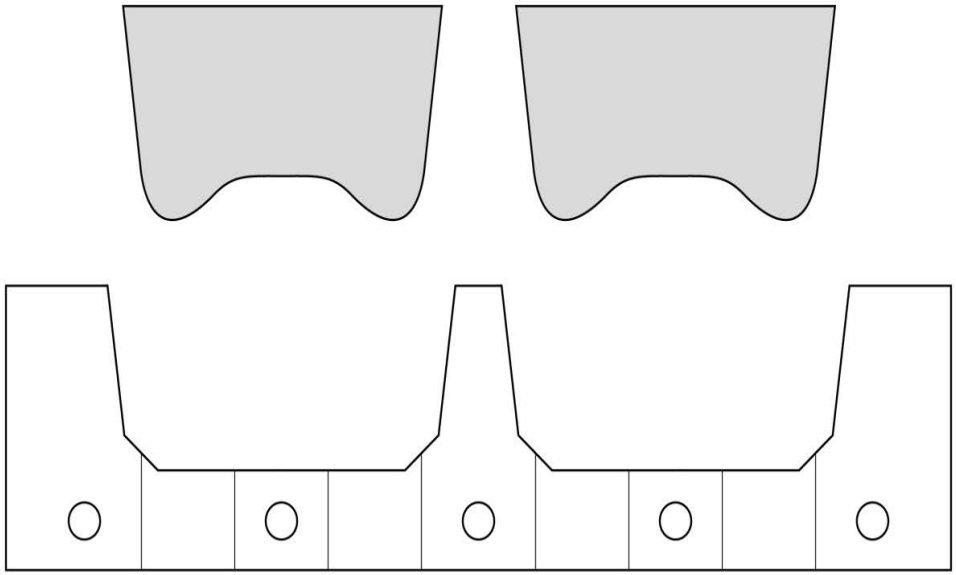
	Cumulative time (sec)	Time of steps	Processing Operation and # steps
3 strokes	6.3	1.58/3.15/ 4.72/6.30	1. **Sheet Reheating** (in 4 steps)
	6.4		2. **Sheet Transfer** **Air properties**
Pre-stretching (0.1 sec)	6.5	6.42/6.44 6.46/6.48/ 6.50	3. **Mold Displacement** (in 5 steps) **Plug Displacement**
Stretching (0.6 sec)	7.1	6.62/6.74/ 6.86 6.98/7.10	4. **Pressure-vacuum Application** (in 5 steps)
	8.8		5. **Cooling in mold**
	11.8		6. **Cooling outside the mold**

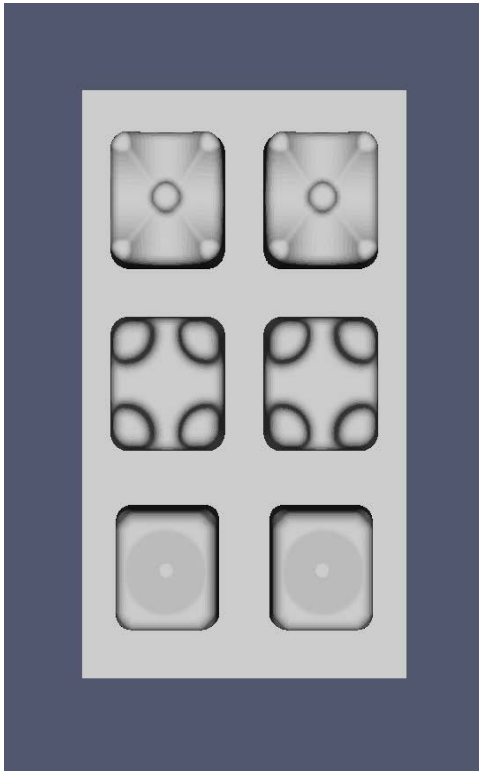
Run the simulation …

As per requirement, the software runs the simulation **(calculation time)**

- Resolving ALL equations until a converged solution is obtained for ALL nodes
- Calculation time function of:
  - Number of nodes (37 791 nodes)
  - Number of steps and sub-steps (55 steps and sub-steps)
  - Number of iterations to converge (50 max.)
  - …

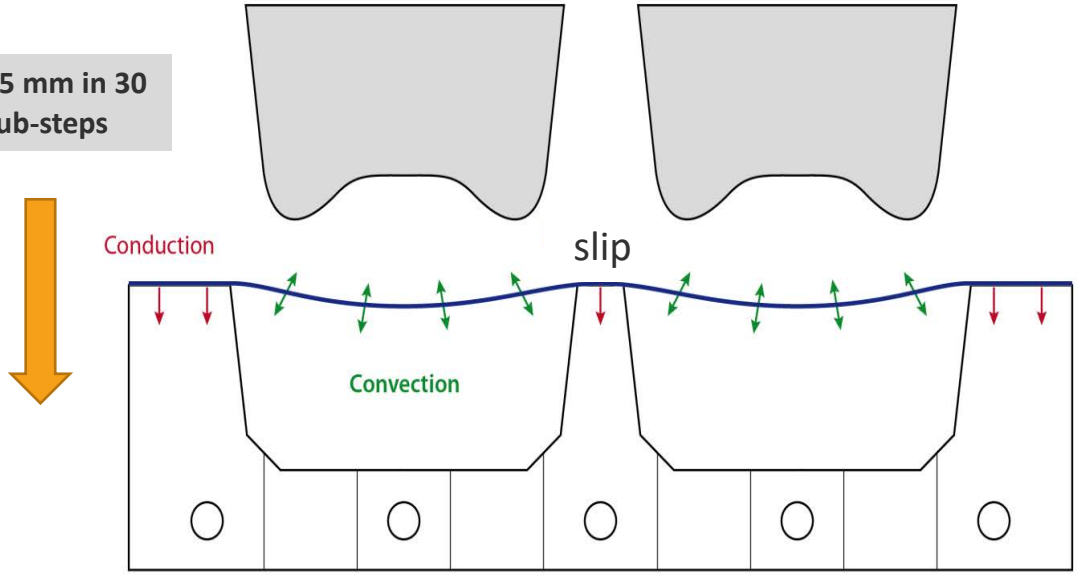
Simulation (graphic representation)

