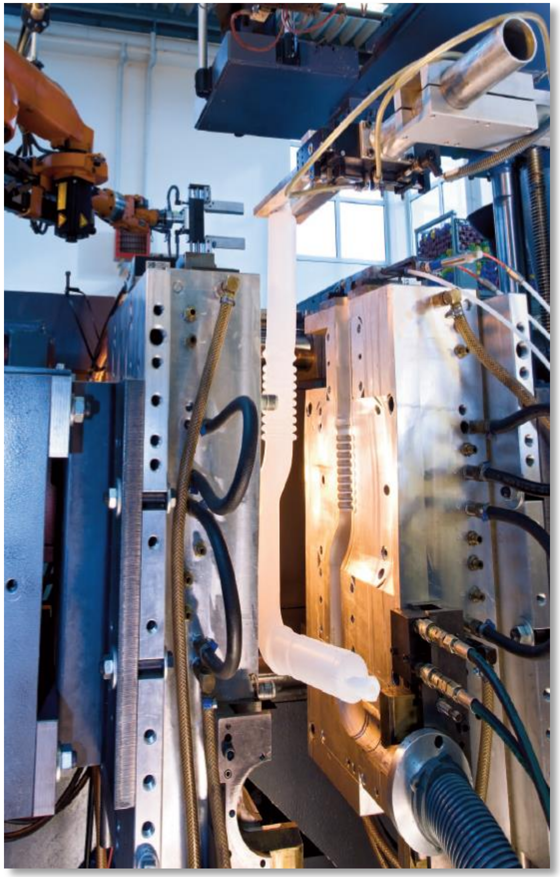
Simulation of shrinkage and warpage of extrusion blow molded parts



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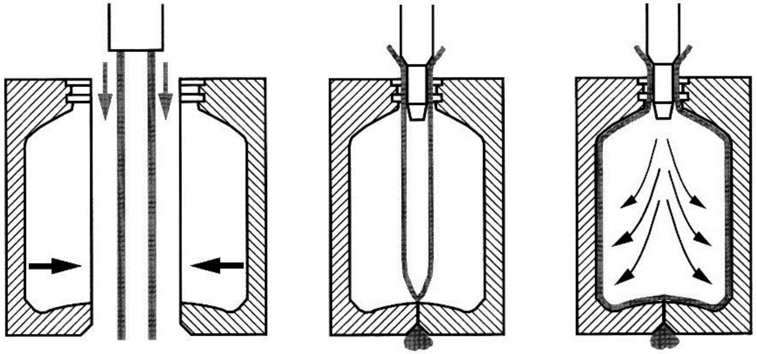
3DEXPERIENCE® Conference

Darmstadt, 19.-21. November 2019

Content

1. Introduction



Source: Thielen et al.: Blasformen von Kunststoffhohlkörpern. Munich : Hanser, 2006 [1]

1. Parison extrusion
2. Mold closing
3. Inflation
4. Demolding

Technical parts

Source: www.kautex-group.com/de/ [2]

1. Introduction

- One of the major problems in extrusion blow molding is the prediction of shrinkage and warpage

- Due to increasing quality demands and shorter cycle times, the use of CAE methods is becoming increasingly important

- Even if the current simulation models achieve good results in some cases, the prediction accuracy is still low for some process conditions

- **Reasons for this are:**
  - Strong dependencies on the process conditions
  - Missing interfaces between different CAE tools
  - Complex time and temperature dependent material behaviour

Objective: Increasing the prediction accuracy of the simulation models through improved material descriptions and improved interoperability between different CAE tools!

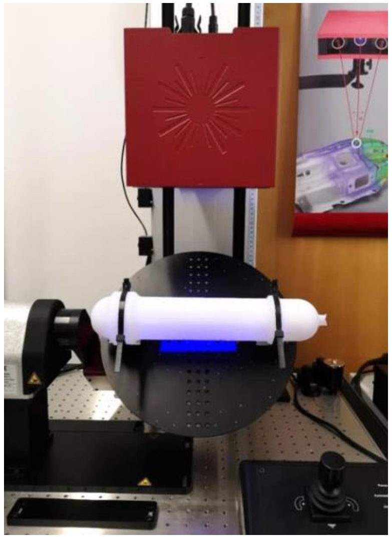
Source: www.rikutec.de [3]

2. Experimental investigation of the part shrinkage

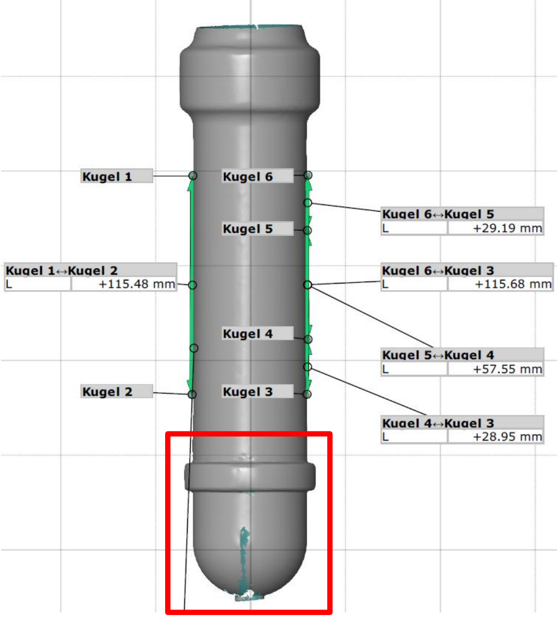
Shrinkage Measurement:

