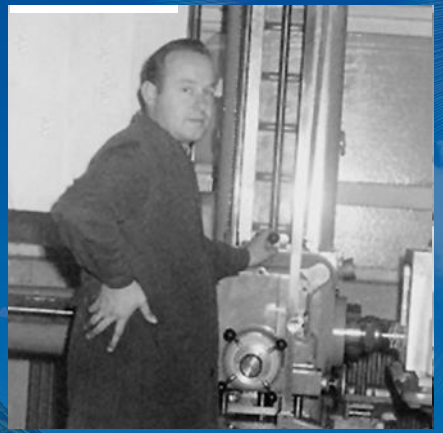
Simulation and its Validation of the Injection Stretch Blow Molding Process of Containers in Consumer Packaged Goods Industry

O. Valtiner, 4a Technology Day 2020, Werfenweg, March 3rd – 4th 2020

Agenda

- ***ALPLA – who we are***
- *Modelling & Simulation @ ALPLA*
- *ISBM Process*
- *ISBM Process simulation*
- *Validation*

Alpenplastik ALPLA



1955 Hard, Austria

Alwin and Helmuth Lehner

Market segments

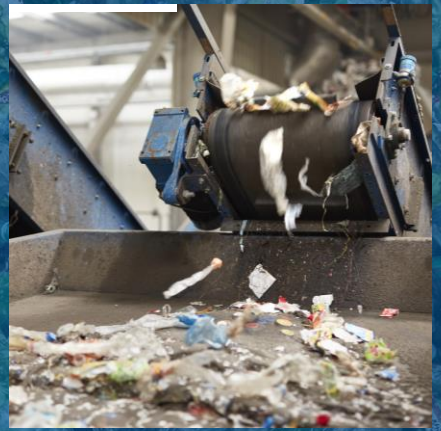
Our high-quality packaging

Recycling

Prospective overall recycling capacity

100,000 tonnes
of granules made of
post-consumer PET bottles

50,000 tonnes
of granules made of
post-consumer PE bottles

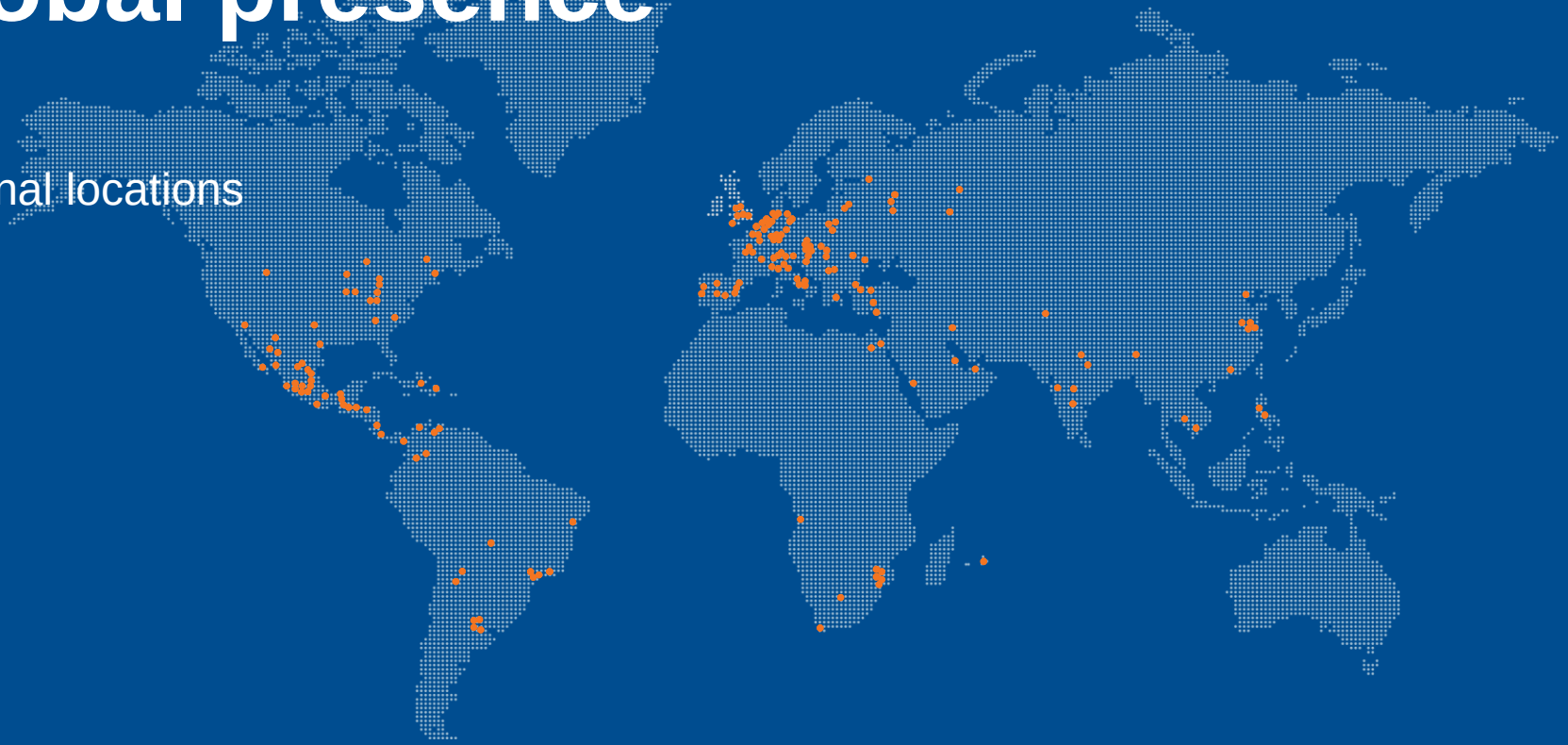


Our recycling plants

- PRT Wöllersdorf in Austria
- PRT Radomsko in Poland
- PRT Wolfen in Germany
- IMER in Mexico
- Suminco and Replacal in Spain

Global presence

Regional locations



Global presence

		@ 4a TT 2018	@ 4a TT 2016
Sales (2019)	**3,800 Mil. €**	3,400	3,130
Employees worldwide	**20,900**	19,300	16,000
Production sites	**181**	176	160
Countries worldwide	**46**	45	41

Leader in technology

Production technologies

Extrusion blow moulding (EBM)

Injection stretch blow moulding (ISBM)

Injection moulding (IM)

Injection blow moulding (IBM)

Agenda

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- *ISBM Process simulation*
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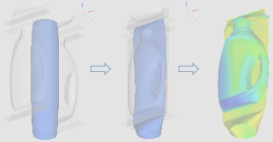
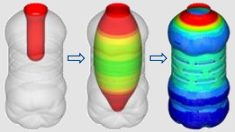
Modelling & Simulation @ ALPLA

Process simulation ⇨ Distributions of: Thickness, Stiffness,… ⇨ Product simulation

EBM

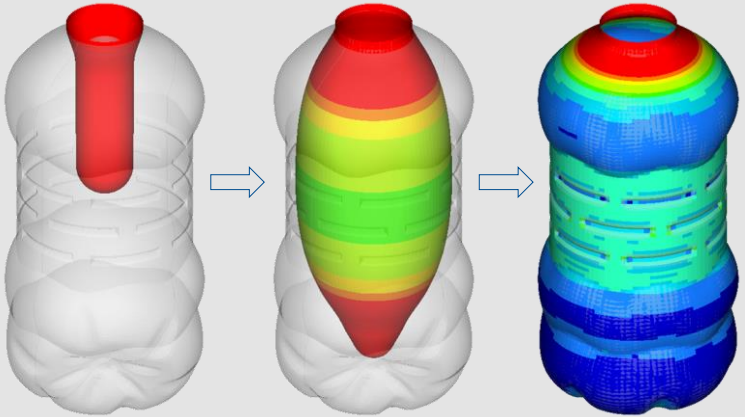


ISBM



IM

ISBM
(**I**njection **S**tretch **B**low **M**olding)



Bulging

Top load

etc

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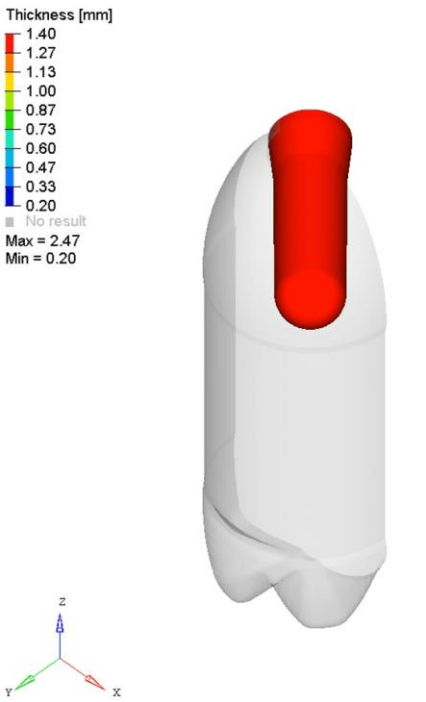
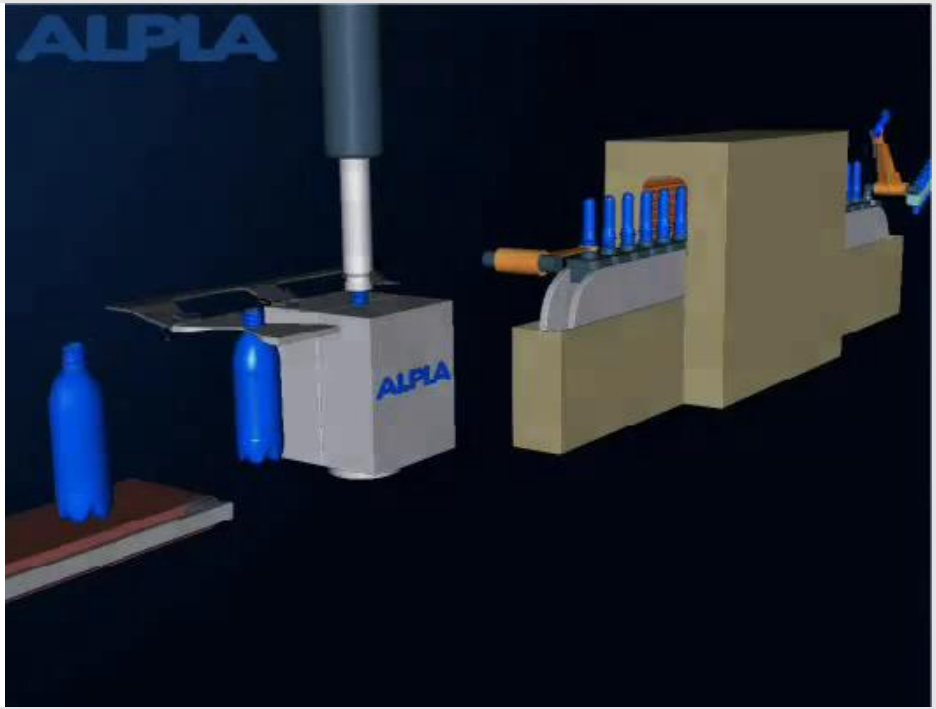
ISBM Process

Injection **S**tretch **B**low **M**olding

Principal process parameters:

- Preform temperature
- Stretch rod velocity
- Pre blow pressure
- Pre blow delay
- Main blow pressure
- Main blow delay





