Presented at the COMSOL Conference 2009 Milan

Level Set Method for Fully Thermal-Mechanical Coupled Simulations of Filling in Injection and Micro-Injection Molding Process

Site de Plasturgie de l'INSA de Lyon
LamCOs - GRPP

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Pôle Européen de Plasturgie

- ✓ **Technical center dedicated to Injection Molding**
- ✓ **50 people for 4,8 M€ turnover in 2008**
- ✓ **3 business units :**
  - ➢ ***Advanced materials***
  - ➢ ***Process and tools***
  - ➢ ***Design and simulation***

SIMTEC

- ✓ **Comsol Certified Consultant Company**

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- ✓ **Comsol Certified Consultant Company**
- ✓ **Expertise Fields:**
  - ➢ ***Electromagnetism***
  - ➢ ***Structural Mechanics***
  - ➢ ***Heat Transfer modeling***
  - ➢ ***CFD***

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The « Microstructure » research project

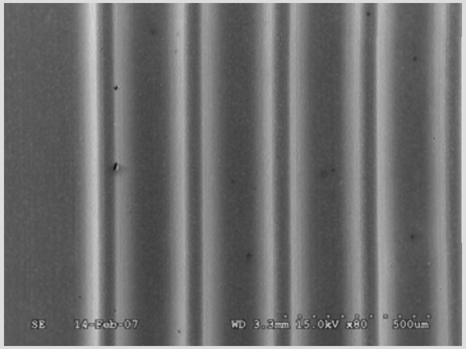
Objectives

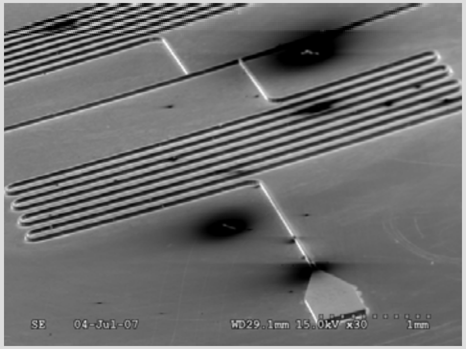
✓ **Analyze, understanding and knowledge acquisition necessary to replicate microstructures on thermoplastic parts, with the injection-molding process**

Double approach

✓ **From a technological point of view**

- ➢ **New mold concept developments** (vacuum, compression,...).
- ➢ **Mold insert tooling technologies** : usual tooling, laser (classical laser machining, femto-second laser, selective laser melting), µ-EDM, and LIGA UV technology.
- ➢ **Applications** in bio-medical analyses, optics or connectors.





The « Microstructure » research project

- ✓ **From a theoretical point of view**
  - ➢ The PEP needs to study further physical phenomena that occur during the process. Why ?
    - ✓ The commercial codes (Moldflow, REM 3D, etc...) are very useful to solve 90 % of the problems, but for the last 10 %, they do not take into account some phenomena that could have influence in specific configurations such as micro-injection molding (complex thermal effects, surface effects...)
    - ✓ We can’t modify or add further physical phenomena
    - ✓ The PEP purpose is definitely not to develop new calculations codes for the polymer processing industry...

The « Microstructure » research project

How injection process works?

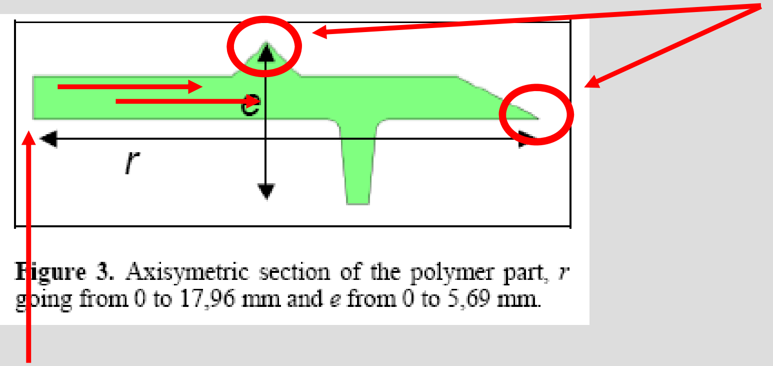


Figure 3. Axisymetric section of the polymer part, *r* going from 0 to 17,96 mm and *e* from 0 to 5,69 mm.

2D axisymetry

II. Governing equations

1. Coupled Navier-Stokes and Level Set equations

$$\begin{cases} \rho \dfrac{\partial u}{\partial t} + \rho u.\nabla u = \nabla.\left[- pId + \eta\left(\nabla u + (\nabla u)^T\right)\right] + \rho g + \sigma\kappa\delta n \\ \nabla.u = 0 \\ \dfrac{\partial \Phi}{\partial t} + u.\nabla\Phi = \gamma\nabla.\left[\varepsilon\nabla\Phi - \Phi(1-\Phi)\dfrac{\nabla\Phi}{|\nabla\Phi|}\right] \end{cases}$$

2. Cross WLF viscosity law

$$\eta = \frac{\eta_0}{\left(1 + \left(\dfrac{\eta_0 \dot{\gamma}}{\tau^*}\right)\right)^{(n-1)}}$$

