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Boost Design Verification Productivity & New VE Coupled Solver

EMEA
Alex Lu

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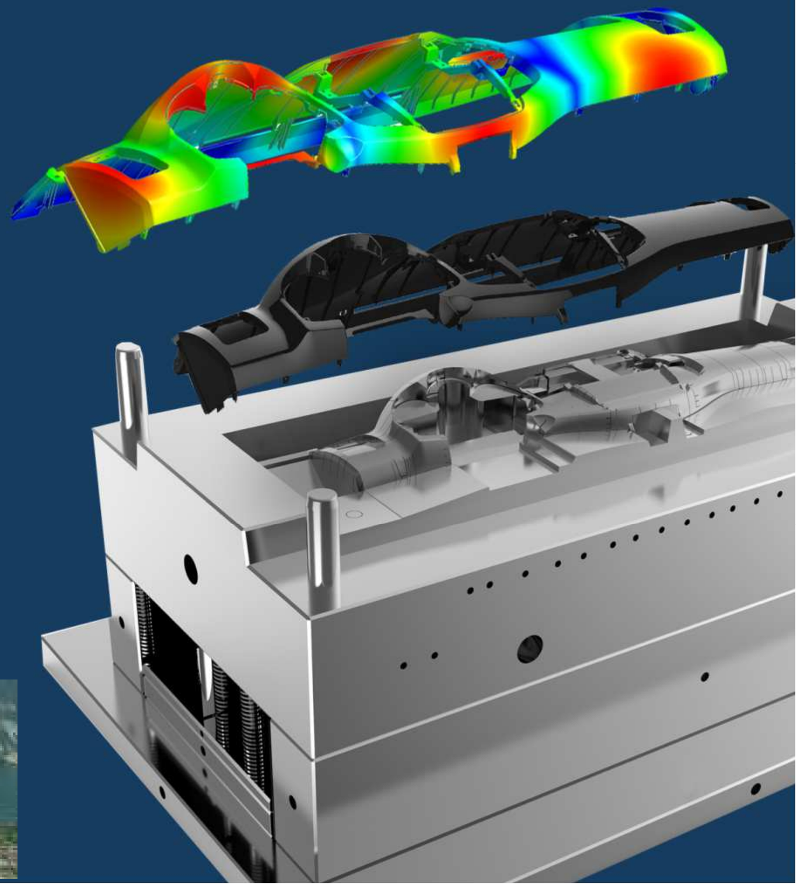

Deciding Gate Position

L / t and Quick Flow

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When it comes to gate design…

> In Designer
  - L / t
    - Improved in R16

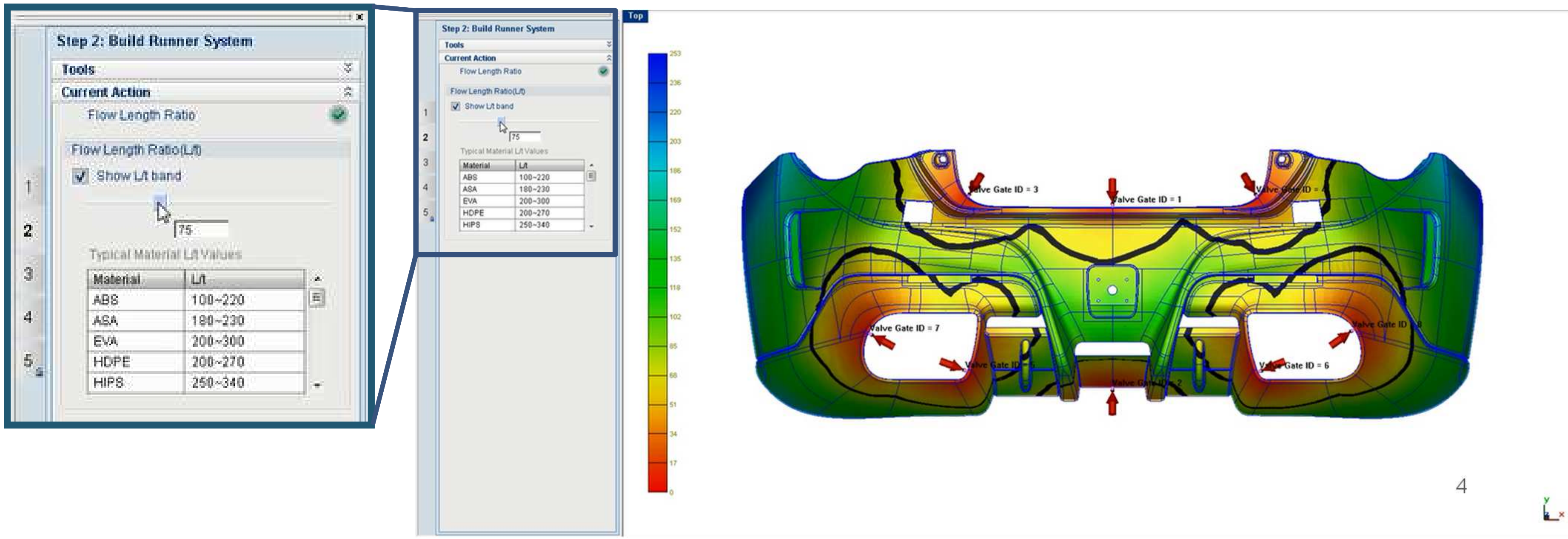
> Quick iteration
  - Quick Flow
    - New in R16

> Further simulation
  - Enhanced flow
    - Normal simulation

Flow Length Ratio (L / t)

> **Flow behavior estimation**
>
> - **Prevent short shot in the gate location designing stage**
>   - **L: Length of the flow front path**
>   - **t: Thickness of the part**

> **Build-in flow length ratio suggestion**
>
> - **Suggest flow length ratio for the different materials**



Flow Length Ratio (L / t)

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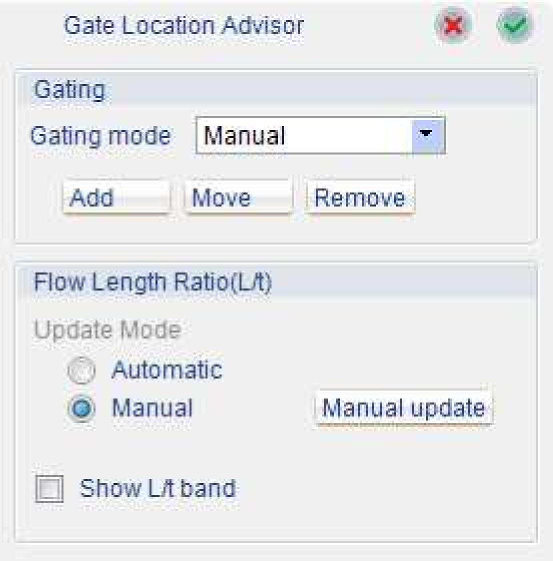
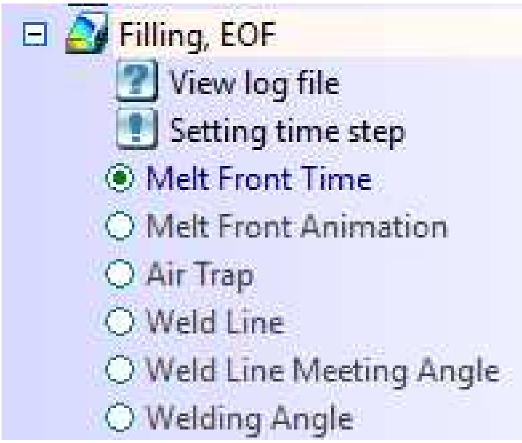
> **Enhancement in R16**
- **Change to gate wizard page in Designer**
  - **Under gate location adviser in Studio**
- **Smoother workflow**
  - **Assign gate location**
  - **Result update**

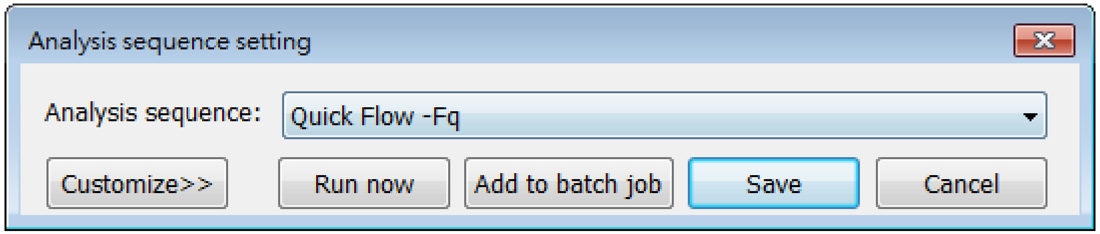


Quick Flow

> New analysis sequence
  - Speedup the iteration in gating design for big parts

> Tips
  - Gate attribute only (hot gate and cold gate available)
  - Support valve gate setting
  - Limited results



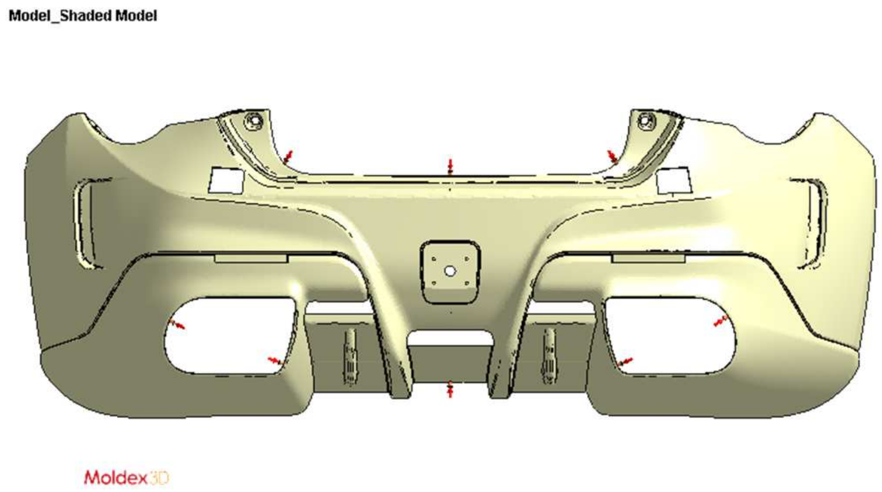


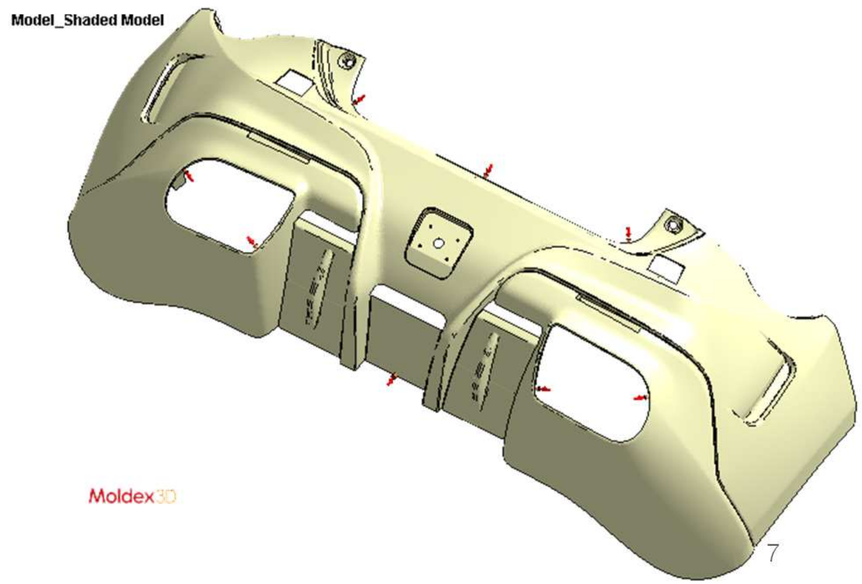
Testing Model

> **Size**
- **Length: 1769 mm**
- **Width: 642 mm**
- **Height: 623 mm**
- **Volume: 5390 c.c.**