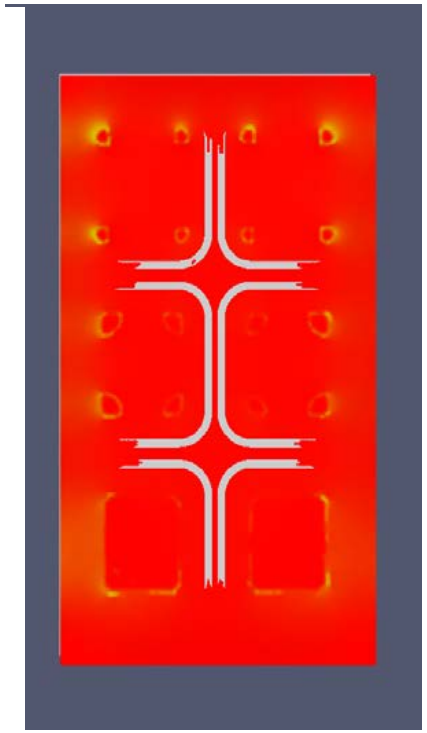




Pre-Stretching (plug & mold movements)

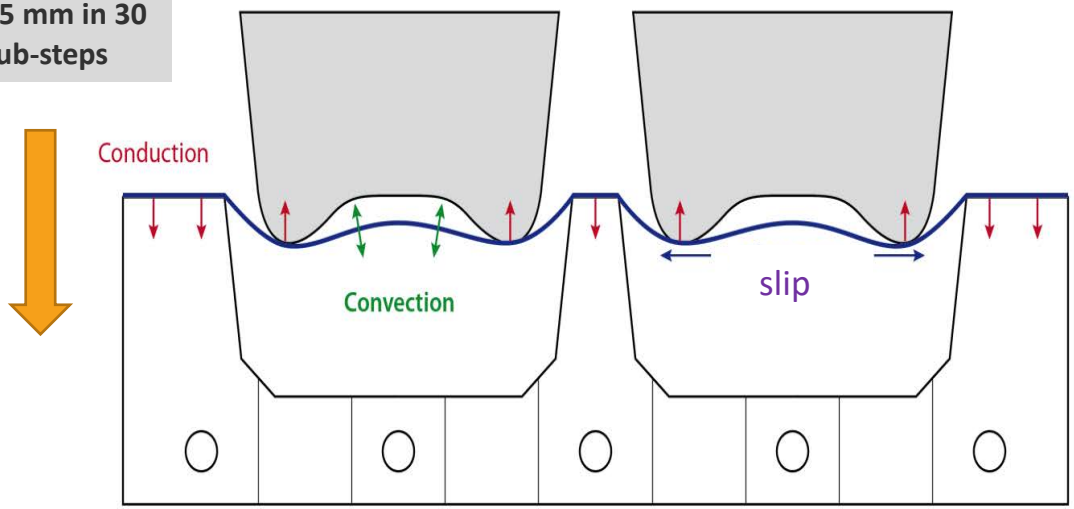
75 mm in 30 sub-steps

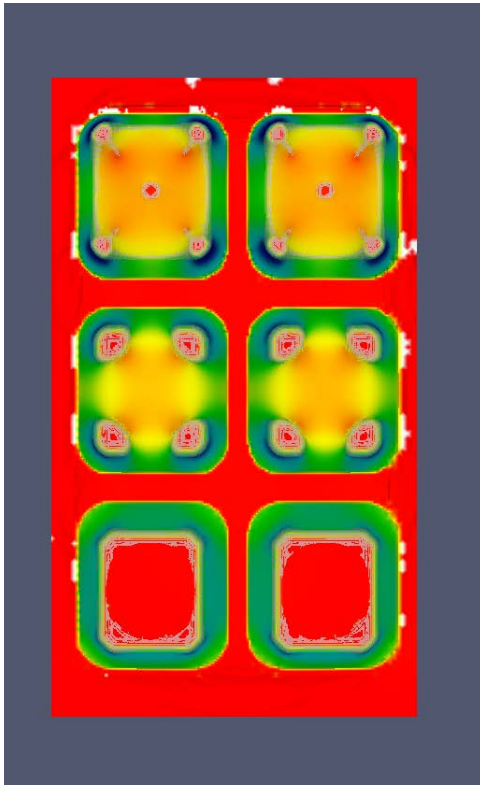




Pre-Stretching (plug movement)

