Glasfaserverstärkte Kunststoffe - 4a Software-Tools im Einsatz

A. Fertschej, P. Reithofer – 4a engineering GmbH

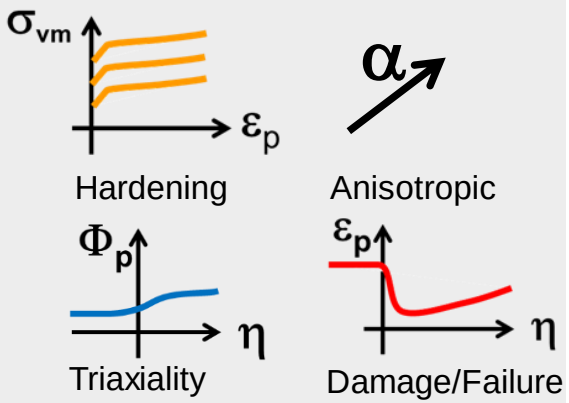
4a Technologietag 2018, Schladming

1. März 2018

4a engineering GmbH
Industriepark 1
A-8772 Traboch
reithofer@4a.co.at
++43 (0) 664 80106 601

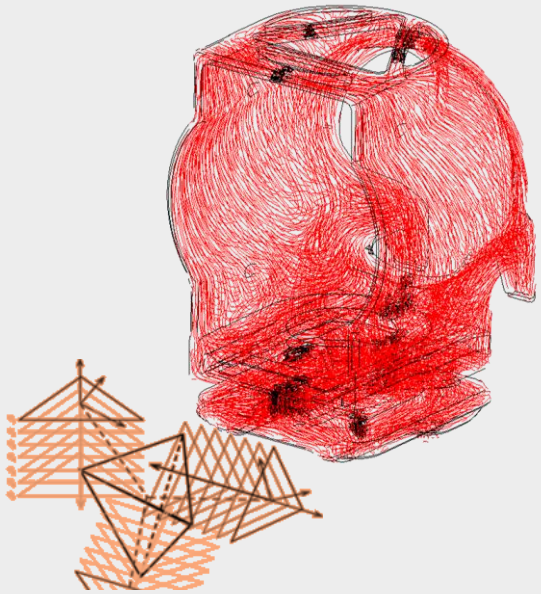
intelligent reliable solutions for plastics, composites, metals, foams, ...