1. **Measurement:**
   6 days after production
   (processing-shrinkage)

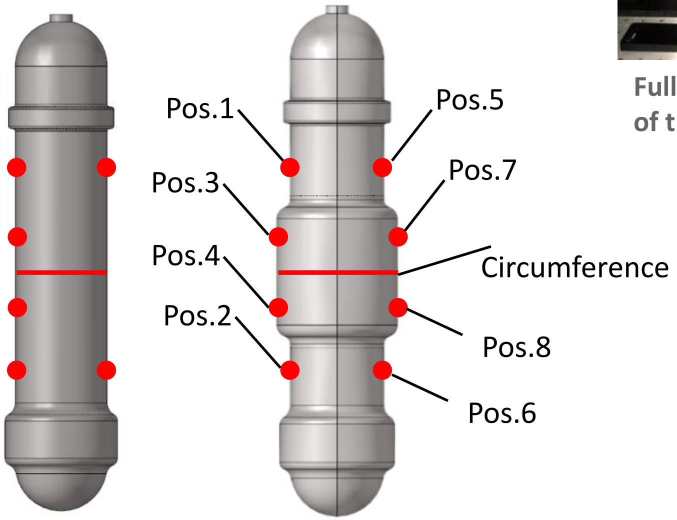
2. **Measurement:**
   6 months after production
   (post-shrinkage)



Fully automated measurement of the part geometry



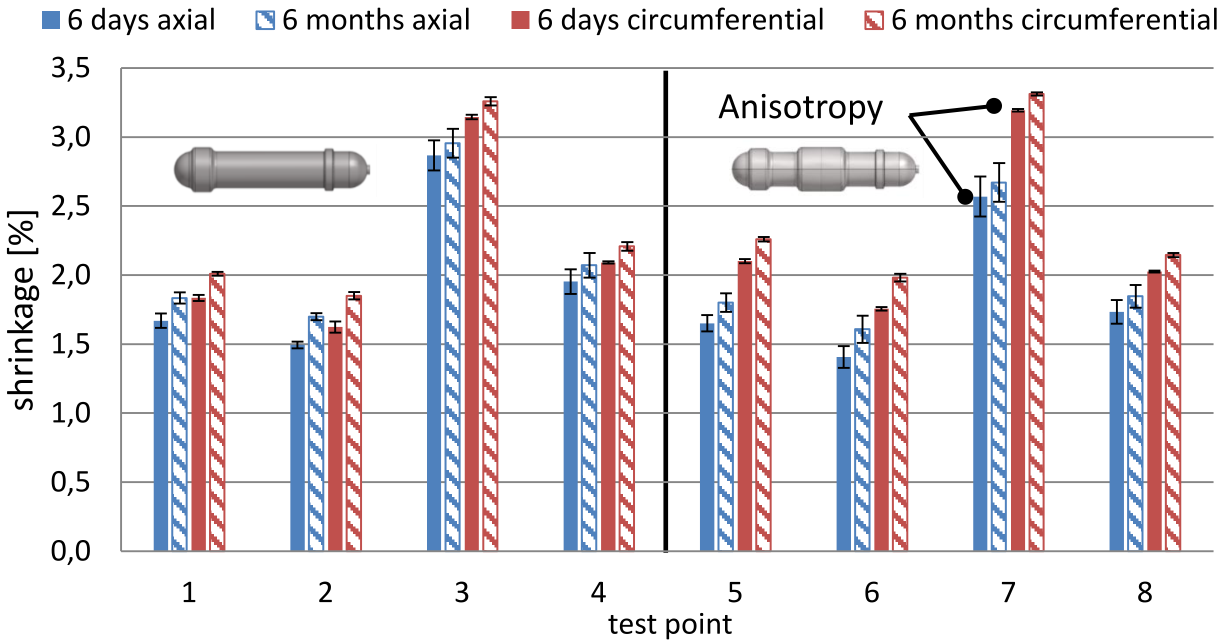
Comparison with CAD Modell



Measuring points

Test Point	Diameter [mm]	Wall Thickness [mm]	Cooling Time [s]	Amount
1	60	2	30	4
2	60	2	60	4
3	60	4	60	4
4	60	4	90	4
5	80	2	30	4
6	80	2	60	4
7	80	4	60	4
8	80	4	90	4

2. Experimental investigation of the part shrinkage



TP	Diameter [mm]	Thickness [mm]	Cooling Time [s]
1	60	2	30
2	60	2	60
3	60	4	60
4	60	4	90
5	80	2	30
6	80	2	60
7	80	4	60
8	80	4	90

- Shrinkage measurements show significant dependencies on the process conditions
- Post shrinkage is very low and therefore negligible
- Shrinkage in circumferential direction is always higher than in axial direction
  - This is in agreement with the results of a former research project called RedPro*[4]

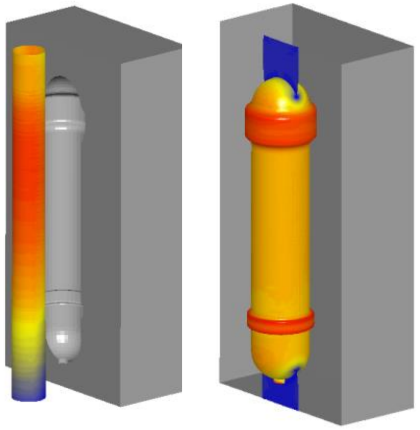
** Reduzierung von Prototypen in der Produktion von Blasformkörpern (RedPro)*

