Simulation of creep behavior for short-fiber reinforced plastic parts

J. Strauch[1], P. Reithofer[2]

[1] Robert Bosch GmbH, Corporate Sector Research and Advance Engineering – Advance Production Technology 1 – Plastics Engineering, Renningen (Germany)

[2] 4a engineering GmbH, Traboch (Austria)

4a technology days – plastics on the test rig
2nd – 4th of March 2020, Werfenweng (Austria)

BOSCH

Agenda

1. Introduction

2. Material characterization

3. Material model and parameter determination

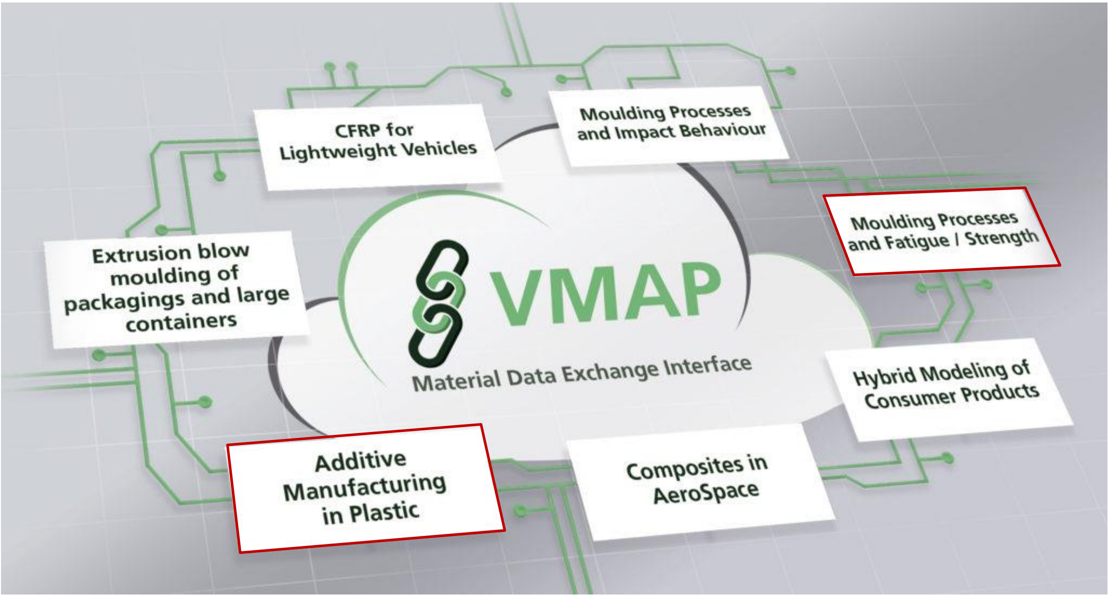
4. Validation

5. Summary/Outlook

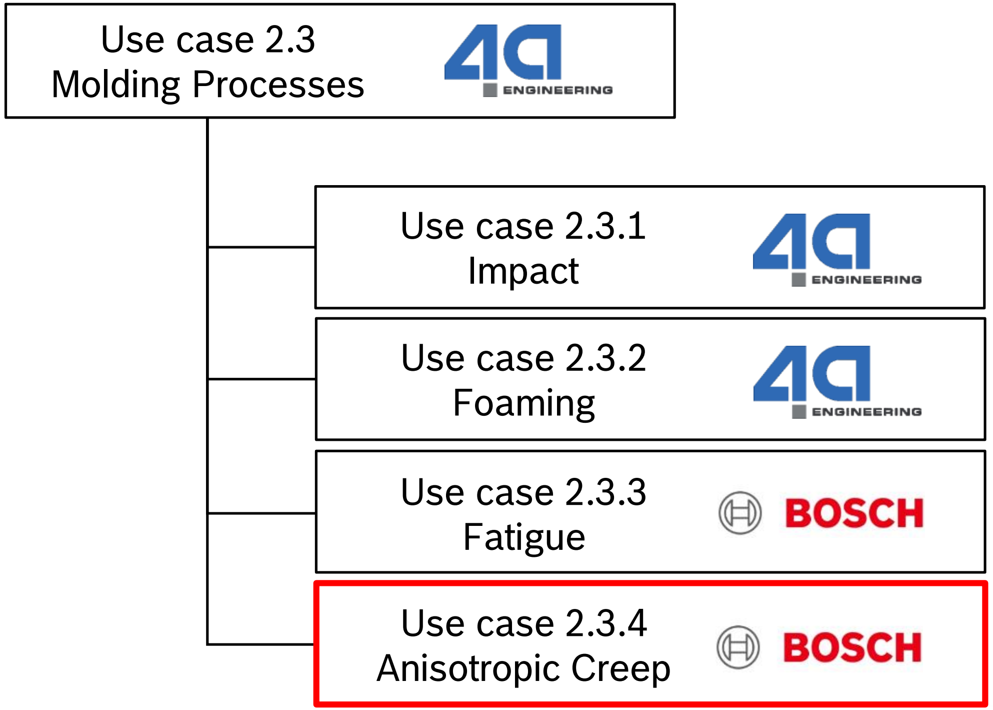
6. Appendix: Mapping with FiberMap

Introduction
VMAP - Industrial use cases

- Robert Bosch is participating in two use cases
  - UC 2.3: (Injection) Molding Processes
  - UC 2.4: Additive Manufacturing in Plastics



- Use case 2.3 is divided into sub use cases
  - Presentation **focuses on** sub-use case “**Creep**”

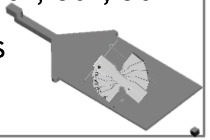


Introduction
Procedure and simulation chain

▶ Procedure

Material characterization (PBT-GF30)

- Tensile specimen (BZ12) milled out of 120 x 80 x 2 mm plate
- Cutting angles 0°, 15°, 30°, 60°, 90°
- Quasi-static tensile tests
- Long-term tensile tests



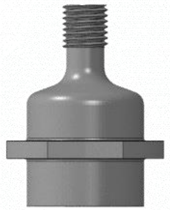
Determination of model parameter

Three steps optimization (Rev. Eng.)

- Transversal Elasticity
- Anisotropic Plasticity
- Anisotropic Creep

Validation

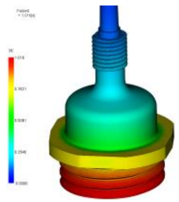
- Injection molded demonstrator Bosch bottle specimen
- Long-term tensile tests



▶ Simulation chain

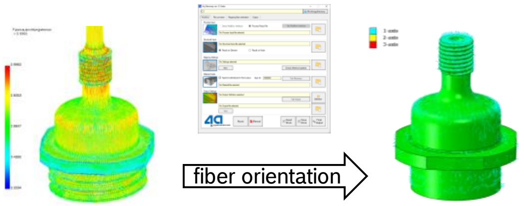
Injection molding simulation

AUTODESK MOLDFLOW



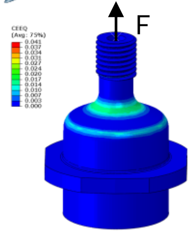
Mapping

FIBERMAP



Structural simulation (Creep)