VALIMAT



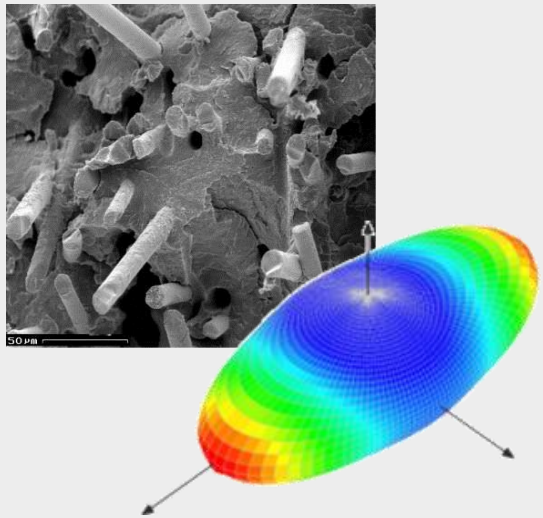
from test to validated material cards

FIBERMAP



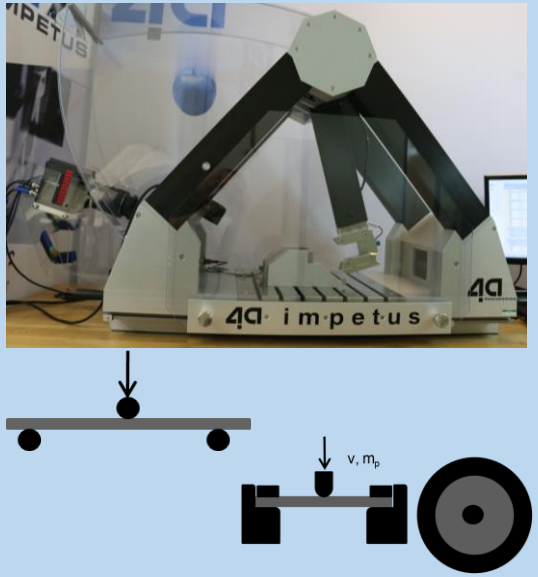
individual mapping process information

MICROMEC



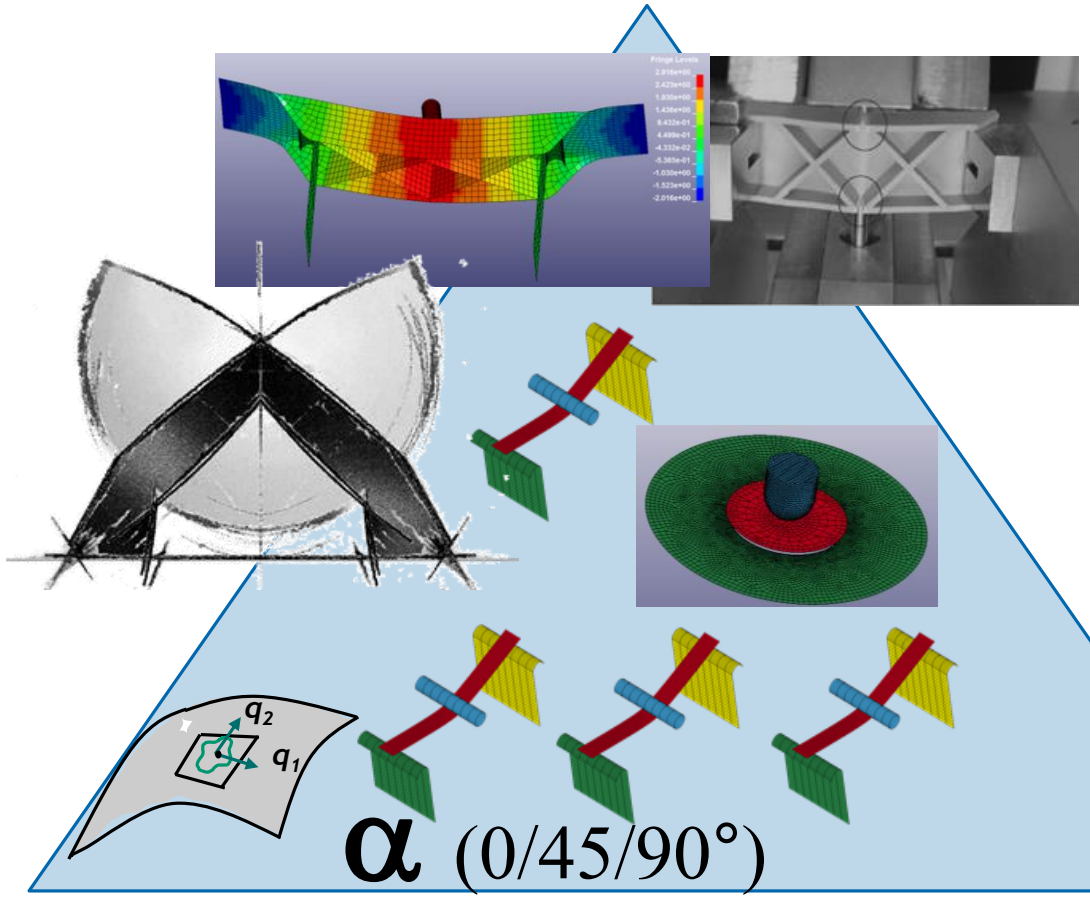
3D anisotropic material cards

IMPETUS

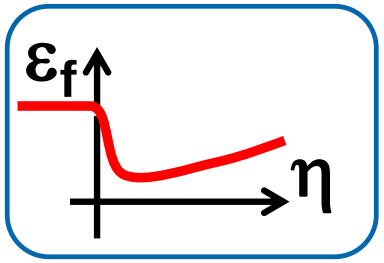


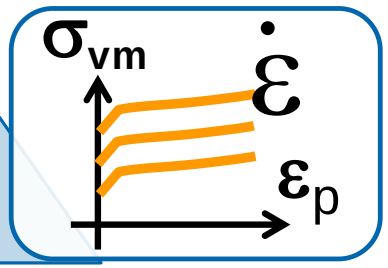
efficient dynamic testing

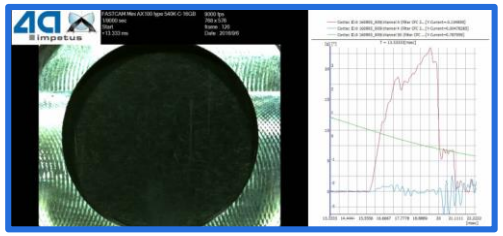
Materialcharakterisierung mit IMPETUS

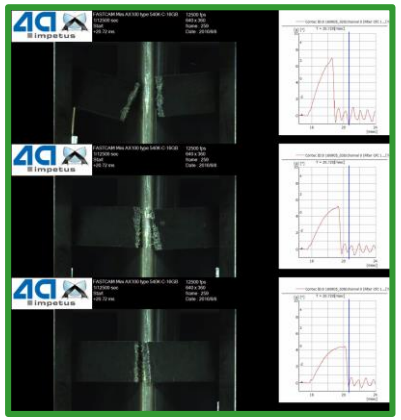


component validation



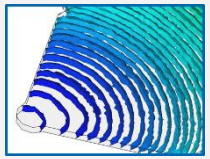






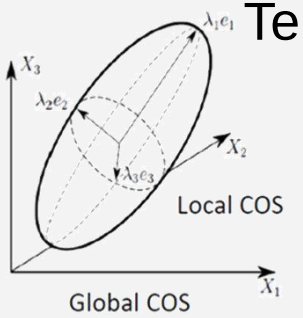
Material models – actual approaches

Process simulation



$$a_{ij} = \begin{bmatrix} a_{xx} & a_{xy} & a_{xz} \\ & a_{yy} & a_{yz} \\ & & a_{zz} \end{bmatrix}$$

Tensor 2nd order



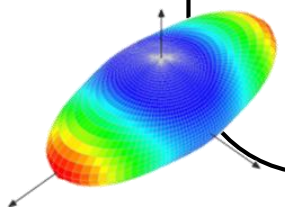
CADMOULD 3D-F SIMULATION

Moldex3D MOLDING INNOVATION

MOLDFLOW

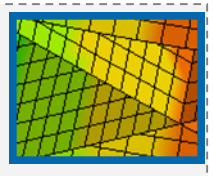
FIBERMAP

$$C^{-1} = \begin{bmatrix} \frac{1}{E_1} & -\frac{\nu_{21}}{E_2} & -\frac{\nu_{31}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{12}}{E_1} & \frac{1}{E_2} & -\frac{\nu_{32}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{13}}{E_1} & -\frac{\nu_{23}}{E_2} & \frac{1}{E_3} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{23}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{31}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{21}} \end{bmatrix}$$



MICROMEC

Structural simulation

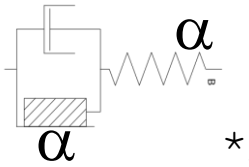


Homogenization (Micro Scale)
Mean Field Theory

$$\bar{\sigma}^{C} = \varphi\bar{\sigma}^{F} + (1-\varphi)\bar{\sigma}^{M}$$

*MAT_215

Composite (Macro Scale)
Hill Plasticity



*MAT_157

LSTC Livermore Software Technology Corp.
LS-DYNA®

Material models – implementation in VALIMAT

Material behaviour	
Material source	Implemented
Elasticity	Not isotropic elastic
Plasticity	Yes
Failure/Damage	Damage
Material card	*MAT_ANISOTROPIC_ELASTIC_PLASTIC (*MAT_157)
Deformation	2D+Distribution
Damage/Failure	2D
Materialcard id	3D
Density	2D+Distribution
Plasticity	HILL 2D (Lankford)
Function (Hardening, Elastic curve form)	
Curve 1	4a model (nue 0.5)
Strain range upto	0.2
Sampling points	50
Bias factor	10
Strain rate dependency	Table
Micromec	Short fiber reinforced plastics

Name	Start	const...	from	to	Variance	Condi...	Description
GroupName: 10_elasticity							
xm_core_perc	20	✓	(NULL)	(NULL)	(NULL)		volume fraction
c_C11	MMEC	✓	(NULL)	(NULL)	(NULL)		constitutive matrix 11
c_C12	MMEC	✓	(NULL)	(NULL)	(NULL)		constitutive matrix 12
c_C13	MMEC	✓	(NULL)	(NULL)	(NULL)		constitutive matrix 13
c_C14	MMEC	✓	(NULL)	(NULL)	(NULL)		constitutive matrix 14

1 Faserorientierungsverteilung möglich (Kern/Rand)

Material behaviour	
Material source	Implemented
Elasticity	Not isotropic elastic
Plasticity	Yes
Failure/Damage	None
Material card	*MAT_MICROMEC (*MAT_215)
Deformation	7215_MICROMEC_215+Distribution (2D)
Damage/Failure	7215_MICROMEC_215+Distribution (2D)
Materialcard id	7215_MICROMEC_215 (3D)
Density	7215_MICROMEC_215 (3D) + PARAMETER
Plasticity	vonMISES
Function (Hardening, Elastic curve form)	
Curve 1	Bilinear
Strain range upto	0.2
Sampling points	50
Bias factor	10
Strain rate dependency	Table
Micromec	None

GroupName: 99_user							
xm_PHI	0.129	✓	(NULL)	(NULL)	(NULL)		volume fraction
xm_LD	50	✓	(NULL)	(NULL)	(NULL)		aspec ratio
xm_core_perc	20	✓	(NULL)	(NULL)	(NULL)		core thickness in percentage
xm_a11	0.65	✓	(NULL)	(NULL)	(NULL)		fiber orientation a11 - outer layer
xm_a11c	0.65	✓	(NULL)	(NULL)	(NULL)		fiber orientation a11 - core layer
xm_a33	0.05	✓	(NULL)	(NULL)	(NULL)		fiber orientation a33

2 Faserorientierungsverteilungen möglich (Kern/Rand)

Materialcharakterisierung – Biegeversuche mit VALIMAT

⊟ Micromec	Short fiber reinforced plastics
⊟ Matrix	None
Density of the matrix	User defined
E-Modulus	Particle
Poisson's ratio	Short fiber reinforced plastics
Yield strength	Long fiber reinforced plastics
Strength at Break	Endless fiber reinforced plastics
Failure strain	Fabrics
⊟ Fiber	
Fillerlength	200
Fillerdiameter	10
Phi or Psi	φ
Phi	0
Psi	35
Fillermaterial	E-Glas
⊟ Orientation	
⊟ Fillerorientationtype	CA lin. OF
Fillerorientationvalue 1	0.7
Fillerorientationvalue 2	0.28
⊞ Strength	