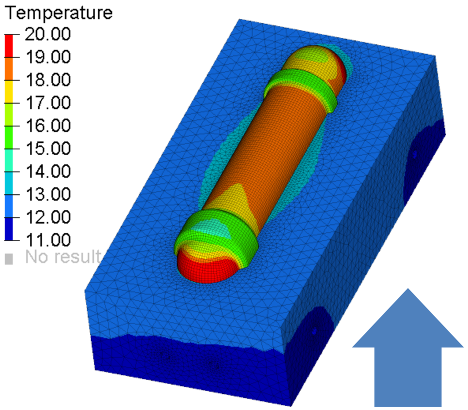
3. Cooling Simulation and Shrinkage Analysis

Blow Molding Simulation

Cooling Simulation

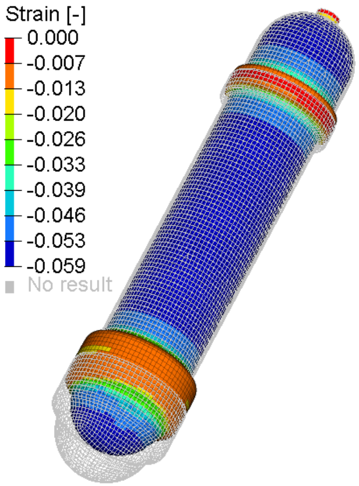
Shrinkage and Warpage





CFD-Simulation of the cooling channels

full or sequentially coupled



Wall Thickness

Local Stresses

Local Strains

Temperatures

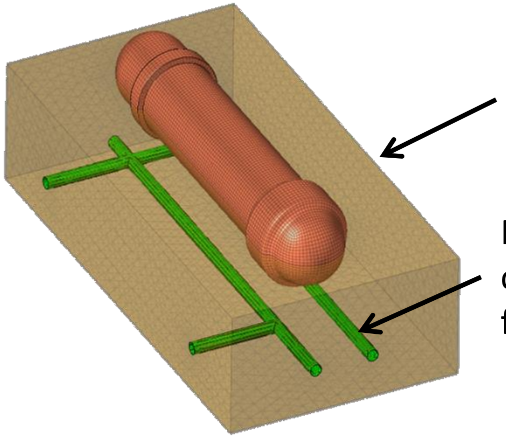
Deformation, Residual Stresses

3. Cooling Simulation and Shrinkage Analysis

Cooling Simulation in 3-Steps

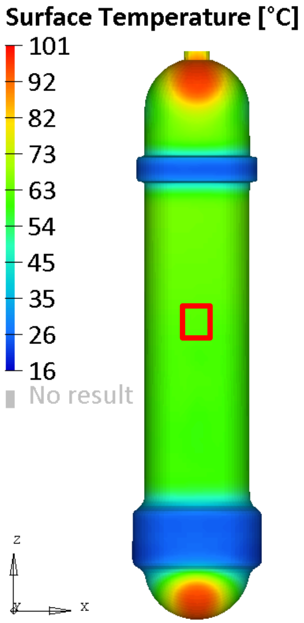
1. Cooling under form constraint
2. Demolding
3. Cooling under ambient air

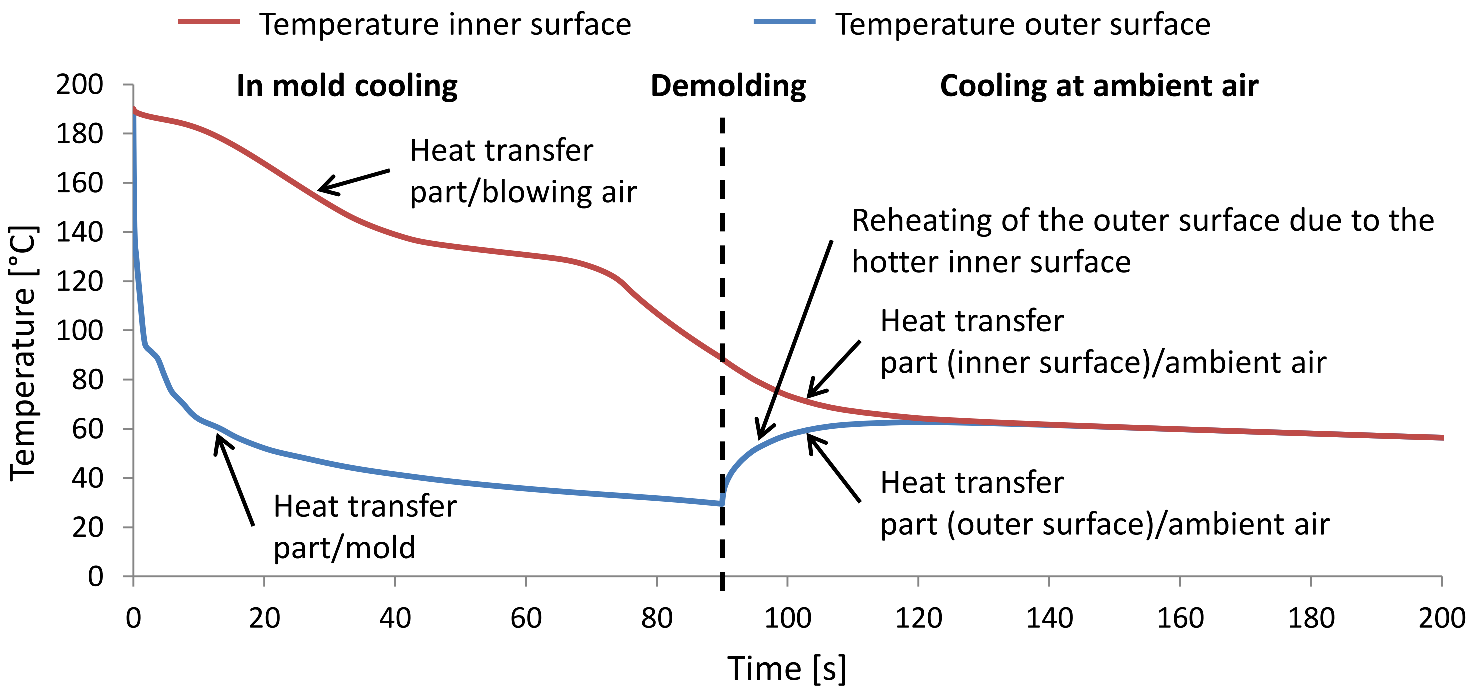
Temperature dependent material parameters for density, specific heat capacity and heat conduction according to Kipping [5]