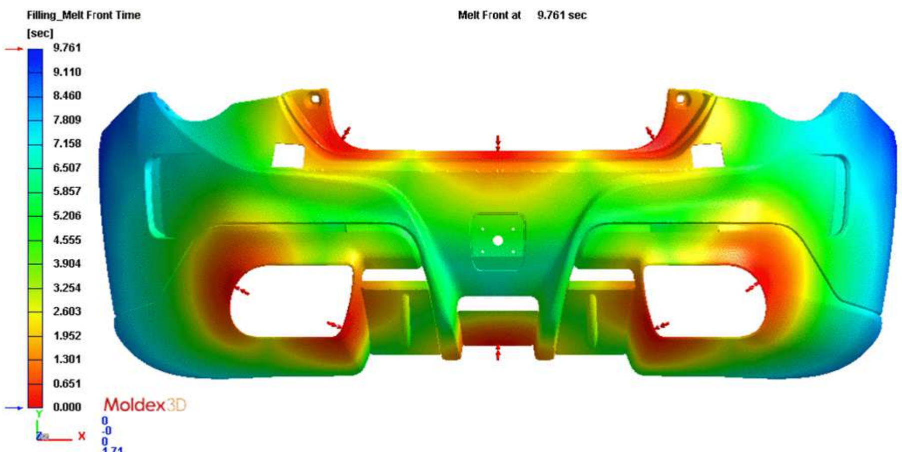
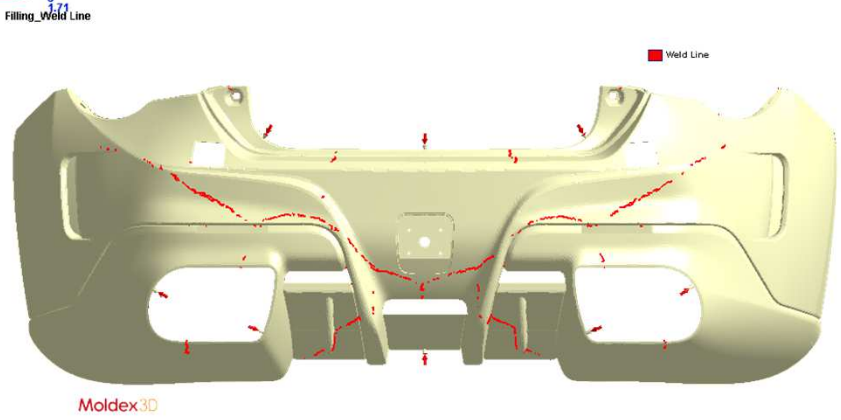
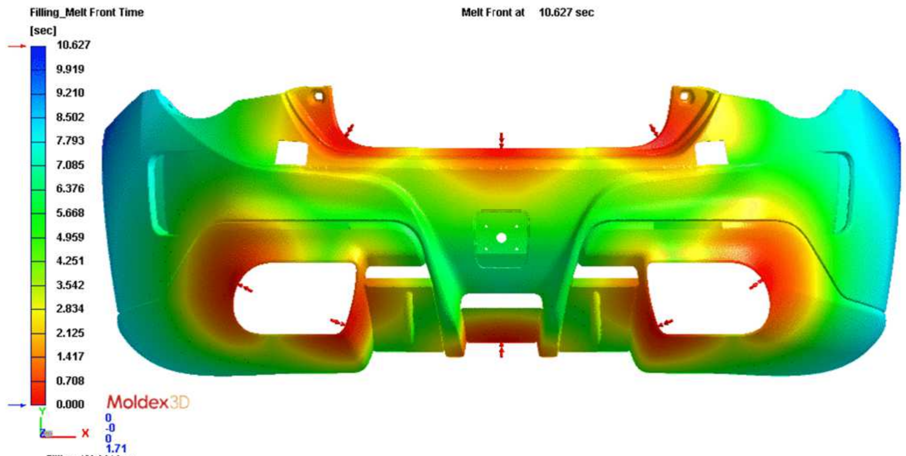
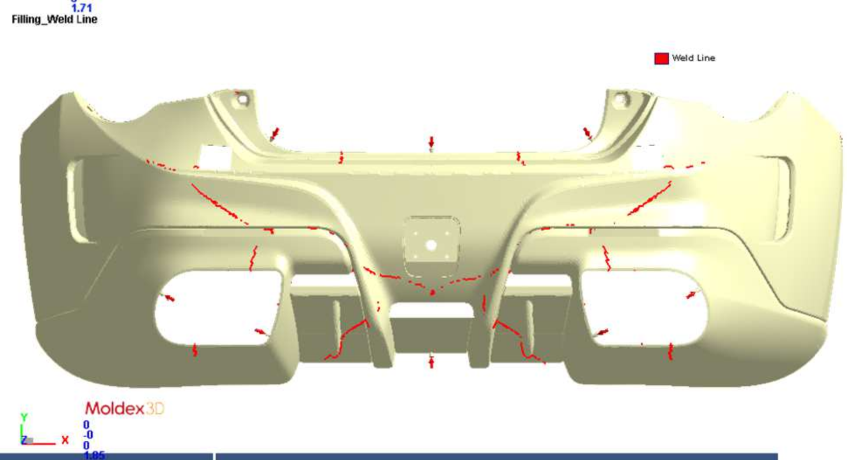
> **Mesh Information**
- **Mesh Type: 3Layers BLM**
- **Element number: 1.95M**

> **Machine Information**
- **CPU: Intel E5-1620v2 3.7GHz**
- **RAM: 32GB**





Comparison

Quick Flow	Conventional Simulation
 	 

	Quick Flow	Enhance Flow
CPU Time	574 sec (9.5 min)	5,657 sec (94 min)

Moldex3D Coupled VE-Flow Technology

New VE-Flow Solver Advantages

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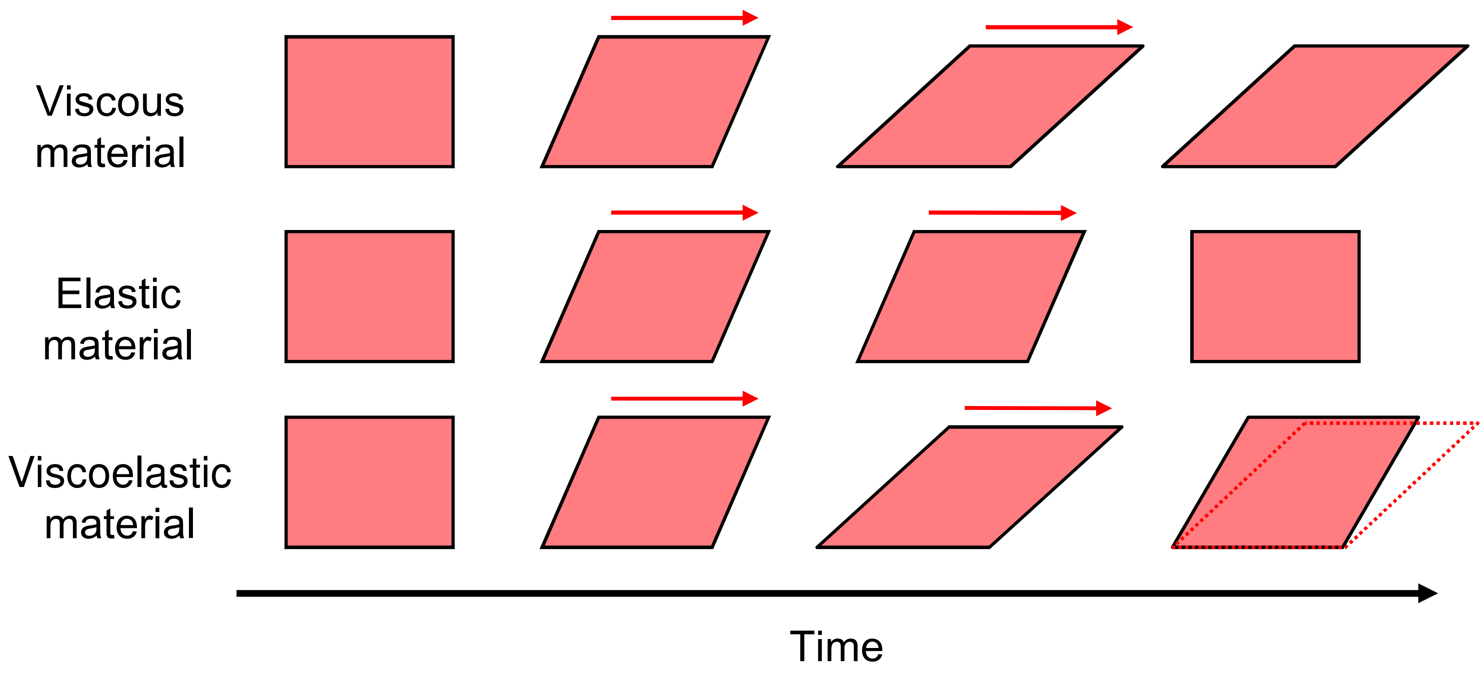
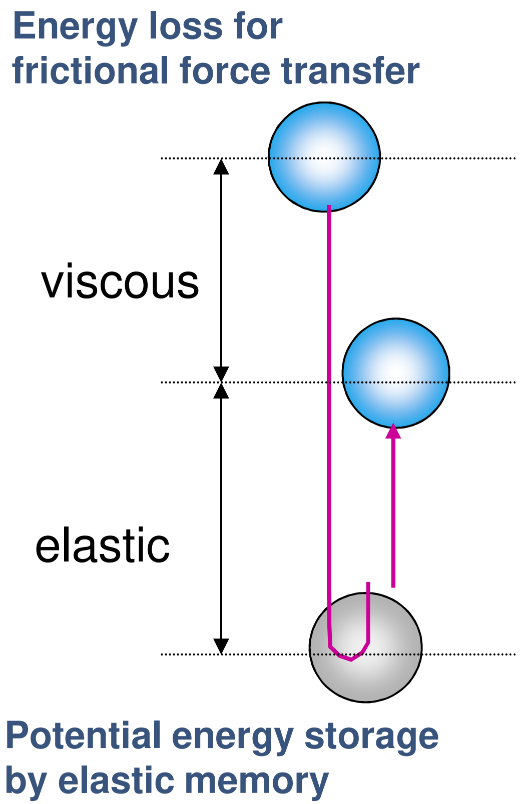
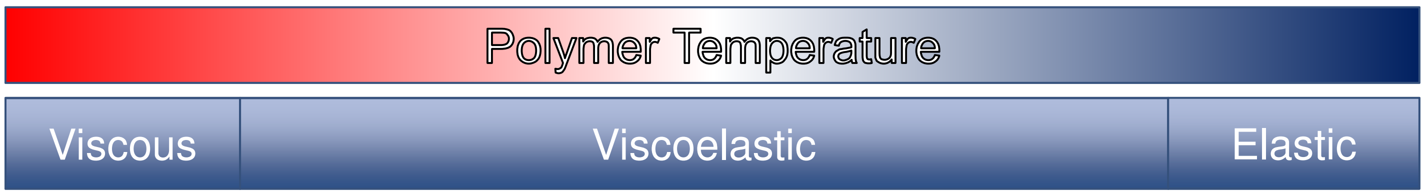
Material Viscoelastic Behavior