DASSAULT SYSTEMES



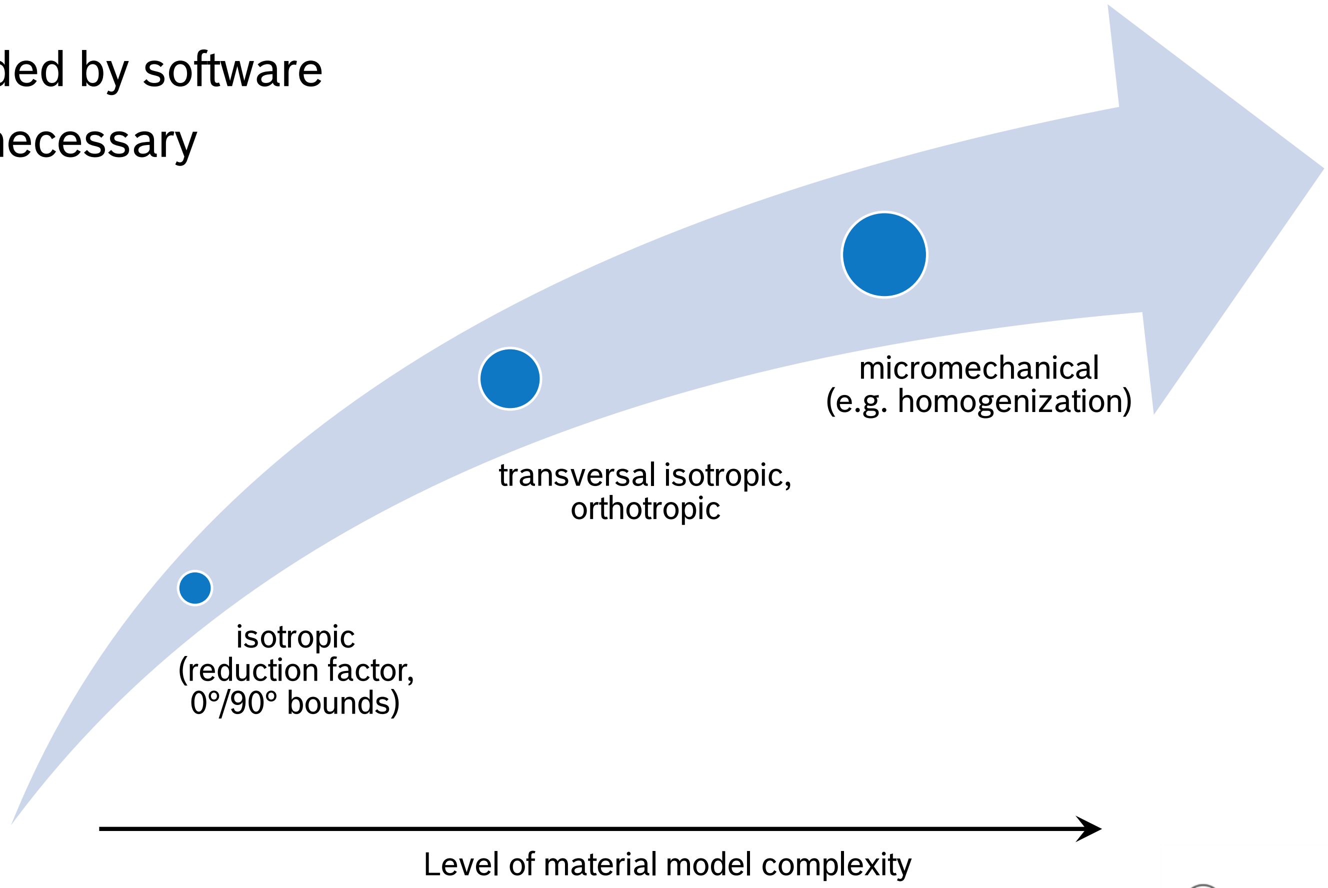
Introduction
Modeling of fiber reinforced thermoplastics

Goal

- Use standard material models, provided by software
- Simple as possible and complex as necessary

Assumptions

- Elasto-viscoplastic approach
- Primary and secondary creep only



Agenda

1. Introduction

2. Material characterization

3. Material model and parameter determination

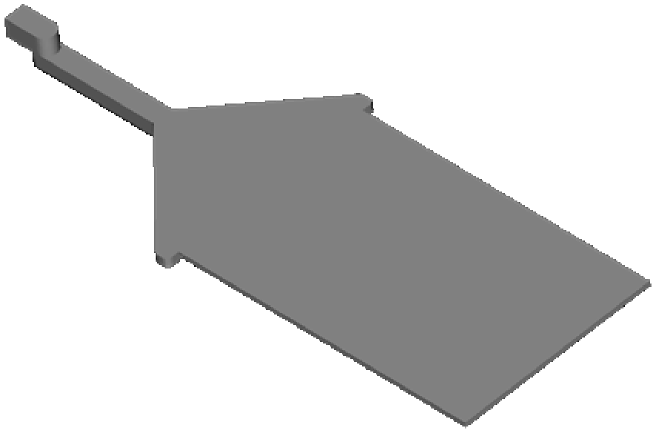
4. Validation

5. Summary/Outlook

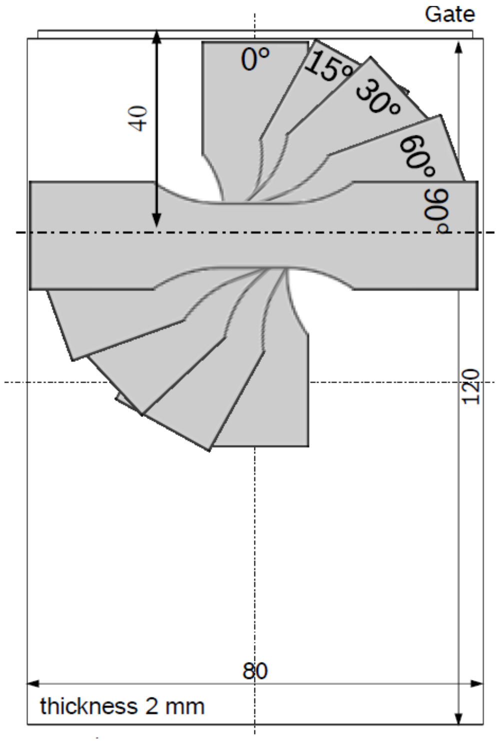
6. Appendix: Mapping with FiberMap

Material characterization
Preparation of test specimen

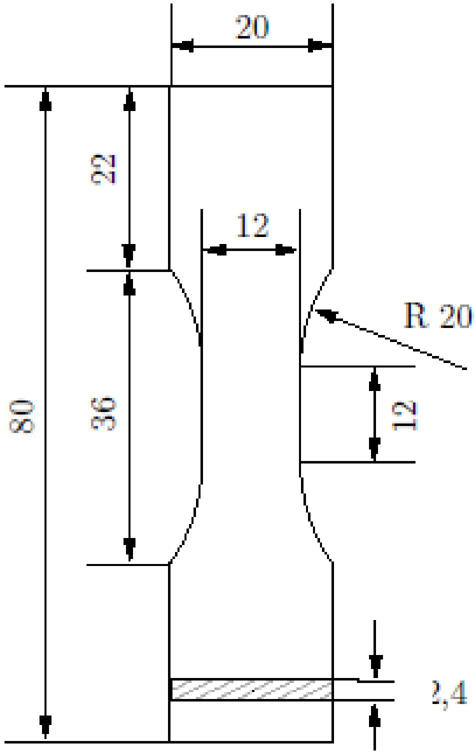
- Injection molded plate 120 x 80 x 2 mm³