Heat transfer between mold and ambient air (free convection)

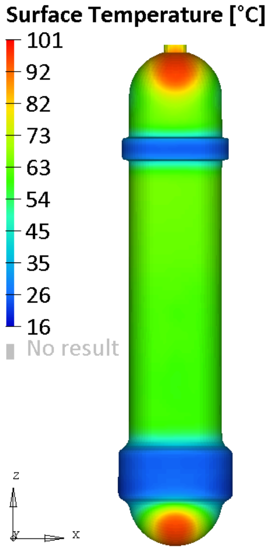
Heat dissipation in the cooling channels due to forced convection





3. Cooling Simulation and Shrinkage Analysis

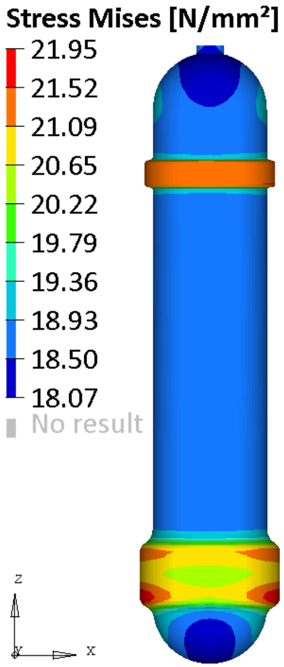
Cooling Simulation

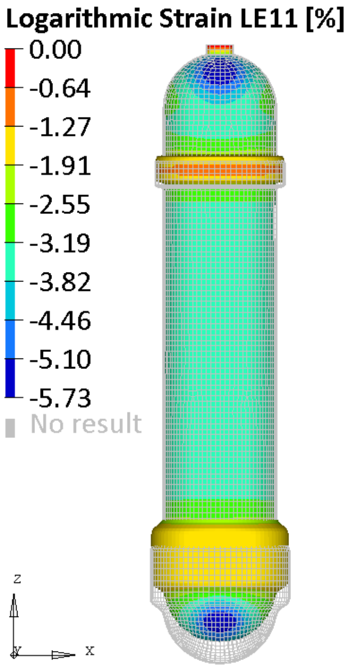


Temperatures

Step 1:
Cooling under form constraint

Step 2:
Demolding





Build up of residual stresses

Free shrinkage

Material Modelling:

- Linear viscoelastic

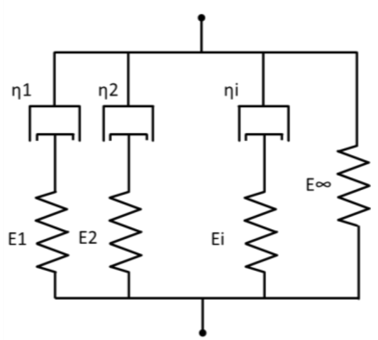
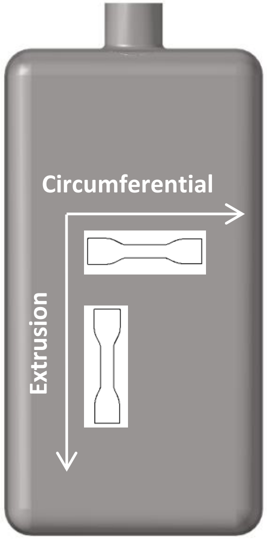
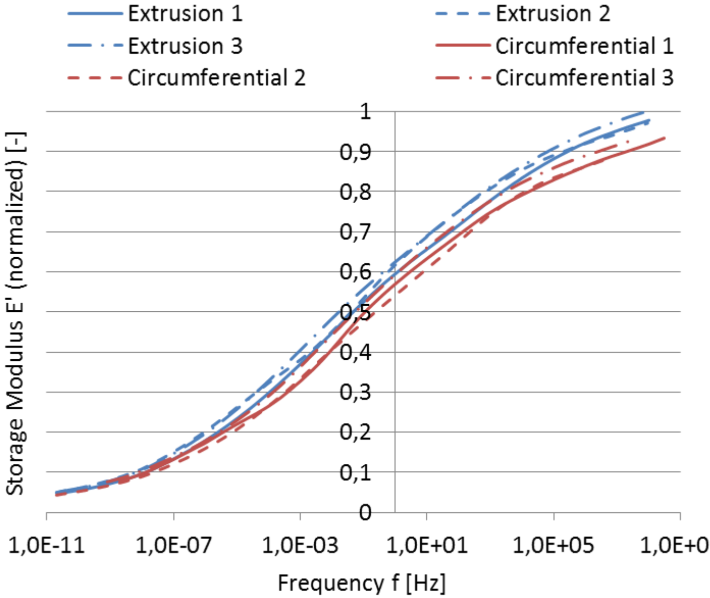