> The complicated real polymer behavior



Viscoelasticity

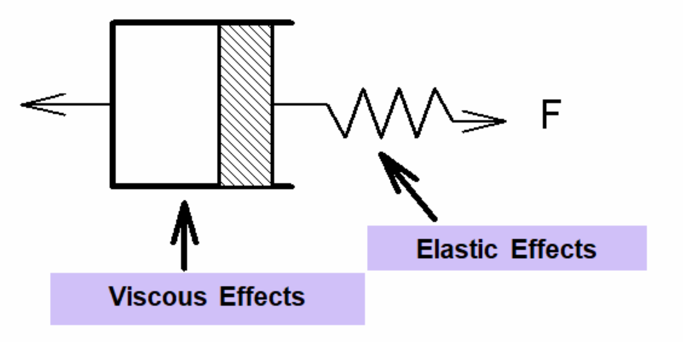


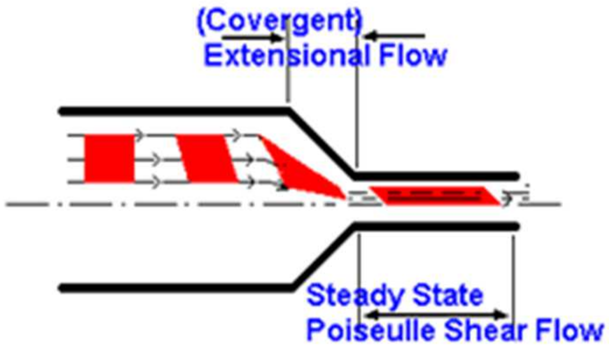


Viscoelasticity, VE Mathematical Model

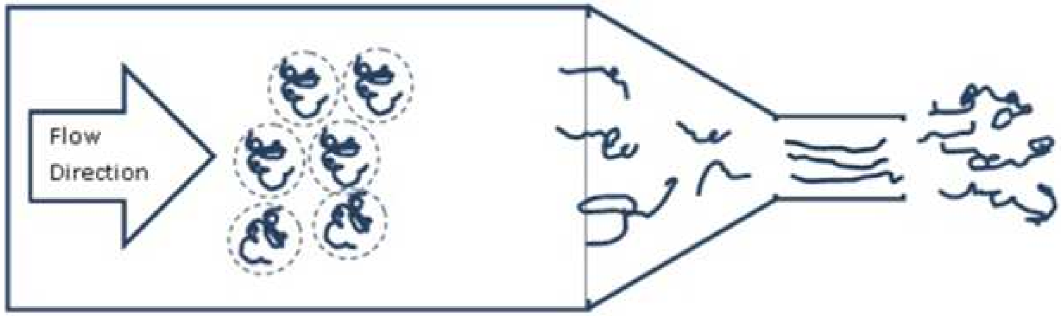
- The VE constitutive equation used to describe the non-linear property of polymer chain in real scenario

Linear viscoelastic model (Maxwell model)



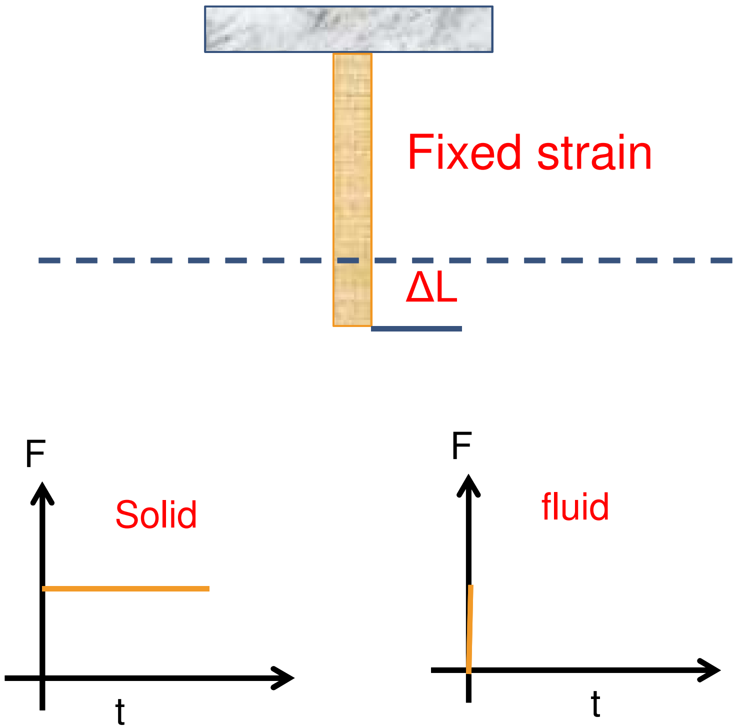


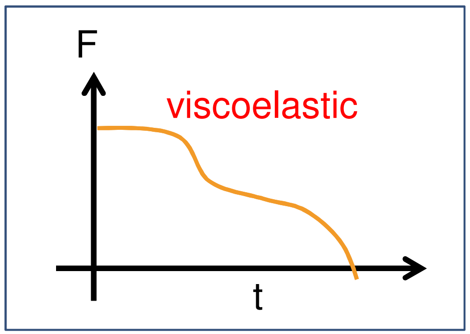
$$\sigma + \lambda \frac{d\sigma}{dt} = \eta \frac{d\varepsilon}{dt}$$



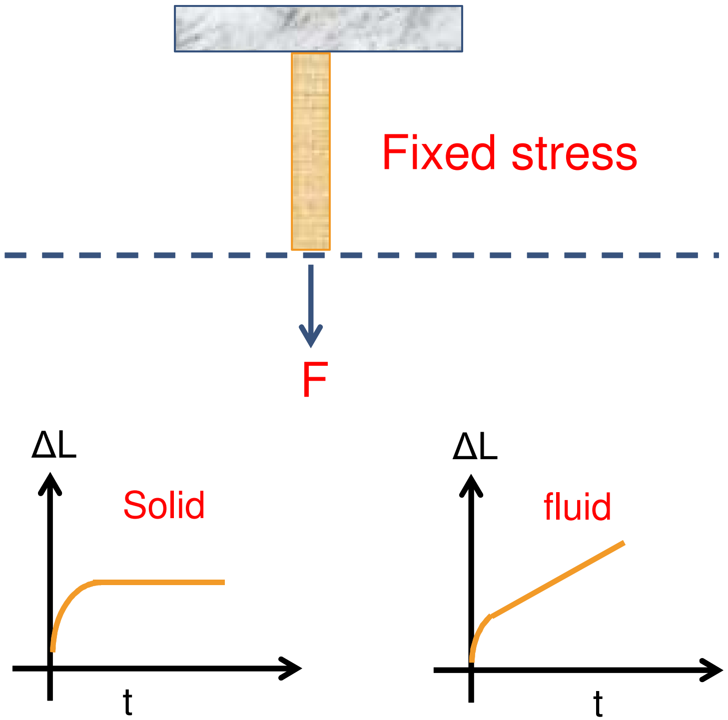
Stress Relaxation and Creep

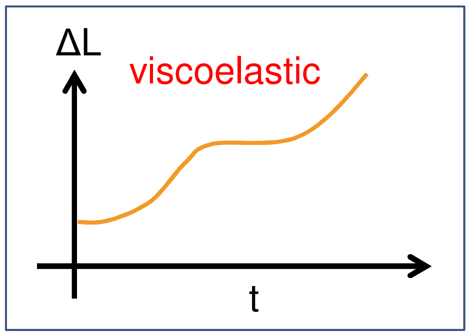
Stress Relaxation





Creep





VE Property Characterization in CAE Lab

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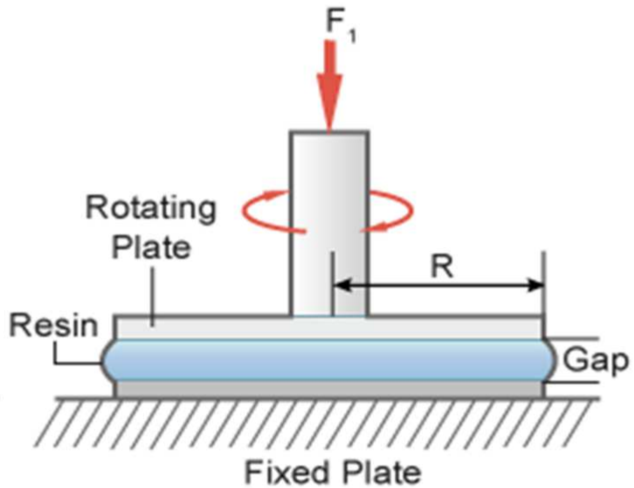
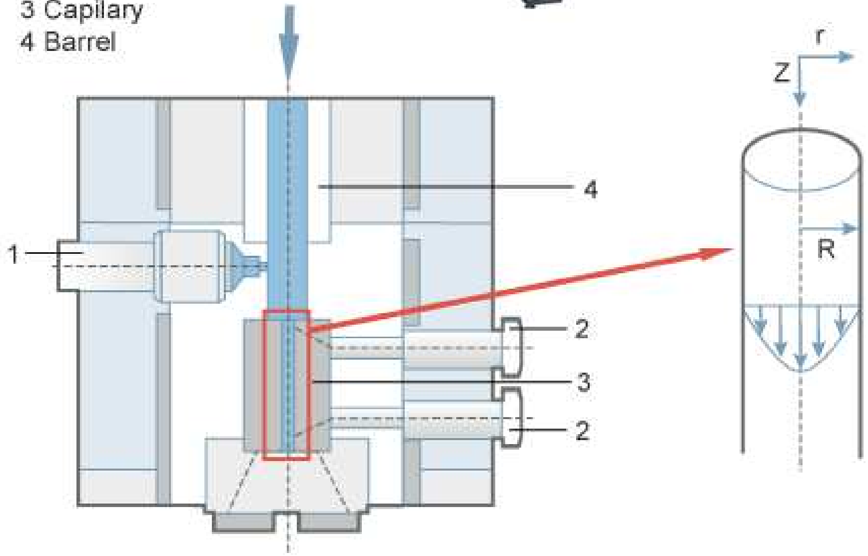
> Rotational rheometer
  - **linear VE (Low shear)**



> Capillary rheometer
  - **Non-linear VE (high shear)**

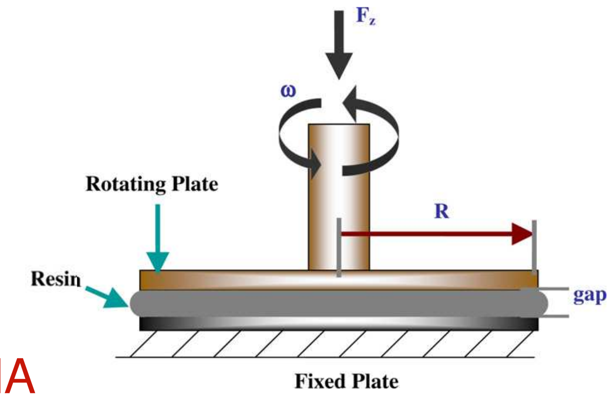


VE Property Characterization in CAE Lab

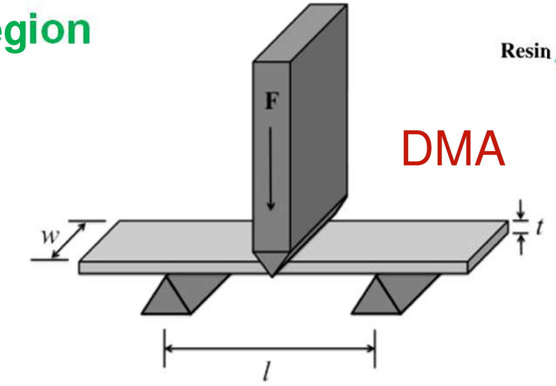
> **Structure VE**
- **Dynamic mechanical analysis, DMA**
  - (1) Glassy region
  - (2) Glass transition region
  - (3) Rubbery region