- Extraction of specimen

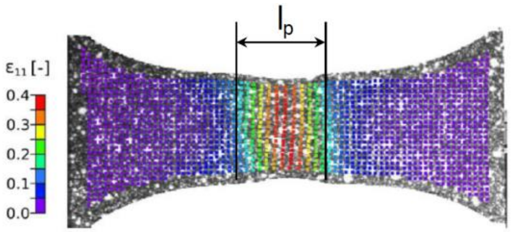


- Dimensions BZ12 specimen



Material characterization
Quasi-static tensile tests

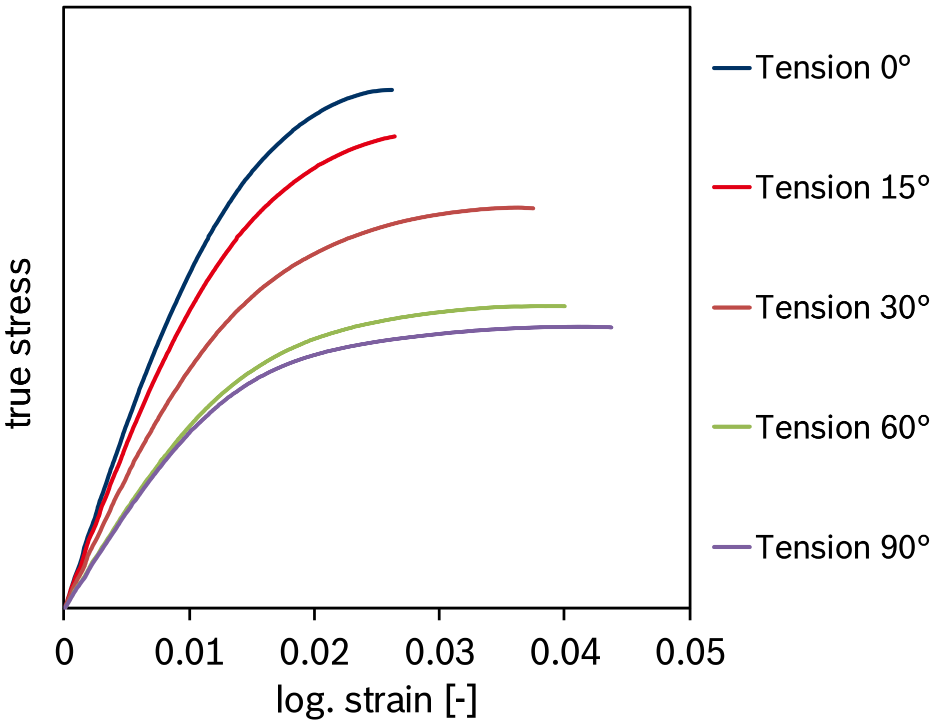
- Tensile testing machine (Zwick Z020)
  - Test lab: Fraunhofer LBF, Darmstadt
  - Digital Image Correlation (Vic2D, Limess)



  - Calculation of true stress σ_w

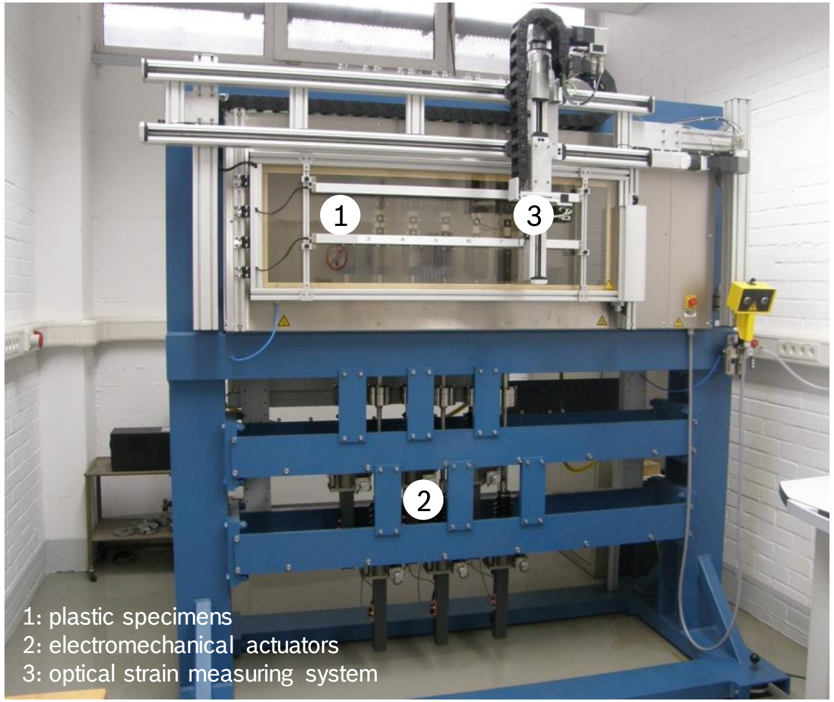
$$\sigma_w = \frac{F}{A_0 e^{2\varepsilon_{22}}}$$

- Stress-strain curves @23°C (PBT-GF30)

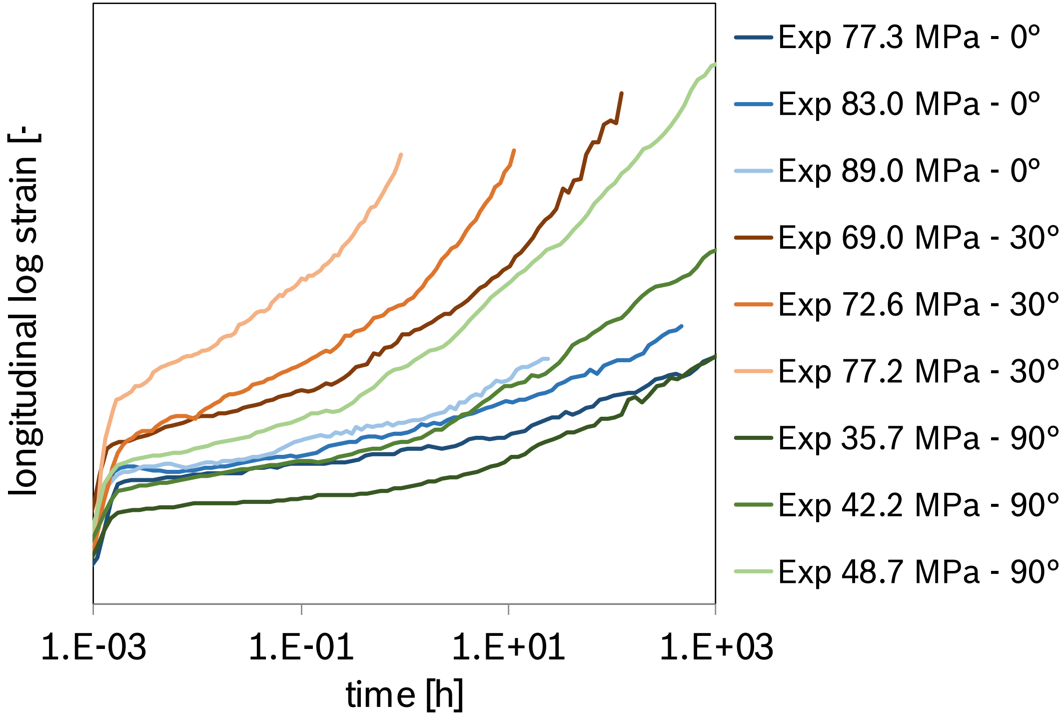


Material characterization
Long-term tensile tests

- Creep testing machine (Coesfeld)
  - Test lab: Robert Bosch GmbH, Renningen



- Creep curves @23°C (PBT-GF30)



[Robert Bosch GmbH, CR/APP2-Moosbrugger, -Klostermann, -Schneider]

Agenda

1. Introduction

2. Material characterization

3. Material model and parameter determination

4. Validation

5. Summary/Outlook

6. Appendix: Mapping with FiberMap

Material model and parameter determination
ABAQUS material model

Abaqus command	Model Type / No. of parameter	Parameter definition
*elastic, type=engineering constants	Orthotropic model: • 9 parameter per temperature Transversal isotropic model: • 5 parameter per temperature	E_{11}, E_{22}, E_{33}, ν_{12} , ν_{13}, ν_{23}, G_{12} ,G_{13}, G_{23}, T E_{11}, E_{22}, ν_{12} , ν_{23}, G_{12} and the dependent variables $E_{33} = E_{22}$ $\nu_{13} = \nu_{12}$ $G_{13} = G_{12}$ $G_{23} = E_{22}/(2(1+\nu_{23}))$
*plastic, hardening=user	Reduced G'sell Jonas model: $\sigma = \sigma_y(1 - w_1 e^{-w_2 \varepsilon_{pl}})\ e^{h\varepsilon_{pl}^2}$ • 4 parameter	σ_y, w_1, w_2, h
*creep, law=time	Power law model (time hardening): $\dot{\varepsilon}_{cr} = k \cdot \sigma^p \cdot t^n$ • 3 parameter per temperature	k, p, n, T
*potential	Hill potential for anisotropic plastic yielding • 6 parameter per temperature	R_{11}, $\mathbf{R_{22}}$, R_{33}, $\mathbf{R_{12}}$, R_{13}, $\mathbf{R_{23}}$, T Assumptions in current model: R_{11}=1 R_{33}=R_{22} R_{13}=R_{12}

Material model and parameter determination
Case 1: Transversal parameter fitting

- Optimization workflow (Reverse engineering)
  - Step 1: Transversal isotropic elastic parameter