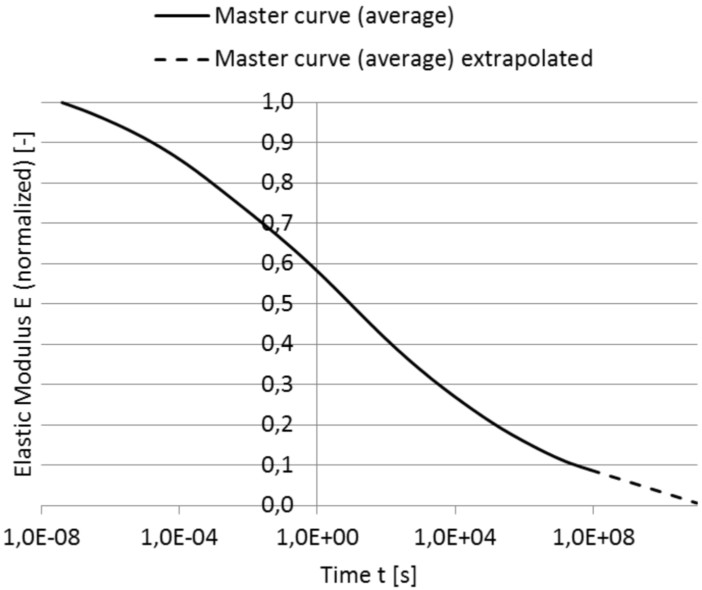
Illustration of the general Maxwell-Model

- Temperature dependent thermal expansion coefficient according to Kipping [5] and Henrichs [6]