75 mm in 30 sub-steps

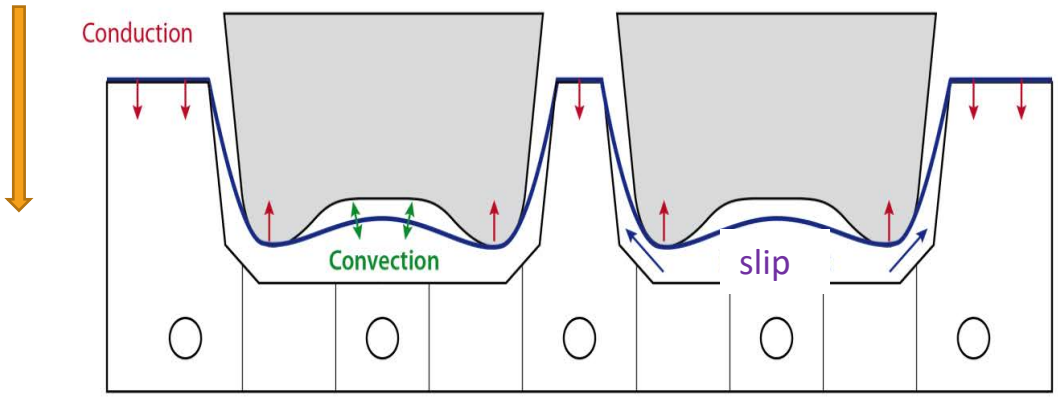


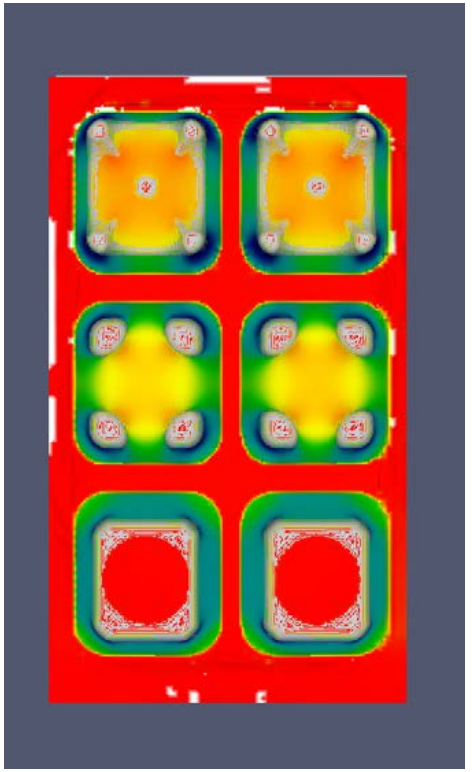


Pre-Stretching (plug & mold movements)

75 mm in 30 sub-steps

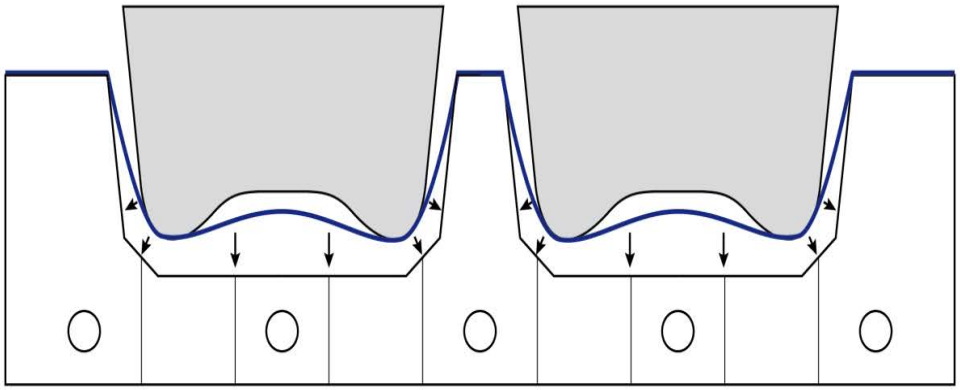
Pre-Stretching

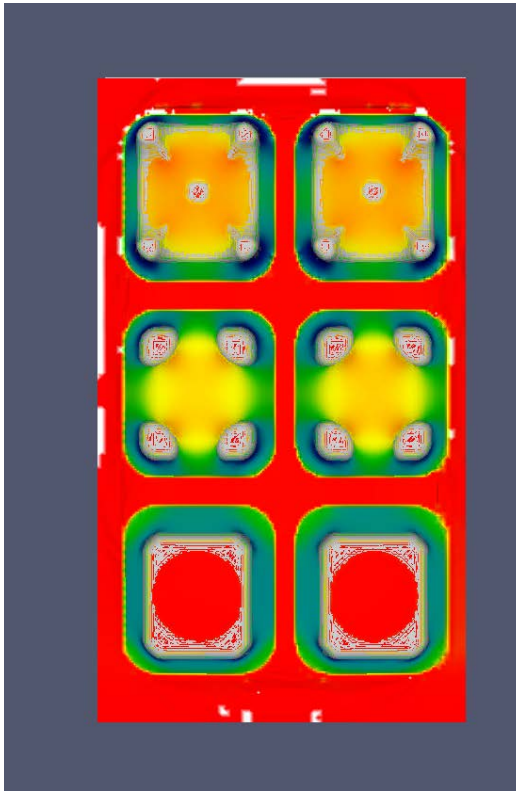




Time before stretching by application of vacuum

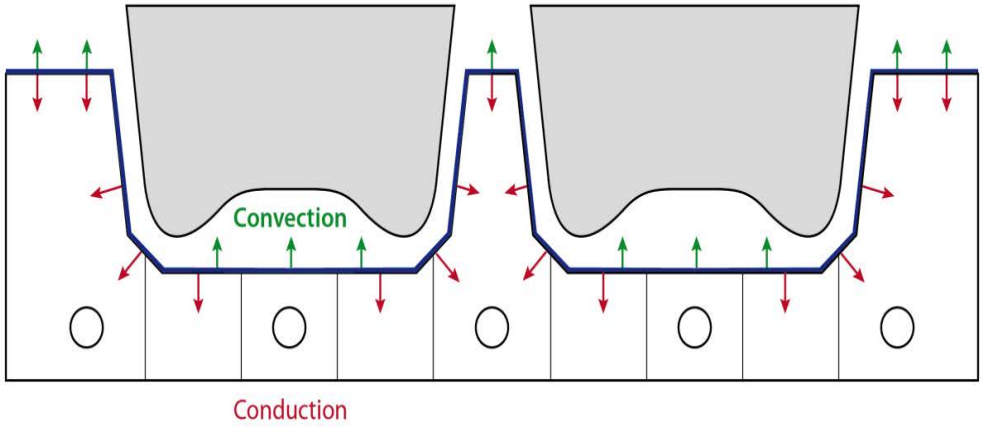
Pre-Stretching

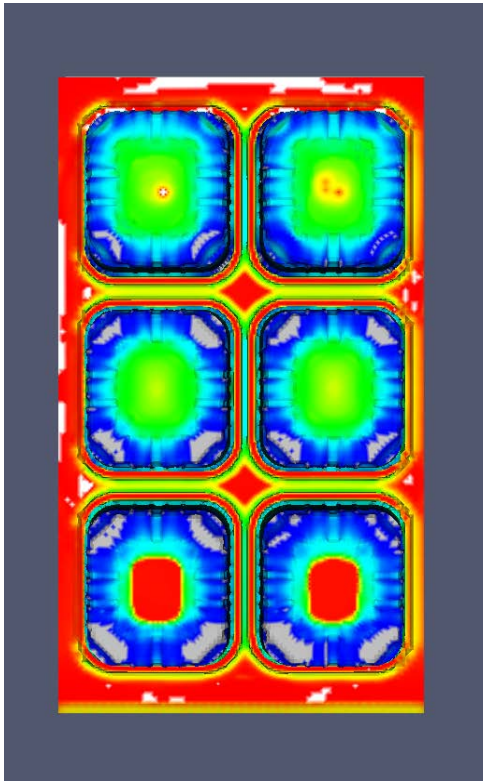




Stretching (vacuum)