MICROMEC
VALIMAT

Materialcharakterisierung – Biegeversuche mit VALIMAT

160223_006 | Material | Designvariablen | Layers

⊟ Strain rate dependency	Table
⊞ Strain rate dependency	Johnson Cook
⊟ Micromec	User defined
⊟ Matrix	
Density of the matrix	900
E-Modulus	1500
Poisson's ratio	0.3
Yield strength	15
Strength at Break	17
Failure strain	0.05
⊟ Fiber	
Fillerlength	1000
Fillerdiameter	20
Phi or Psi	φ
Phi	12.9
Psi	30.1
Fillermaterial	E-Glas
⊟ Orientation	
⊟ Fillerorientationtype	CA lin. OF
Fillerorientationvalue 1	0.6
Fillerorientationvalue 2	0.33

matrix data

filler data

orientation data *

Composite Density	1126	[g/dm³]
c_C11	6172	[MPa]
c_C12	1808	[MPa]
c_C13	1231	[MPa]
c_C14	0	[MPa]
c_C15	0	[MPa]
c_C16	0	[MPa]
c_C22	4135	[MPa]
c_C23	1181	[MPa]
c_C24	0	[MPa]
c_C25	0	[MPa]
c_C26	0	[MPa]
c_C33	2616	[MPa]
c_C34	0	[MPa]
c_C35	0	[MPa]
c_C36	0	[MPa]
c_C44	1554	[MPa]
c_C45	0	[MPa]
c_C46	0	[MPa]
c_C55	888.6	[MPa]
c_C56	0	[MPa]
c_C66	957.5	[MPa]
y_r00	1	[1]
y_r45	0.5105	[1]
y_r90	0.2665	[1]
y_scalematrix0	3.076	[1]

* possibilities:
1) µ-CT
2) process simulation
3) experience

Materialcharakterisierung – Biegeversuche mit VALIMAT

160223_006 | Material | Designvariablen | Layers

Name	Start	const...	Description
GroupName: 10_elasticity			
c_C11	MMEC	☑	constitutive matrix 11
c_C12	MMEC	☑	constitutive matrix 12
c_C13	MMEC	☑	constitutive matrix 13
c_C14	MMEC	☑	constitutive matrix 14
c_C15	MMEC	☑	constitutive matrix 15
c_C16	MMEC	☑	constitutive matrix 16
c_C22	MMEC	☑	constitutive matrix 23
c_C23	MMEC	☑	constitutive matrix 23
c_C24	MMEC	☑	constitutive matrix 24
c_C25	MMEC	☑	constitutive matrix 25
c_C26	MMEC	☑	constitutive matrix 26
c_C33	MMEC	☑	constitutive matrix 33
c_C34	MMEC	☑	constitutive matrix 34
c_C35	MMEC	☑	constitutive matrix 35
c_C36	MMEC	☑	constitutive matrix 36
c_C44	MMEC	☑	constitutive matrix 44
c_C45	MMEC	☑	constitutive matrix 45
c_C46	MMEC	☑	constitutive matrix 46
c_C55	MMEC	☑	constitutive matrix 55
c_C56	MMEC	☑	constitutive matrix 56
c_C66	MMEC	☑	constitutive matrix 66

160223_006 | Material | Designvariablen | Layers

Name	Start	const...	Description
GroupName: 10_elasticity			
GroupName: 20_yield			
y_0	90	■	yield stress
y_scale...	MMEC	☑	yield scale 11 direction
y_r00	MMEC	☑	yield hill anisotropy ratio 0°
y_r45	MMEC	☑	yield hill anisotropy ratio 45°
y_r90	MMEC	☑	yield hill anisotropy ratio 90°
GroupName: 21_hardening			
h_ET	50	■	
h_y	90	☑	
GroupName: 31_strainrate			
v_epspkt	0.01	☑	initial strain rate threshold
v_p	15	■	strain rate scale (1/vp)
GroupName: 51_failure			
xf_NUM...	0.75	☑	Number of failed integration points prior to

MMEC – Design Variable calculated by micro mechanic model

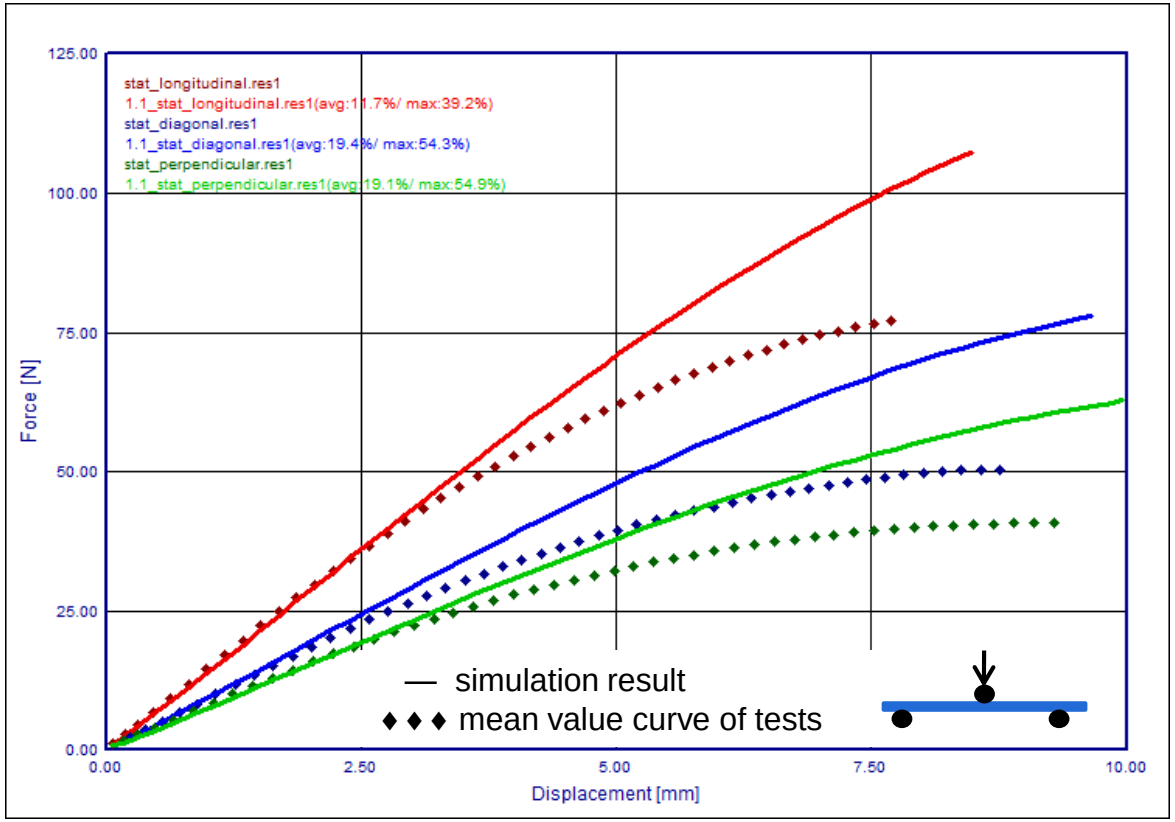
Less free Design Variables left for material parameter identification