3. Cooling Simulation and Shrinkage Analysis

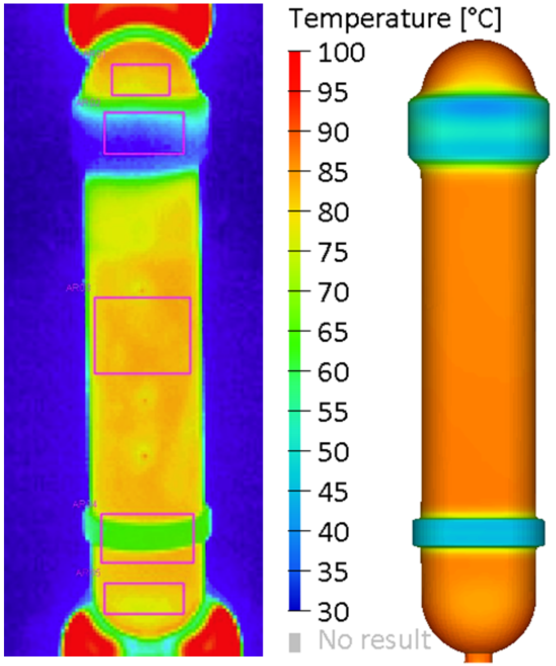


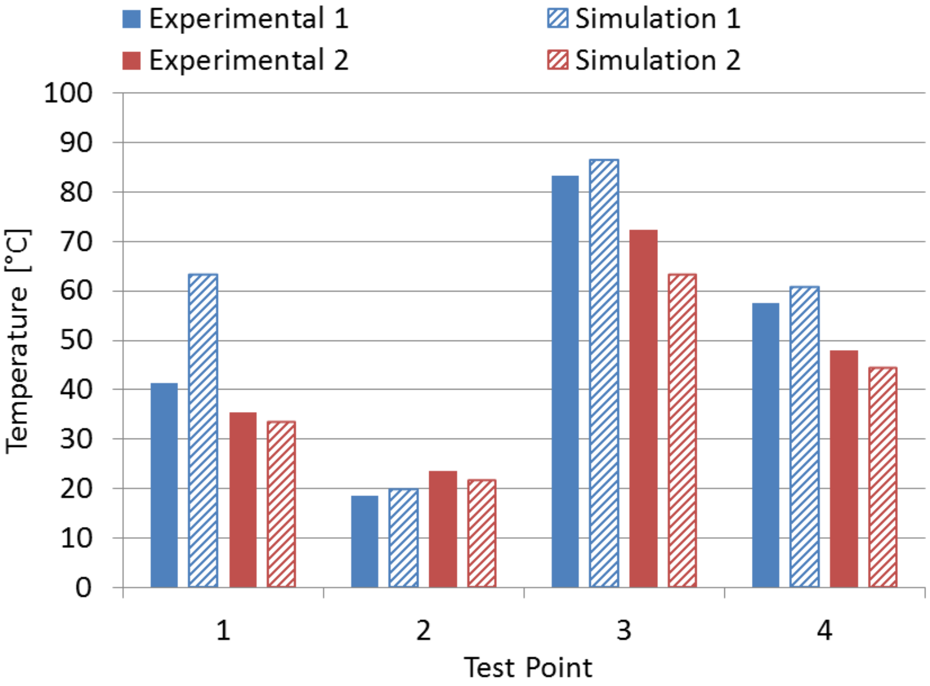




- Determination of storage modulus via dynamic mechanical analysis (DMA)
- Time-Temperature-Superposition: $\log(\alpha_{\mathrm{T}}) = -\frac{C_1(T-T_{\mathrm{ref}})}{C_2+(T-T_{\mathrm{ref}})}$ (WLF-Equation)
- Translation (frequency/time) according to Sommer [7]: $f = \frac{1}{2\pi t}$
- Calibration of the linear viscoelastic general Maxwell Model: $E(t) = E_0\left(1 - \sum_{j=1}^{N} g_j \cdot \left(1 - e^{\frac{-t}{\tau_j}}\right)\right)$
- Temperature dependent thermal expansion coefficient according to Kipping [5] and Henrichs [6]