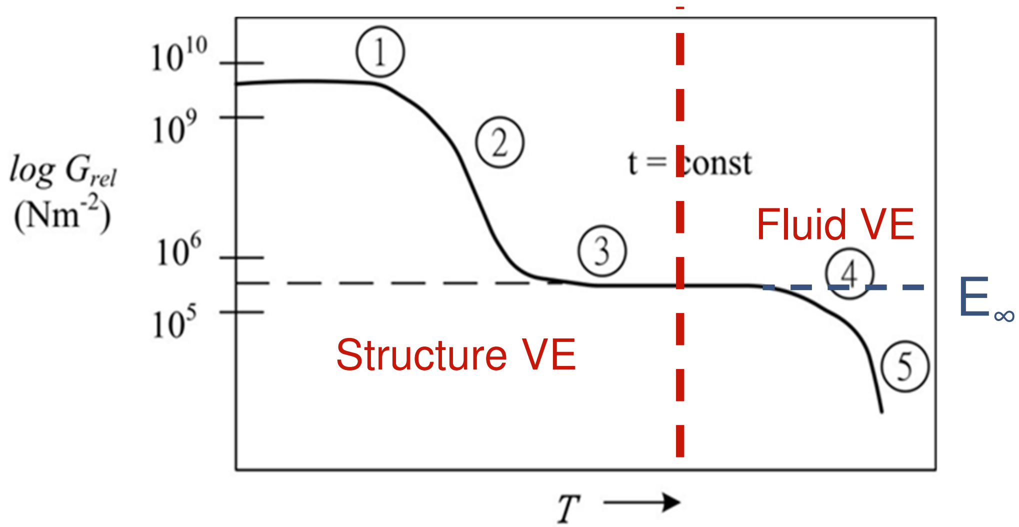
> **Fluid VE**
- **Rotational rheometer**
  - (3) Rubbery region
  - (4) Viscoelastic fluid
  - (5) Viscous fluid

Rotational rheometer



DMA





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Core Technology Revolution in Flow Solver

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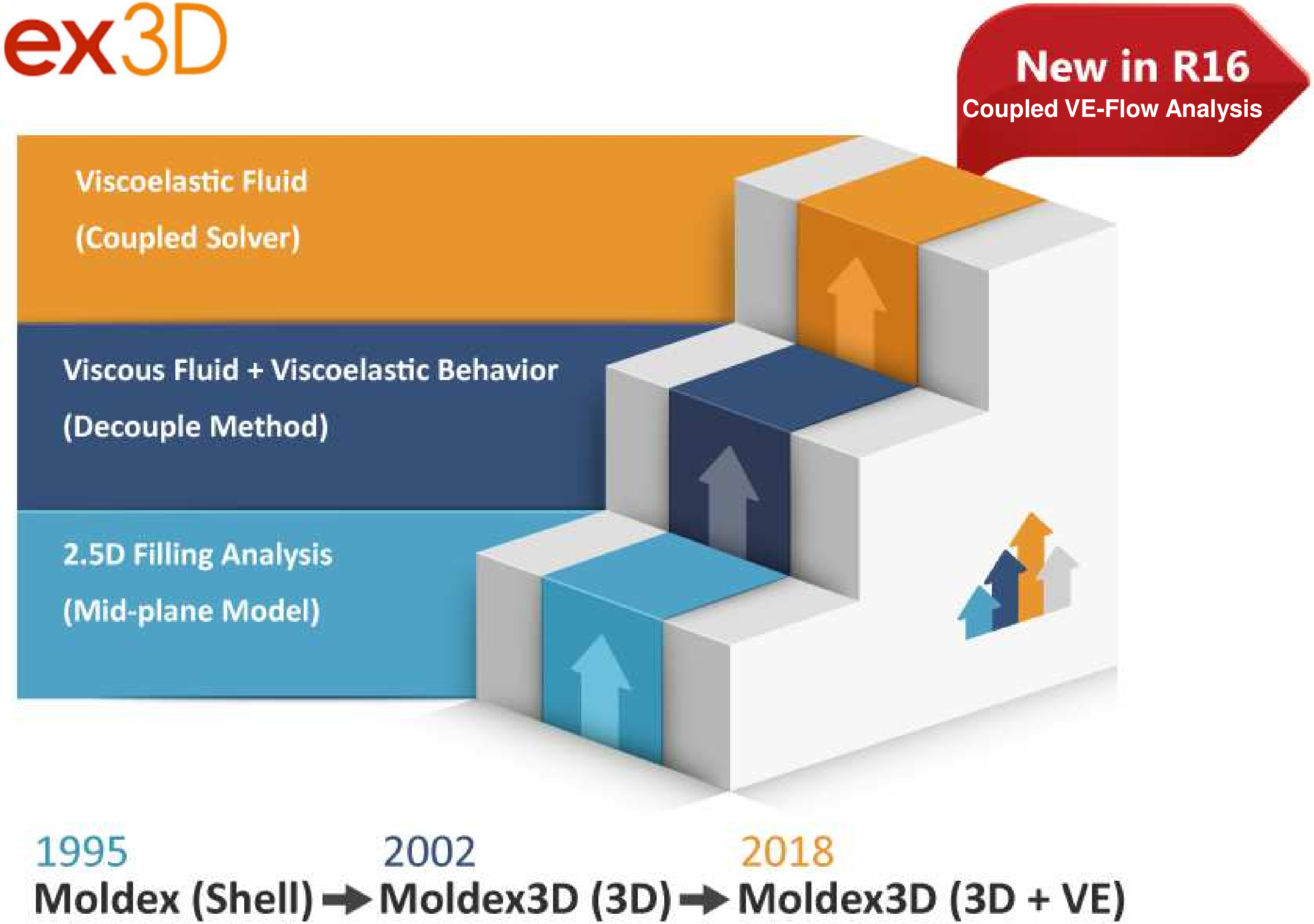

New Generation of Viscoelastic Flow Solver

> Fluid Analysis with Coupled VE Technology
  - The viscoelastic (VE) character of plastics is taken into account and coupled during the molding simulation
  - Upgrade kernel from viscous fluid to viscoelastic fluid to simulate the phenomena such as die swell, jetting, and buckling

Benefit

> Improved optics and warpage prediction
> Pioneered analysis technology of Viscoelastic Fluid
> One step further to explore the tricky issues such as ear flow, tiger stripe and more……

The Improvement from Generalized Newton Fluid to Viscoelastic Fluid

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> ## Generalized Newton Fluid (GNF)

- **The material is considered as the viscous fluid, and the viscosity is variable, which depends with shear rate value**
- **This assumption is used in most of simulation software. It's easy to maintain the calculation stability without considering the Viscoelastic nature equation. But the estimation of stress will not be informative enough to describe the real material curve and complicated polymer behavior. Besides, the stress will be zero once fluid stops flowing, therefore the residual stress will not be accurate enough**

$$\tau = \eta(T, \dot{\gamma})\left(\nabla \mathbf{u} + \nabla \mathbf{u}^T\right)$$

> ## Viscoelastic fluid (VE Fluid)

- **Viscoelastic fluid property is between Elastic solid and Viscous fluid, the VE constitutive equation is necessary to describe this phenomena**
- **There are different VE constitutive equation models from literature. And the most important thing is to match the material objectivity**
- **Only VE equation is capable of dealing with polymer material curve, but the calculation convergence is more challenging compared to the GNF model. Due to the improvement of computer capacity nowadays, the VE flow simulation will be the core technology in the near future**

$$\tau + \lambda(T, \dot{\gamma})\left(\frac{\partial \tau}{\partial t} + \mathbf{u} \cdot \nabla \tau - \nabla \mathbf{u}^T \cdot \tau - \tau \cdot \nabla \mathbf{u}\right) = \eta(T, \dot{\gamma})\left(\nabla \mathbf{u} + \nabla \mathbf{u}^T\right)$$

Birefringence Pattern Comparison between Experiment and Simulation in Contraction Flow

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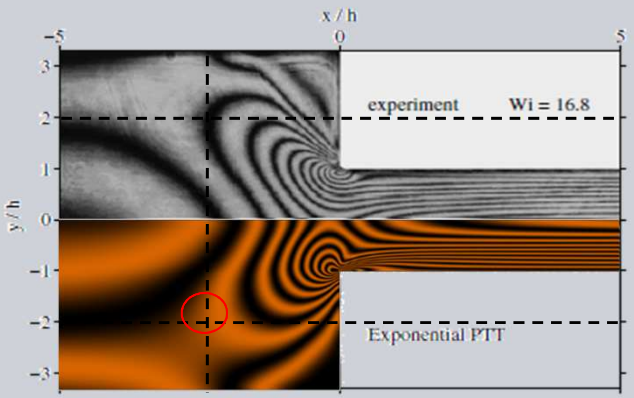
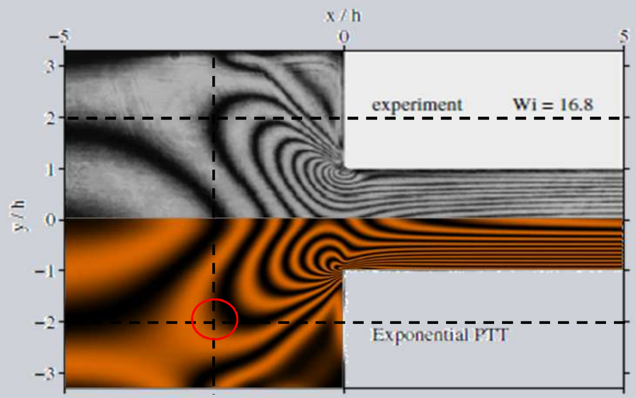
> Accurate prediction acquired by Coupled VE-Flow solver