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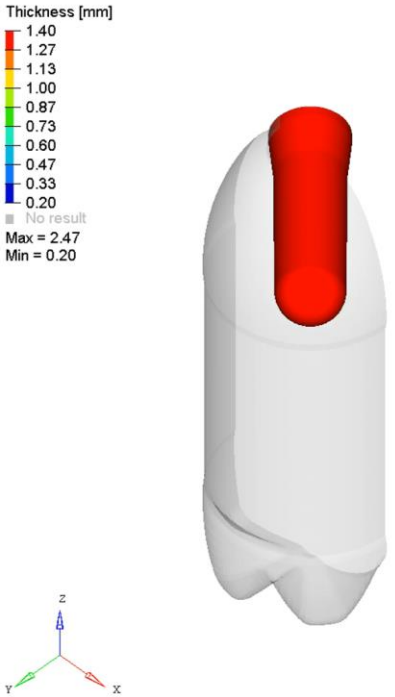

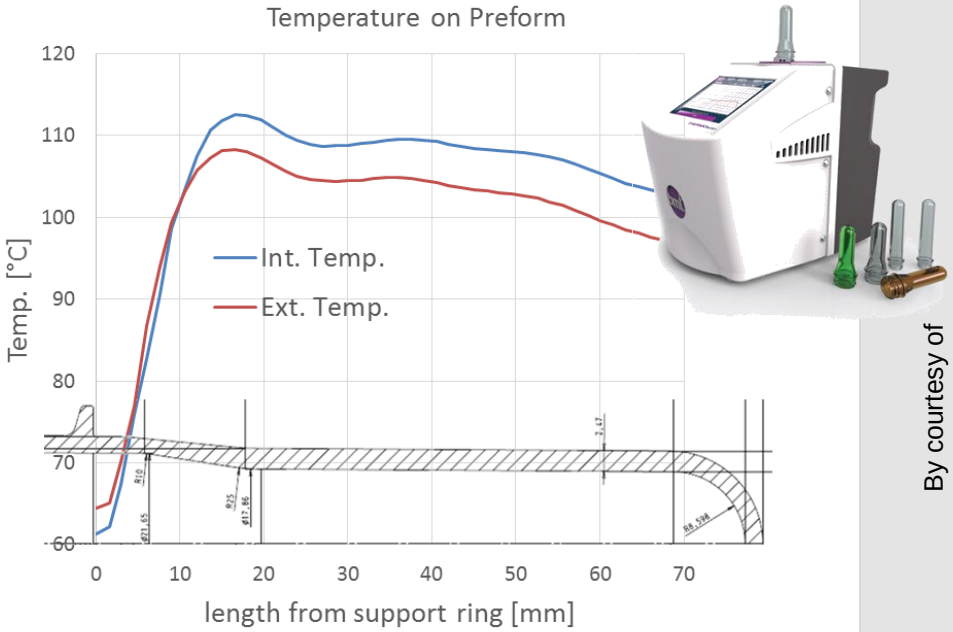

By courtesy of "bmt – Blow Moulding Technologies"

ISBM Process

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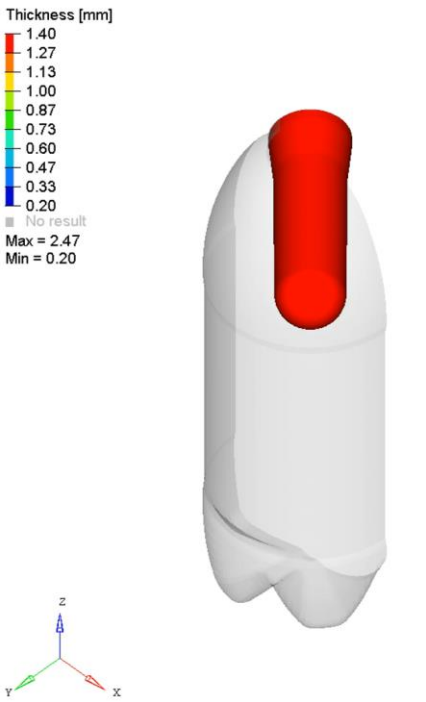

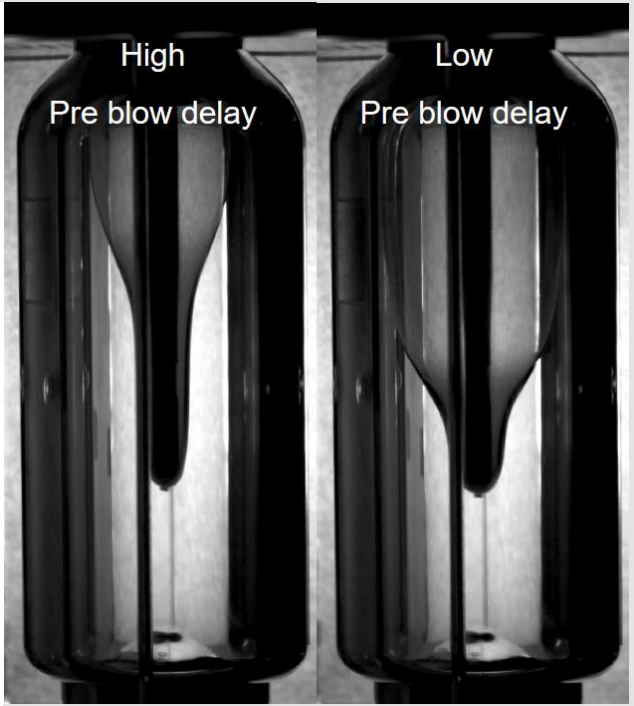

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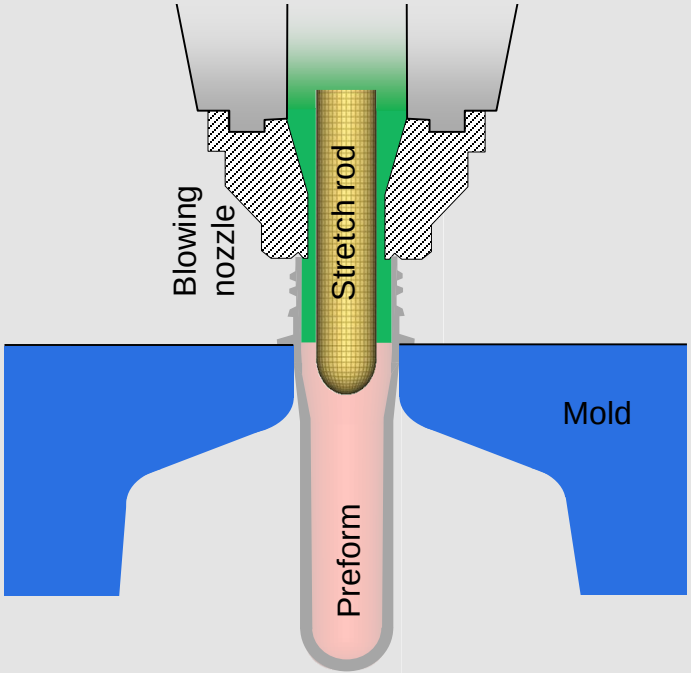
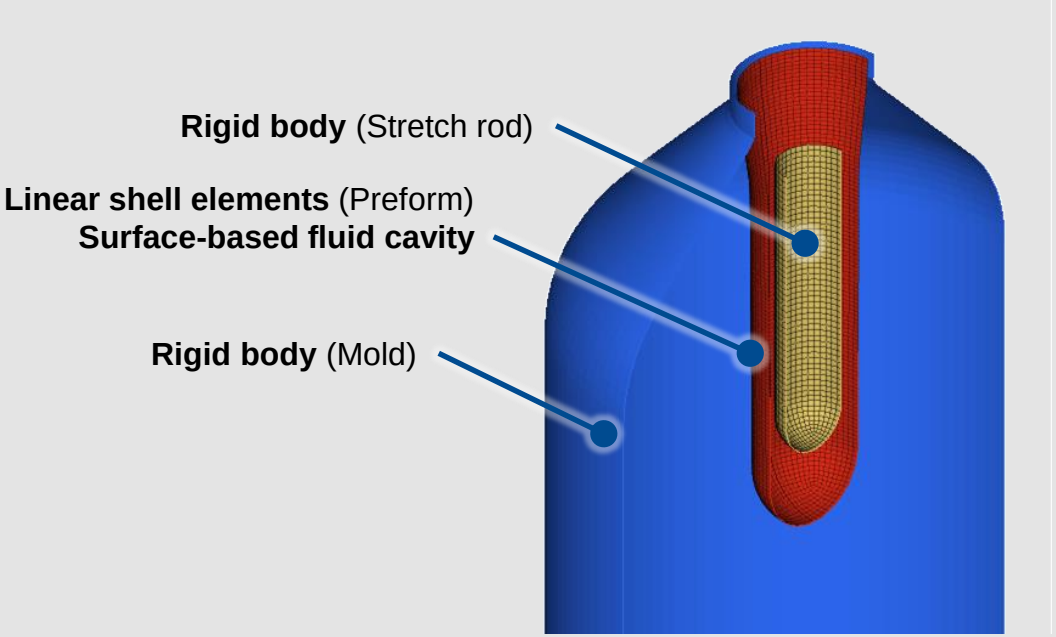
- *Validation*

ISBM Process simulation

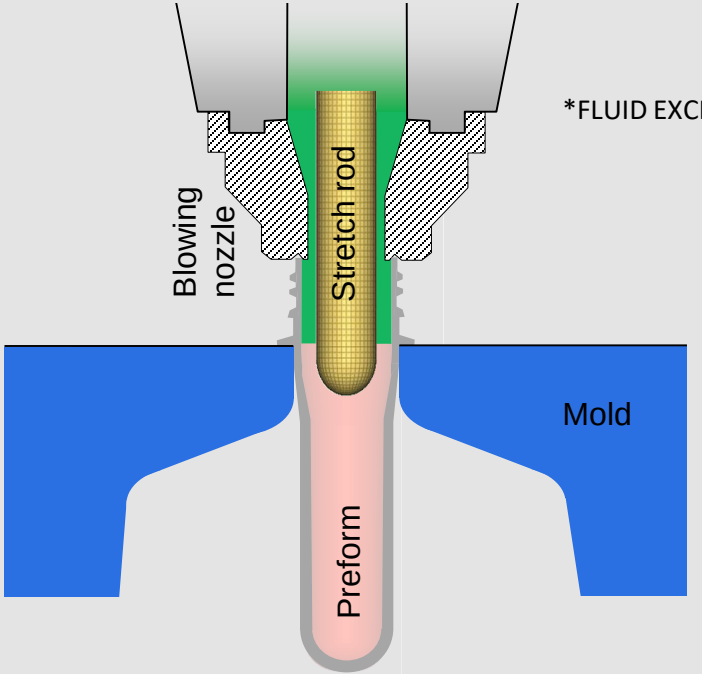
FEM Model (Abaqus/Explicit)





ISBM Process simulation

FEM Model (Abaqus/Explicit)



Pressure supply (p)