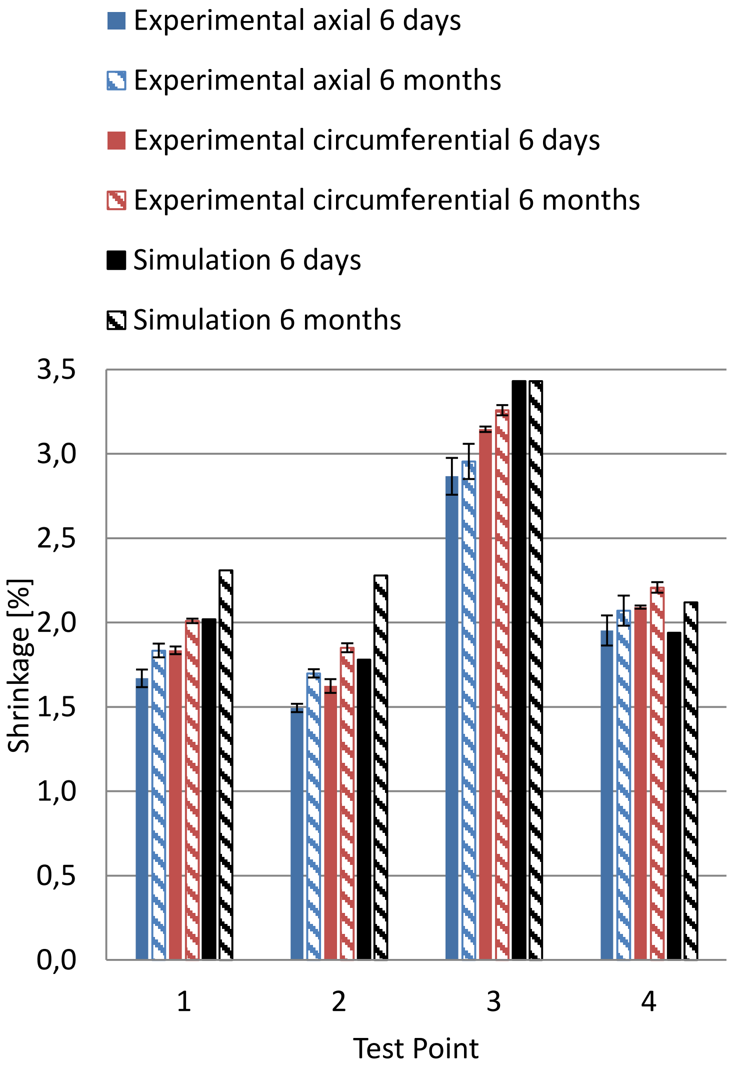
4. Results and Discussion

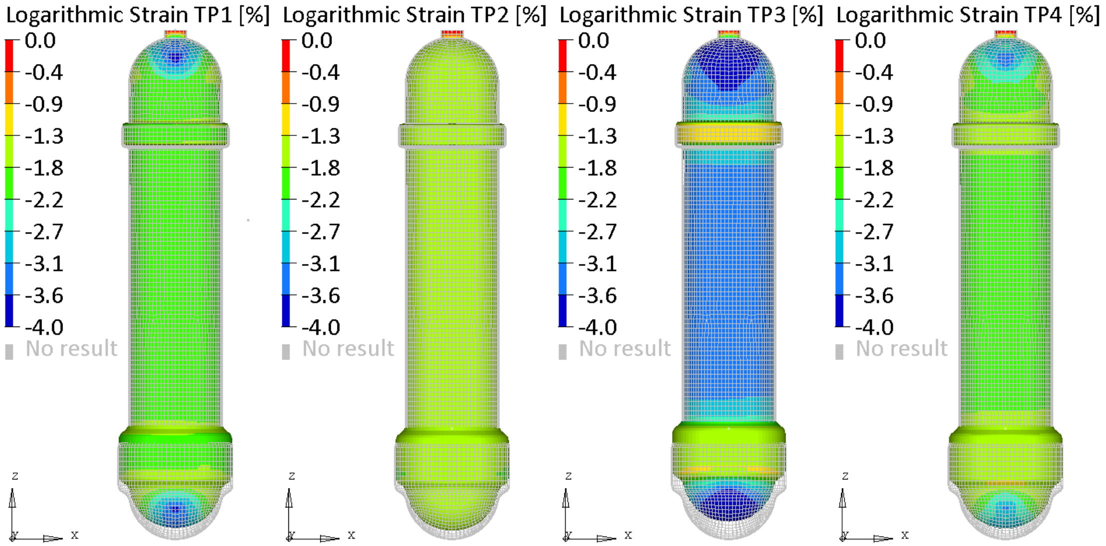




- After demolding, the surface temperature was measured at 2 time points
  - The first measurement (experimental 1) was carried out 20s after demolding
  - The second measurement (experimental 1) was carried out 300s after demolding
- Only 1 part per test point was measured
- TP1 shows the largest deviation
- The biggest uncertainties are the heat transfer coefficients

4. Results and Discussion





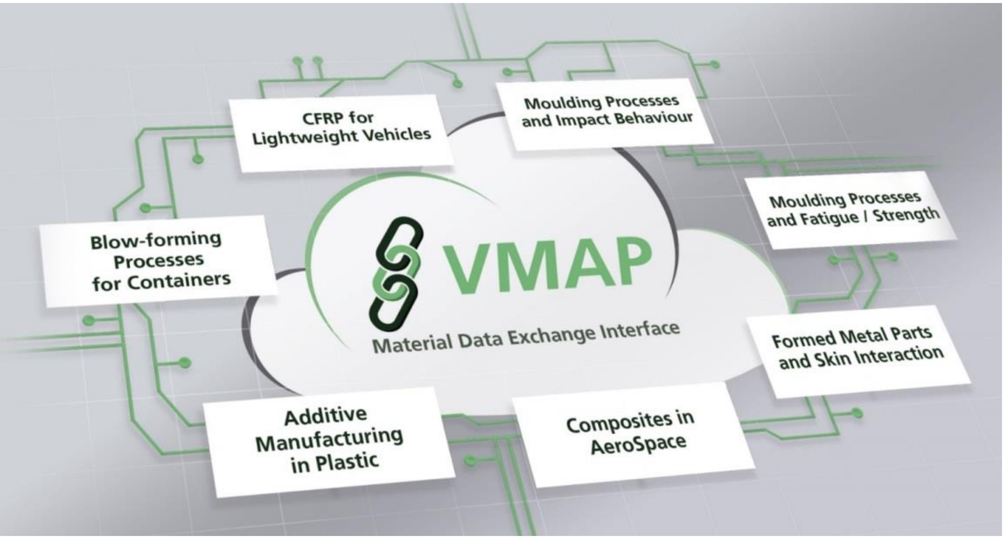
- ○ The simulation results of the processing-shrinkage are in good agreement with the experimental results
- ○ However, the results of the post shrinkage deviate significantly
- ○ After 6 months, the shrinkage of TP2 even exceeds the shrinkage of TP4
- ○ In addition, the results are available only at 2 discrete times
- ○ A dynamic measurement immediately after demolding would provide valuable information

4. Results and Discussion
The VMAP interface standard

Interoperability of Engineering Data within Integrated CAE Workflows

- **defined international standard**
- **integrated import/export and translation tools**
- **supported by leading software vendors**

The VMAP standard and import/export interface tools will provide users with a vendor-neutral methodology of transferring material and engineering data between different CAE software along the whole simulation process chain.



http://vmap.eu.com/

29 Partners from 6 countries

The VMAP project will be demonstrated by different manufacturing use cases:

- extrusion blow molding (Rikutec, Hagen Stiftung)
- composite light weight vehicles (AUDI, KIT)
- injection molding (Bosch)
- hybrid modelling of consumer products (Philips)
- composite component in aerospace (Convergent)
- additive manufacturing (Bosch)

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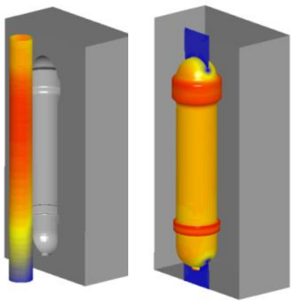
4. Results and Discussion
CAE-Workflow using VMAP

VMAP

Blow Molding Simulation

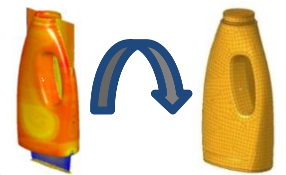


Wall Thickness
Local Stresses
Local Strains

Own Interface [8]:
- Degrees of stretching
- Orientation
- Wall thickness

VMAP

Mapping (MpCCI)

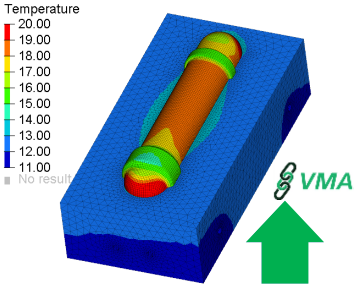


VMAP

VMAP

Cooling Simulation

Shrinkage and Warpage



VMAP

CFD-Simulation of the cooling channels

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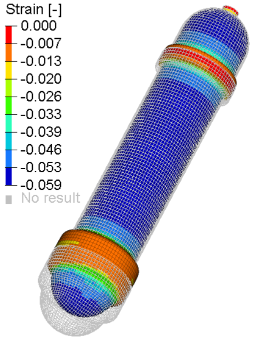