Materialcharakterisierung – Biegeversuche mit VALIMAT

Material card	*MAT_COMPOSITE_DAMAGE (*MAT_022)
Deformation	7500_MAT22
Damage/Failure	None
Materialcard id	1000000
Density	-1203.270310622
Plasticity	None
Function (Hardening, Elastic curve form)	
Strain rate dependency	None
Micromec	User defined
Matrix	
Density of the matrix	900
E-Modulus	1800
Poisson's ratio	0.3
Yield strength	50
Strength at Break	70
Failure strain	0
Fiber	
Fillerlength	200
Fillerdiameter	10
Phi or Psi	ψ
Phi	18.5
Psi	40
Fillermaterial	E-Glas
Orientation	
Fillerorientationtype	CA lin. OF
Fillerorientationvalue 1	0.7
Fillerorientationvalue 2	0.28
Strength	
Fracture	None
Postfracture	None
Loadcases	
Casename	stat_longitudinal
Casename	stat_diagonal
Casename	stat_perpendicular
Results	

Composite Density	1224	[g/dm³]
c_E11	6941	[MPa]
c_E22	3810	[MPa]
c_E33	2689	[MPa]
c_G12	1840	[MPa]
c_G23	1055	[MPa]
c_G31	1038	[MPa]
c_nue21	0.2029	[1]
c_nue31	0.1103	[1]
c_nue32	0.2432	[1]

1st step:
Elastic material behavior

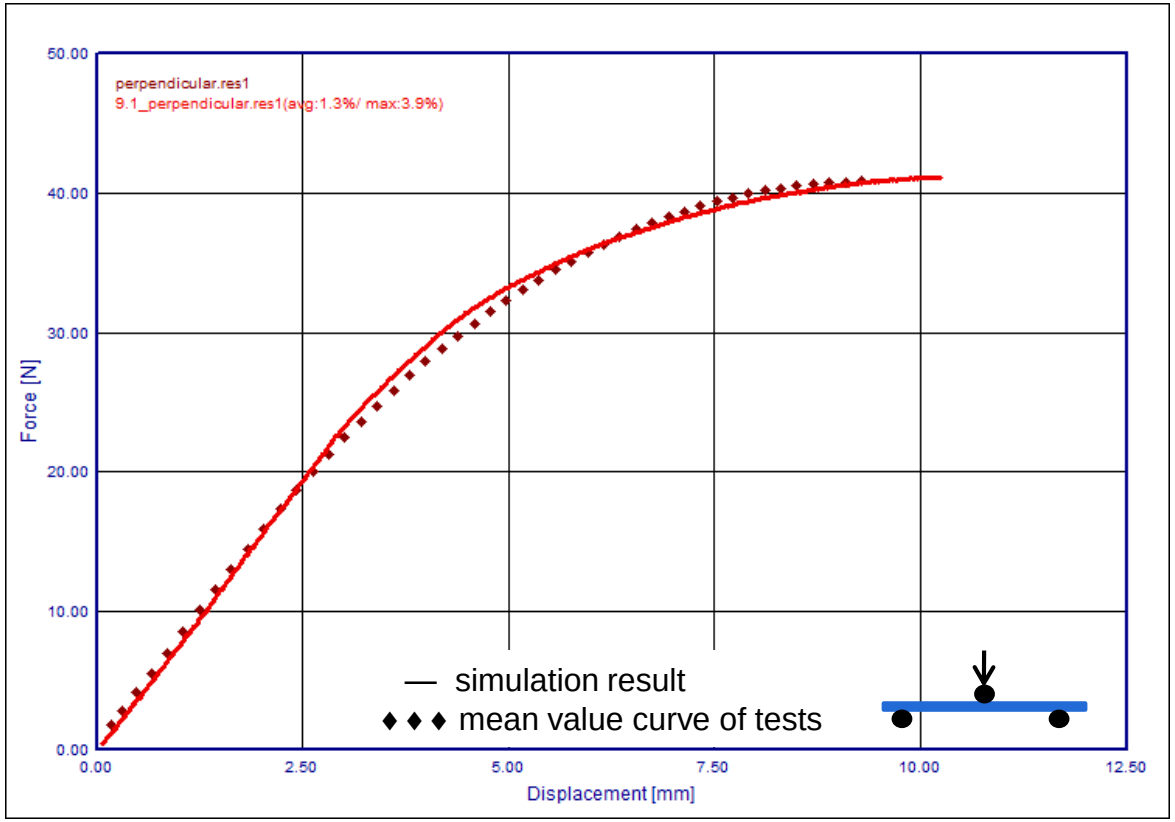


longitudinal
diagonal
perpendicular

Materialcharakterisierung – Biegeversuche mit VALIMAT

	Name	Start	const...	from	to	Variance	Condi..
	c_C45	MMEC	☑	(NULL)	(NULL)	(NULL)	
	c_C46	MMEC	☑	(NULL)	(NULL)	(NULL)	
	c_C55	MMEC	☑	(NULL)	(NULL)	(NULL)	
	c_C56	MMEC	☑	(NULL)	(NULL)	(NULL)	
	c_C66	MMEC	☑	(NULL)	(NULL)	(NULL)	
▲	GroupName: 20_yield						
	y_0	23.78486	☐	15	50	(NULL)	
	y_r00	MMEC	☑	(NULL)	(NULL)	(NULL)	
	y_r45	MMEC	☑	(NULL)	(NULL)	(NULL)	
	y_r90	MMEC	☑	(NULL)	(NULL)	(NULL)	
	y_scale...	MMEC	☑	(NULL)	(NULL)	(NULL)	
▲	GroupName: 21_hardening						
	h_y	23.785	☑	5	150	50	=y_0
	h_ET	1500	☐	500	1500	(NULL)	