*FLUID CAVITY, ADDED VOLUME= 123456

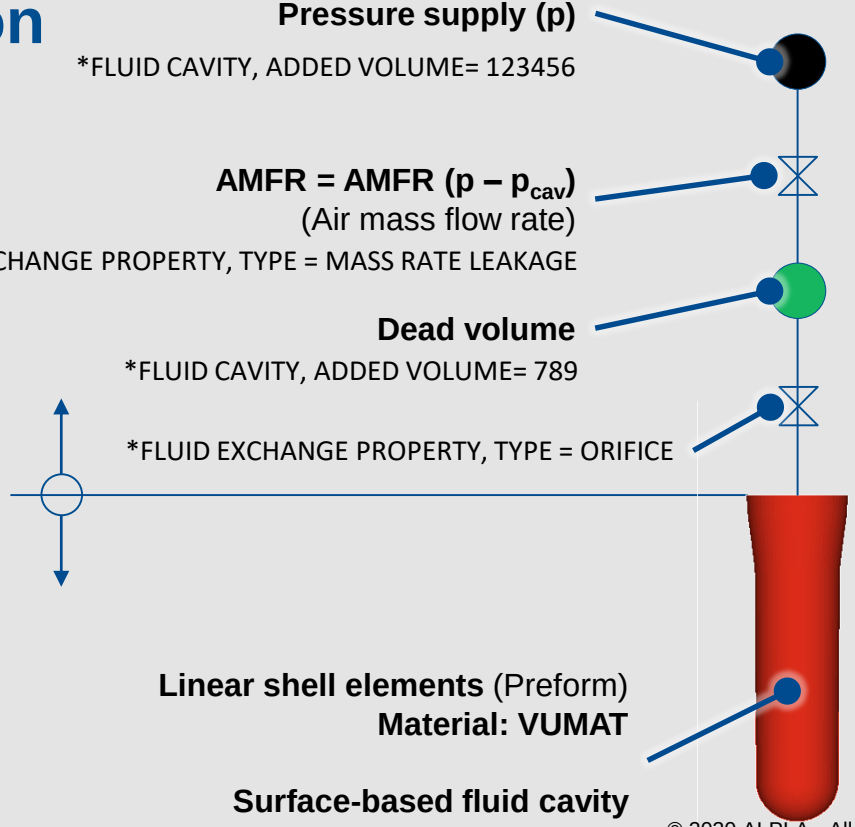
AMFR = AMFR ($p - p_{cav}$)
(Air mass flow rate)

*FLUID EXCHANGE PROPERTY, TYPE = MASS RATE LEAKAGE

Dead volume

*FLUID CAVITY, ADDED VOLUME= 789

*FLUID EXCHANGE PROPERTY, TYPE = ORIFICE



Linear shell elements (Preform)
Material: VUMAT

Surface-based fluid cavity
(p_{cav} = DOF)

*FLUID CAVITY, SURFACE = abc

ISBM Process simulation

FEM Model (Abaqus/Explicit)

Pressure supply (p)

*FLUID CAVITY, ADDED VOLUME= 123456

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Linear shell elements (Preform)
Material: VUMAT

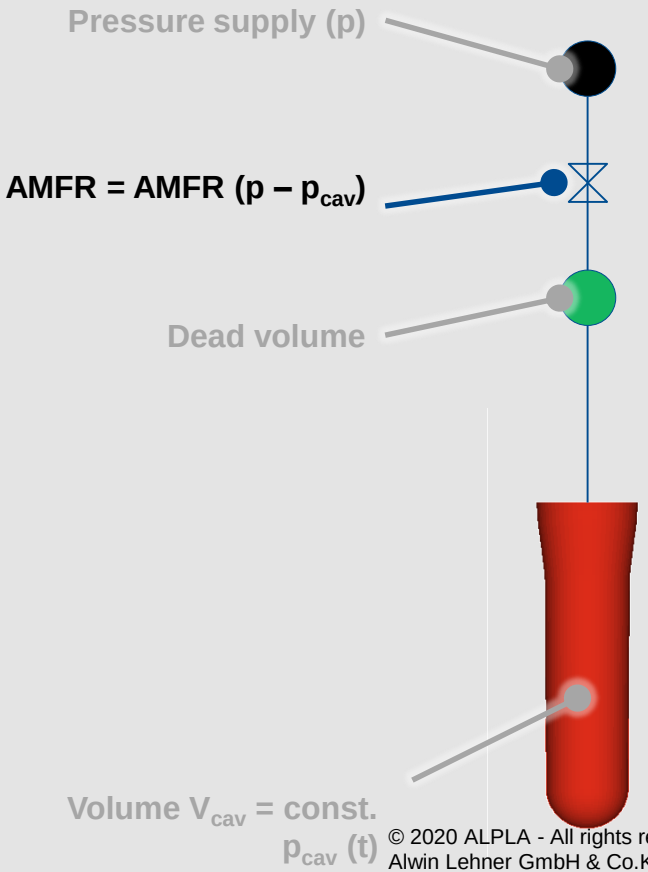
Surface-based fluid cavity
(p_{cav} = DOF)
*FLUID CAVITY, SURFACE = abc

ISBM Process simulation

AMFR (Air mass flow rate)

Rigid blow experiments on ISMB machine:

- Defined pressure supply (p)
- Defined volume V: Dead volume + preform (V_{cav} = const.)

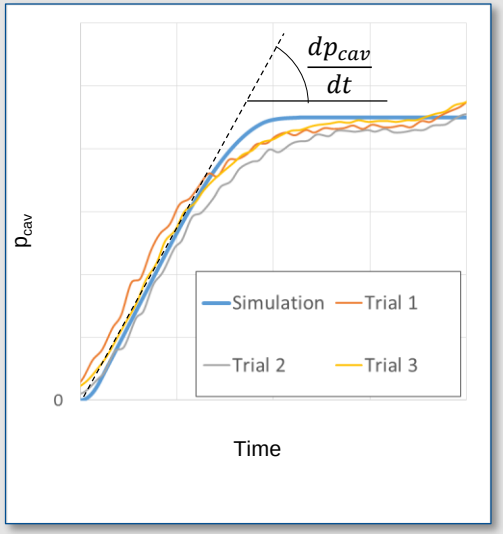


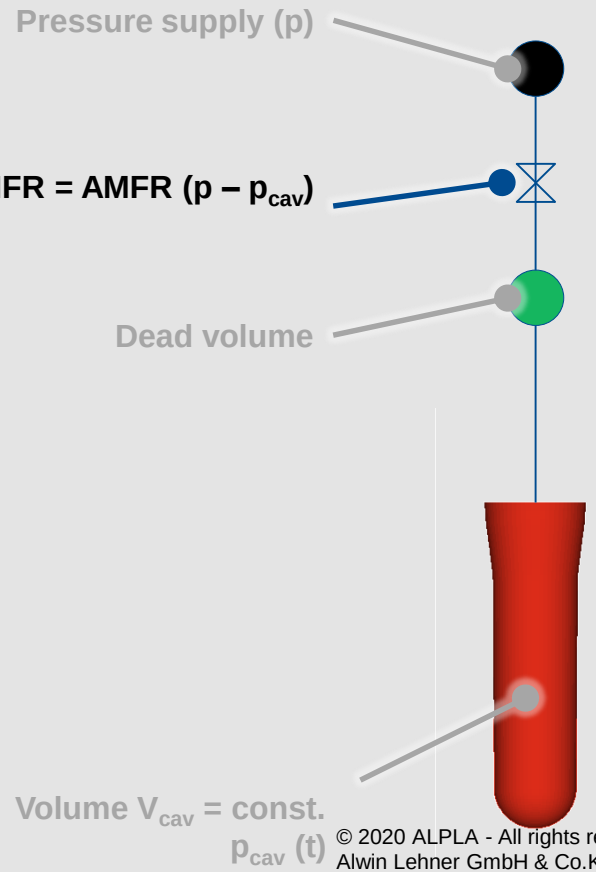
ISBM Process simulation

AMFR (Air mass flow rate)

Rigid blow experiments on ISMB machine:

- Defined pressure supply (p)
- Defined volume V: Dead volume + preform (V_{cav} = const.)
- Measure pressure in preform (p_{cav} (t))





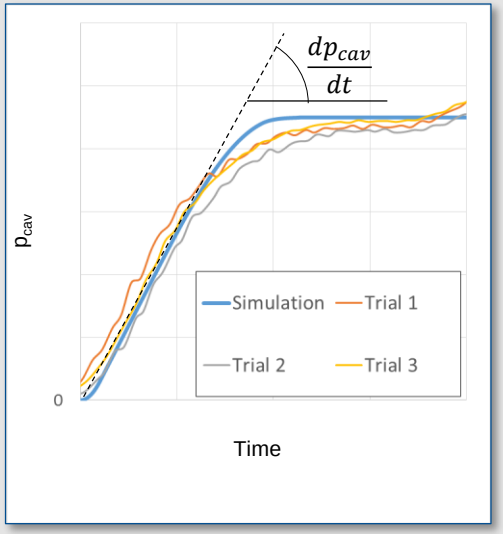
ISBM Process simulation

AMFR (Air mass flow rate)

Ref: Y. Salomeia, G. H. Menary, C. G. Armstrong, J. Nixon & S. Yan: "Measuring and modelling air mass flow rate in the injection stretch blow moulding process", Springer-Verlag France, 2015

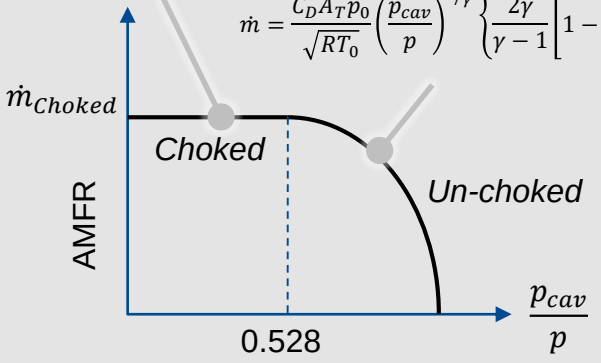
Rigid blow experiments on ISMB machine:

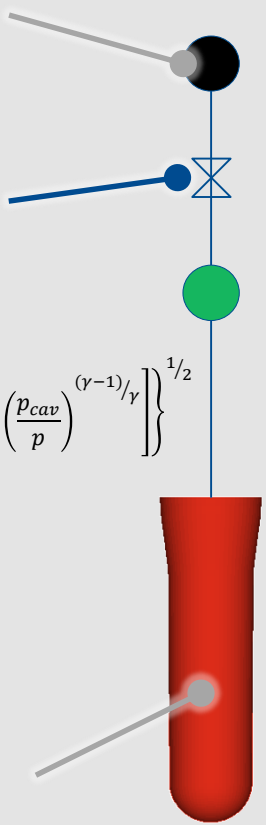
- Defined pressure supply (p)
- Defined volume V: Dead volume + preform (V_{cav} = const.)
- Measure pressure in preform (p_{cav} (t))
- Derive Chocked mass flow rate assuming isothermal conditions



$$\dot{m}_{Choked} = \frac{C_D A_T p_0}{\sqrt{RT_0}} \gamma^{1/2} \left(\frac{2}{1+\gamma}\right)^{(1+\gamma)/2(\gamma-1)}$$

$$\dot{m} = \frac{C_D A_T p_0}{\sqrt{RT_0}} \left(\frac{p_{cav}}{p}\right)^{1/\gamma} \left\{\frac{2\gamma}{\gamma-1}\left[1-\left(\frac{p_{cav}}{p}\right)^{(\gamma-1)/\gamma}\right]\right\}^{1/2}$$





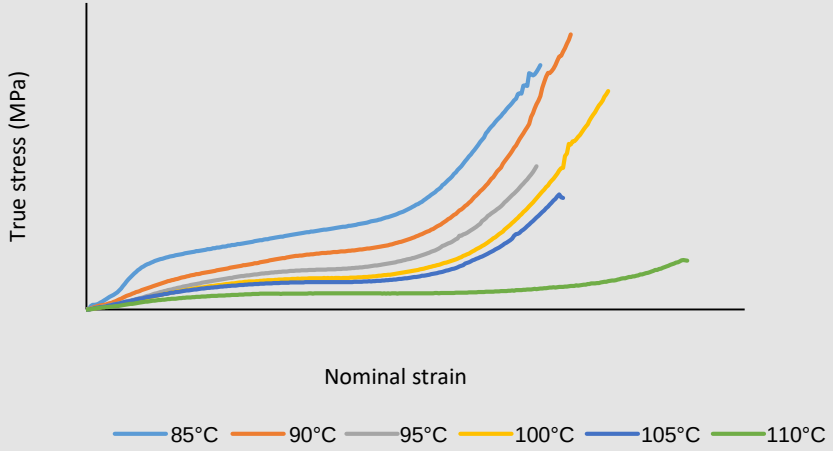
$$\dot{m}_{Choked} = \frac{dp_{cav}}{dt}\frac{V}{RT}$$