E_{11}	E_{22}	ν_{12}	ν_{23}	G_{12}

  - Step 2: Plastic hardening parameter

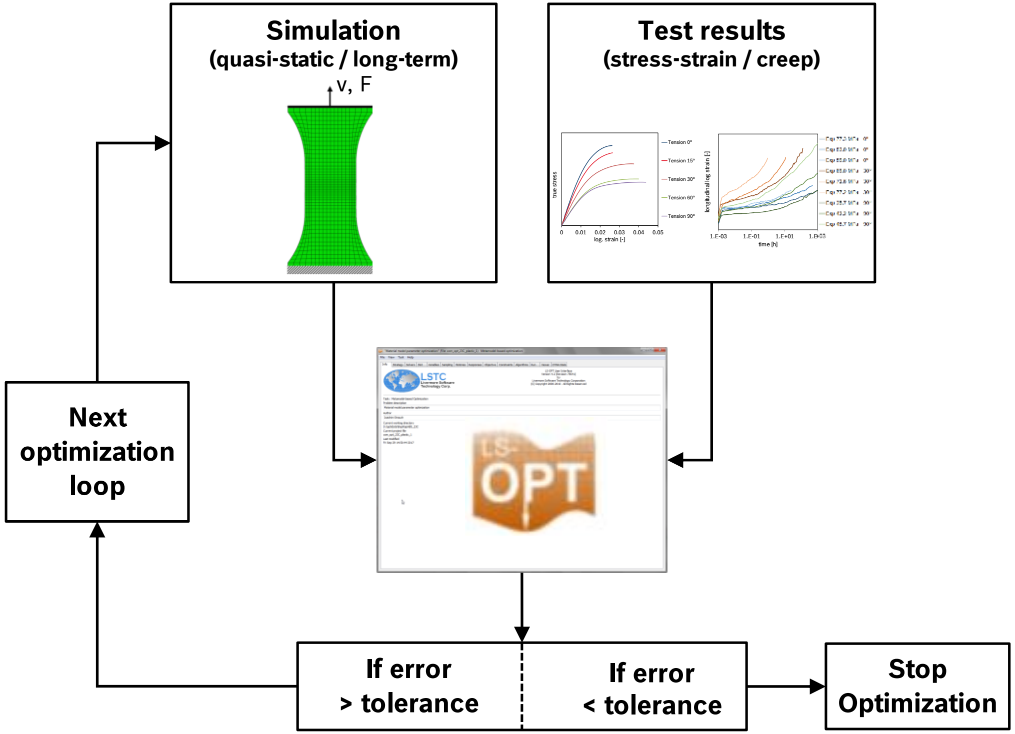
σ_y	w_1	w_2	h

Hill coefficients

R_{11}	R_{22}	R_{12}	R_{23}

  - Step 3: Time hardening creep parameter

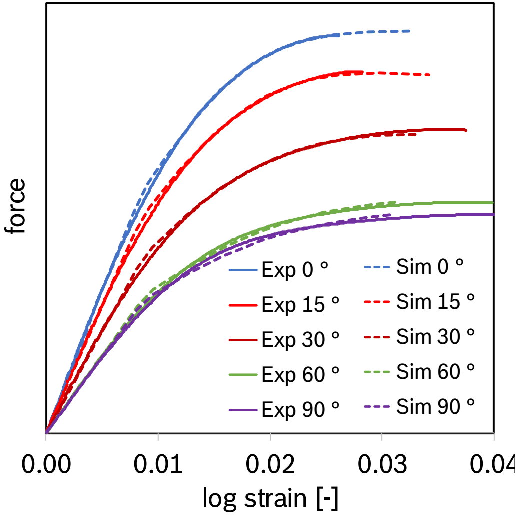
k	p	n



Material model and parameter determination

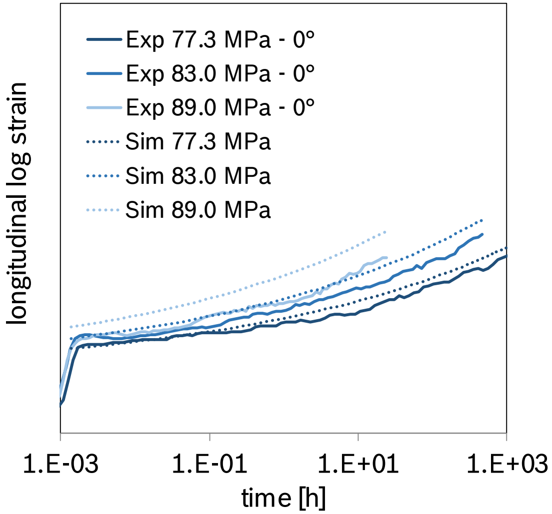
Case 1: Parameter fitting results

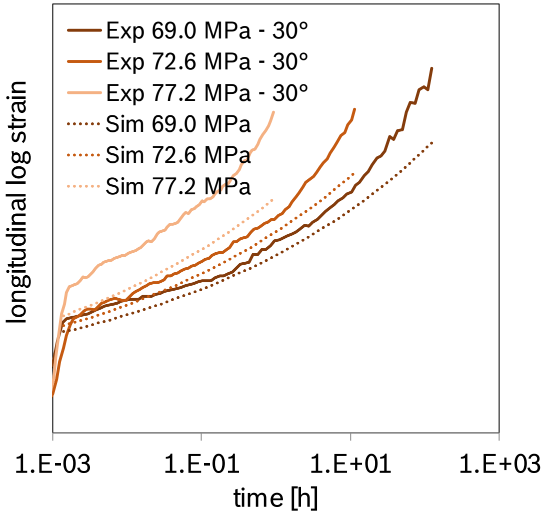
▶ Quasi-static

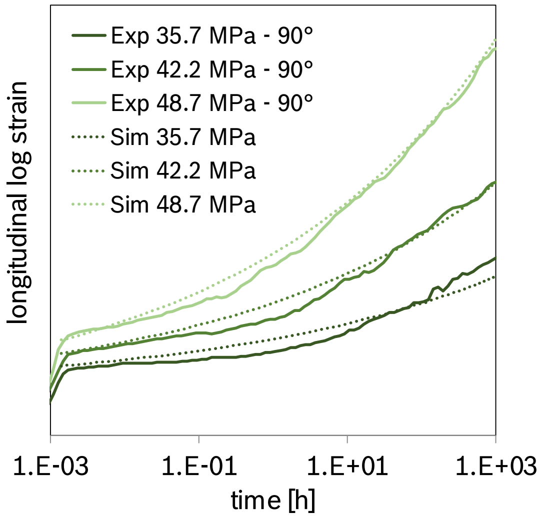


Mesh BZ12: 8856 elements (C3D8)

▶ Long-term (creep)





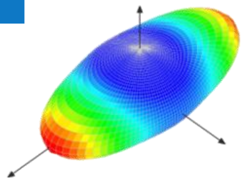


Material model and parameter determination
Case 2: Orthotropic parameter fitting

- Workflow
  - Step 1: Determine orthotropic elastic parameter with VALIMAT®/MICROMEC®

E_{11}	E_{22}	E_{33}	ν_{12}	ν_{13}	ν_{23}
G_{12}	G_{13}	G_{23}			

Hill coefficients



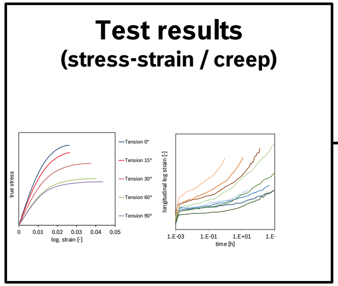
R_{11}	R_{22}	R_{33}	R_{12}	R_{13}	R_{23}