2nd step:
Optimizing the hardening parameters

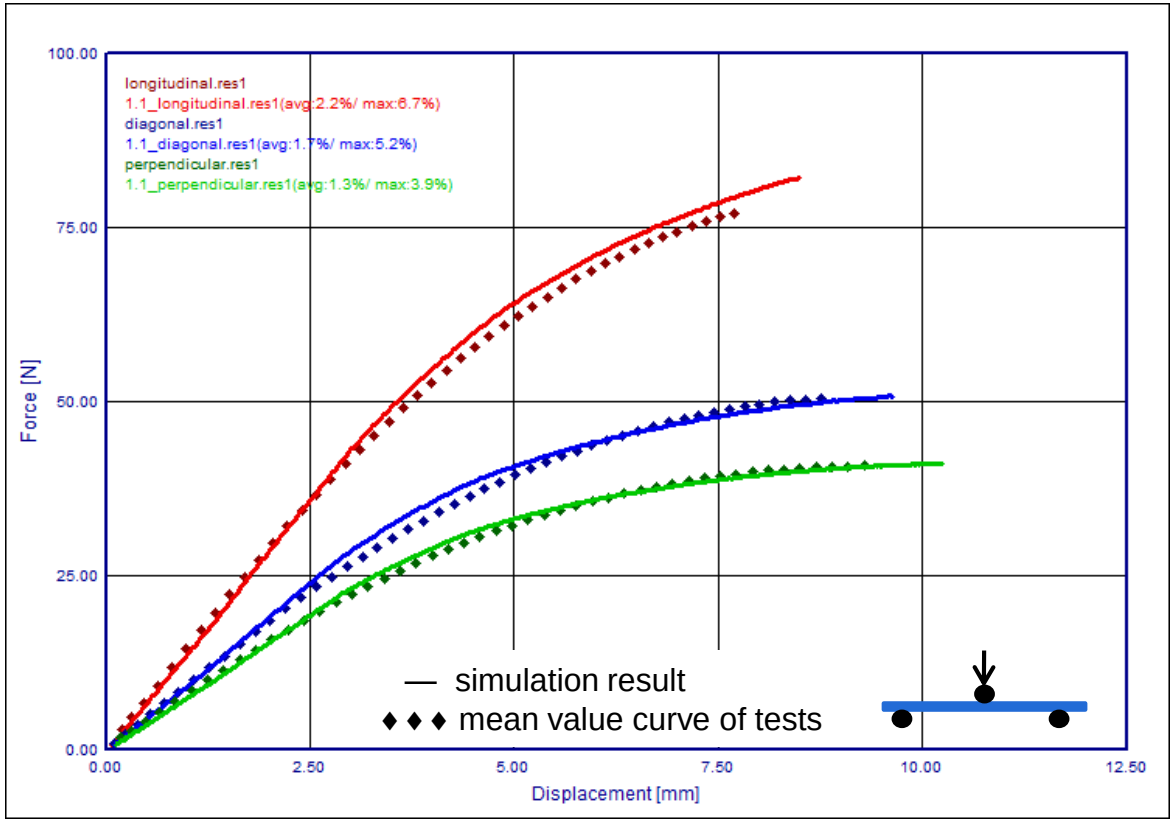


perpendicular

Materialcharakterisierung – Biegeversuche mit VALIMAT

	Name	Start	const...	from	to	Variance	Condi..
	c_C45	MMEC	☑	(NULL)	(NULL)	(NULL)	
	c_C46	MMEC	☑	(NULL)	(NULL)	(NULL)	
	c_C55	MMEC	☑	(NULL)	(NULL)	(NULL)	
	c_C56	MMEC	☑	(NULL)	(NULL)	(NULL)	
	c_C66	MMEC	☑	(NULL)	(NULL)	(NULL)	
▲	GroupName: 20_yield						
	y_0	23.78486	☐	15	50	(NULL)	
	y_r00	MMEC	☑	(NULL)	(NULL)	(NULL)	
	y_r45	MMEC	☑	(NULL)	(NULL)	(NULL)	
	y_r90	MMEC	☑	(NULL)	(NULL)	(NULL)	
	y_scale...	MMEC	☑	(NULL)	(NULL)	(NULL)	
▲	GroupName: 21_hardening						
	h_y	23.785	☑	5	150	50	=y_0
	h_ET	1500	☐	500	1500	(NULL)	

3rd step:
Validating on all tests

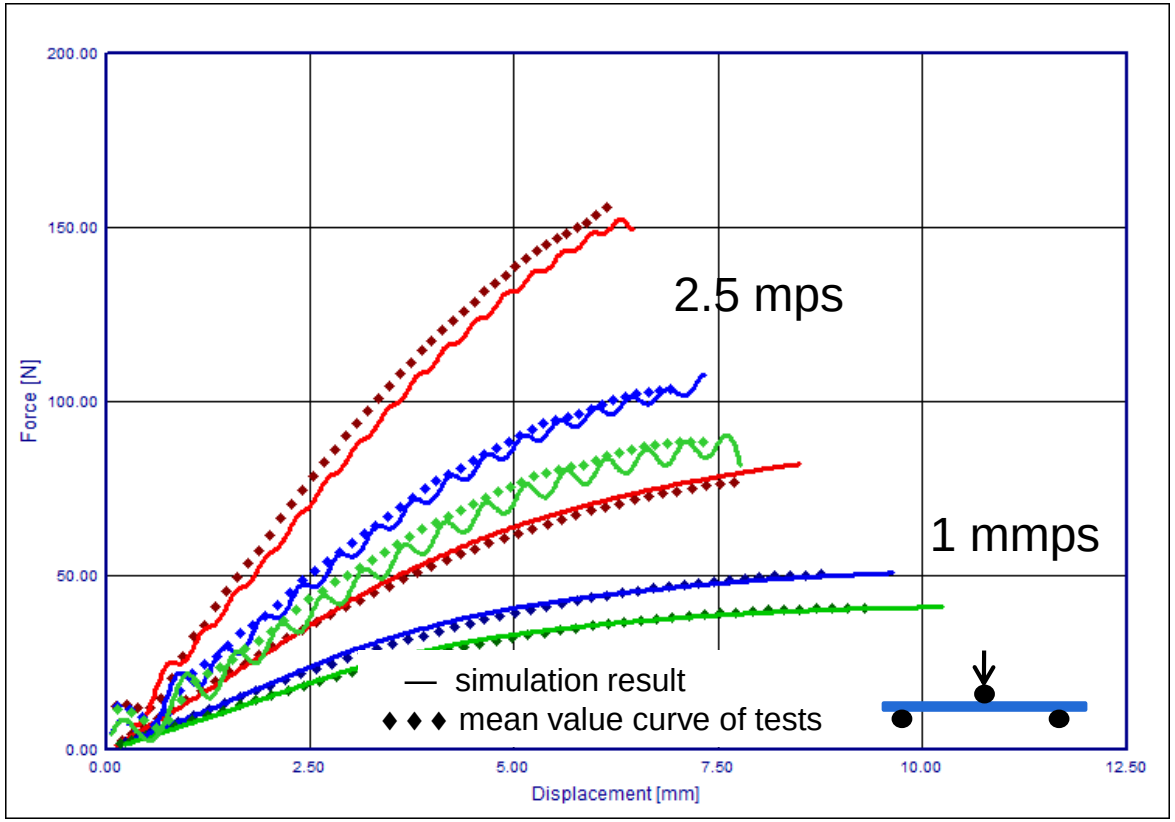


longitudinal
diagonal
perpendicular

Materialcharakterisierung – Biegeversuche mit VALIMAT

	Name	Start	const...	from	to	Variance	Condi..
	c_C45	MMEC	☑	(NULL)	(NULL)	(NULL)	
	c_C46	MMEC	☑	(NULL)	(NULL)	(NULL)	
	c_C55	MMEC	☑	(NULL)	(NULL)	(NULL)	
	c_C56	MMEC	☑	(NULL)	(NULL)	(NULL)	
	c_C66	MMEC	☑	(NULL)	(NULL)	(NULL)	
▲	GroupName: 20_yield						
	y_0	23.78486	☐	15	50	(NULL)	
	y_r00	MMEC	☑	(NULL)	(NULL)	(NULL)	
	y_r45	MMEC	☑	(NULL)	(NULL)	(NULL)	
	y_r90	MMEC	☑	(NULL)	(NULL)	(NULL)	
	y_scale...	MMEC	☑	(NULL)	(NULL)	(NULL)	
▲	GroupName: 21_hardening						
	h_y	23.785	☑	5	150	50	=y_0
	h_ET	1500	☐	500	1500	(NULL)	
▲	GroupName: 31_strainrate						
	v_p	11.38	☑	5	10	(NULL)	
	v_epspkt	0.0001	☑	0.001	1	(NULL)	

4th step:
Add the strain rate dependency



longitudinal
diagonal
perpendicular

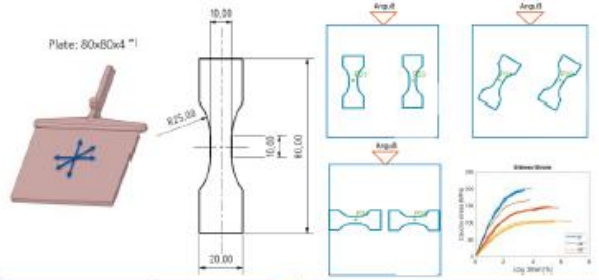
Glasfaserverstärkte Kunststoffe - 4a Software-Tools im Einsatz

Hirtenberger. Ingenuity. Engineered.