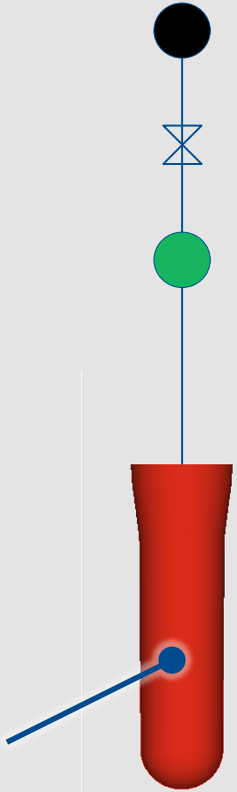
ISBM Process simulation

Material: VUMAT (Abaqus/Explicit)

Material properties of PET:

- **Temperature dependency**





Linear shell elements
Material: VUMAT

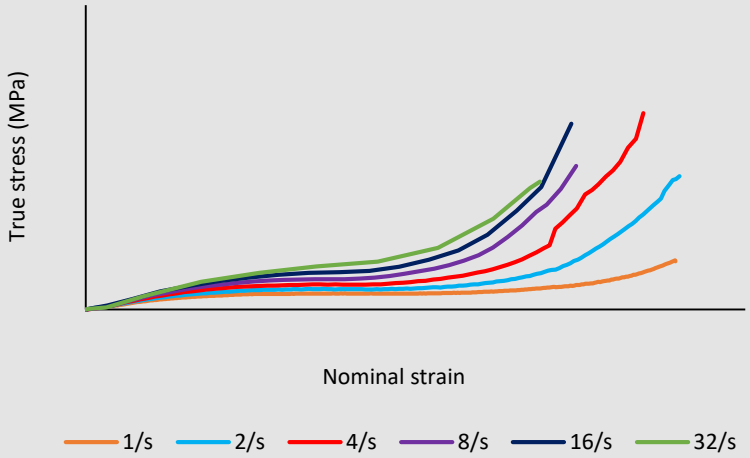
Ref: Venkata Sivaramahari Narendran Anumula:
"Prediction of process-induced mechanical properties for stretch blow moulding of PET bottles",
PhD Thesis, Queen's University Belfast, 2018

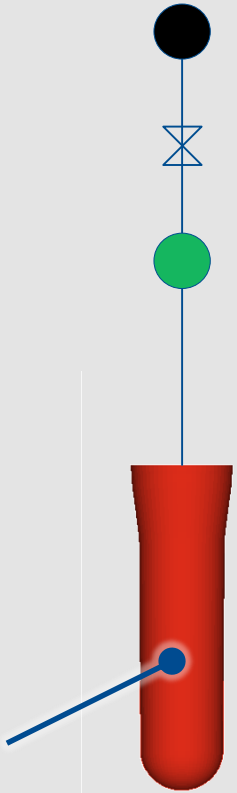
ISBM Process simulation

Material: VUMAT (Abaqus/Explicit)

Material properties of PET:

- Temperature dependency
- **Rate dependency**





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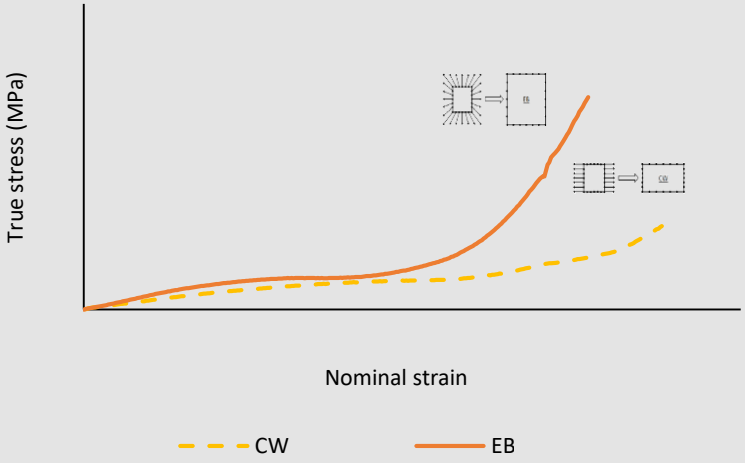
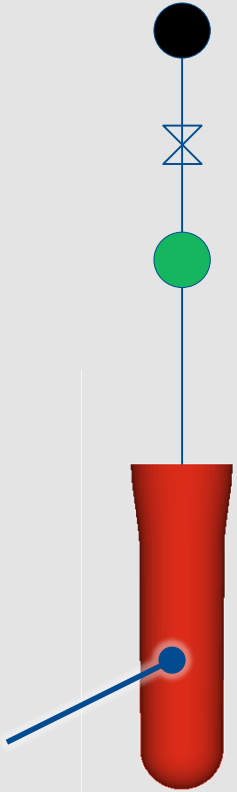
ISBM Process simulation

Material: VUMAT (Abaqus/Explicit)

Material properties of PET:

- Temperature dependency
- Rate dependency
- **Deformation dependency**





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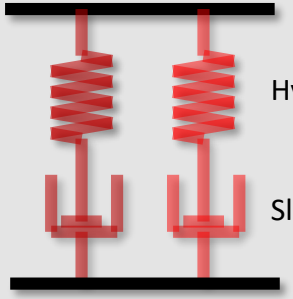
ISBM Process simulation

Material: VUMAT (Abaqus/Explicit)

Material model: Buckley material model

Linear elasticity

Eyring viscous flow



Hyperelastic

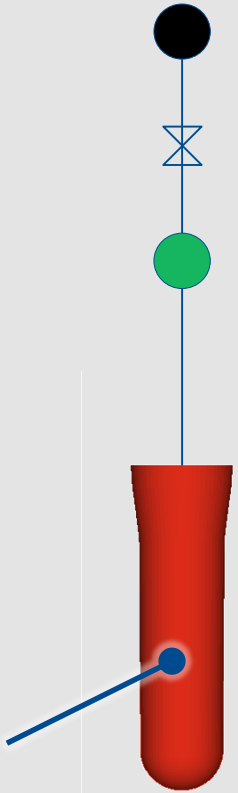
Slippage flow

Bond stretching part (σ_b)

- Glassy ($T_g \leq T \leq \sim 100°C$)

Conformational part (σ_c)

- Rubbery ($\sim 100°C \leq T \leq \sim 105°C$)
- Viscous flow regime ($105°C \leq \sim T$)



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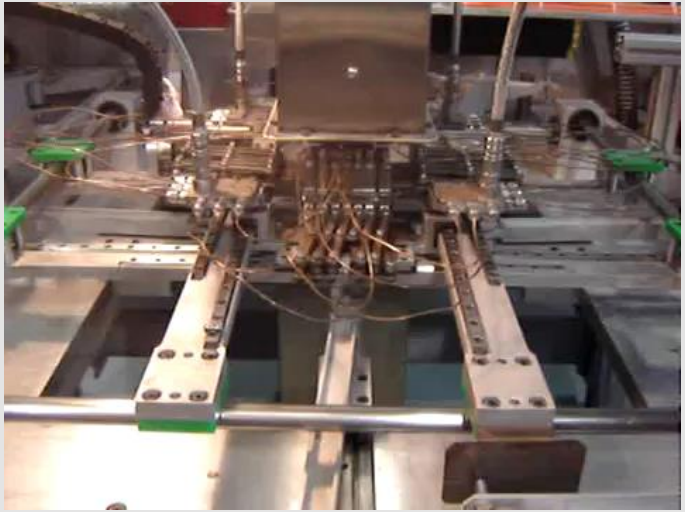
ISBM Process simulation

Material: VUMAT (Abaqus/Explicit)

Material characterization

- Biaxial tension



By courtesy of
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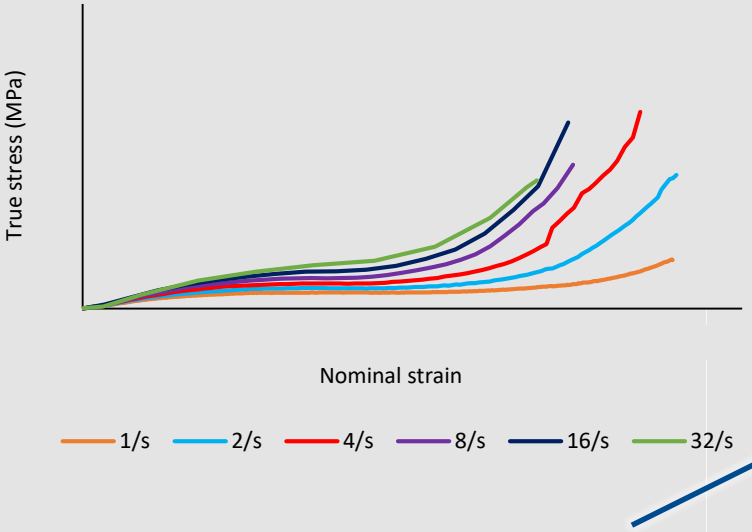
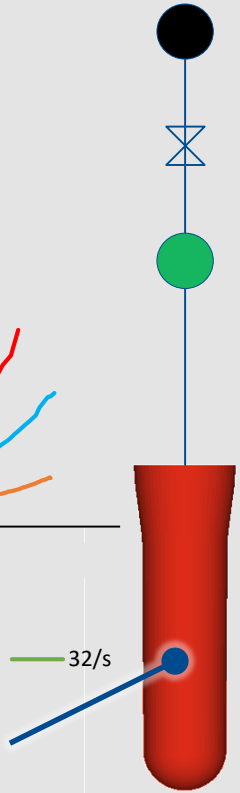




Linear shell elements
Material: VUMAT

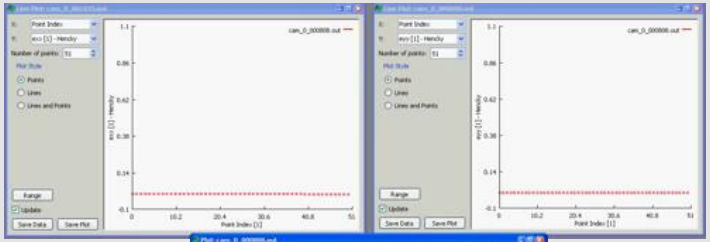
ISBM Process simulation

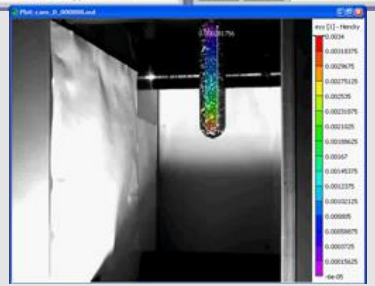
Material: VUMAT (Abaqus/Explicit)