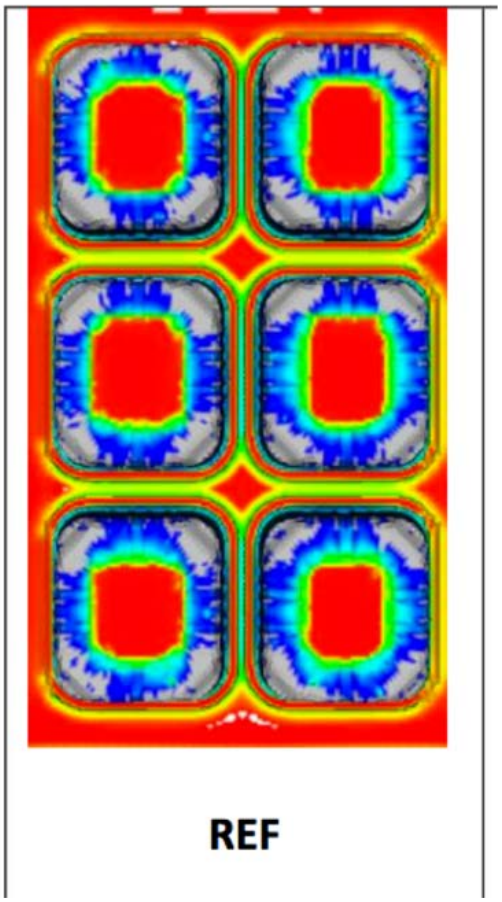
Final Stretching

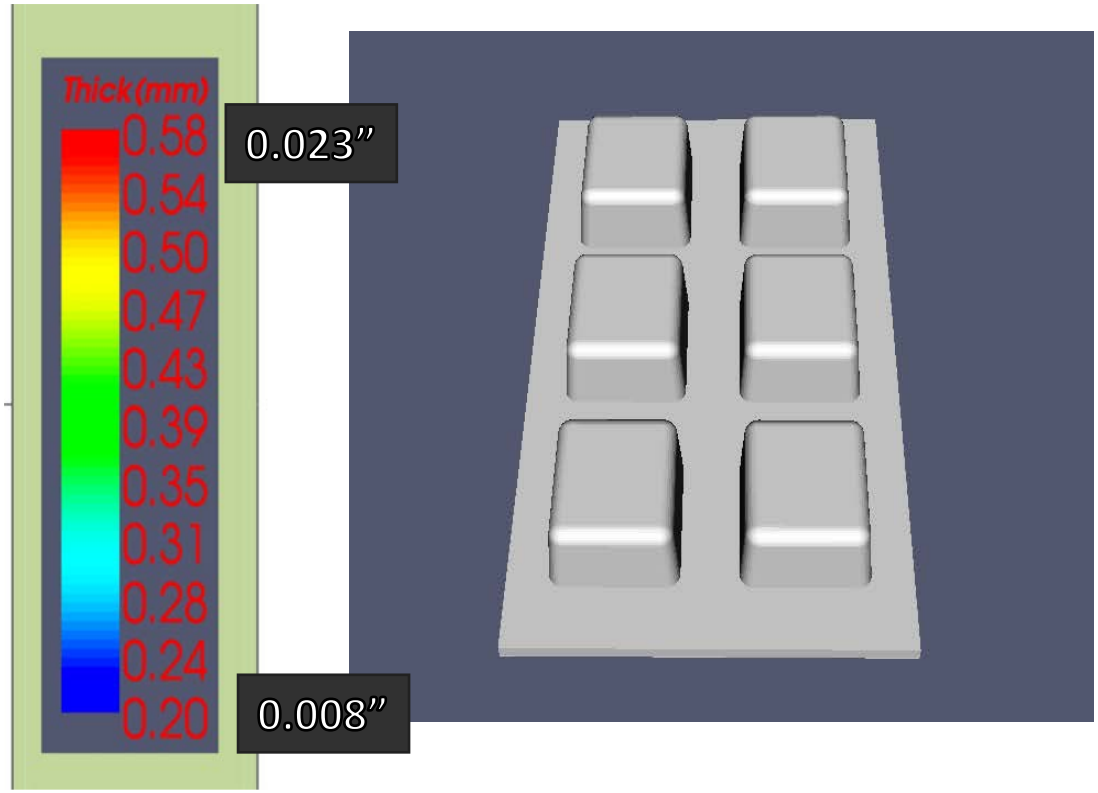




5. Results (WTD) obtained from simulations

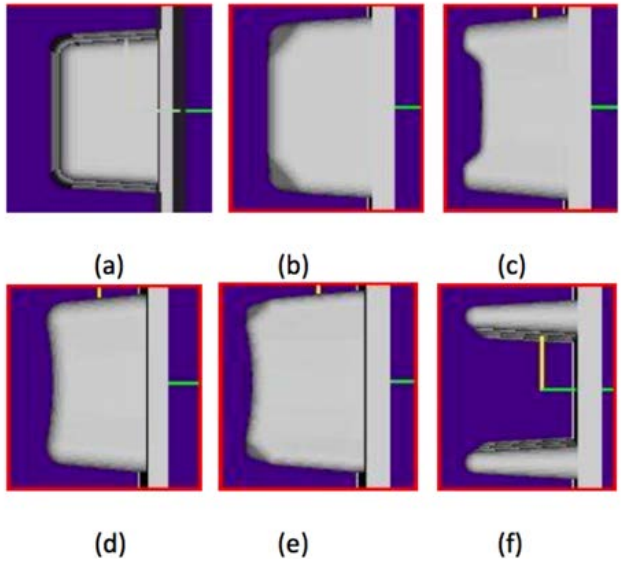
- Regular plug geometry. (P0 or REF)