<table>
<tr><th></th><th>GNF fluid (Decouple)</th><th>VE fluid (Coupled VE-Flow)</th></tr>
<tr><td>Exp. PTT</td><td>
</td><td>
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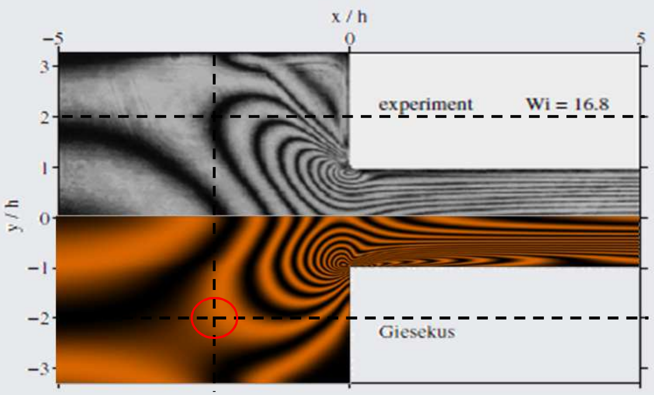
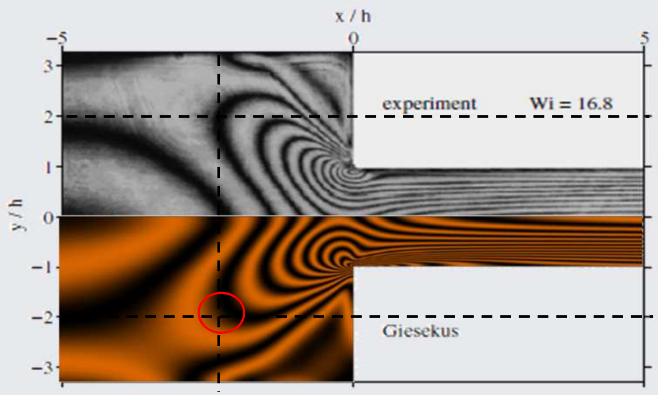
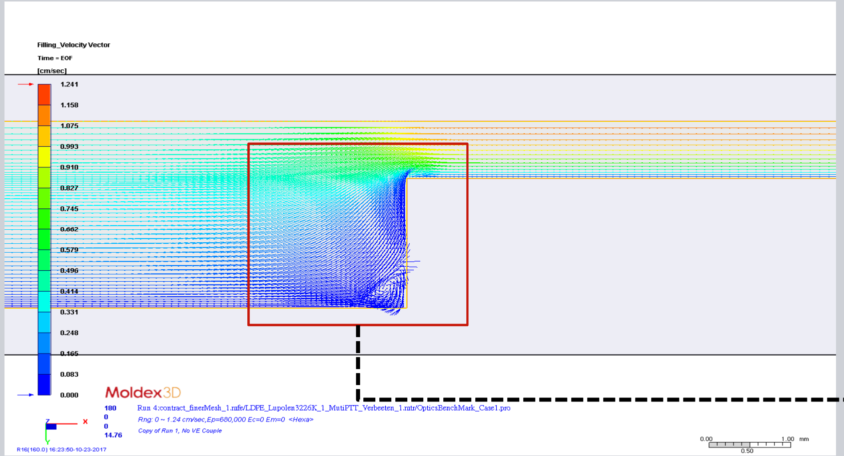
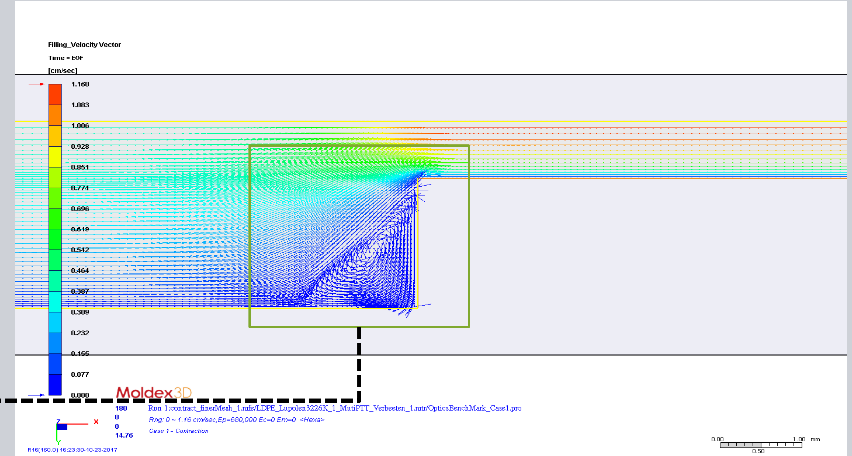
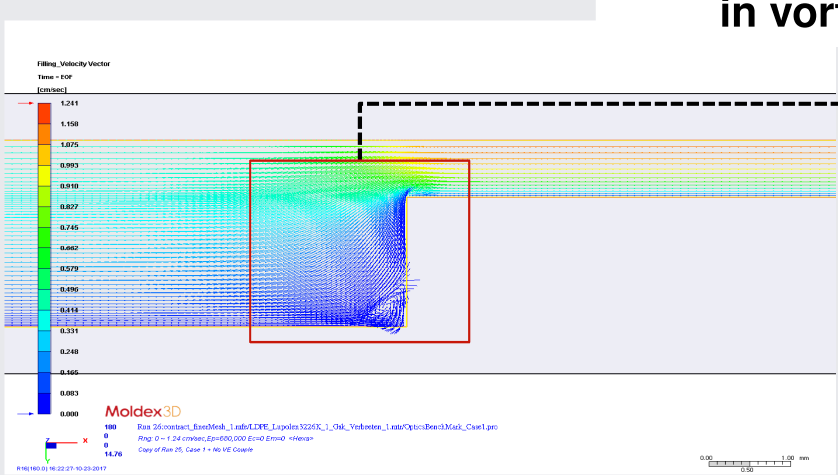
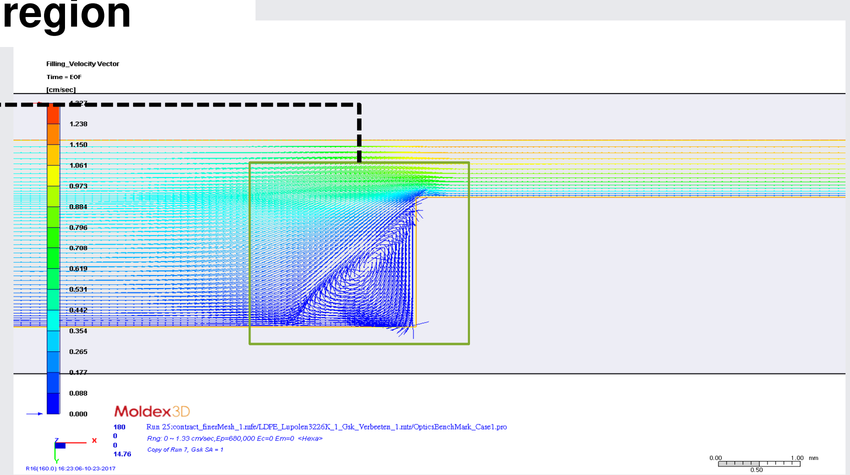
<tr><td>Giesekus</td><td>
</td><td>
</td></tr>
</table>

Wilco M. H. Verbeeten “Computational Polymer Melt Rheology”

Flow Velocity Vector Comparison between Decoupled Flow Solver and Coupled VE-Flow Solver

	Decoupled Flow solver	Coupled VE Solver
Exp. PTT		
Giesekus		

The significant difference in vortex region

Die Swell Effect Verification

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> Two-phase flow patterns caused by Viscoelastic property
  - **Oldroyd-B model**
    - $\lambda = 0 \sim 0.667$

S_r : Swelling Ratio, $S_r = \frac{D_{max}}{D}$

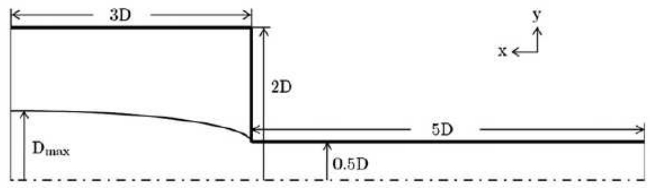
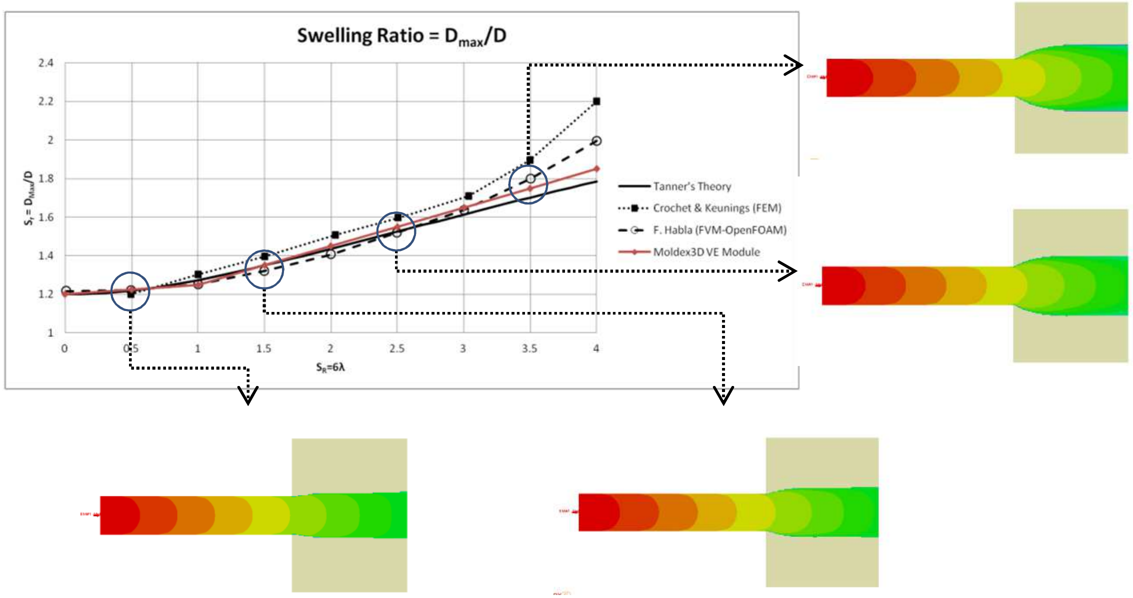
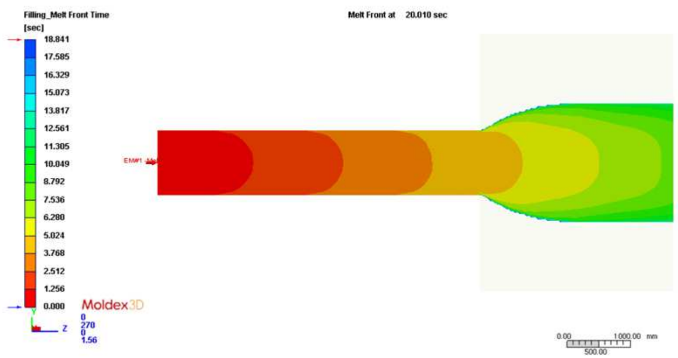


Fig. 4. Geometry and boundary conditions of the Die Swell domain.



Animation of melt front for $S_R = 4.0$

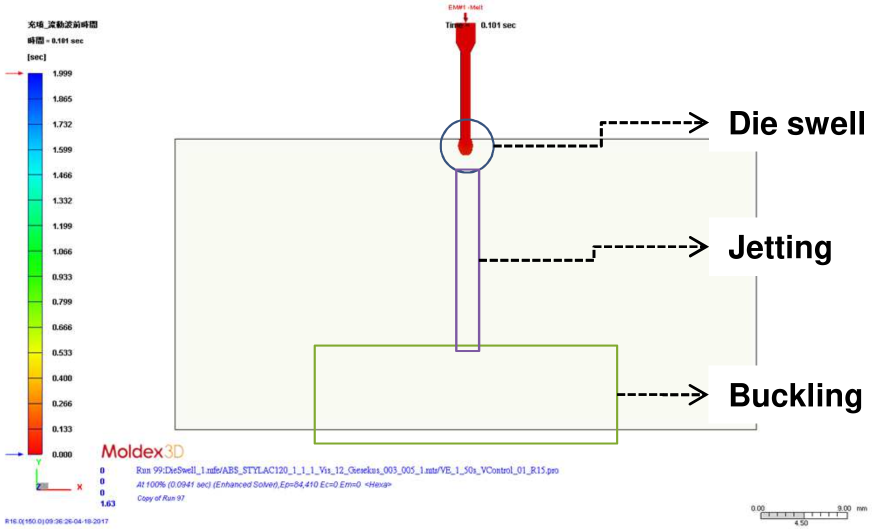


Ref. : F. Habla Numerical Simulation of Viscoelastic two-phase flows using openFOAM (Chemical Engineering Sci. 2011)