3. Thermal influence

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u.\nabla T - \nabla.\left[k\nabla T\right] = Q$$

$$Q = 2\eta_{(\dot{\gamma},T)}\left(u_r^2 + \frac{1}{2}(u_z + v_r)^2 + \frac{u^2}{r^2} + v_z^2\right)$$

$$\eta_0 = D_1 \exp\left[\frac{-A_1(T - T_{ref})}{A_2 + ((T - T_{ref}))}\right]$$

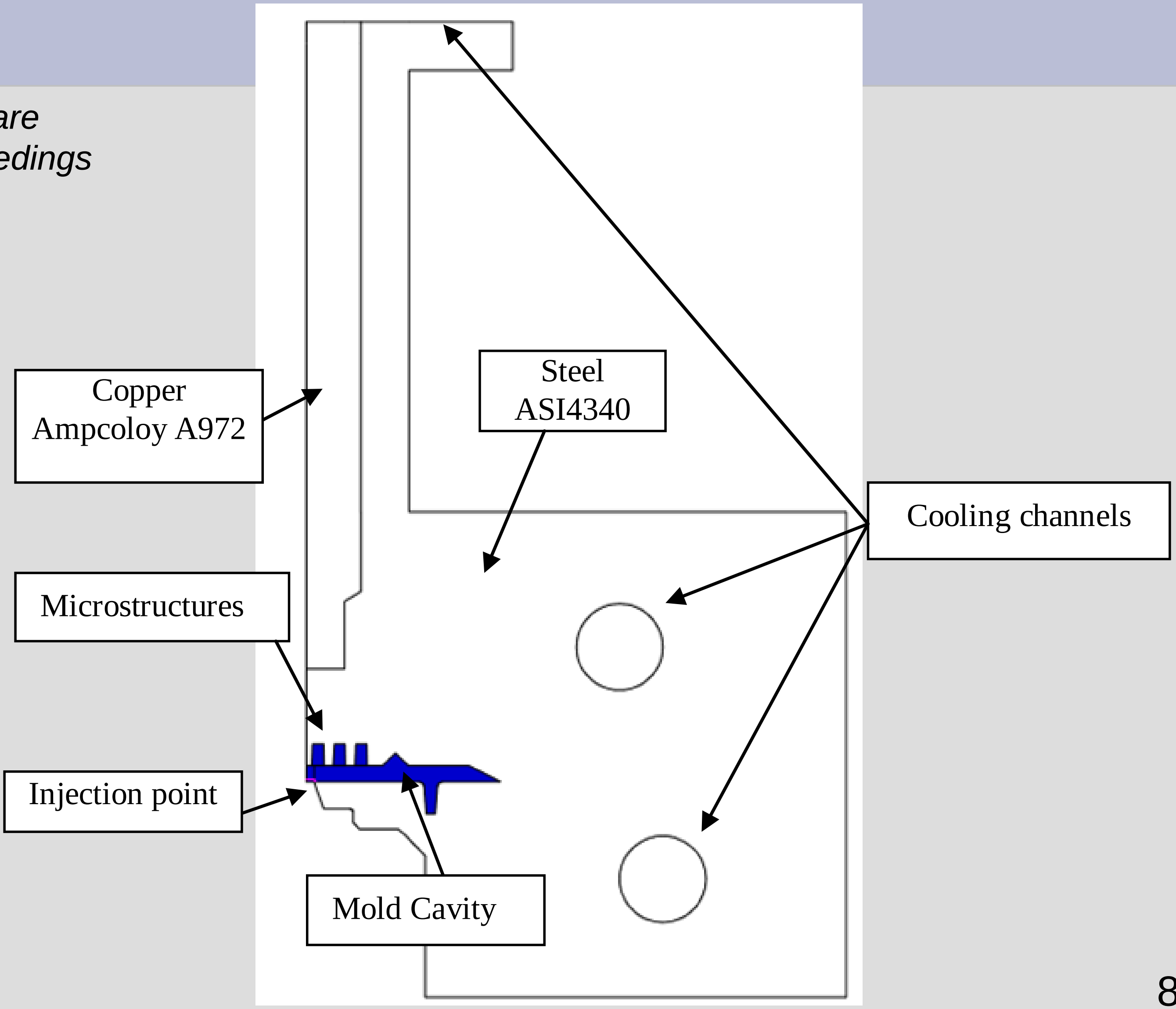
4. Weak compressibility

$$\begin{cases} \rho \dfrac{\partial u}{\partial t} + \rho u.\nabla u = \nabla.\left[- pId + \eta\left(\nabla u + (\nabla u)^T\right) - \left(\dfrac{2\eta}{3} - \kappa_{dv}\right)(\nabla \cdot u) Id\right] \\ \dfrac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0 \end{cases}$$

$$\rho = \frac{pM}{RT}$$

Mold geometry

Parameter values are described in proceedings



IV. Results

- **Weak compressibility results**
- **Transient thermal effects (in the mold)**
- **Filling micro-features**