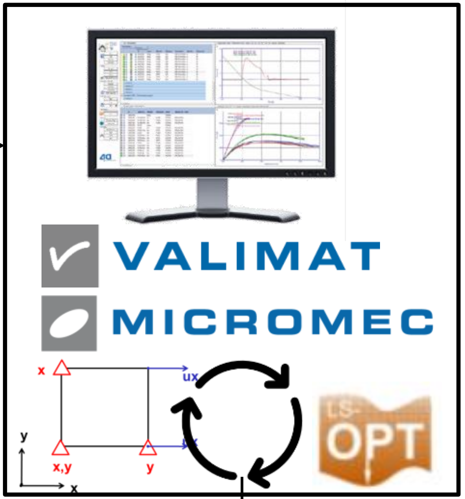
  - Step 2: Reverse engineering - Plastic hardening with VALIMAT®

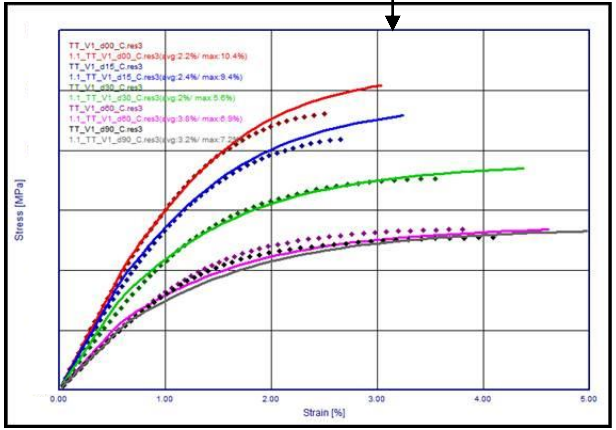
σ_y	σ_H	E_T

  - Step 3: Reverse engineering - Time hardening creep parameter

k	p	n





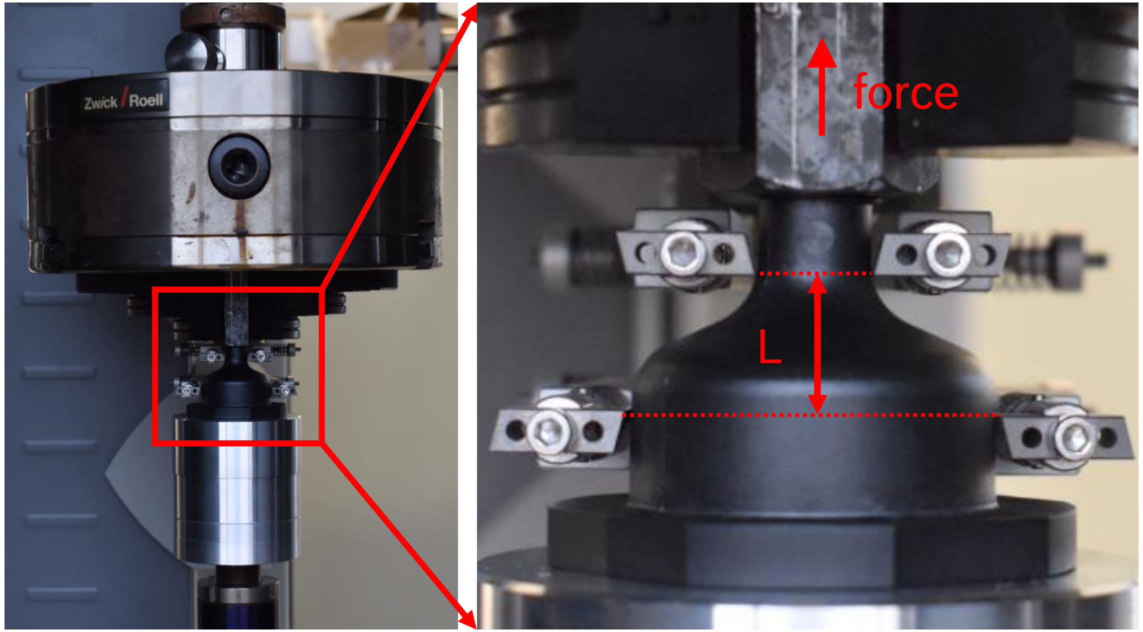


Agenda

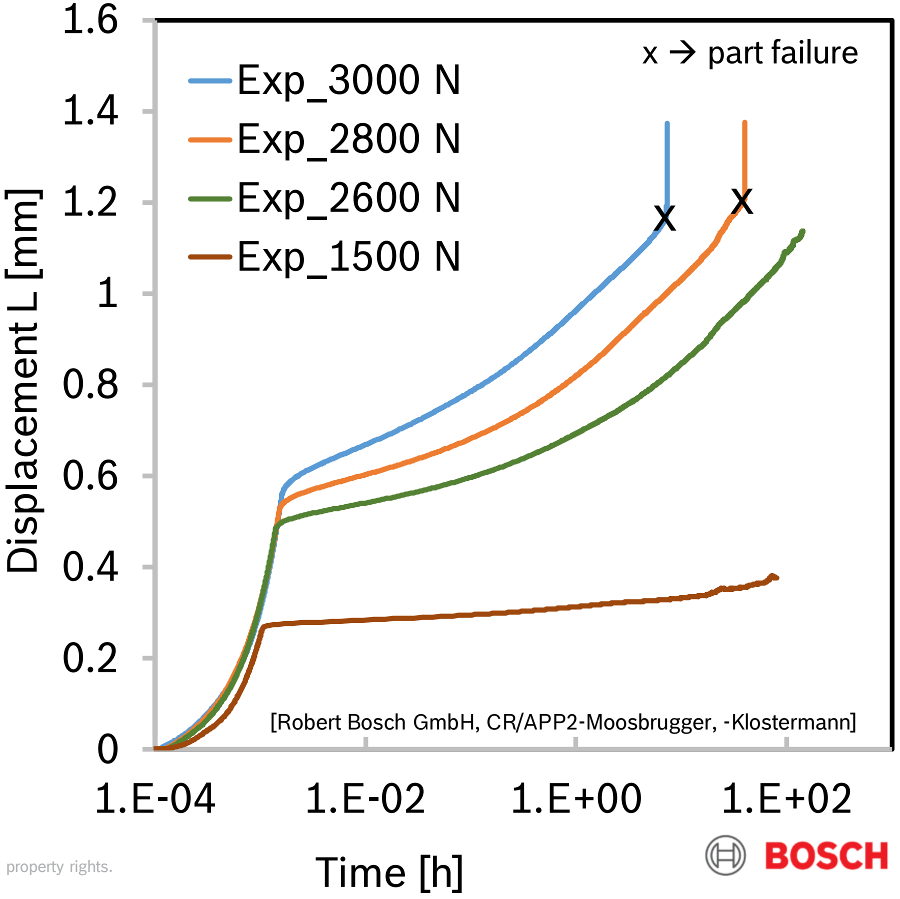
1. Introduction
2. Material characterization
3. Material model and parameter determination
4. **Validation**
5. Summary/Outlook
6. Appendix: Mapping with FiberMap

Validation
Tensile creep tests on bottle specimen

- Tensile testing machine (Zwick Z050)
  - Test lab: Robert Bosch GmbH, Renningen
  - Deformation measurement: clamping extensometer

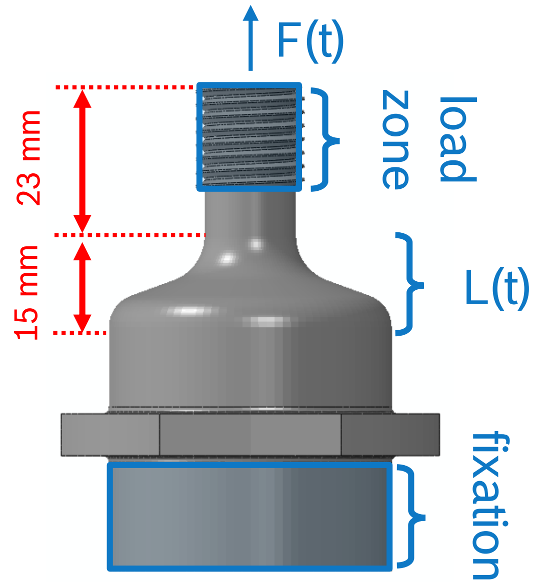


- Creep curves @23°C (PBT-GF30)