Jet Buckling Effect

> Viscoelastic free-surface effects
  - **Die swell**
  - **Jetting**
  - **Bucking**

Time-series animation of melt front time



Simulation result from Literature

Ref. : J. L. Favero, "Viscoelatic fluid analysis in internal and in free surface using the software OpenFOAM

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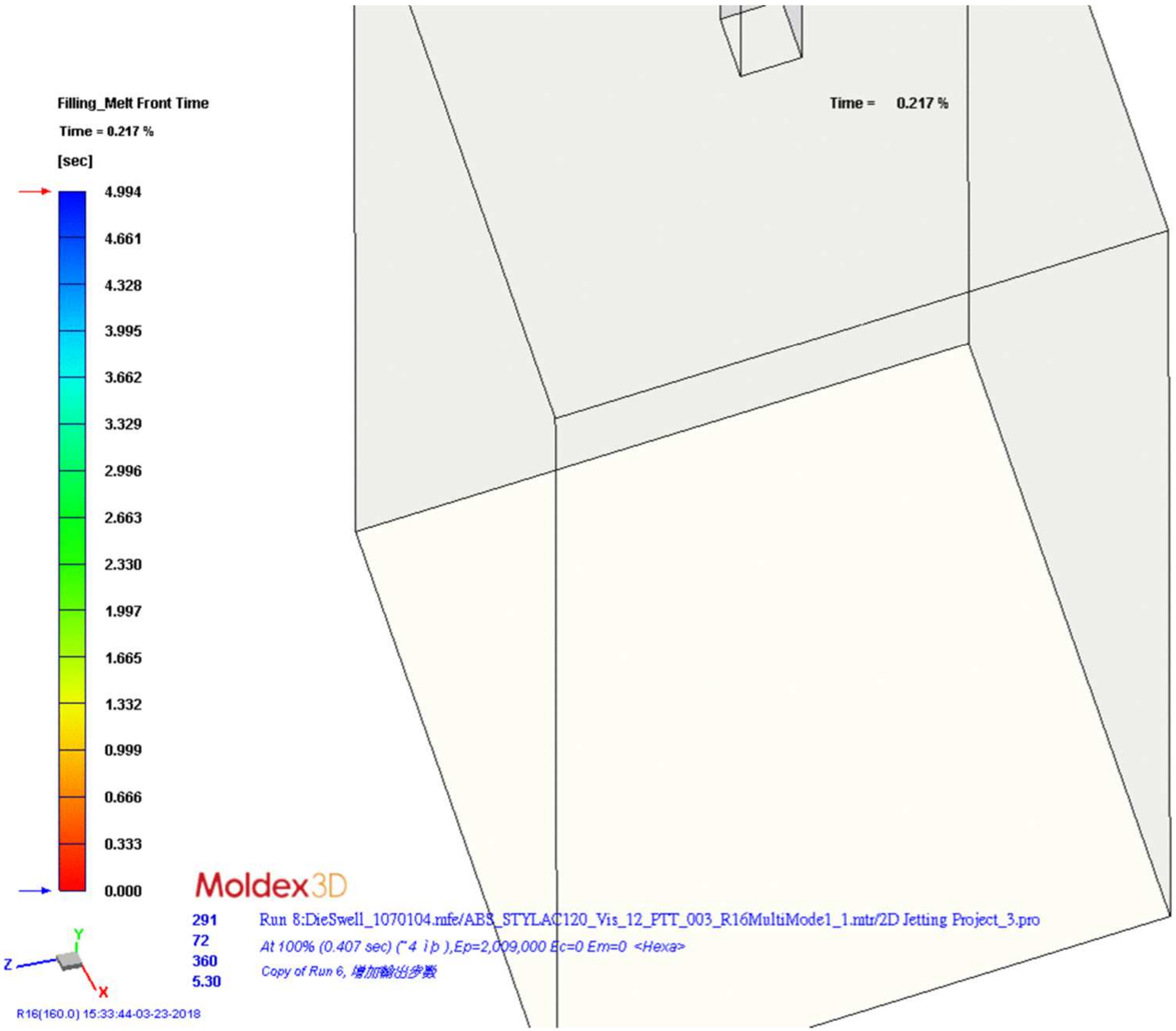
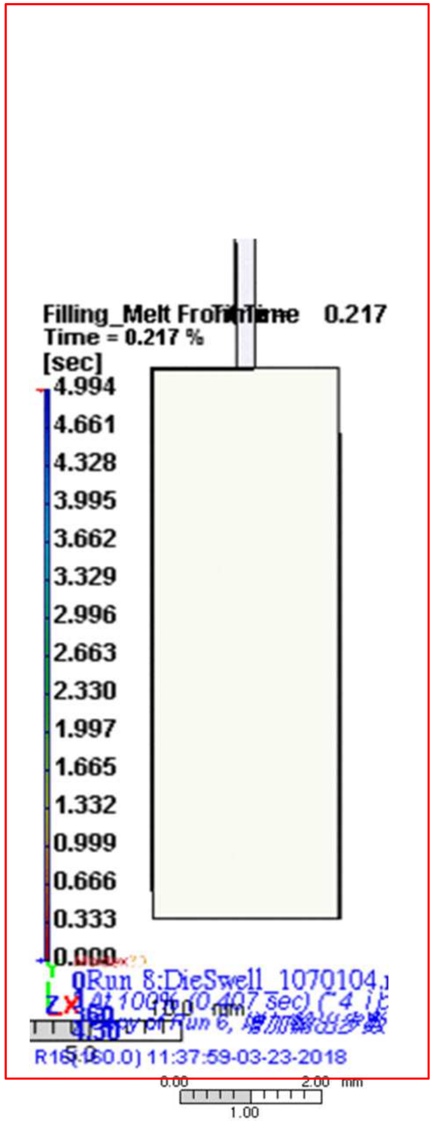
3D Animation

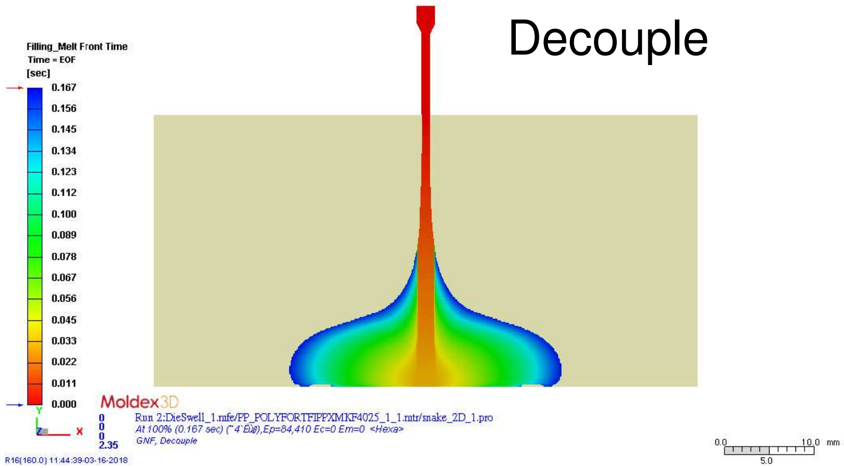


coiling

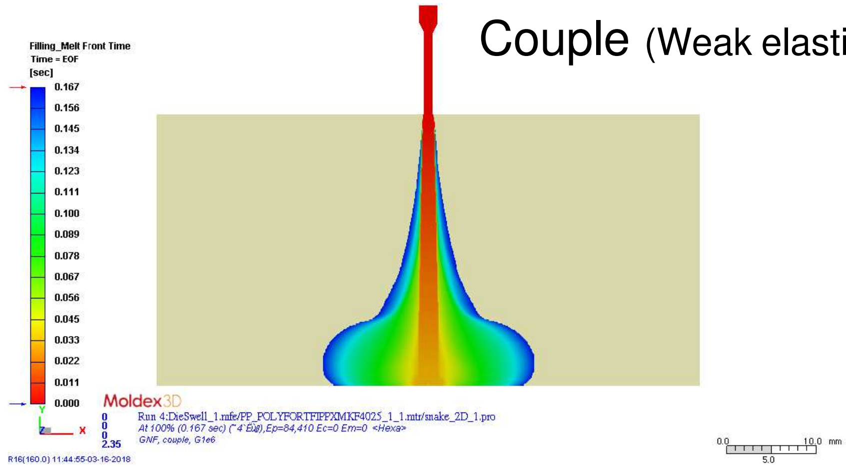


Effect of Viscoelasticity on Polymer Melt Front

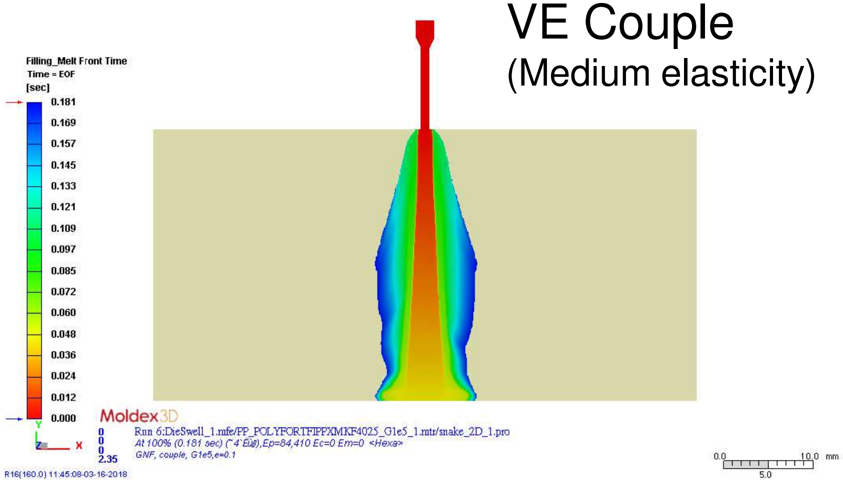
Viscous Fluid
Decouple



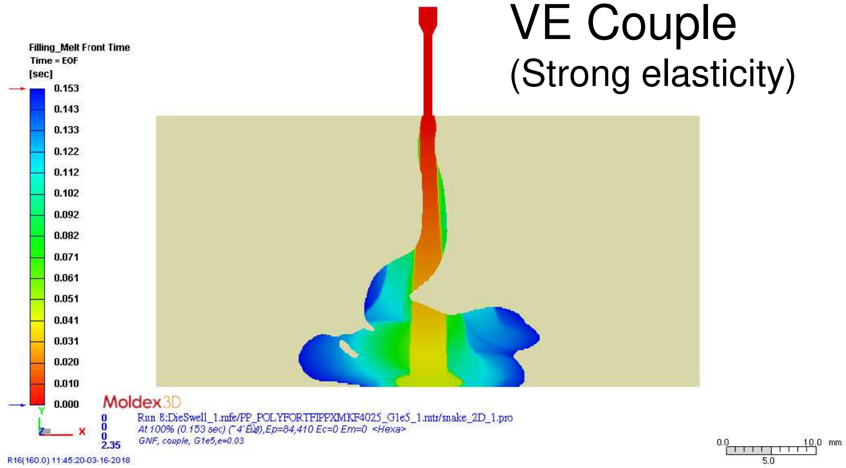
VE Fluid
Couple (Weak elasticity)



VE Couple
(Medium elasticity)



VE Couple
(Strong elasticity)