IV. Results

Weak compressibility results

Newtonian
Isothermal fluid

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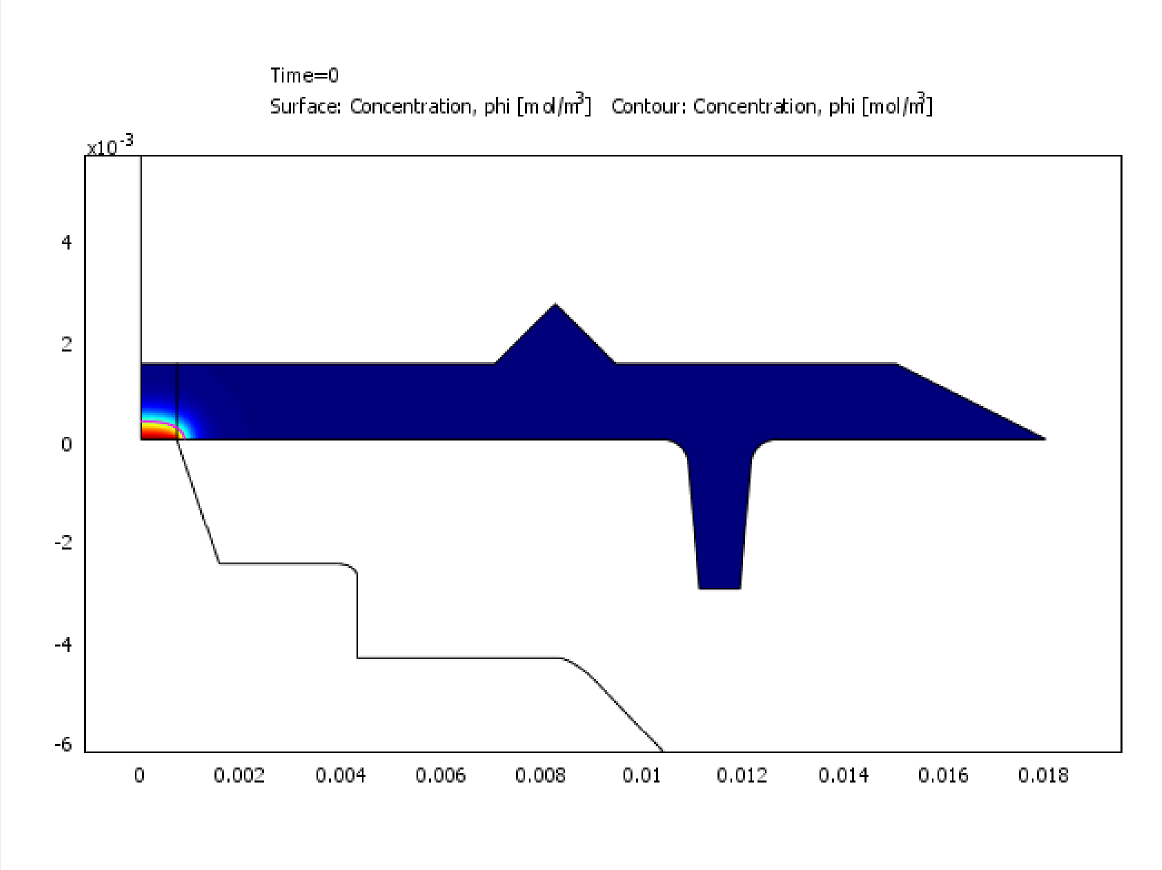
Weak compressibility results