Material characterization

- Free blow

Patterned preform for DIC





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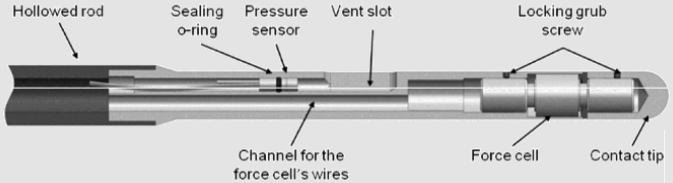
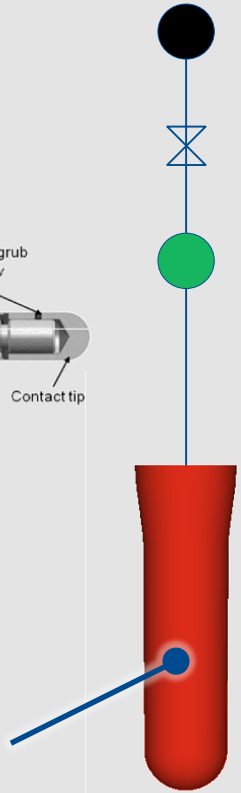


Instrumented stretch rod

- Pressure sensor
- Load cell
- Thermocouple



Linear shell elements
Material: VUMAT

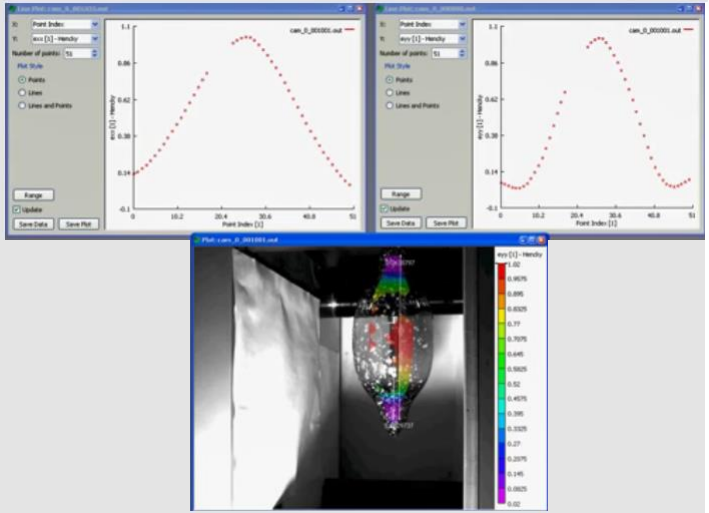
ISBM Process simulation

Material: VUMAT (Abaqus/Explicit)

Ref: Shiyong Yana, Gary Menarya, James Nixona:
"A Novel Methodology to Characterize the Constitutive Behaviour of Polyethylene Terephthalate for the Stretch Blow Moulding Process", Mechanics of Materials 104:93-106, October 2016

Material characterization

- Free blow



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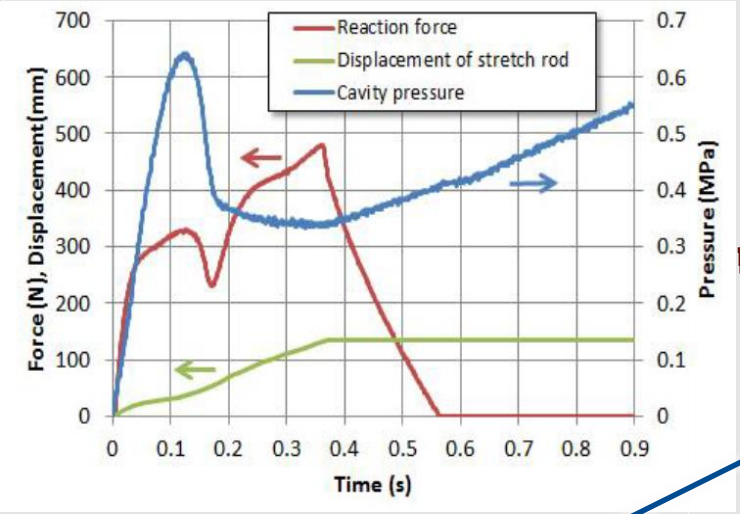


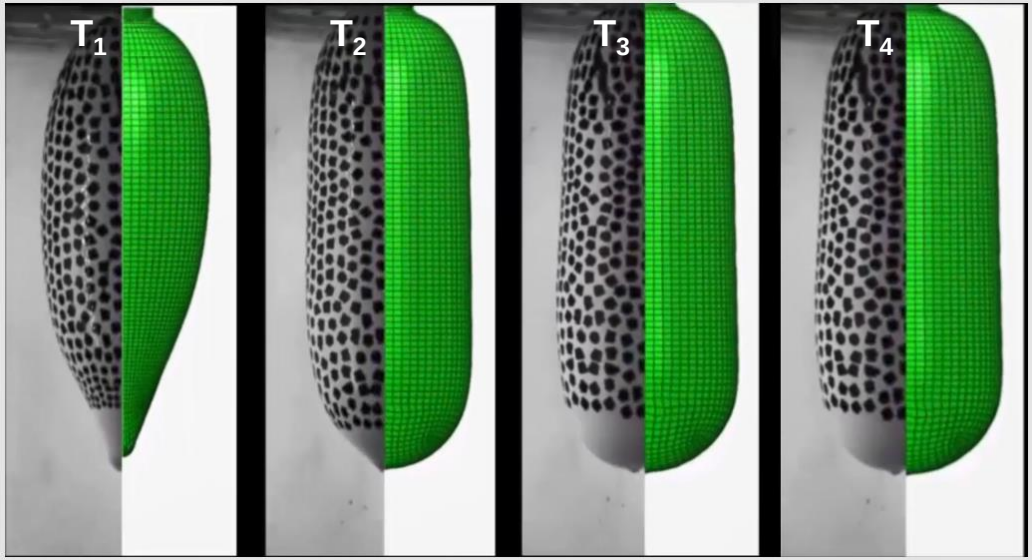
Linear shell elements
Material: VUMAT

ISBM Process simulation

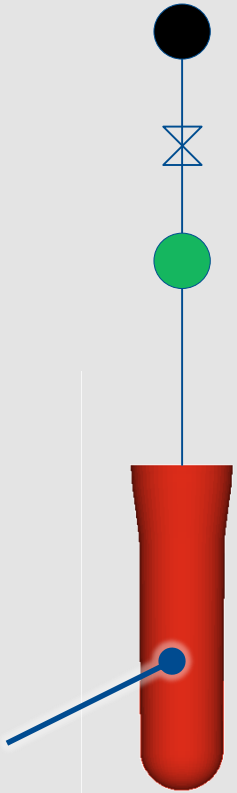
Material: VUMAT (Abaqus/Explicit)

Material characterization

- Validation



By courtesy of Surendra Kumar Ghadai



Linear shell elements
Material: VUMAT

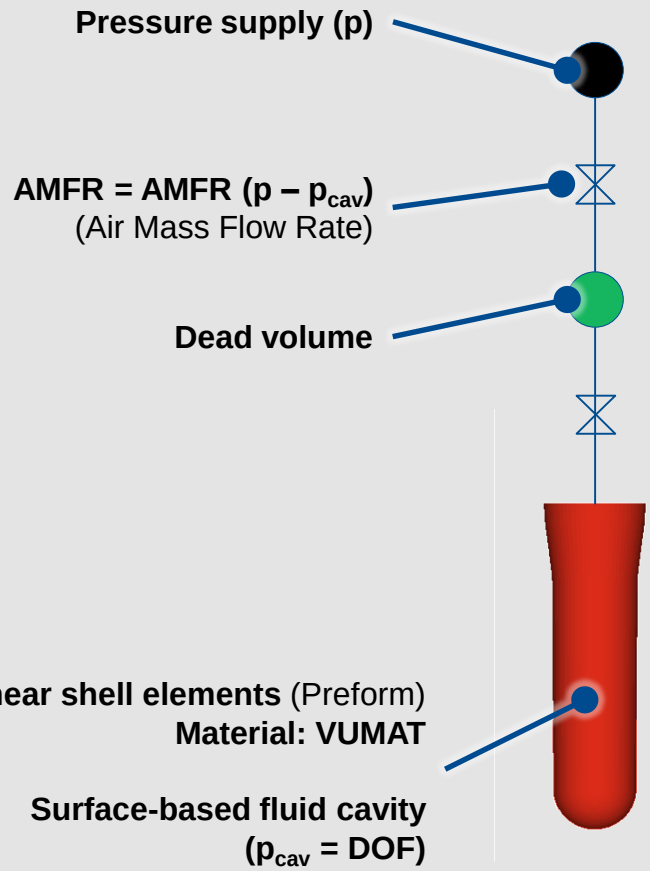
ISBM Process simulation

Summary

Requirements:

- Machine characteristics
  - AMFR
  - Dead volume

- Material model for PET preform
  - VUMAT (Abaqus/Explicit)



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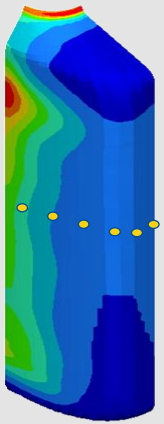
Validation