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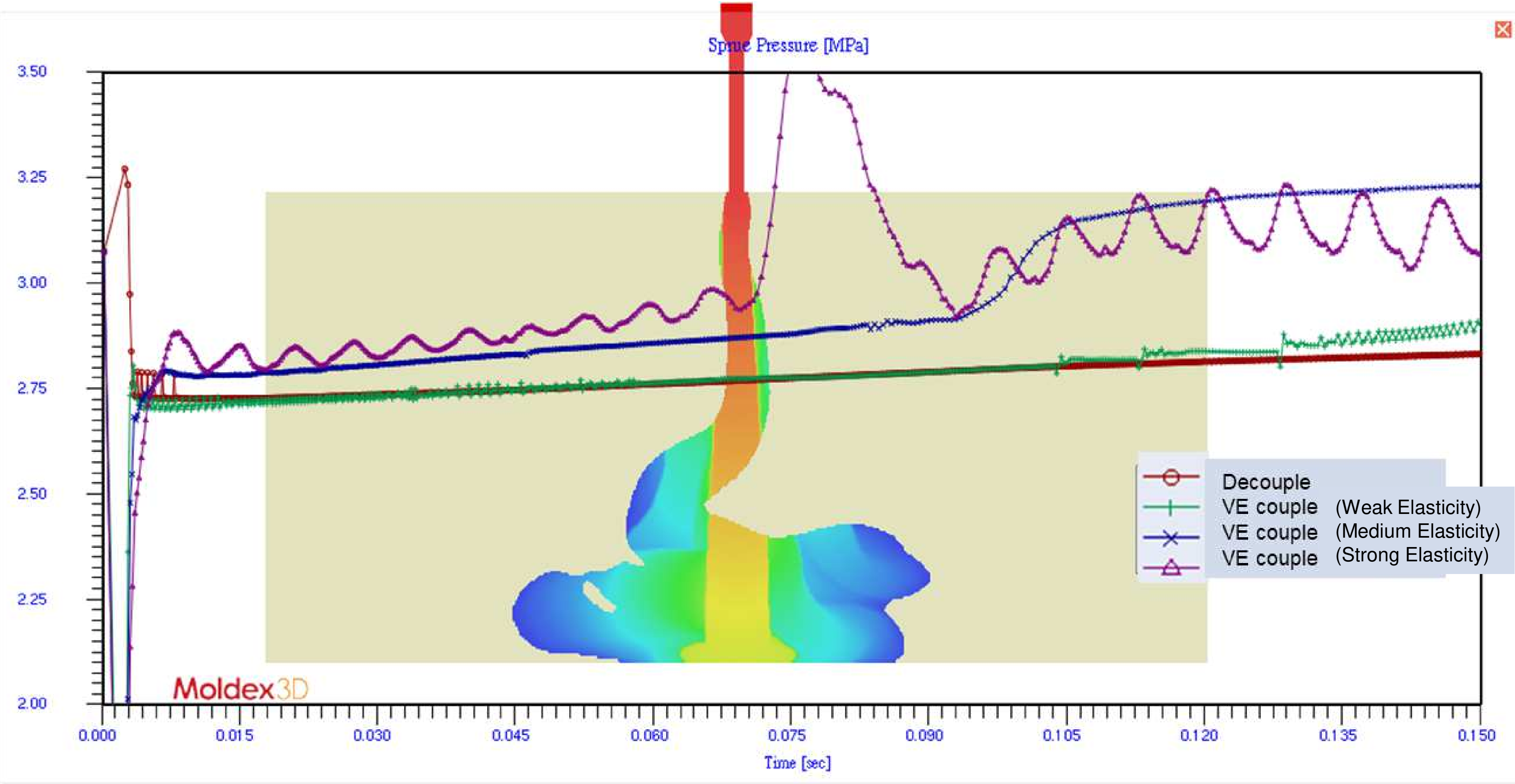
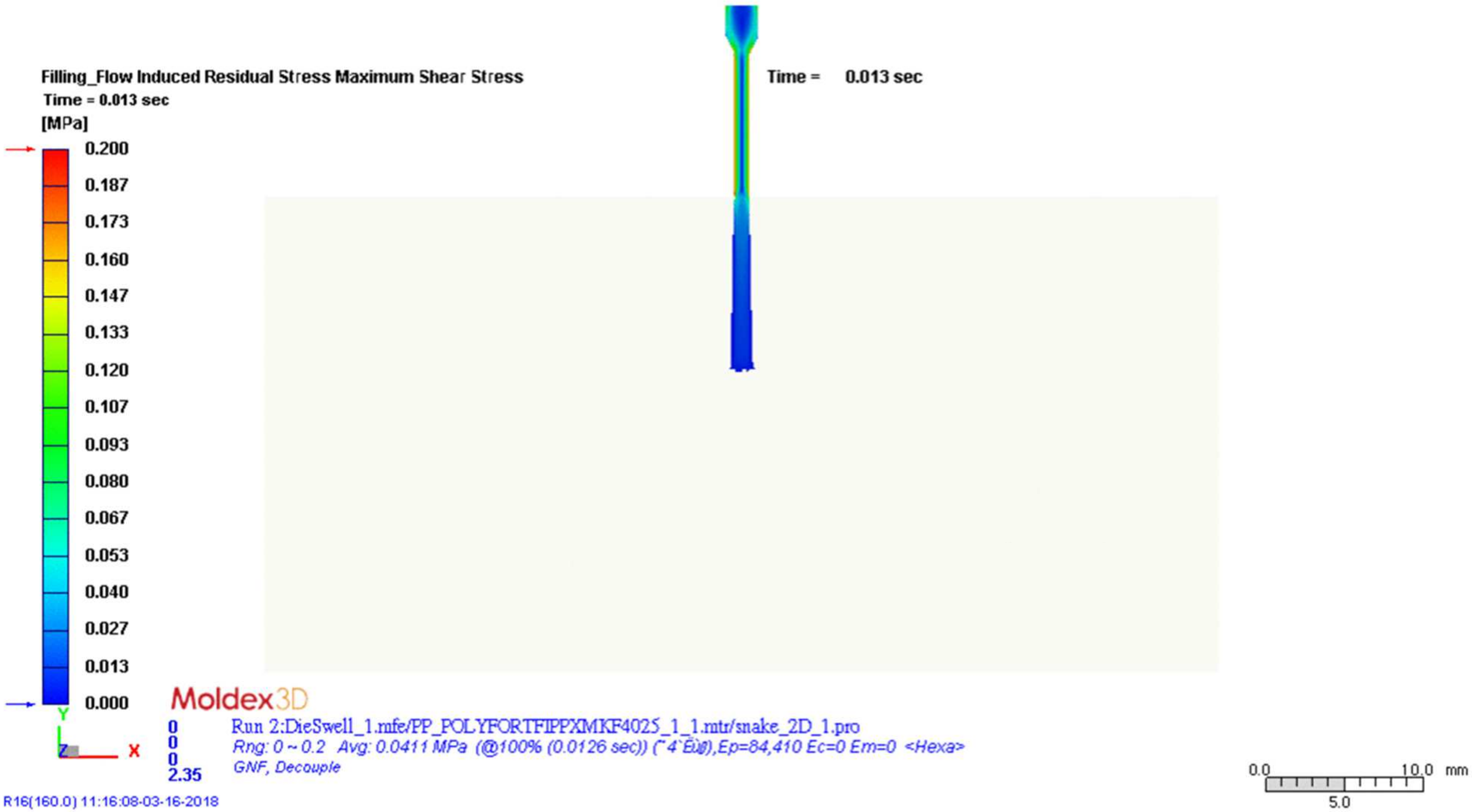
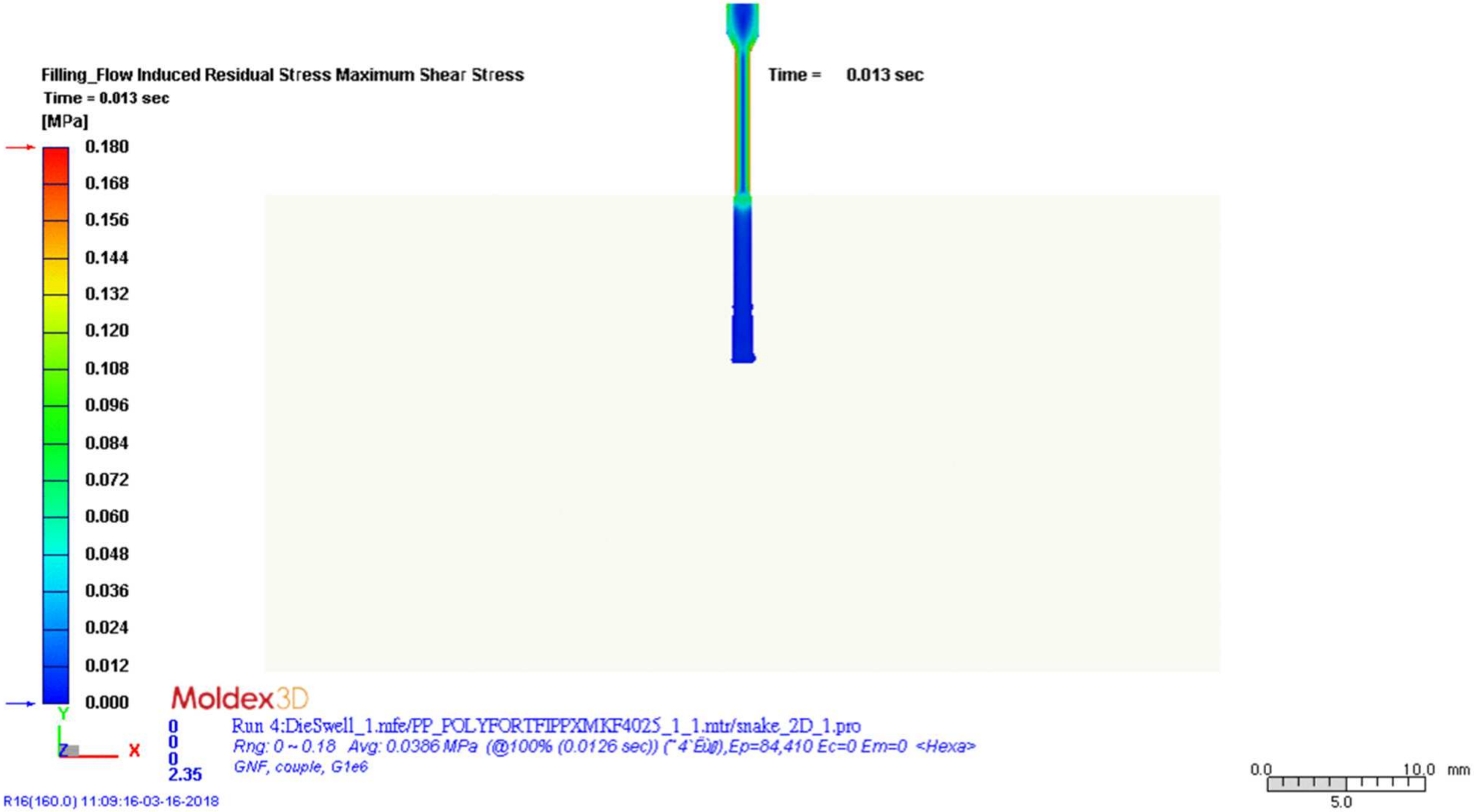
Pressure Comparison