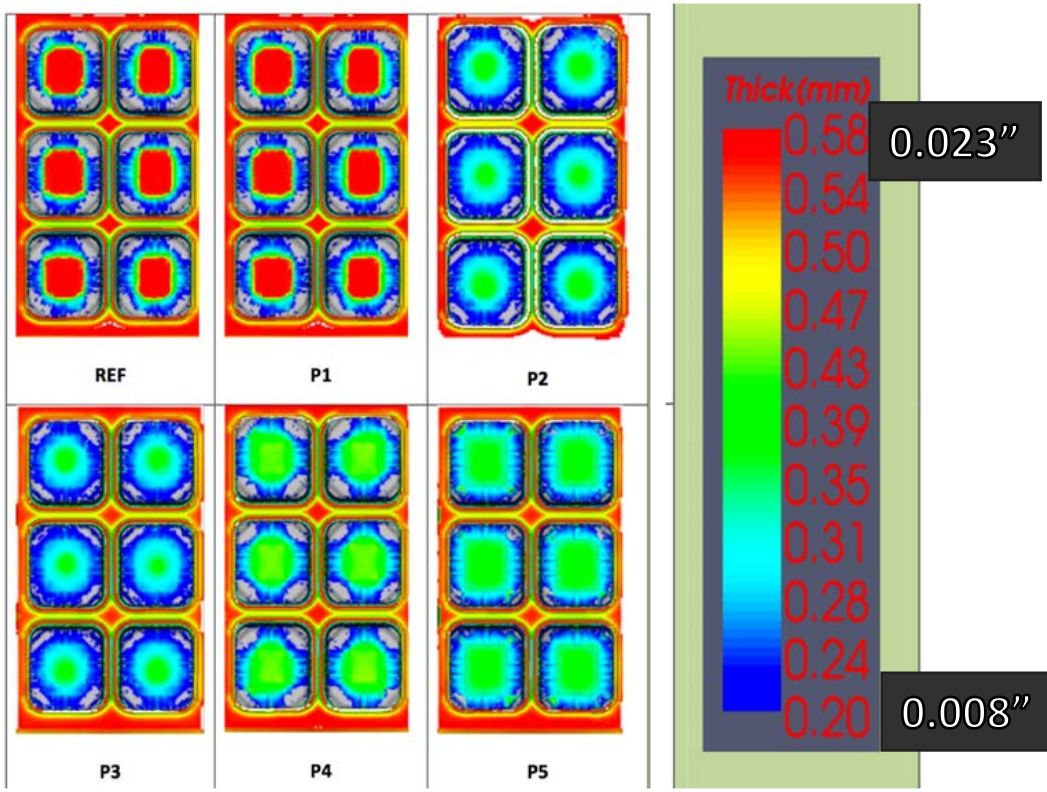




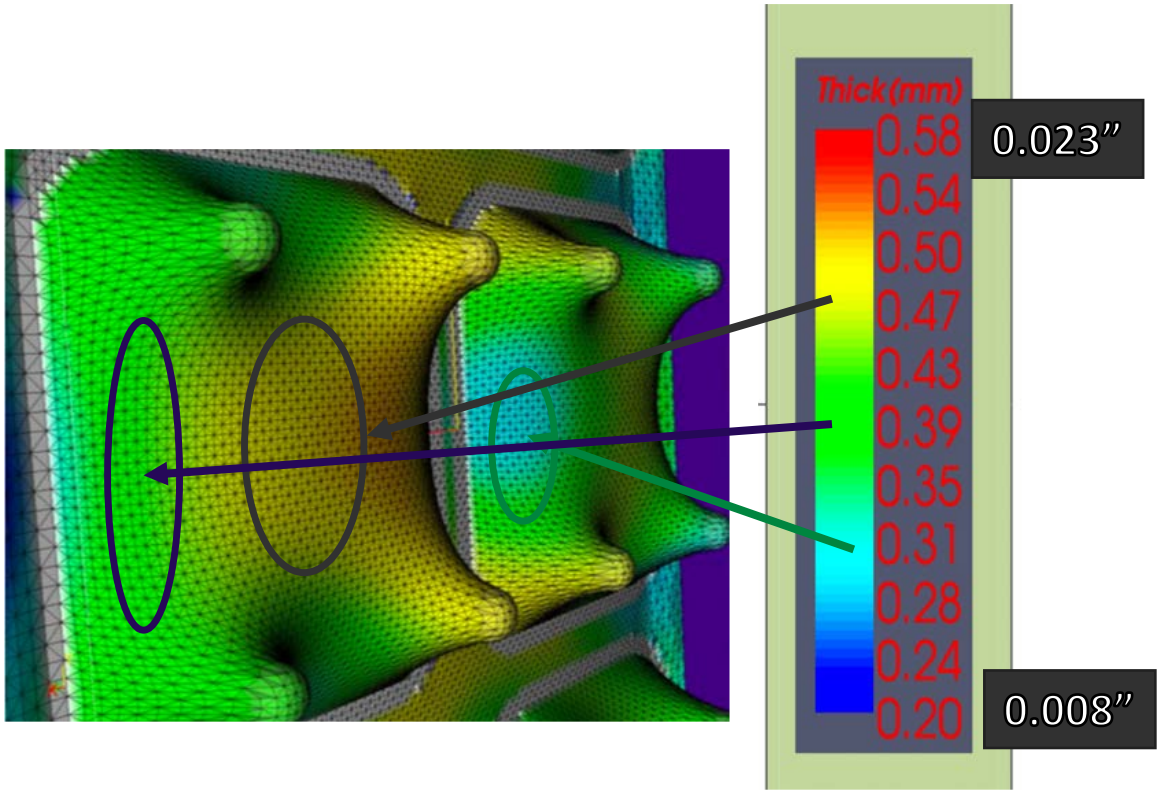
5. Results (WTD) obtained from simulations