Validation
FE-Model

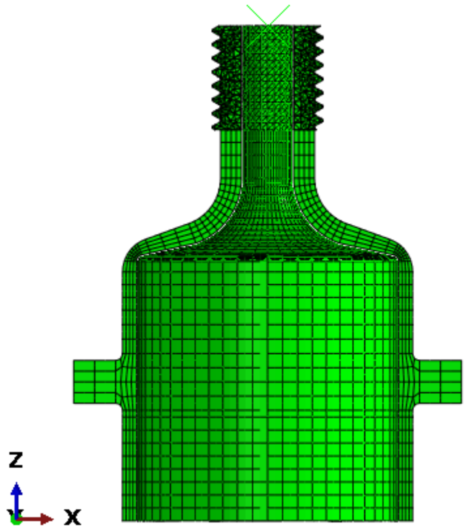
Boundary conditions



Load F(t)

Output displacement L(t)

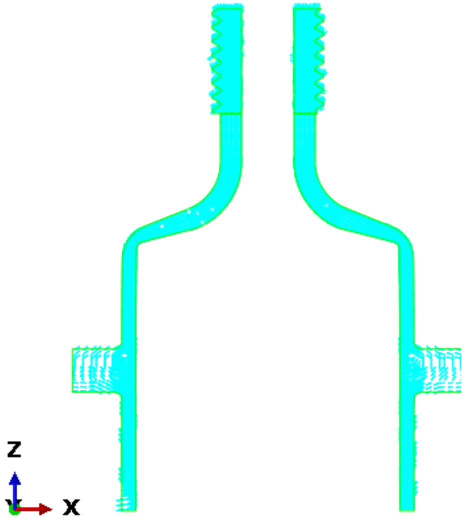
Mesh (only half model shown)



131059 Nodes

61368 Elements (C3D20, C3D10)

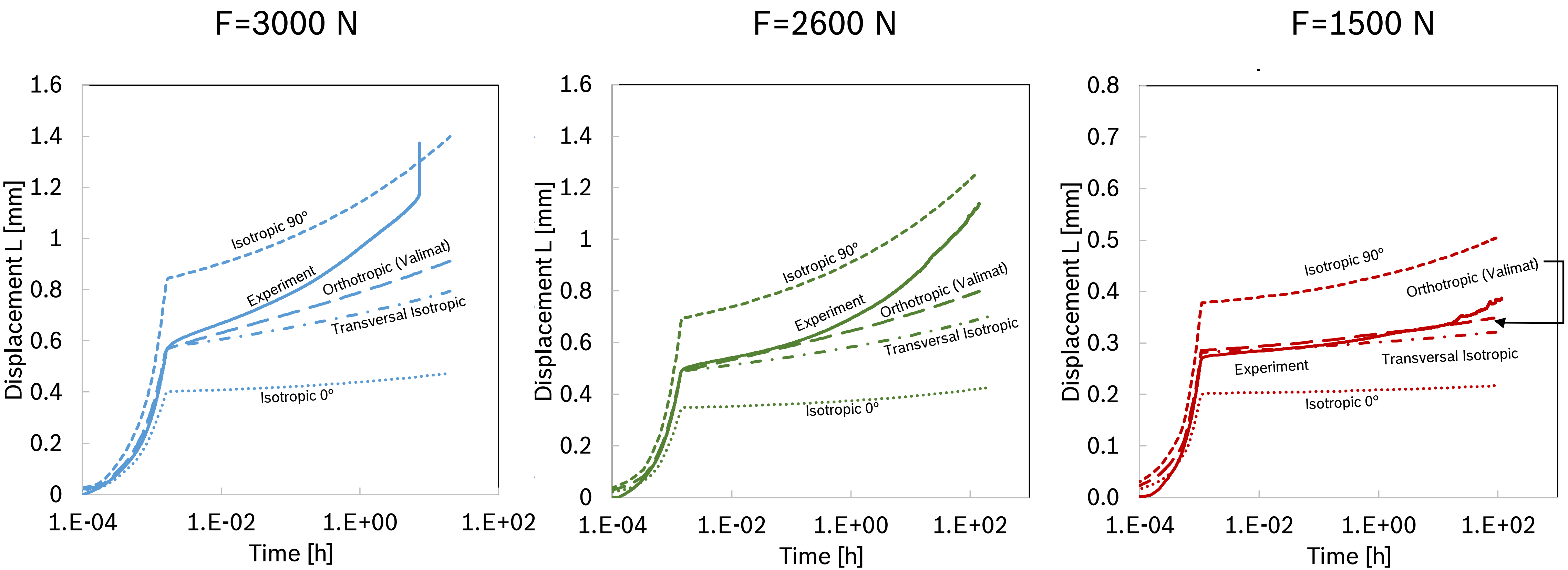
Local coordinate systems (elementwise definition)



Moldflow → Fiber orientation tensor a_{ij}

4a FiberMap → Mapping a_{ij}
→ Principal axis transformation
→ Abaqus distribution table

Validation
Simulation vs. experiment



CR/APP2-Strauch | 2020-03-04

Agenda

1. Introduction
2. Material characterization
3. Material model and parameter determination
4. Validation
5. **Summary/Outlook**
6. Appendix: Mapping with FiberMap

Summary/Outlook
Summary

Specimen level (parameter fitting)

- Stress-strain curves are well covered by transversal isotropic and orthotropic model
- Creep strain curves (most notably with 0° and 45° orientations) show significant deviations

  → Quality of experimental creep curves?

Part level (validation)

- Creep simulations on part level (bottle demonstrator) show significant deviations at
  - higher load levels
  - advanced times

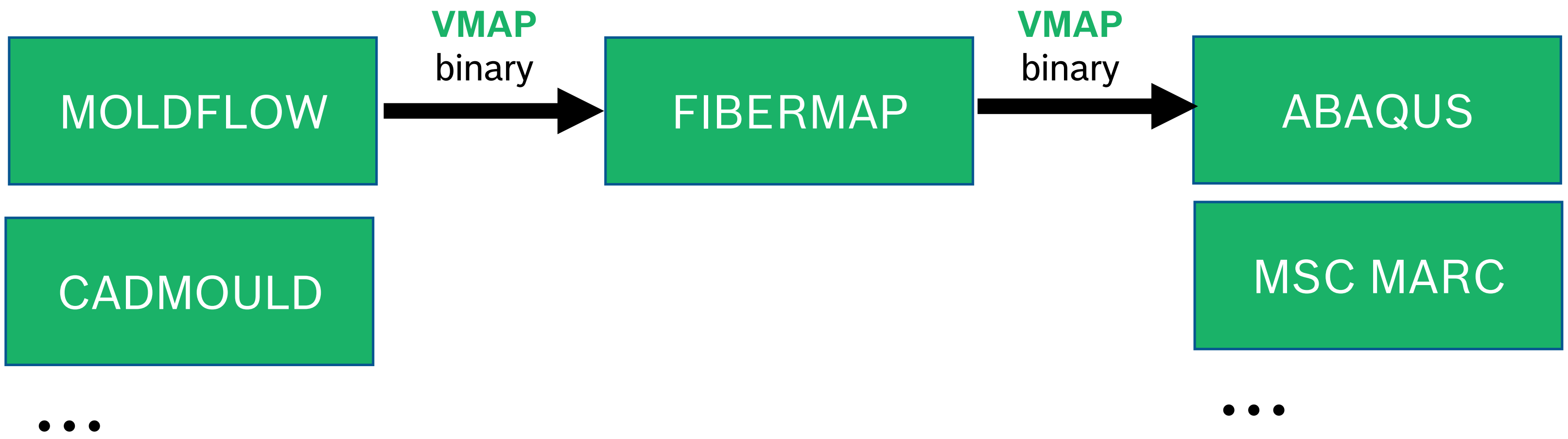
Possible improvements on material model site

  - Cover eigenvalues of fiber orientation tensor (element based material card, micromechanical approach)
  - Cover tertiary creep (creep- damage approach)
  - ...