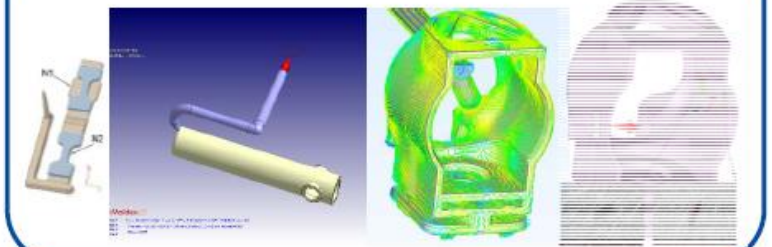
hirtenberger Automotive Safety

Überblick über die Prozesskette

Materialcharakterisierung



Füllsimulationen



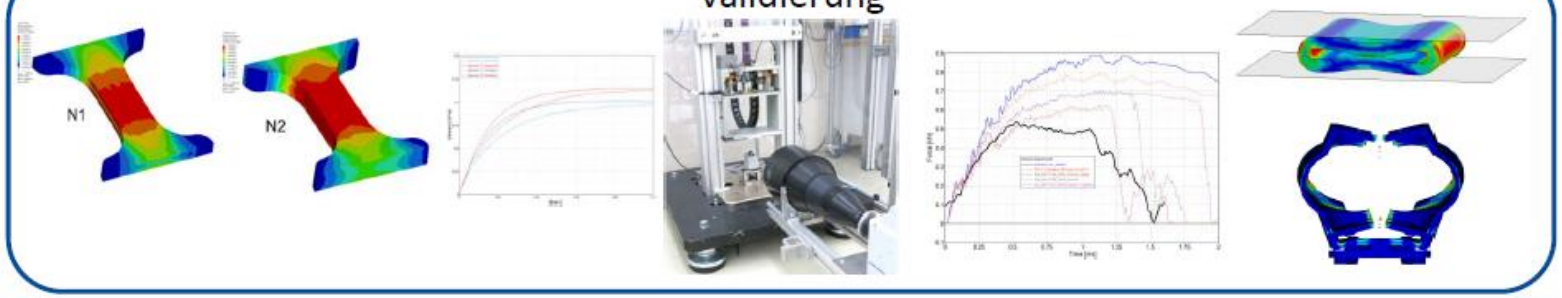
IMPETUS

VALIMAT

Mapping auf Strukturensimulationsnetz

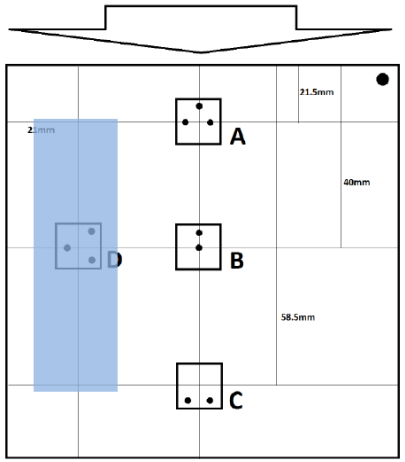
FIBERMAP

Validierung

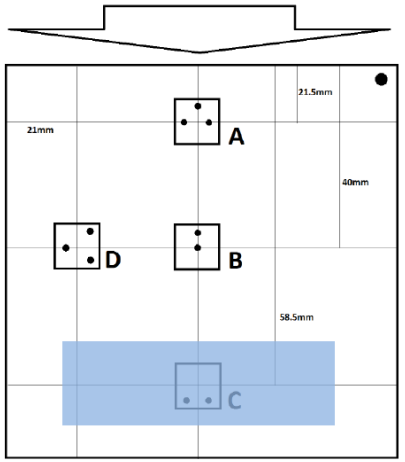


Materialcharakterisierung – Probenposition & µCT-Messung