Newtonian
Isothermal fluid

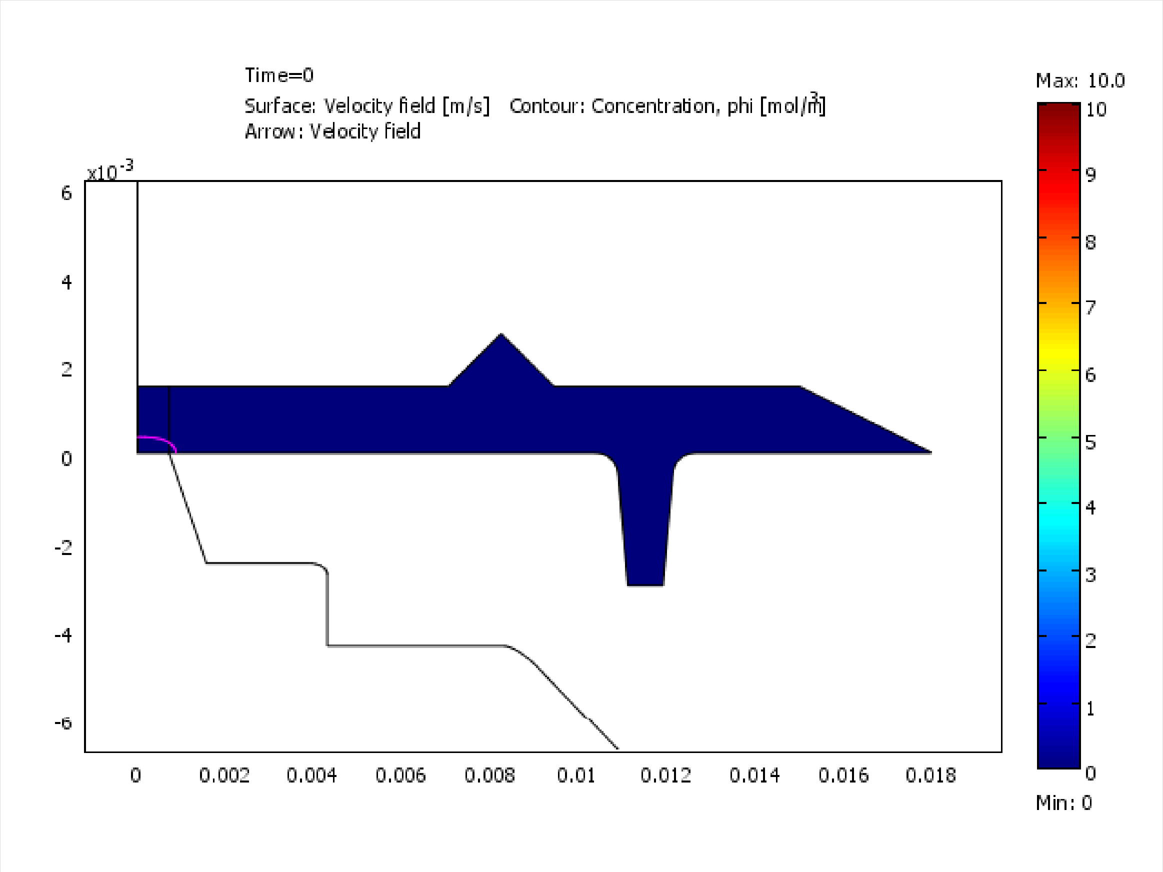


Evolution of the Polymer field according to time

IV. Results

Weak compressibility results

Newtonian
Isothermal fluid



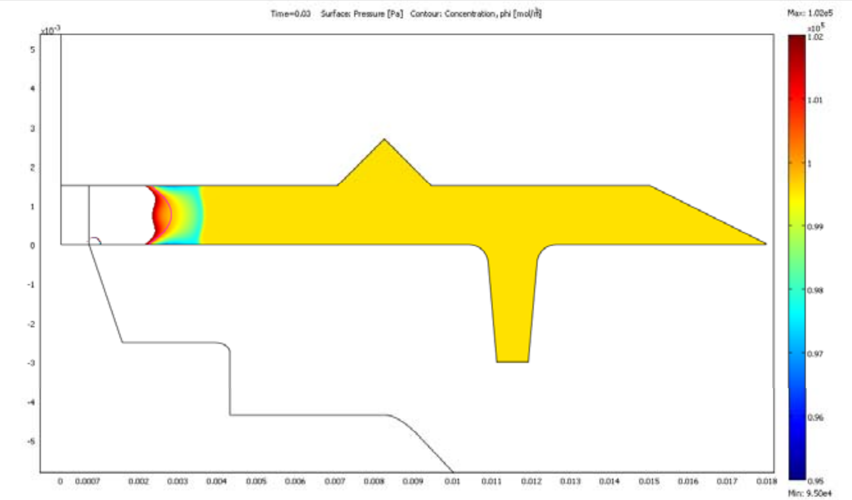
VORTICES IN THE SUBDOMAIN

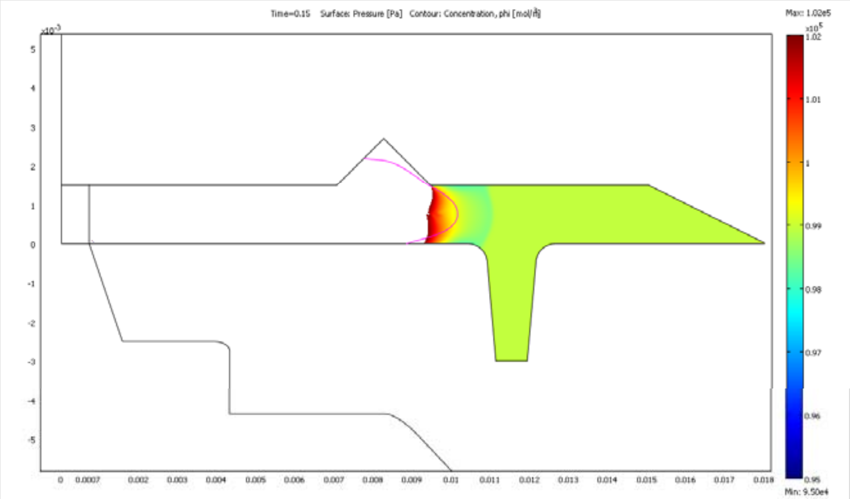
Evolution of the velocity field in the Subdomain.