Summary/Outlook
Outlook

- VMAP – Current status

- VMAP – Outlook



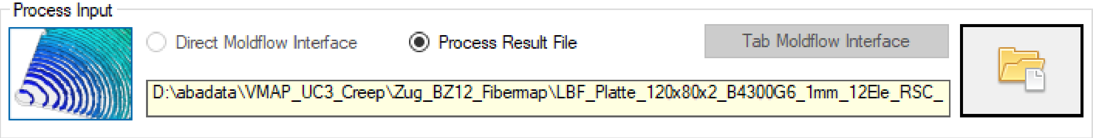
Agenda

1. Introduction
2. Material characterization
3. Material model and parameter determination
4. Validation
5. Summary/Outlook
6. Appendix: Mapping with FiberMap

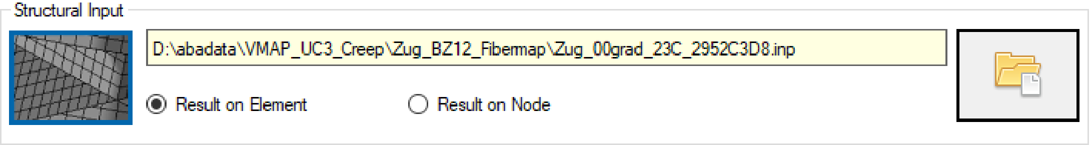
Appendix
Mapping procedure (1)

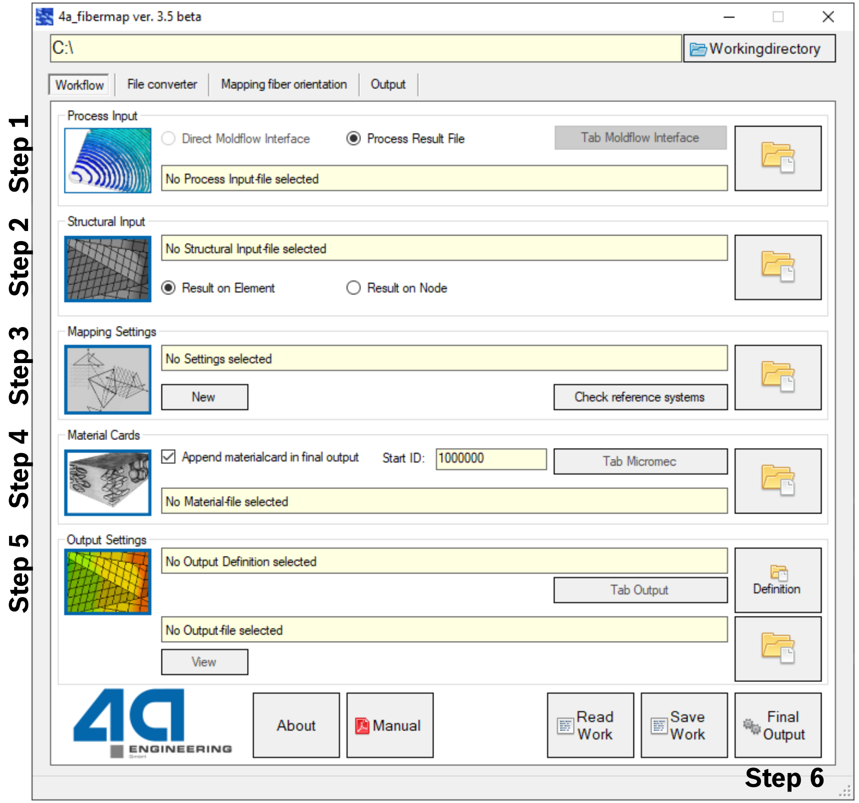
Performing 4a-FiberMap Software

- Step 1:
  - Import Process Result Files (.xml and .pat)
    - Choose .xml first
    - Choose .pat second
  - .process file will automatically be generated from FIBERMAP



- Step 2:
  - Import Structural mesh file (.inp)
    - Result on Element

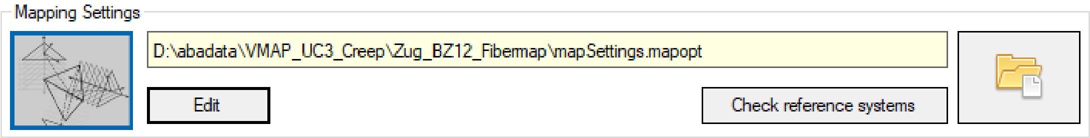




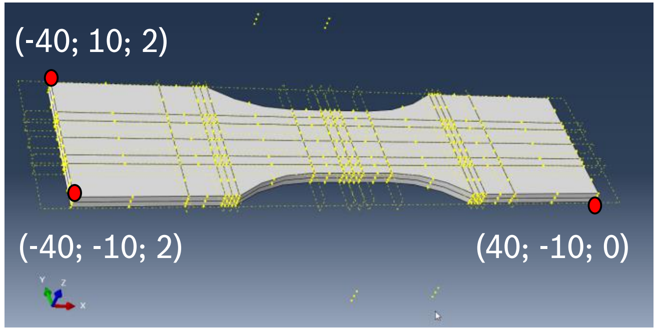
CR/APP2-Strauch | 2020-03-04

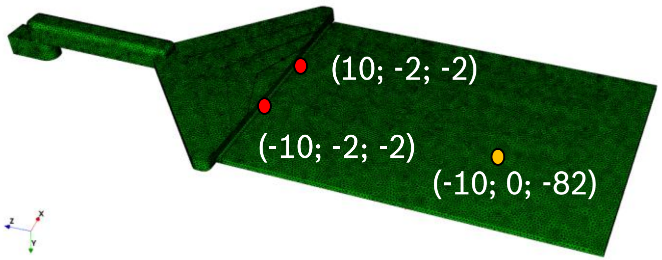
Appendix
Mapping procedure (2)

- Step 3:
  - Click on New button, if no .mapopt file available
    - .mapopt file will be generated

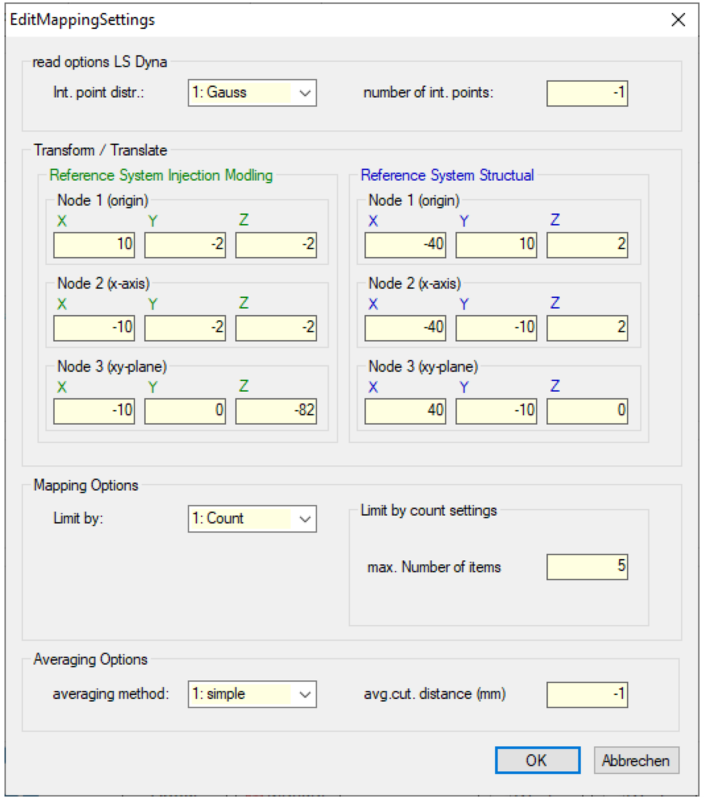


  - Enter transformation coordinates between donor- and acceptor mesh



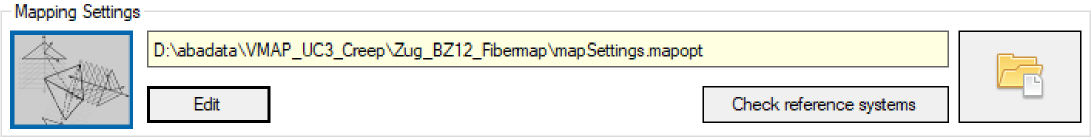


    - Scaling (x 1000) of Moldflow Patran Mesh **<u>will automatically</u>** be performed