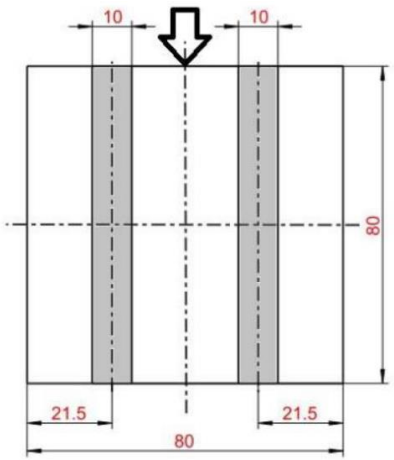
Zugprobe 0°



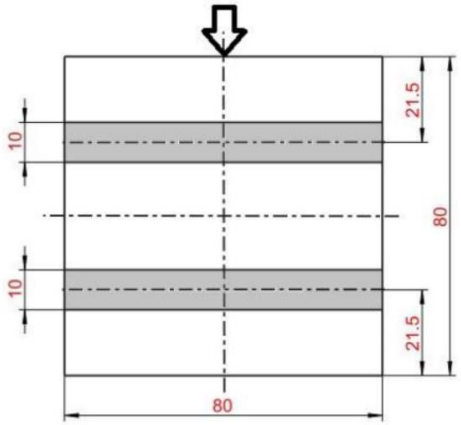
Zugprobe 90°

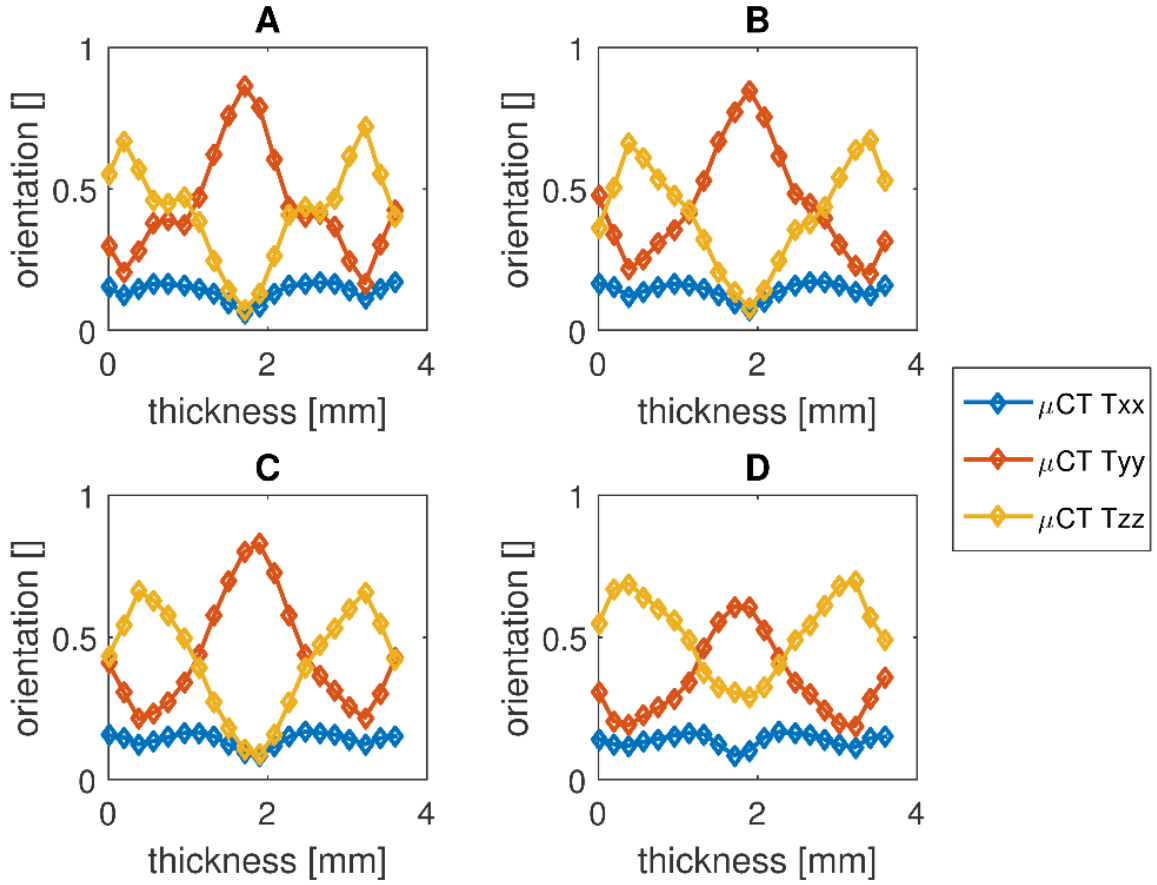


Biegeprobe 0°



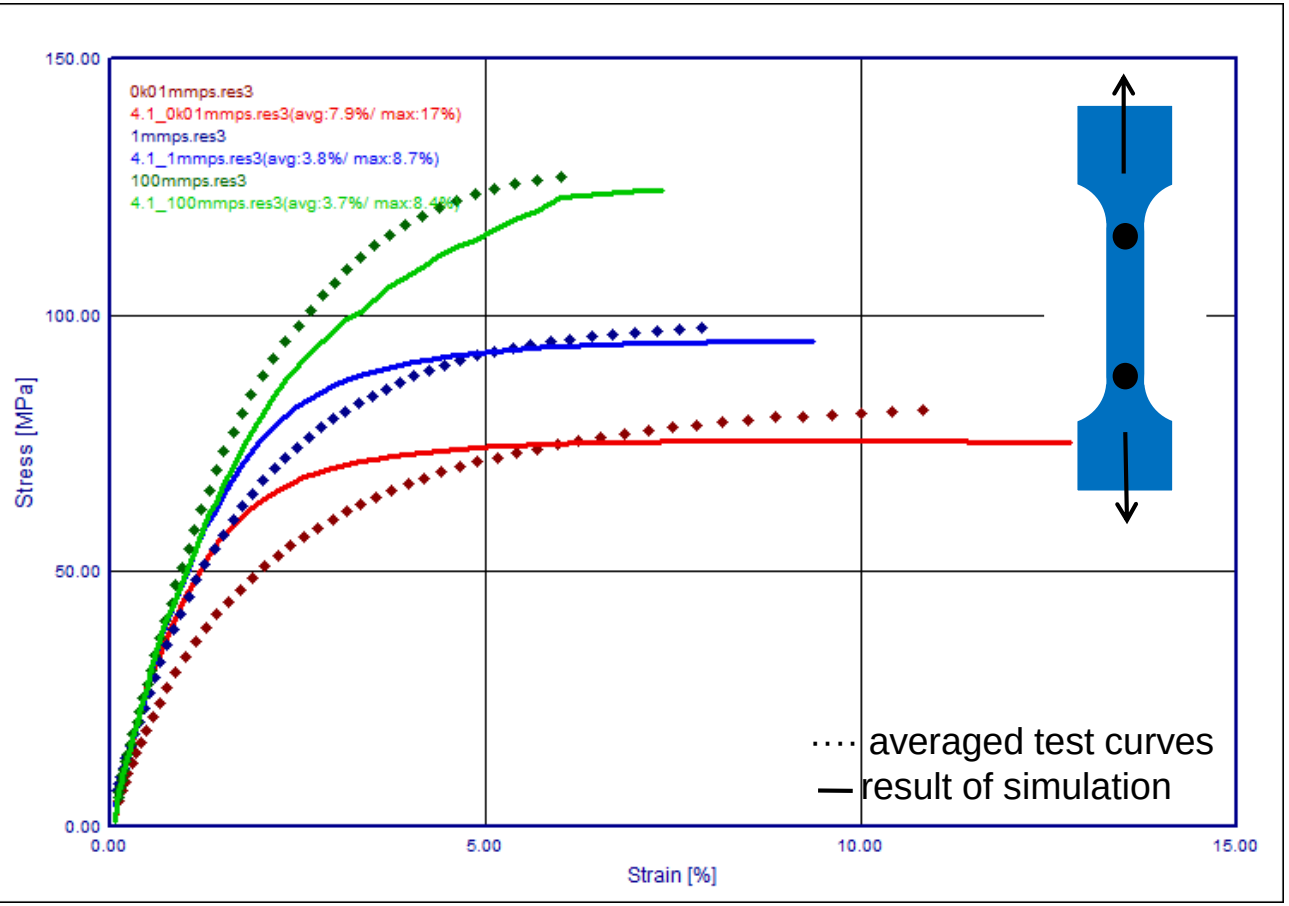
Biegeprobe 90°

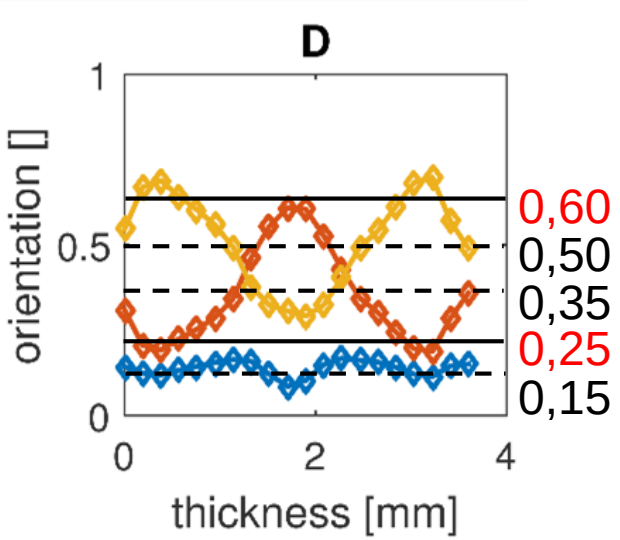




Morak et. al.: Faserorientierungsvorhersage mittels der Spritzgusssimulation, TT16 Schladming