- 1st serie of plug geometries (REF, P1, P2, P3, P4, P5)



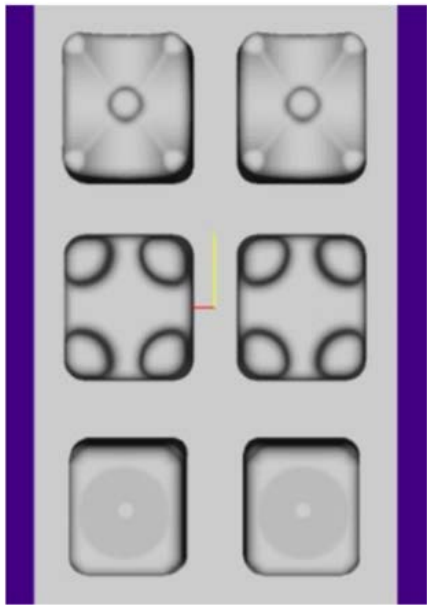


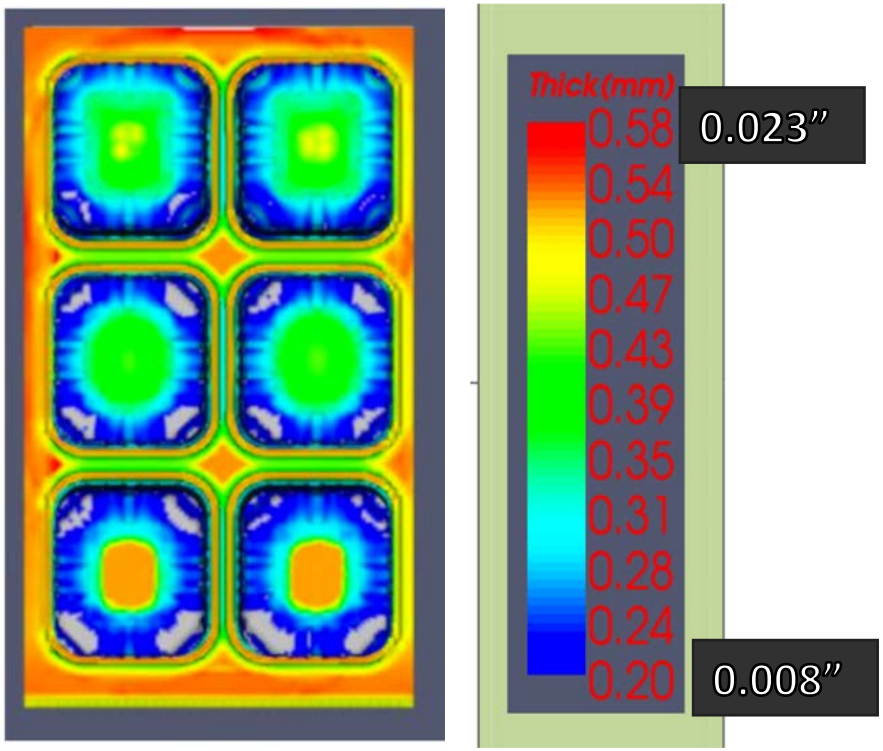
Plug P5 during pre-stretching



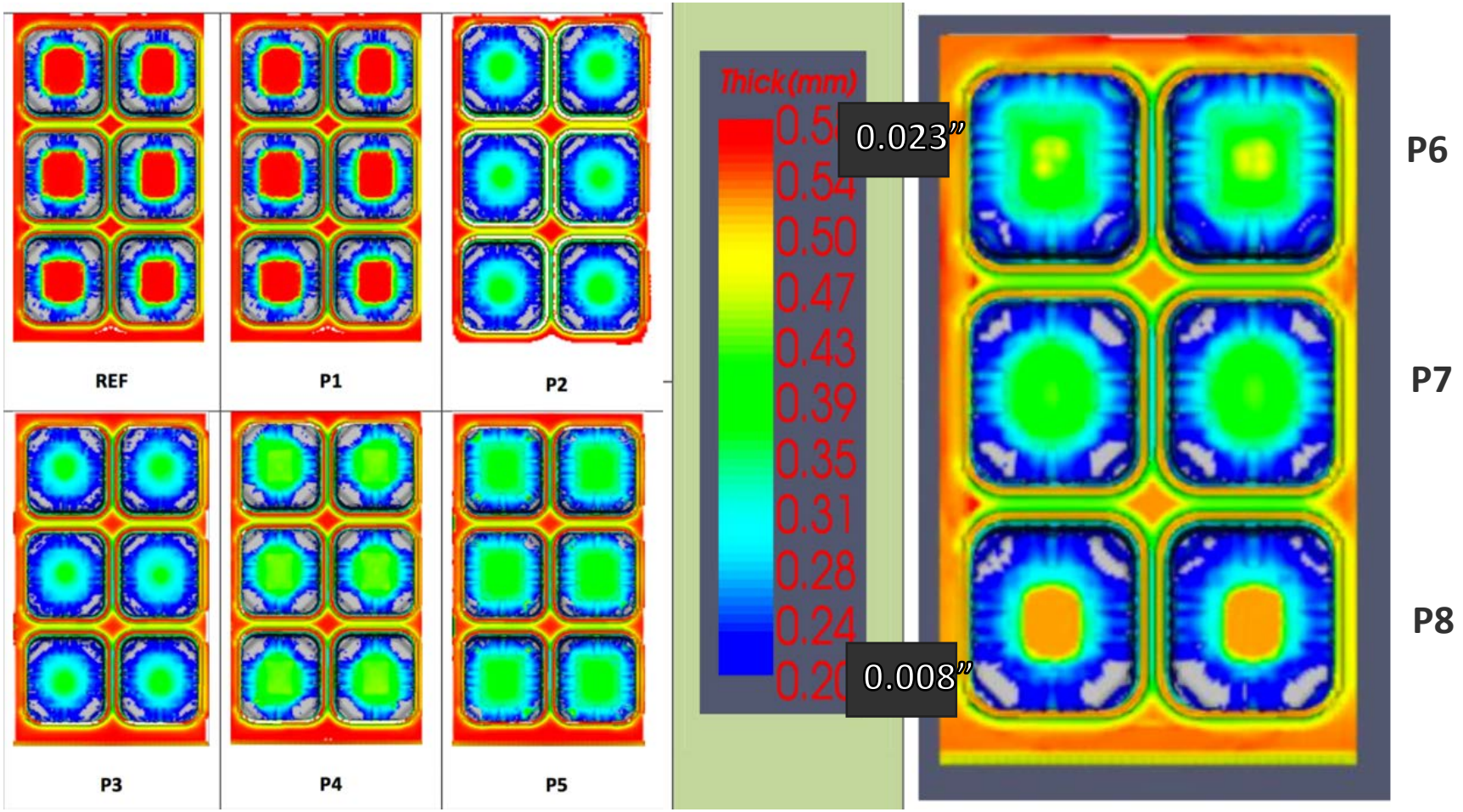
Results (WTD) obtained from simulation

- 2nd serie of plug geometries (P6, P7, P8)