Weak compressibility results

Evolution of the pressure field:

Subpressure area before the Mass front





Pressure field at two different times:

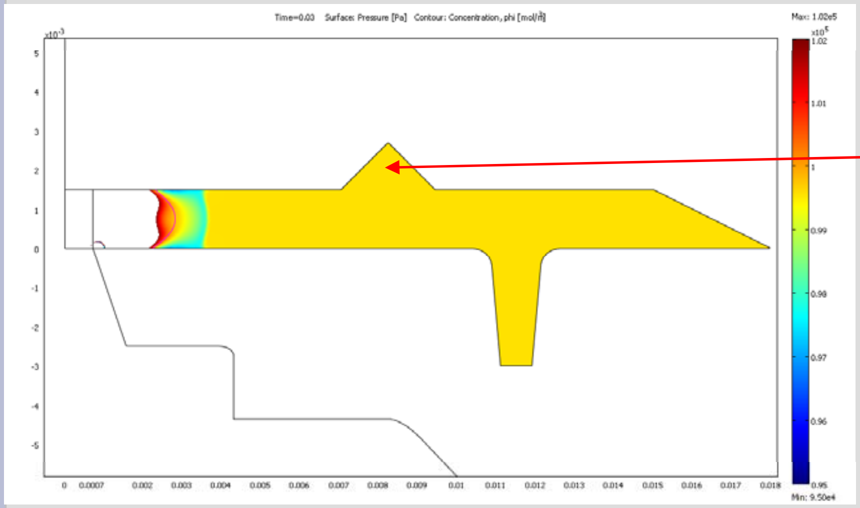
- **RED= High Pressure**
- **BLUE=Low Pressure**

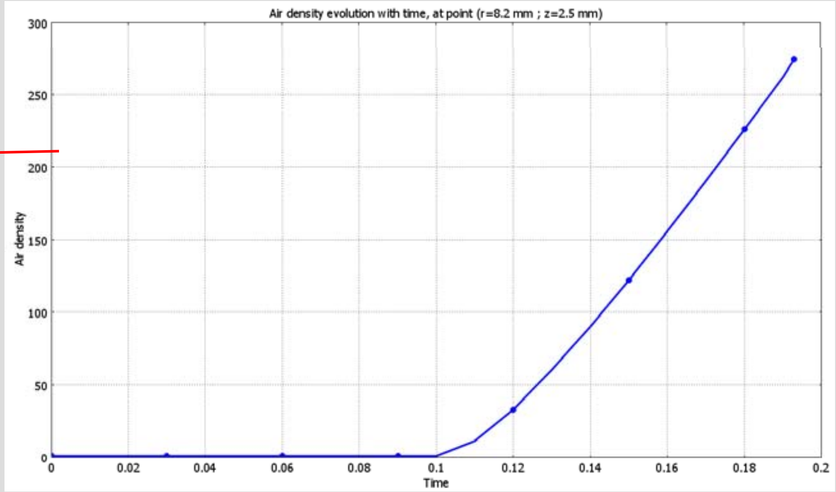
IV. Results

Weak compressibility results

Evolution of the pressure field:

Subressure area before the Mass front





Evolution of the air density, according to time

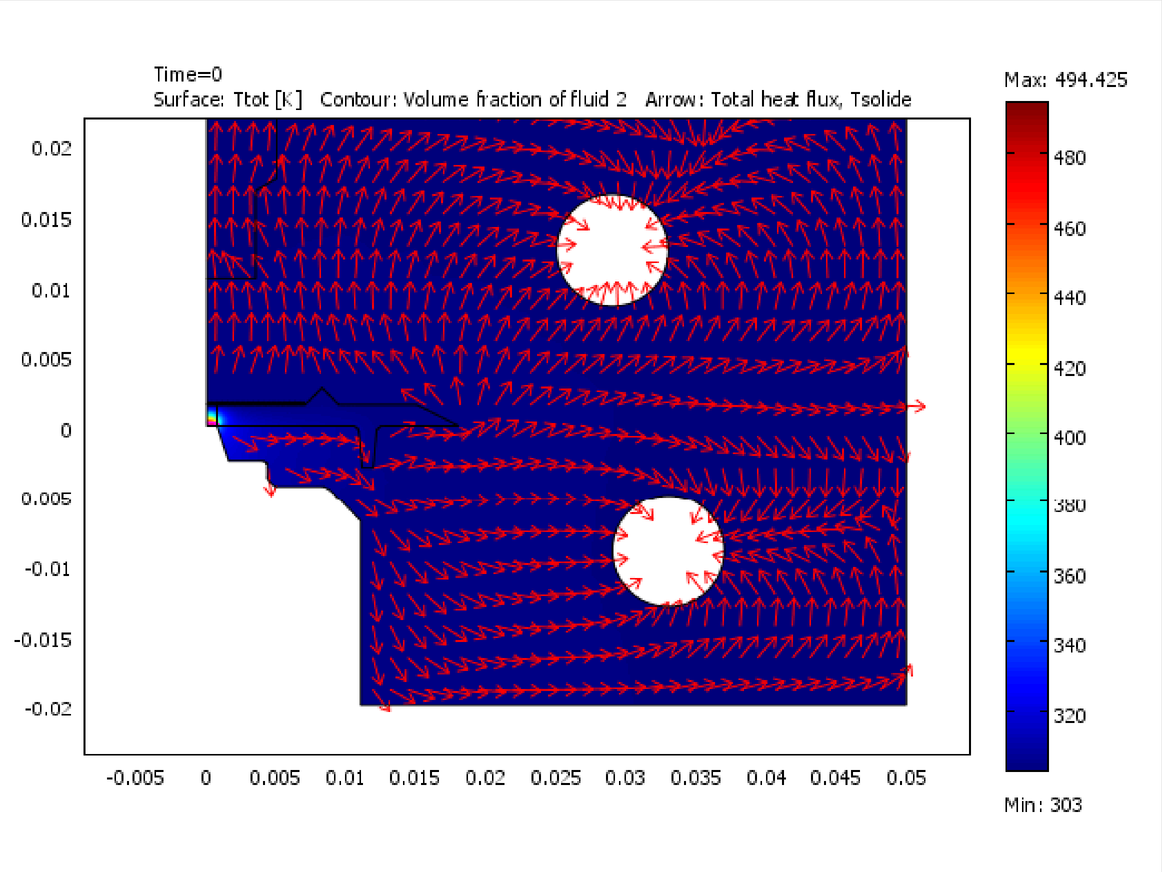
IV. Results

- **Weak compressibility results**
- **Transient thermal effects (in the mold)**
- **Filling micro-features**

IV. Results

Transient thermal effects

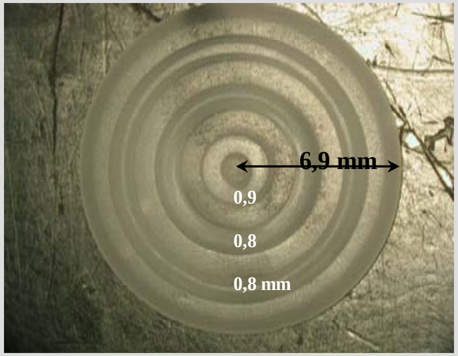
- **Evolution of the Temperature field in the mold**
- **Optimization of the location of the cooling system**



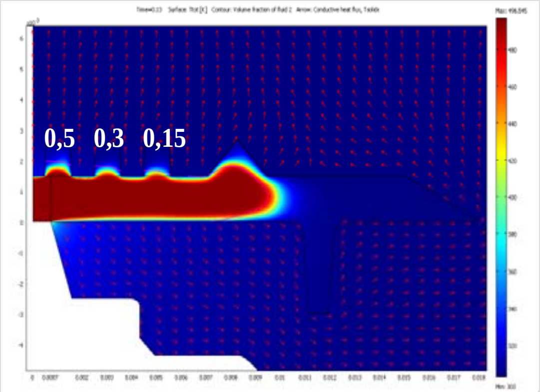
IV. Results

- **Weak compressibility results**
- **Transient thermal effects (in the mould)**
- **Filling micro-features**

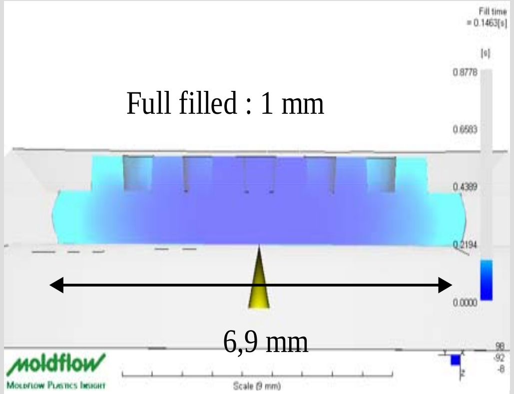
Filling micro-features : comparisons between COMSOL and Moldflow



Exp. data



COMSOL Multi.



Moldflow

IV. Results

Filling micro-features

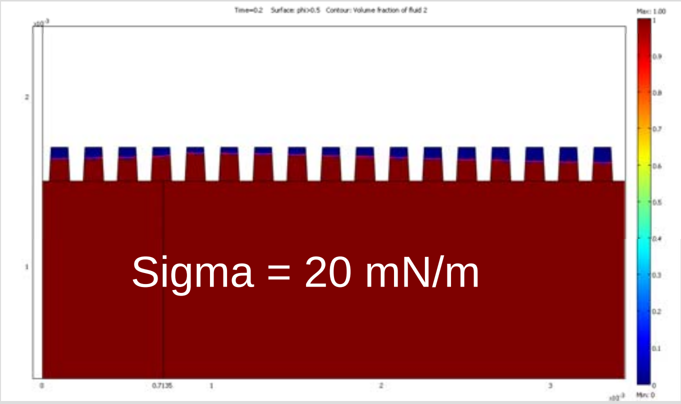
- **Moldflow :**
  - **<u>Advantages</u> : quite fast, some characteristics are ok (filling time, pressure field, cooling time).**
  - **<u>Drawback</u> : no optimization of the shape of the mold (thermal transient), monophasic flow, no surface tension, convergence difficulty with multi-scale approach in 3D**