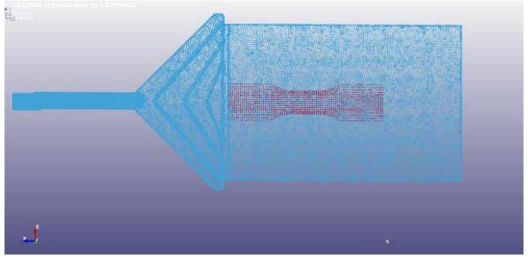


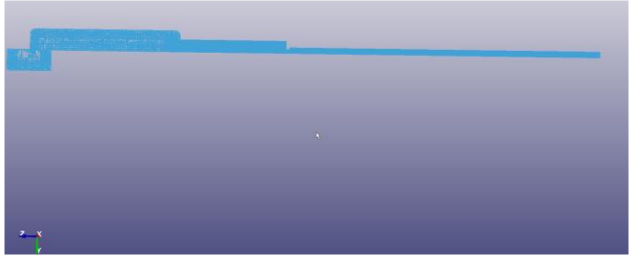
Appendix
Mapping procedure (3)

- Click ‘Check reference systems’ button

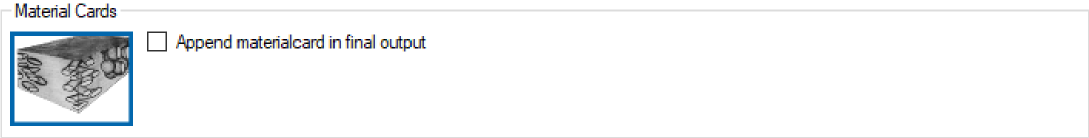


LS-PrePost will automatically be started, to check if transformation was correct



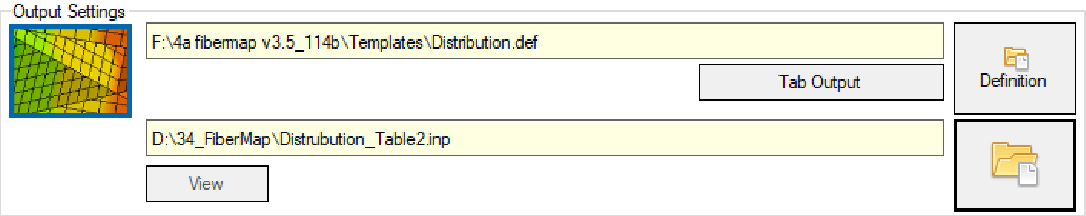


- Step 4:
  - Disable ‘Append materialcard in final output’

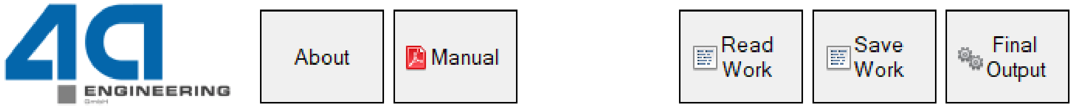


Appendix
Mapping procedure (4)

- Step 5:
  - Choose template file for Table output (Distribution.def)
  - Choose filename of distribution table output



- Step 6:
  - Start mapping process by pressing the ‘Final Output’ Button



Appendix
Mapping procedure (5)

- Step 7:
  - Example of exported distribution table (local coordinate systems element based):

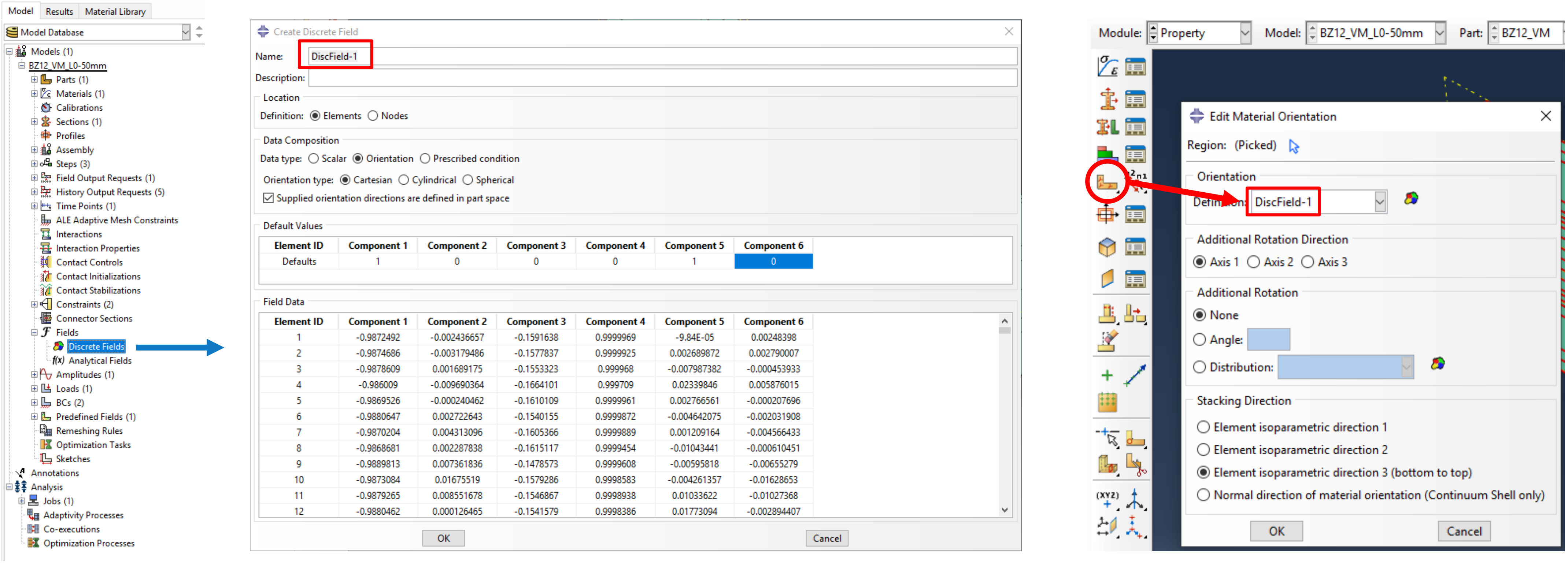
```
*ORIENTATION, NAME=MatOrient
Distr1
3, 0
*DISTRIBUTION TABLE, Name=Table1
COORD3D, COORD3D
*DISTRIBUTION,Name=Distr1, LOCATION=element, TABLE=Table1
 , 1,0,0,0,1,0
      1,    -0.9872492,    -0.002436657,    -0.1591638,    0.9999969,   -9.837202E-05,    0.00248398
      2,    -0.9874686,    -0.003179486,    -0.1577837,    0.9999925,    0.002689872,     0.002790007
      3,    -0.9878609,     0.001689175,    -0.1553323,     0.999968,   -0.007987382,   -0.0004539328
      4,     -0.986009,    -0.009690364,    -0.1664101,     0.999709,     0.02339846,     0.005876015
      5,    -0.9869526,   -0.0002404615,    -0.1610109,    0.9999961,    0.002766561,   -0.0002076956
      6,    -0.9880647,     0.002722643,    -0.1540155,    0.9999872,   -0.004642075,    -0.002031908
      7,    -0.9870204,     0.004313096,    -0.1605366,    0.9999889,    0.001209164,    -0.004566433
      8,    -0.9868681,     0.002287838,    -0.1615117,    0.9999454,    -0.01043441,   -0.0006104513
      9,    -0.9889813,     0.007361836,    -0.1478573,    0.9999608,    -0.00595818,     -0.00655279
     10,    -0.9873084,      0.01675519,    -0.1579286,    0.9998583,   -0.004261357,     -0.01628653
```

  - Include written distribution table into Abaqus input deck:

```
*Solid Section, Elset=BZ12, orientation=MatOrient, material=PBT-GF30
```

Appendix
Mapping procedure (6)

- Step 7 (alternative):
  - Include written distribution table into Abaqus/CAE



CR/APP2-Strauch | 2020-03-04