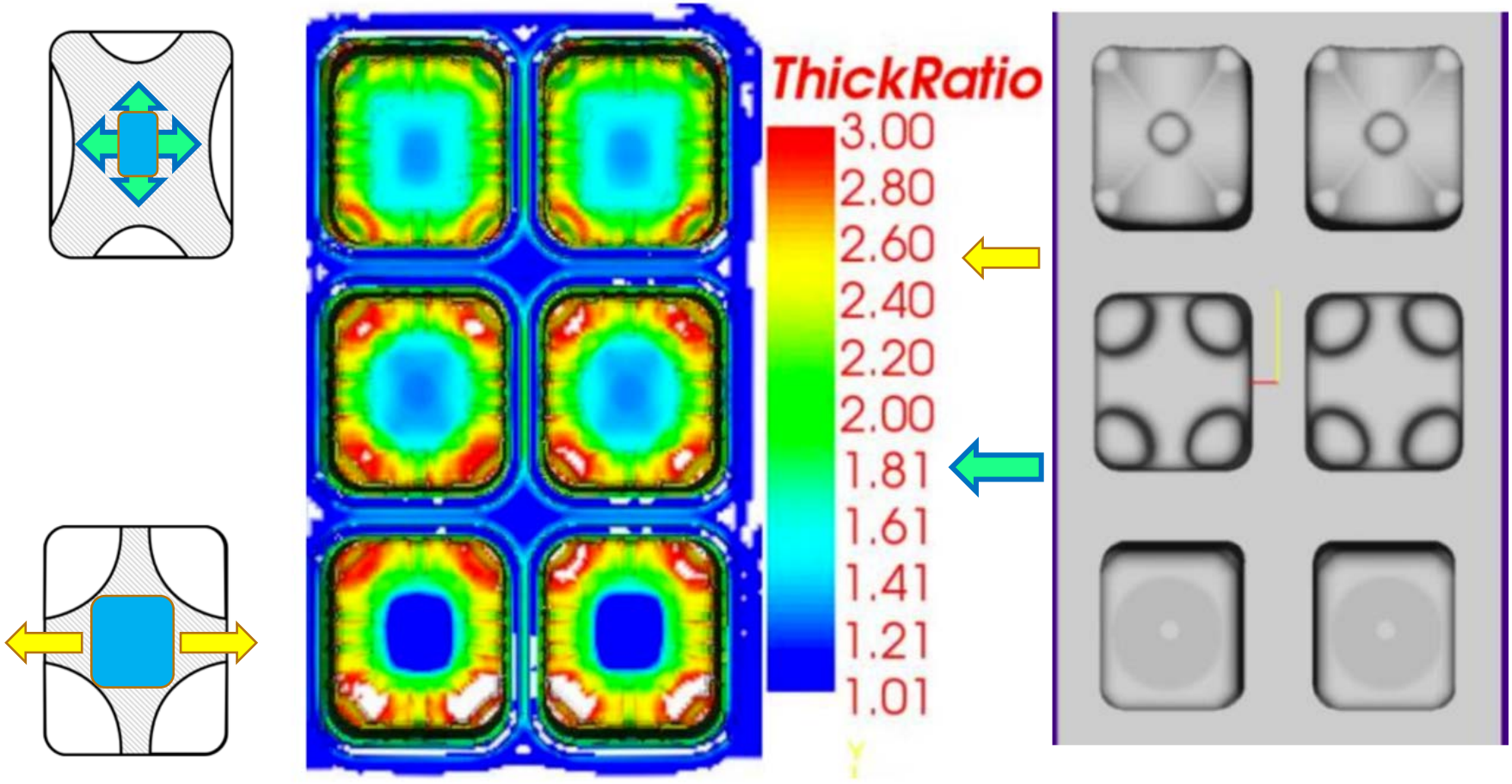




A results recapitulation

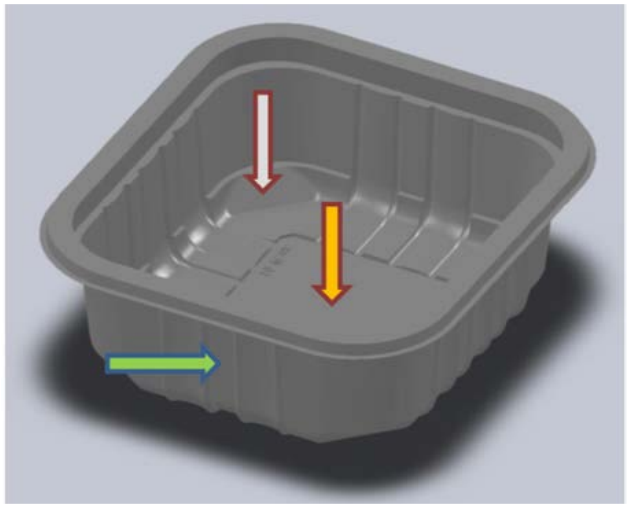


Stretch Ratio on P6, P7 and P8

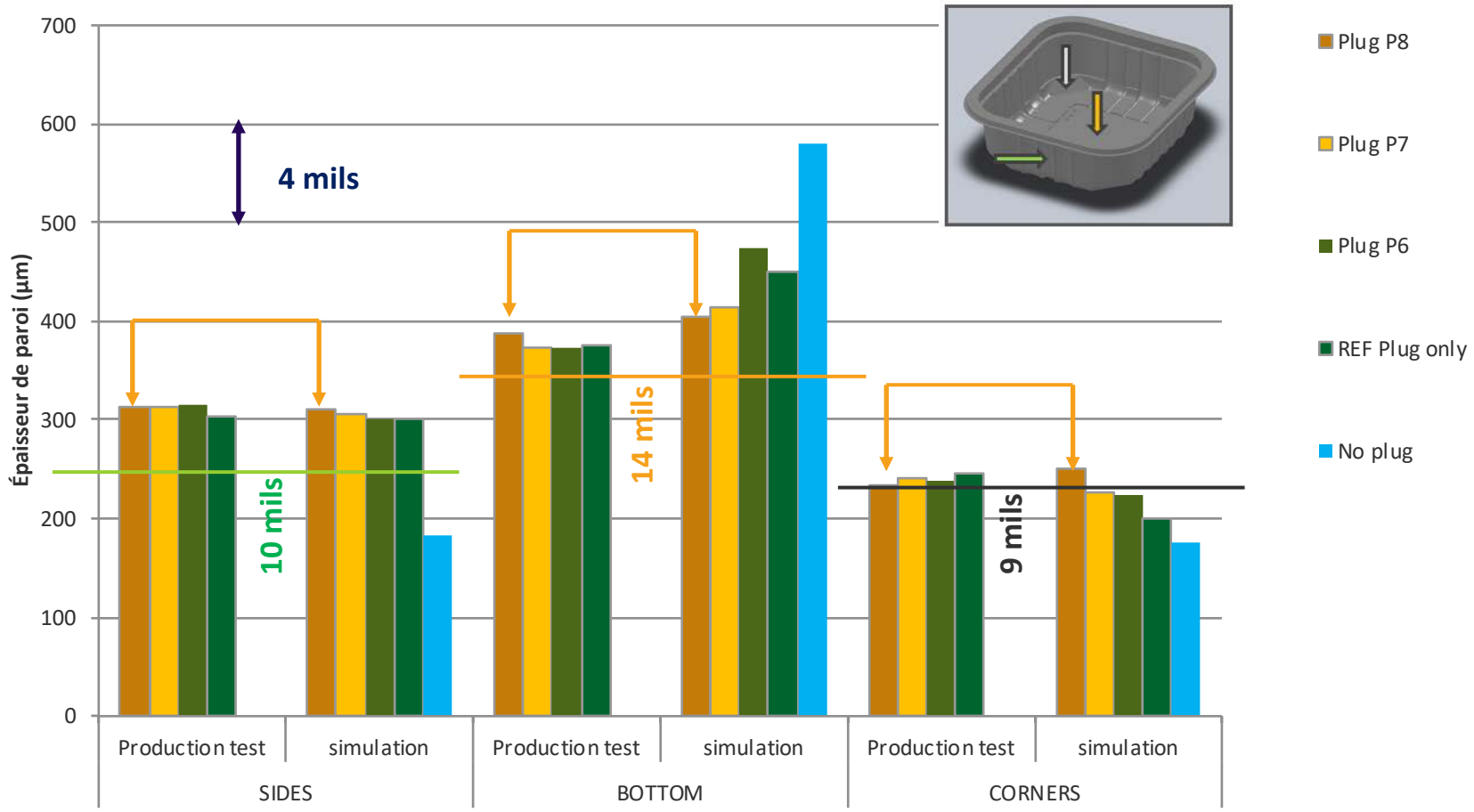


From simulation's results, a "real" production run …

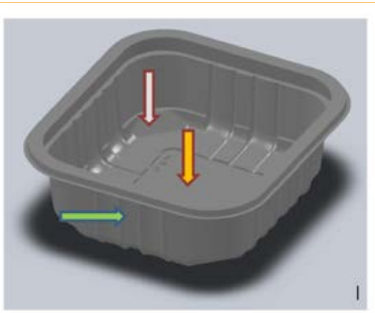
- Minimum QC specs
  - Bottom : 0.355 mm (14 mil)
  - Sides : 0.255 mm (10 mil)
  - Corners : 0.225 mm (9 mil)



5. Simulated results and production results



Outcomes



In plug design (and for similar part geometry)

1. Minimize surface plug-sheet contact
2. Remember that slip conditions are function of
   - Plug material and Coefficient of Friction
   - Plug temperature
   - Plug radius as well
   - … Surface roughness may play a role
3. Get contact only in specific area that may required better control on wall thickness
4. Control plug velocity to adapt to the material behavior

6. Benefits of using software to simulate process

- Reduction of debugging time (new products-parts)
  - big part of the job in already done
- Reduction in raw material costs
  - Significant savings
- Better use of Process Technician and Engineer time:
  - But use their significant inputs and know-how
- Potential savings on tooling reworks
  - CAD modifications and several simulations are easy to run

Benefits of using software to simulate process

- Gain in machine-time (efficiency)
  - 10 new molds/yr X 15 hrs = 150 hrs. X 35 $/hr = **45 000 $ / year**

    (***add. Potential Profit***)
- Possible lower sheet gage
  - Even 1 mil reduction can be 5 -8 % cost reduction in raw material costs **5 - 20 000 $ / yr**
- **Better understanding of thermal material behavior in the process**
- **Reduced time to production**
- **Better understanding of the optimization-technology process**

Costs related

- Annual software license fee
- Engineer(s) trained to use and understand its potential
- Good CAD supporting team
- Good production team opened to new aided technology

OR

- Use of professional engineering firm to do the simulation(s)

Thanks you !

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