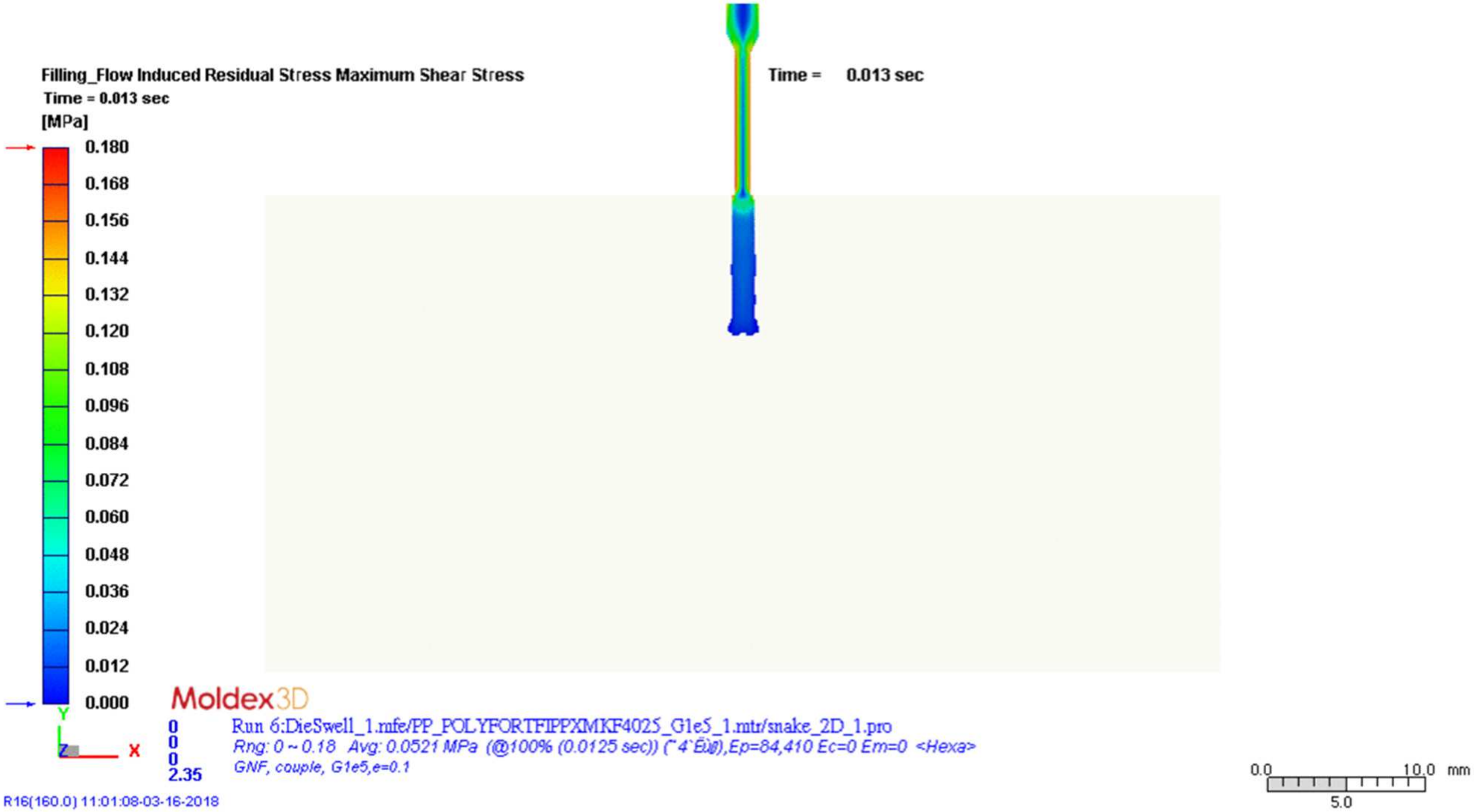
Viscous Fluid (Decouple) - Melt Front Animation



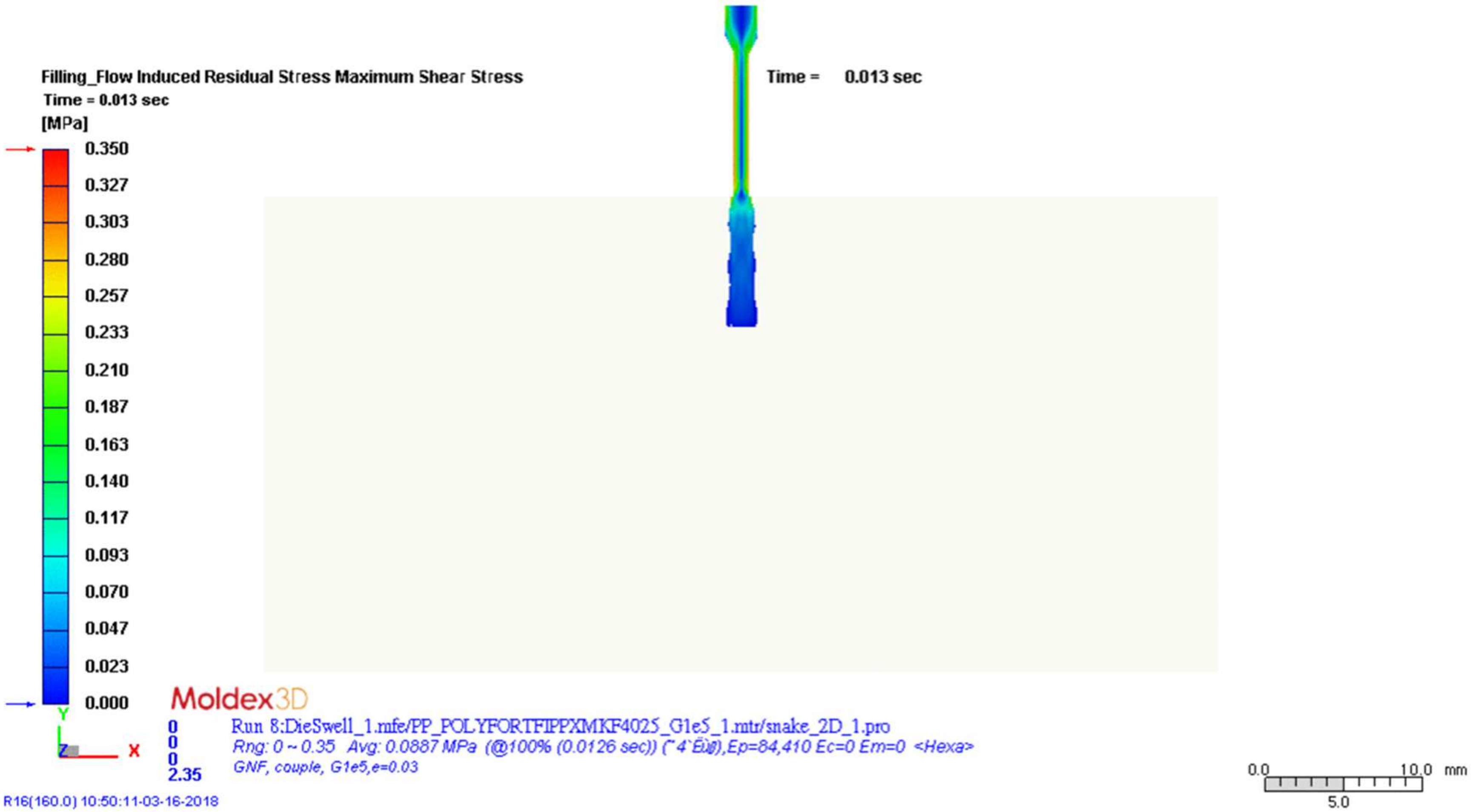
VE Couple (Weak Elasticity) - Melt Front Animation



VE Couple (Medium Elasticity) - Melt Front Animation



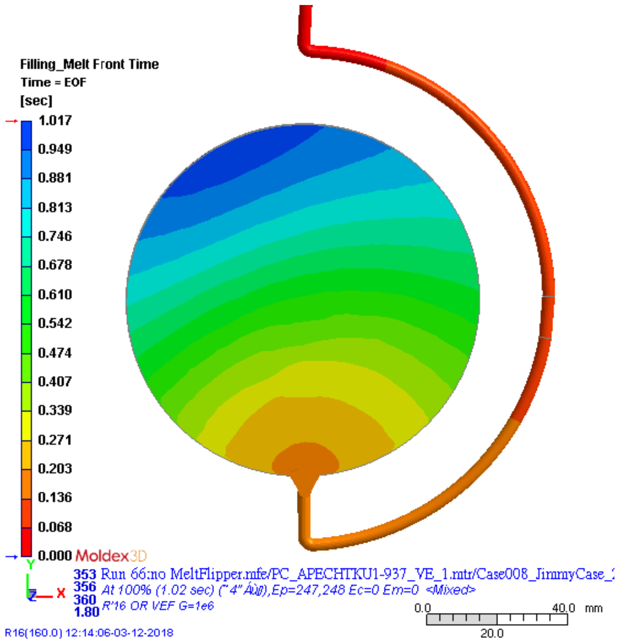
VE Couple (Strong Elasticity) - Melt Front Animation



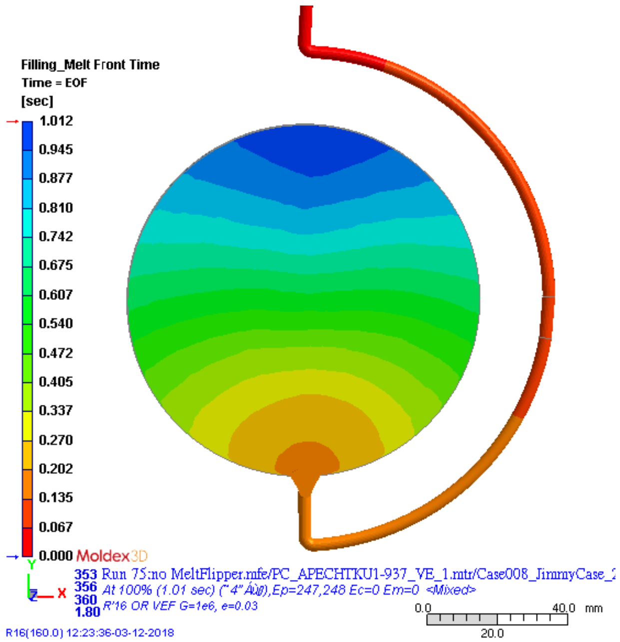
Melt Front of Injection Molded Part

- Viscoelasticity might change melt front a lot, in addition to well known factors, such as geometry, material viscosity, and temperature effect

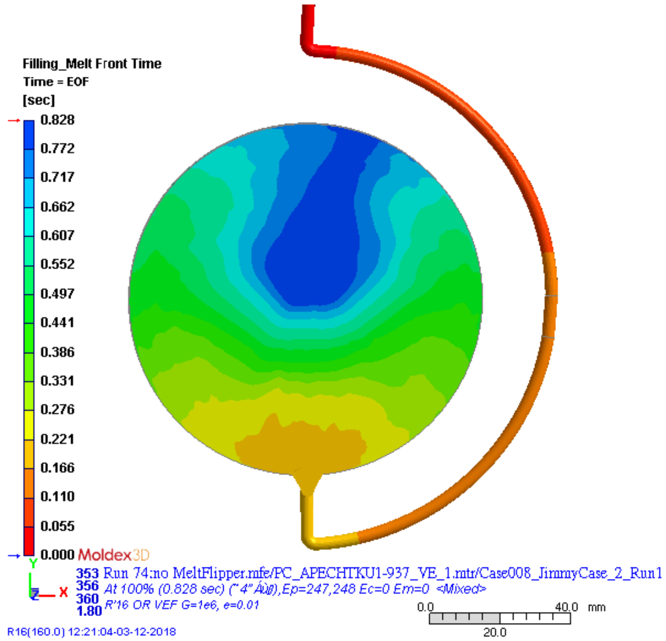
VE Couple (Weak Elasticity)



VE Couple (Medium Elasticity)



VE Couple (Strong Elasticity)



Thank You

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