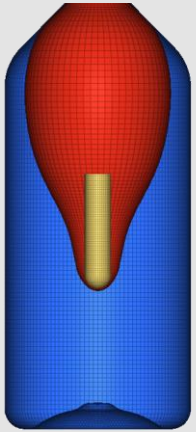
AFTER process

Wall thickness

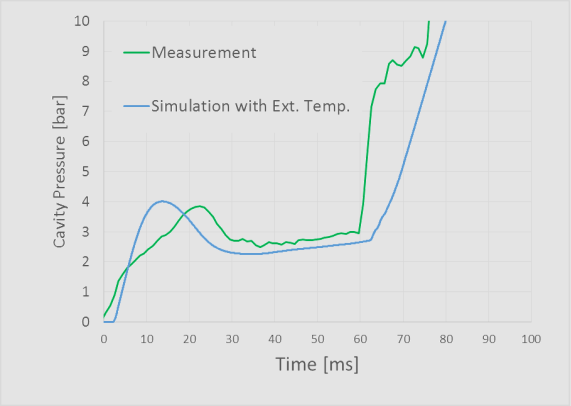


DURING process

Visual validation



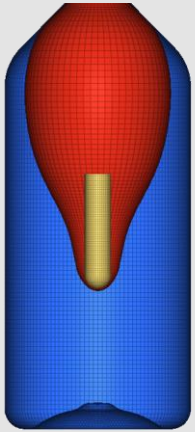
Process conditions



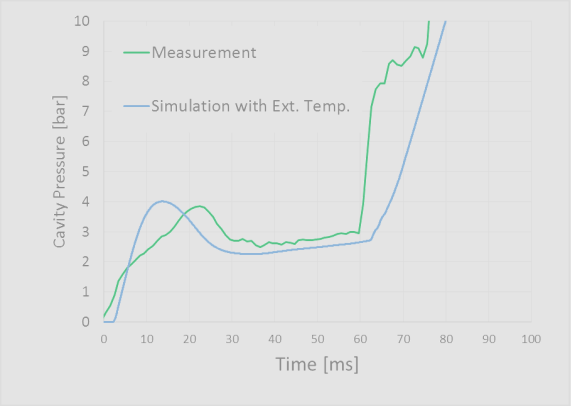
Validation

DURING process

Visual validation



Process conditions



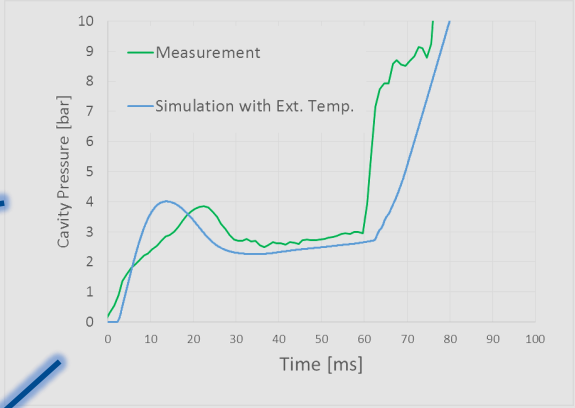
Validation

DURING process

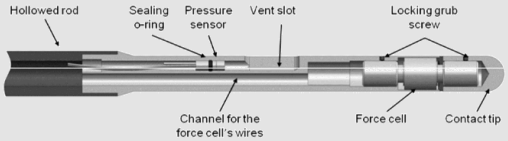
SBM Machine

- Dead volume (DV)
- Air mass flow rate (AMFR)
- Access to sensor system

Process conditions



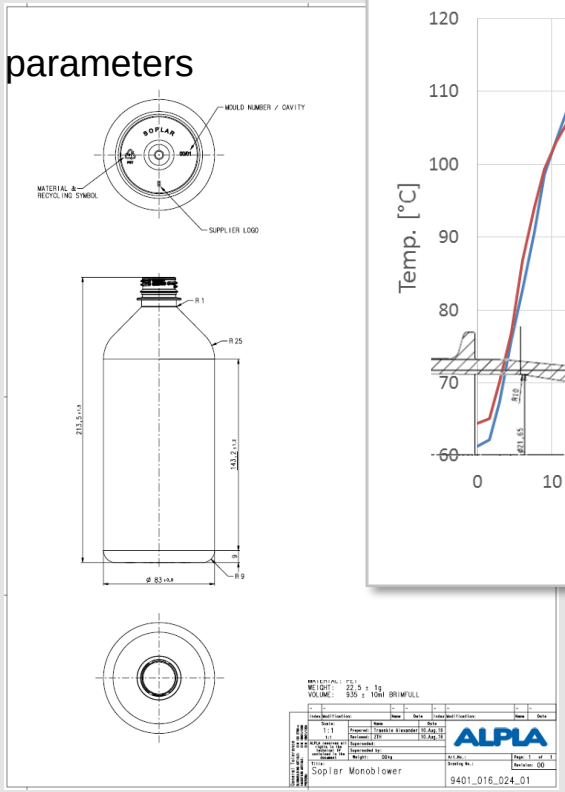
Instrumented stretch rod

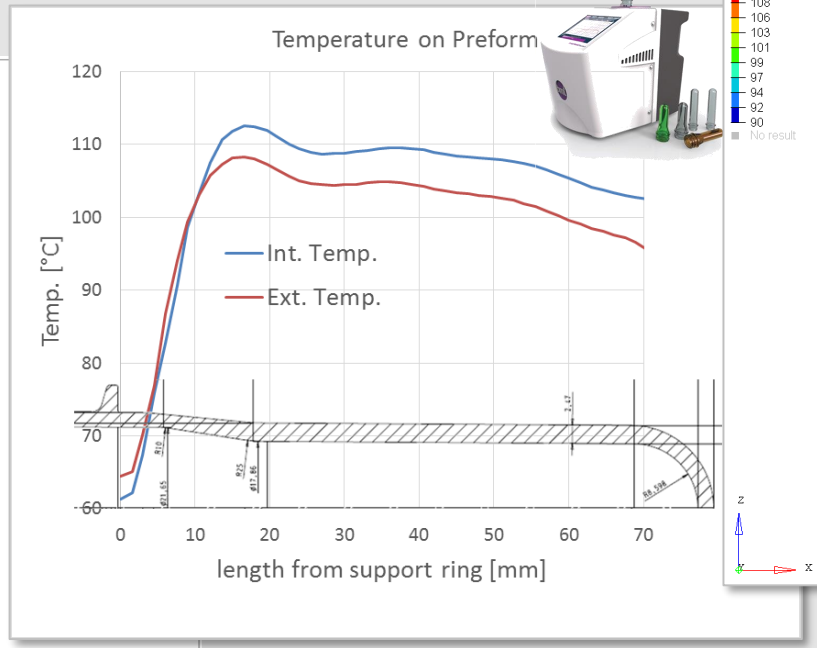


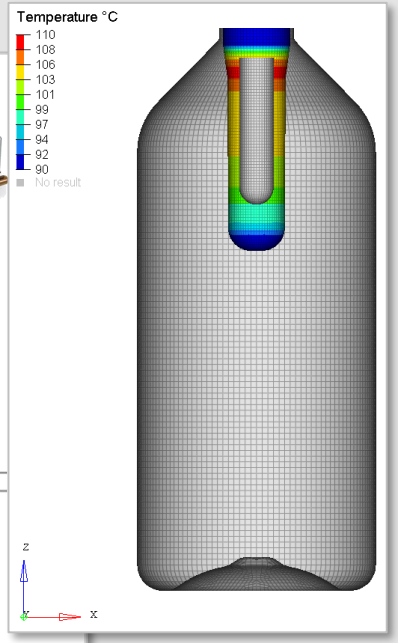
Validation

Test case 1:

- Process parameters



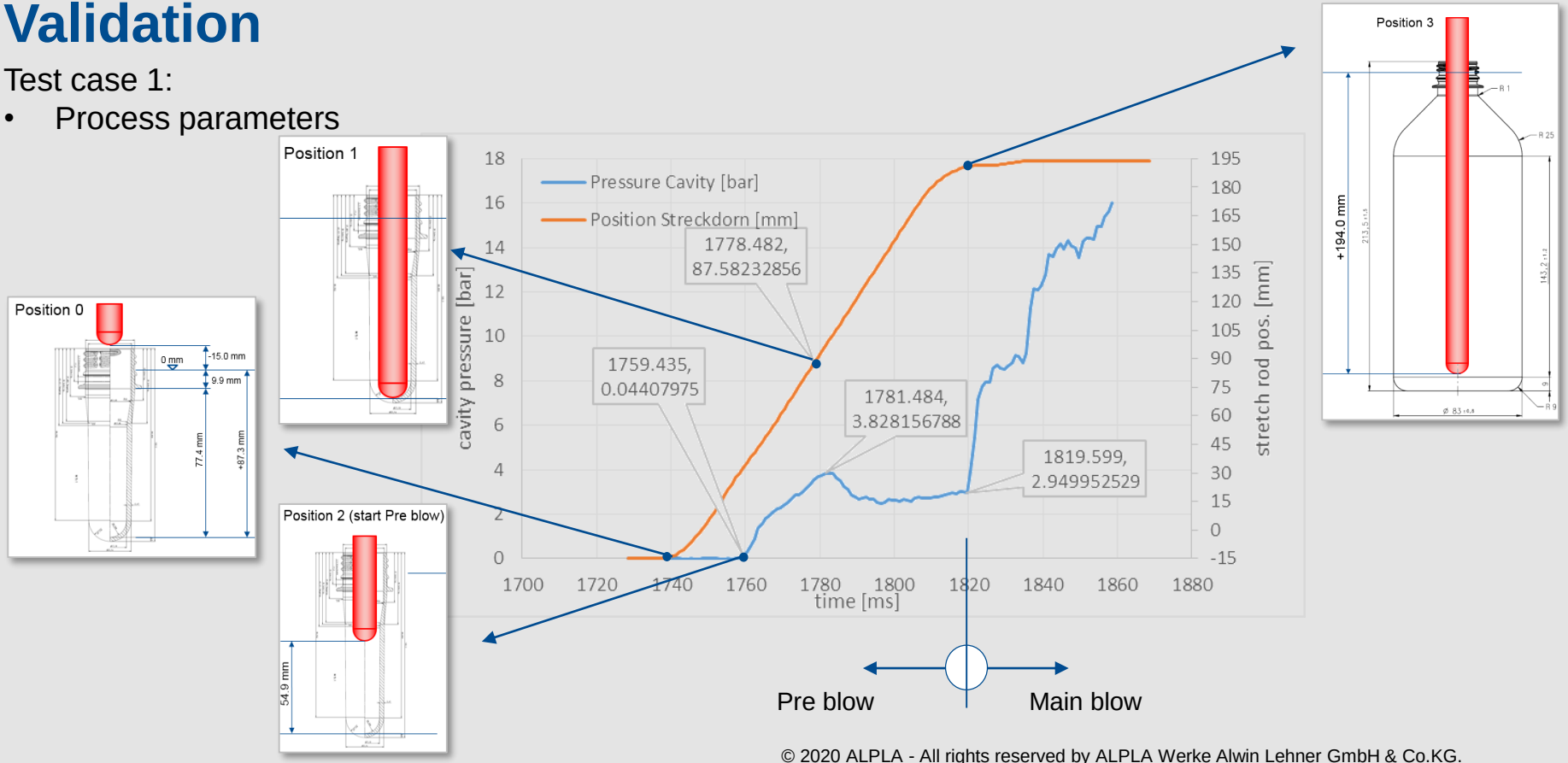




Validation

Test case 1:

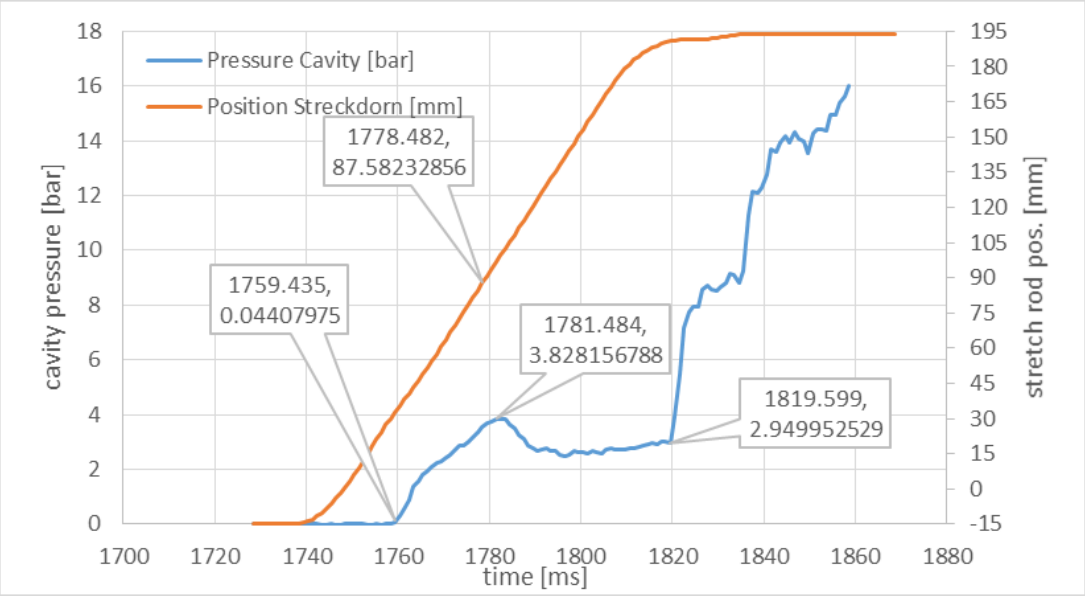
- Process parameters



Validation

Test case 1:

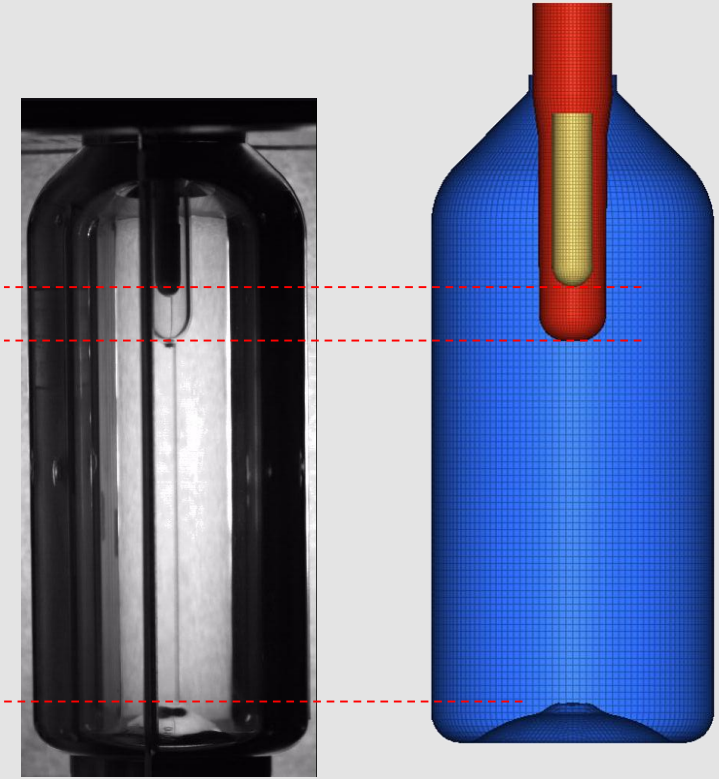
- Process parameters + High speed video



Validation

Test case 1:

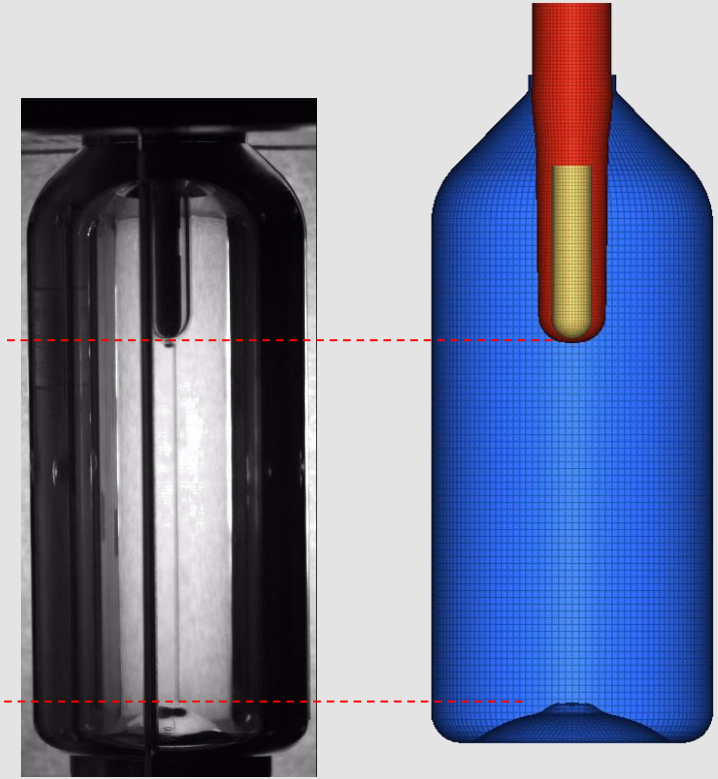
- Visual validation



Validation

Test case 1:

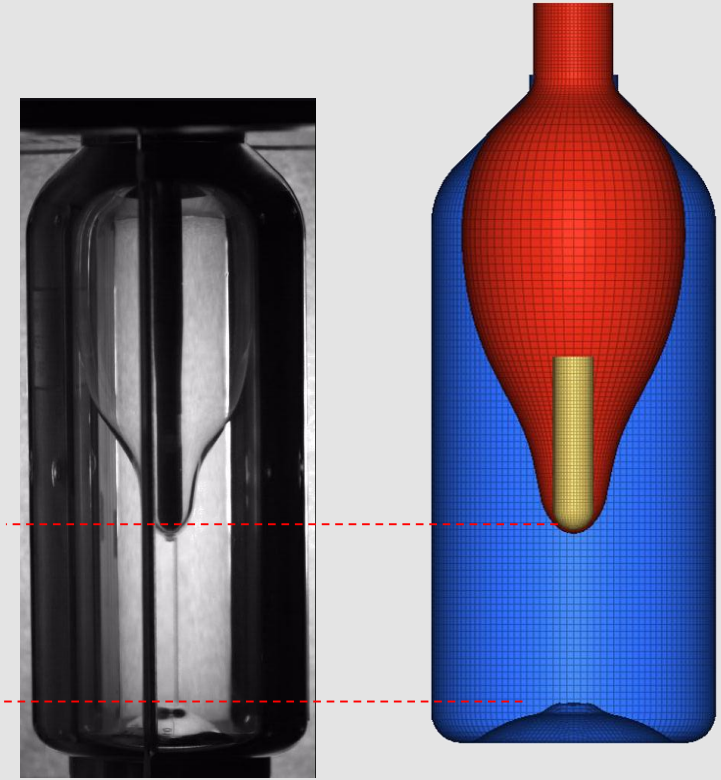
- Visual validation



Validation

Test case 1:

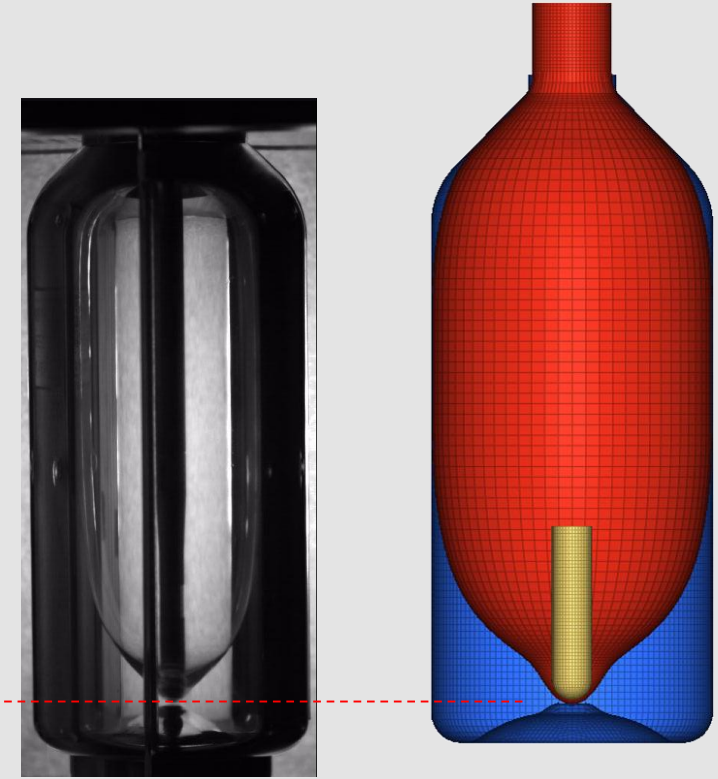
- Visual validation



Validation

Test case 1:

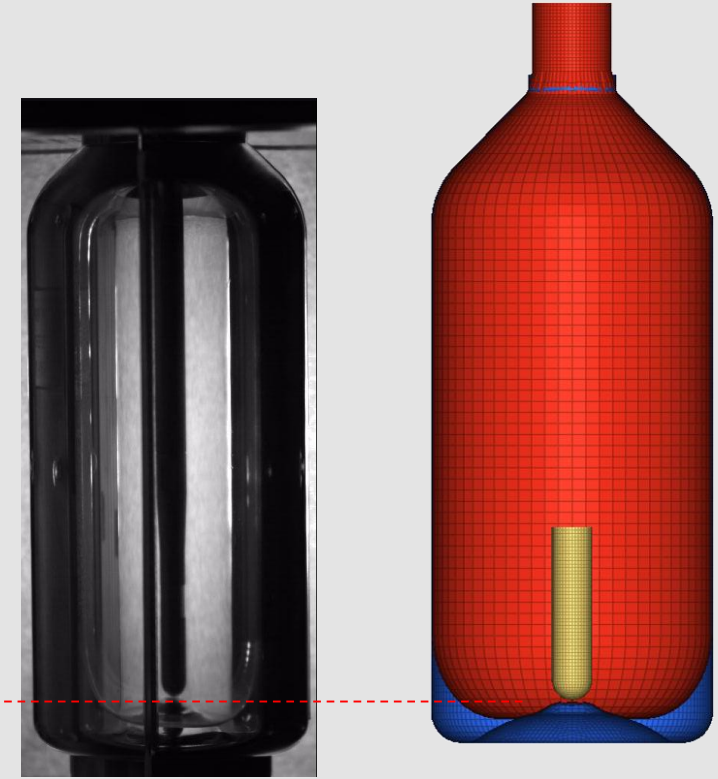
- Visual validation



Validation

Test case 1:

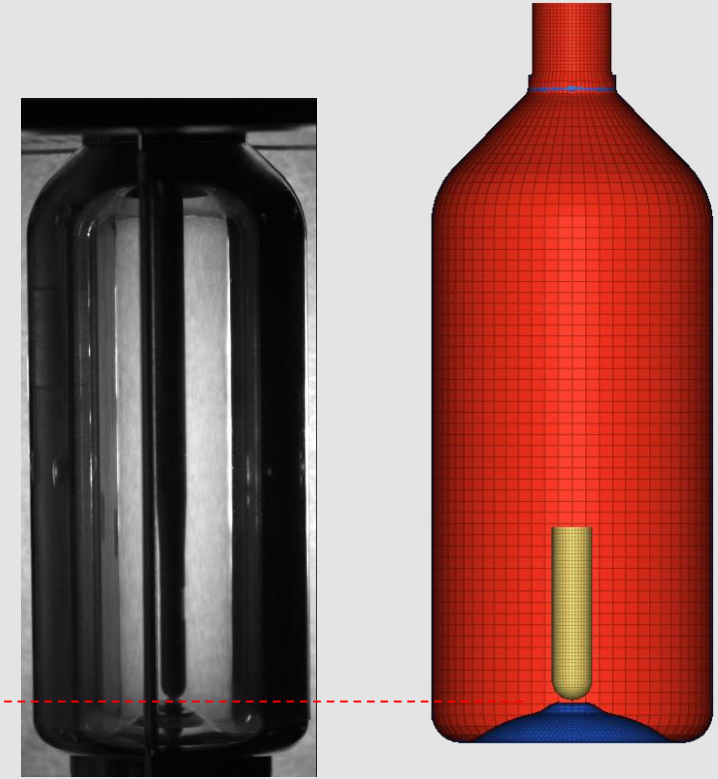
- Visual validation



Validation

Test case 1:

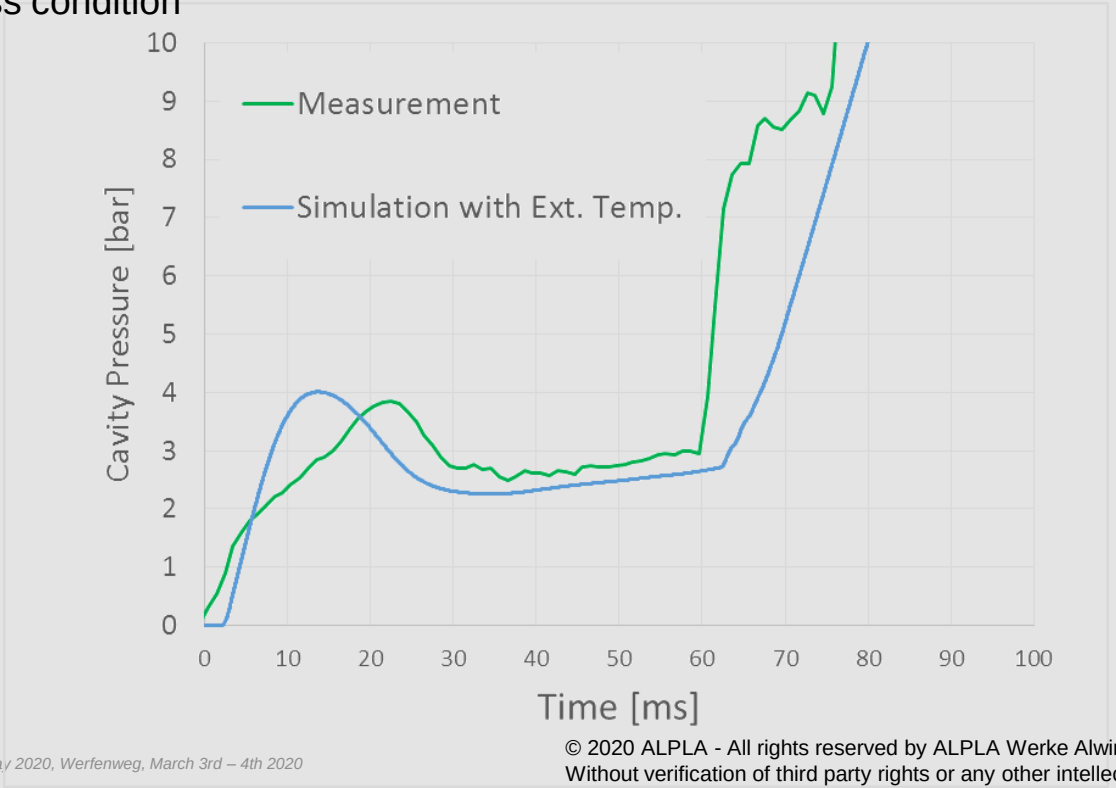
- Visual validation



Validation

Test case 1:

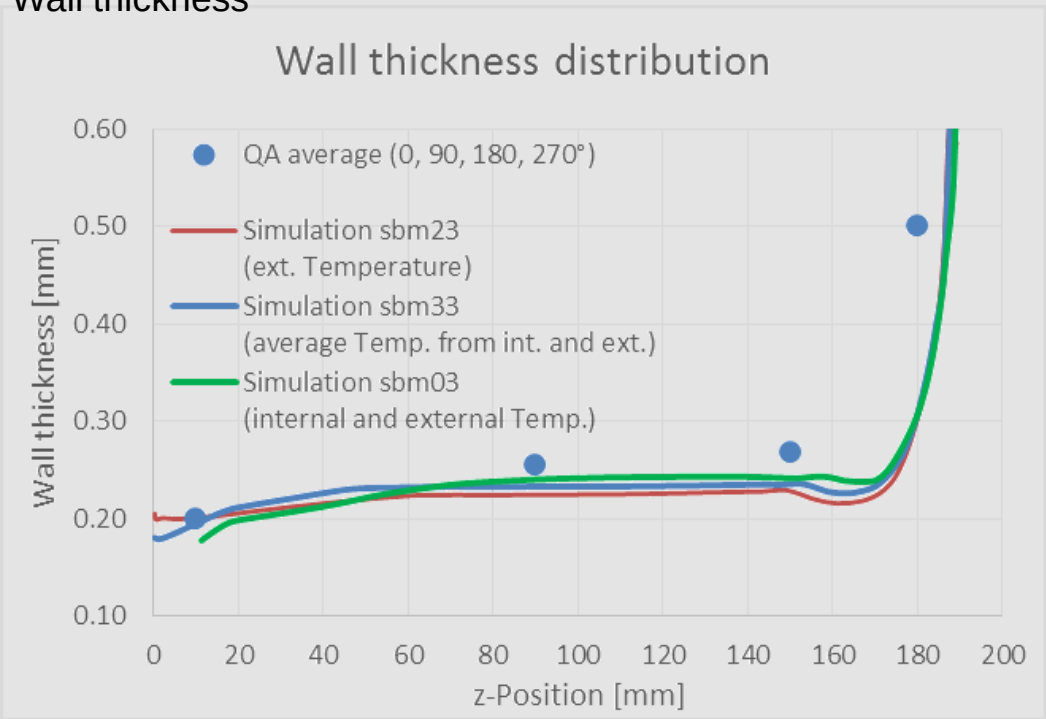
- Validation Process condition



Validation

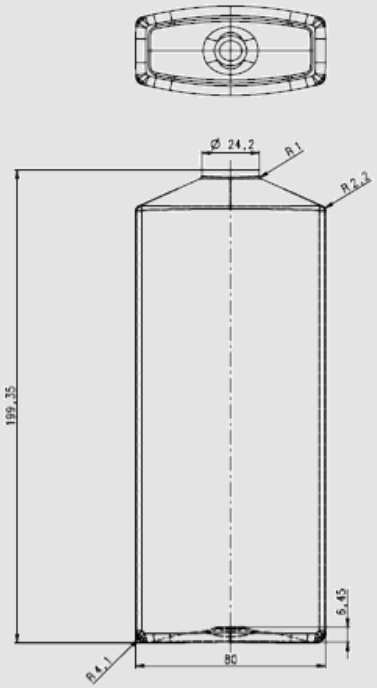
Test case 1:

- Validation Wall thickness

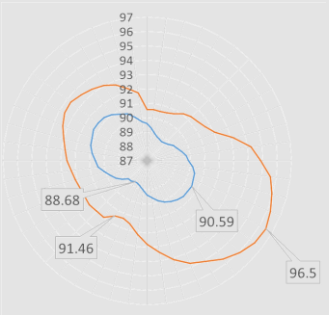


Validation

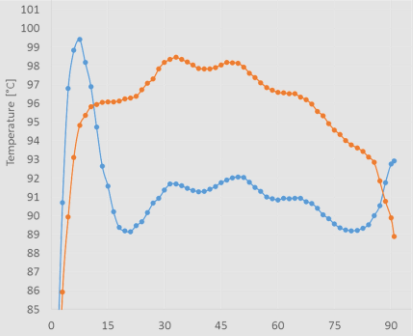
Test case 2:



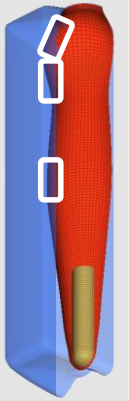
- Oval heating



- Unusual temperature on preform surface



- Friction of preform on mold during pre blow

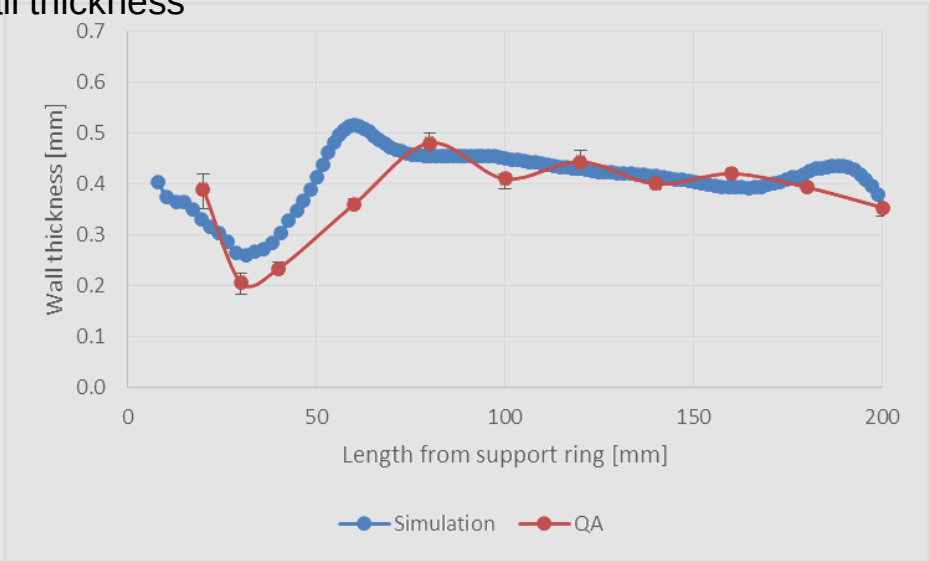


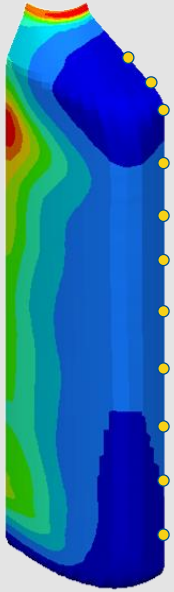
Validation

Test case 2:

- Visual validation, Validation Wall thickness

Wall thickness distribution

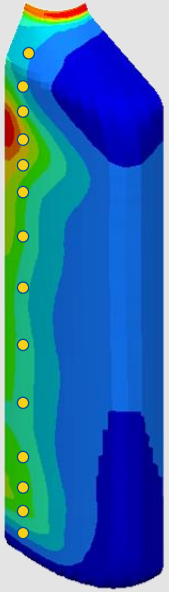


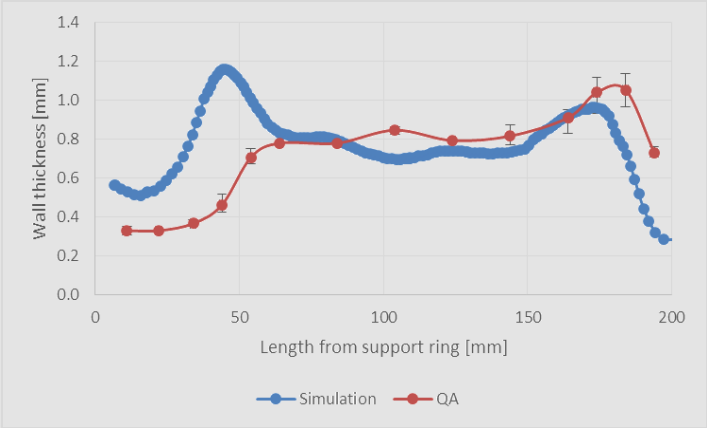


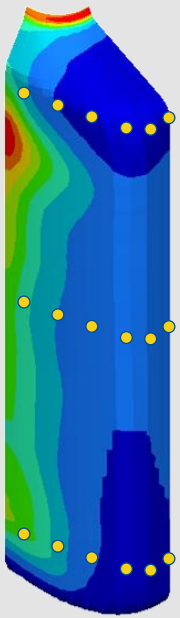
Validation

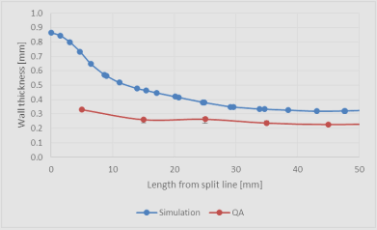
Test case 2:

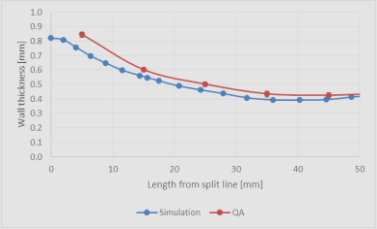
- Validation Wall thickness

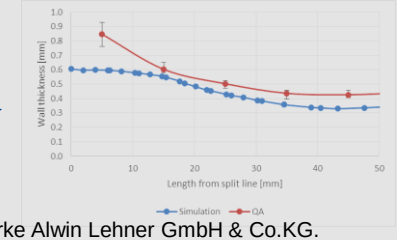












Summary

- *FEM can mimic well ISBM process*
- *Requirements:*
  - SBM Machine characteristic
  Air mass flow rate (AMFR)
  Dead volume
  - User defined material model (VUMAT)
- *Validation shows reliable results*

Acknowledgments

- ***Venkata Sivaramahari Narendran Anumula***

  PhD at Queen's University Belfast

- ***Surendra Kumar Ghadai***

  PhD at Queen's University Belfast

ALPLA

Thank You, Vielen Dank, Merci Beaucoup, Muito Obrigado, Muchas Gracias, Grazie Mille, Teşekkürler, 谢谢, Спасибо, Dziękuję Ci, شكرا