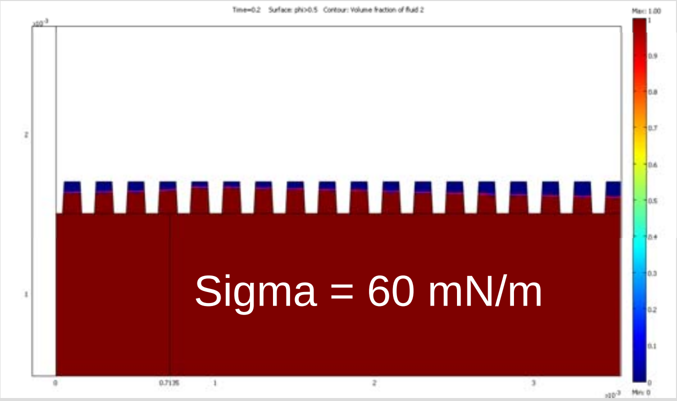
- **COMSOL Multiphysics :**
  - **<u>Drawback</u> : the numerical convergence is difficult to obtain (weakly compressible flow)**
  - **<u>Advantages</u> :**
    - **Strong coupling between equations,**
    - **Enables us to consider diphasic approach and a «real» filling of the cavity,**
    - **Enables us to study some «new» effects, like surface tension,**
    - **Mesh is efficient and easy to use,**
    - **Optimization of the location of the cooling system,**

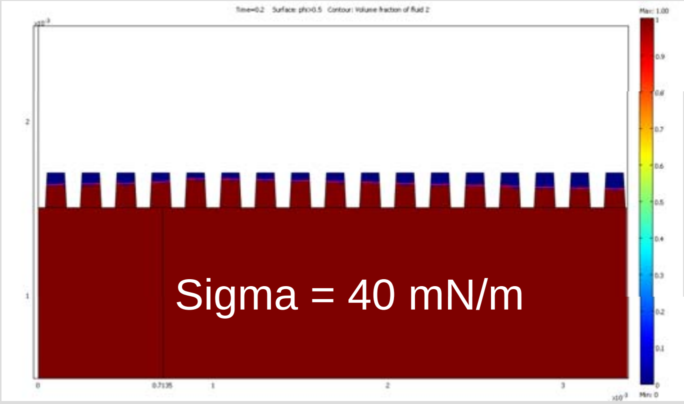
IV. Results

Filling micro-features : Influence of surface tension

GEOMETRY 0,1x0,2 mm





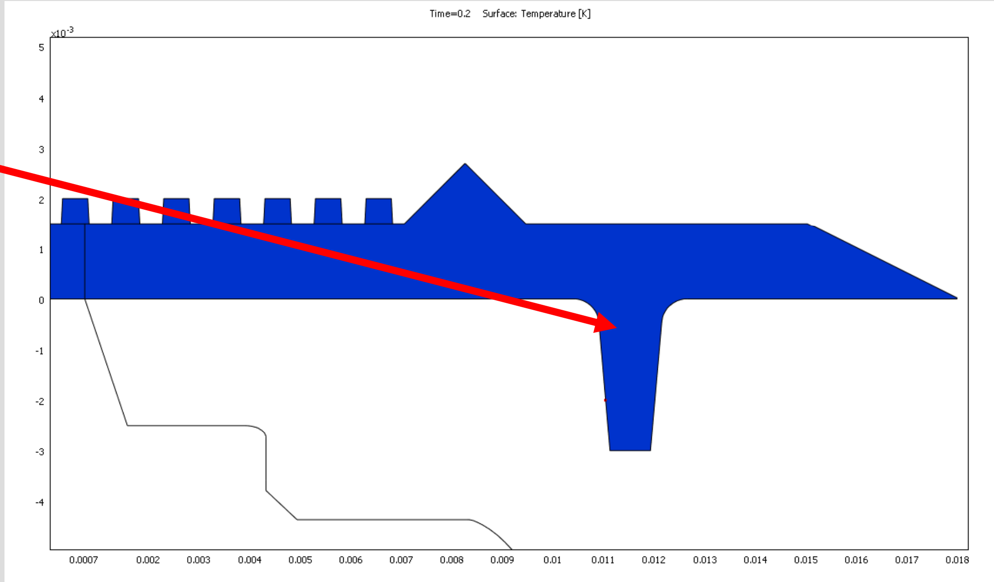


No quantitative influence, despite the low speed of propagation

Filling micro-features : Influence of transient thermal effect in the mold

GEOMETRIY 0.5x0.5 mm

Heating of the mold wall (by conduction inside the mold) before the polymer reach this part?