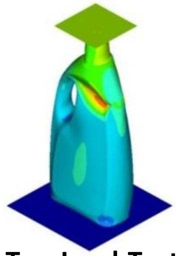
Temperatures

Deformation, Residual Stresses

VMAP

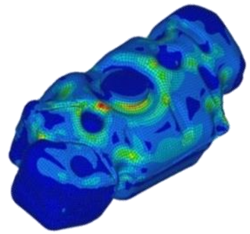
VMAP

Product Simulation



Top-Load-Test

Drop test



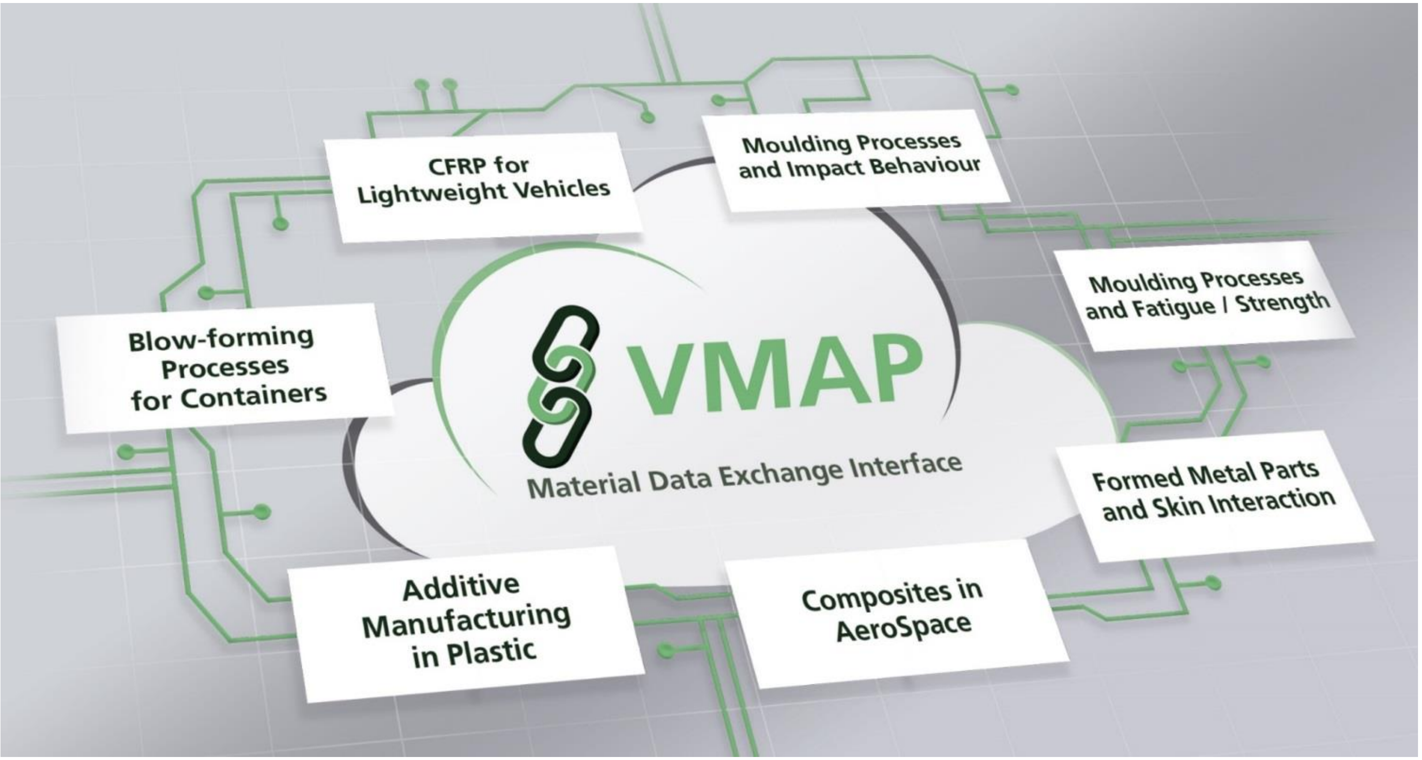
Internal pressure test

5. Summary and Outlook

- Experimental results show strong dependencies from the process conditions
- Post shrinkage is very low and therefore negligible
- In general, the simulation results are in good agreement with the experimental results
- The results of the cooling simulation still show deviations from the measured values
- Reduced development time through utilization of standard interfaces like VMAP
- Based on the preliminary tests, a new experimental study for the shrinkage determination is planned
- Integration of an orthotropic thermal expansion coefficient is in progress
- Additional Material tests in the frequency (DMA) and time (Creep, Relaxation) domain are planned
- Use of more complex nonlinear viscoelastic-plastic material models like the Parallel Rheological Framework (PRF)
- Application to blow molded parts of complex geometry

Acknowledgement

“VMAP - A new Interface Standard for Integrated Virtual Material Modelling in Manufacturing Industry”



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http://vmap.eu.com/

Thank you for your attention!

Literature

[1] Thielen, M. ; Hartwig, K. ; Gust, P.: Blasformen von Kunststoffhohlkörpern. Munich: Hanser, 2006

[2] URL: www.kautex-group.com/de/ Access: 20.09.2019

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