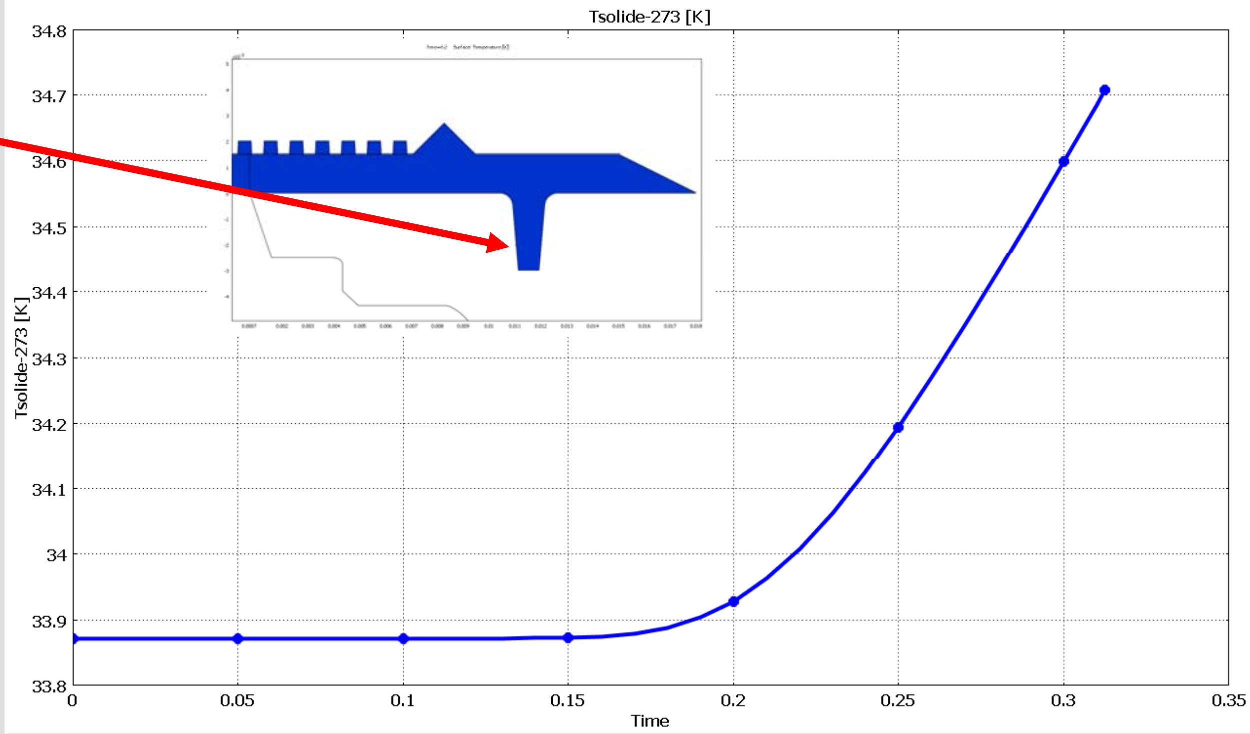
Filling micro-features : Influence of transient thermal effect in the mould

GEOMETRIY 0.5x0.5 mm

Heating of the mold wall (by conduction inside the mold) before the polymer reach this part?

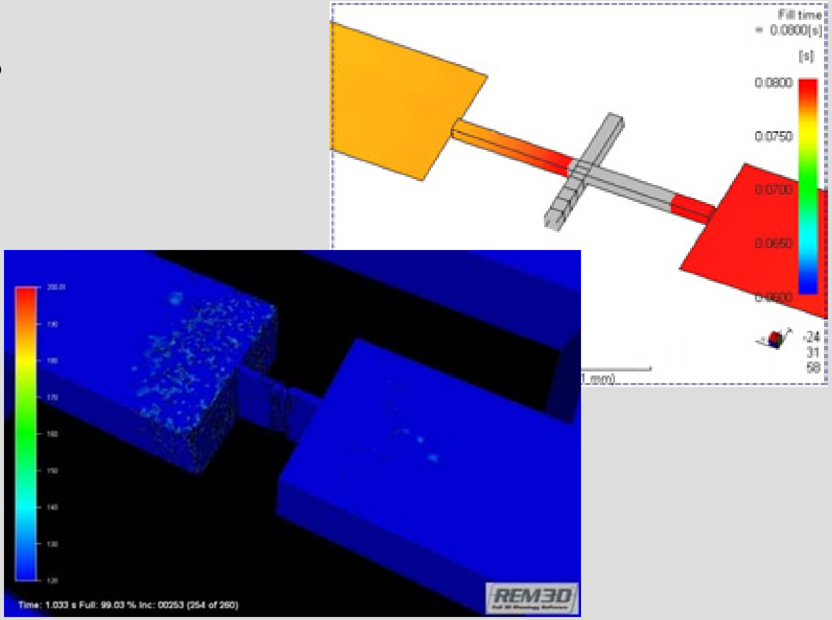
NO!

If the mold is well optimized, no influence of the polymer flow



Motivation of this project:

- **Effect of transient Heat Transfer during the filling?**
- **Which law to apply? Compressibility?**
- **Surface Tension ?**



V. Conclusion

- **With COMSOL MULTIPHYSICS:**
  - **Level Set method to model the air and the polymer**
  - **Pseudo-plasticity Cross Law**
  - **Non-newtonian fluid (dependent on the Temperature)**
  - **Self-heating of the Polymer**
  - **Heat transfer study in the mould and in the print**
  - **Microscale geometry**
  - ***Work on compressibility***

V. Conclusion

Comparison between experience / Comsol / Moldflow

- **For a low shape factor**
  - **Moldflow does not take the air into account, and the filling time is very close to the experimental one**
  - **Comsol takes the air into account (incompressible fluid), whatever the shape factor is. Only a partial filling, and quite far from the exp. result.**

- **For a shape factor equal to 2:**
  - **The numerical necessary time to fill the microfeatures with Moldflow is under-estimated**
  - **With Comsol, this time is over-estimated**

- **→ really need to develop a weak compressible model with COMSOL**

BOTH APPROACHES ARE INTERESTING!

Thanks for your attention... and your questions!

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