Materialcharakterisierung - Zugversuche

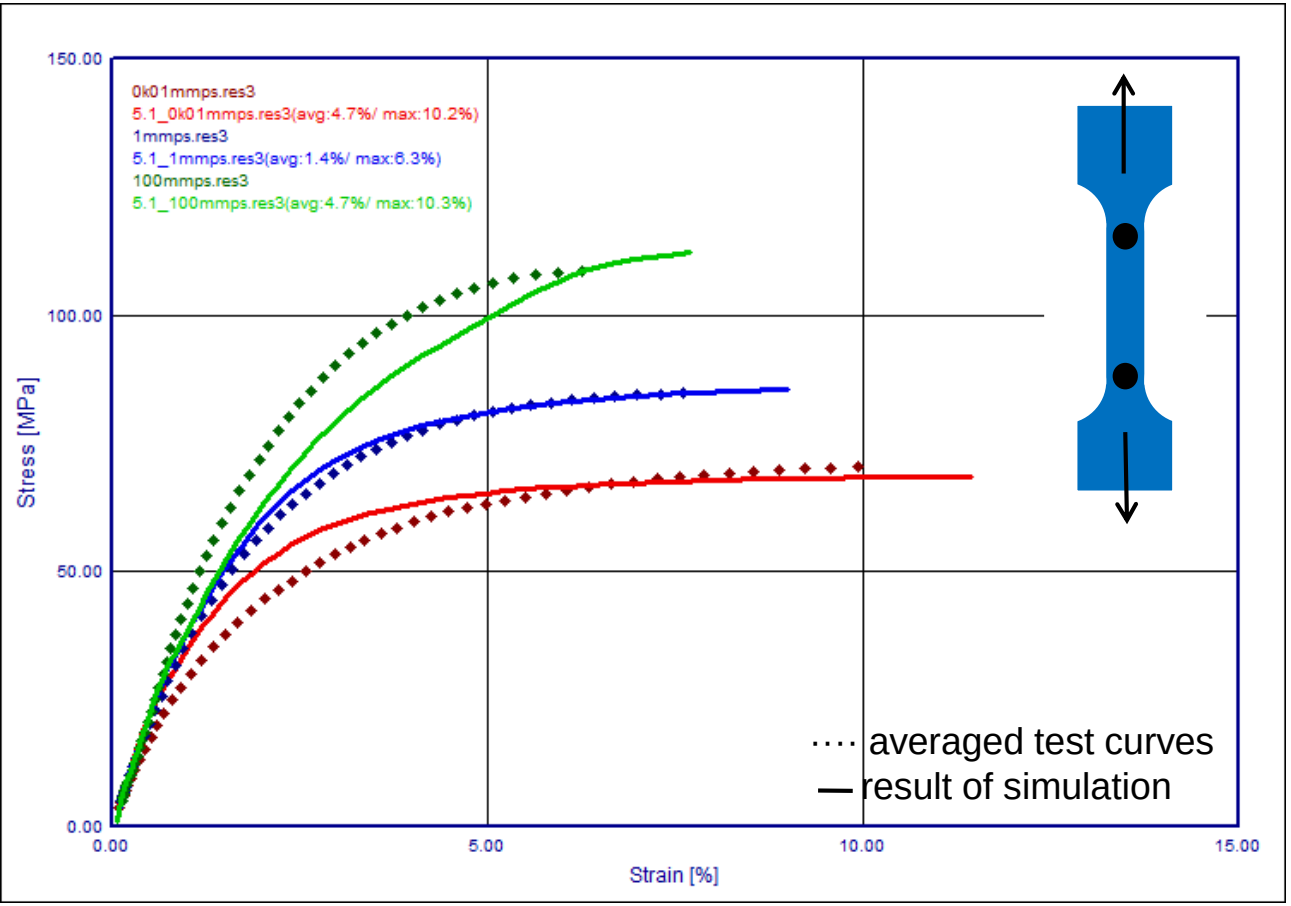


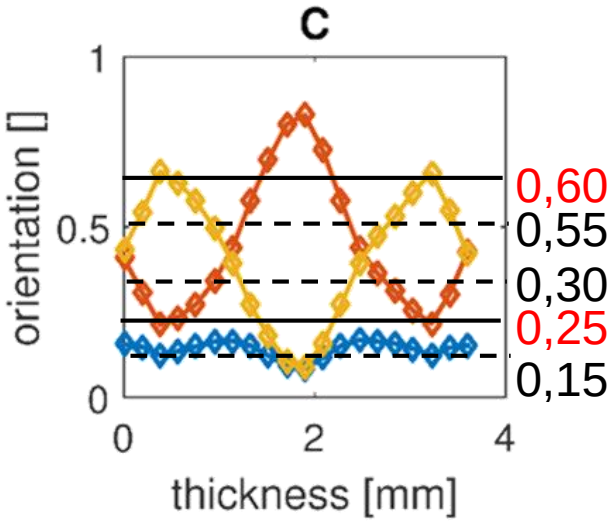


Zugversuch längs

Biegeversuch längs

Materialcharakterisierung - Zugversuche

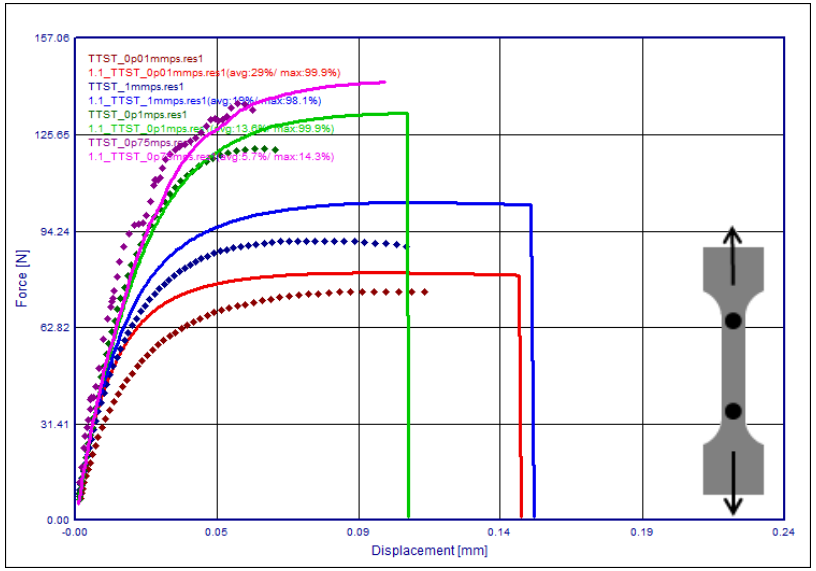




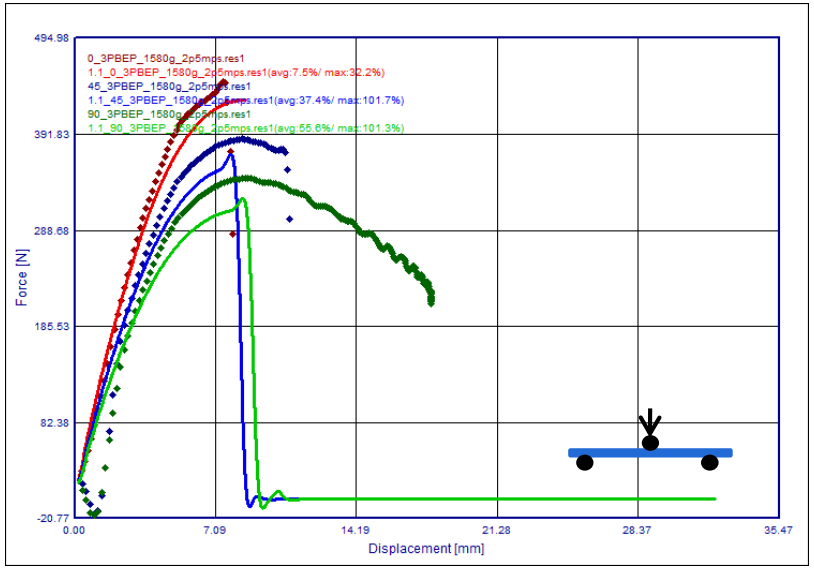
Zugversuch quer
Biegeversuch quer

Zug:
Unterschiedliche Faserorientierung über dem Querschnitt
→ **Schwierige** Anpassung der Materialkarte
Biegung:
Eine Faserorientierung (der Randschicht) ist zu berücksichtigen
→ **Einfache** Anpassung der Materialkarte

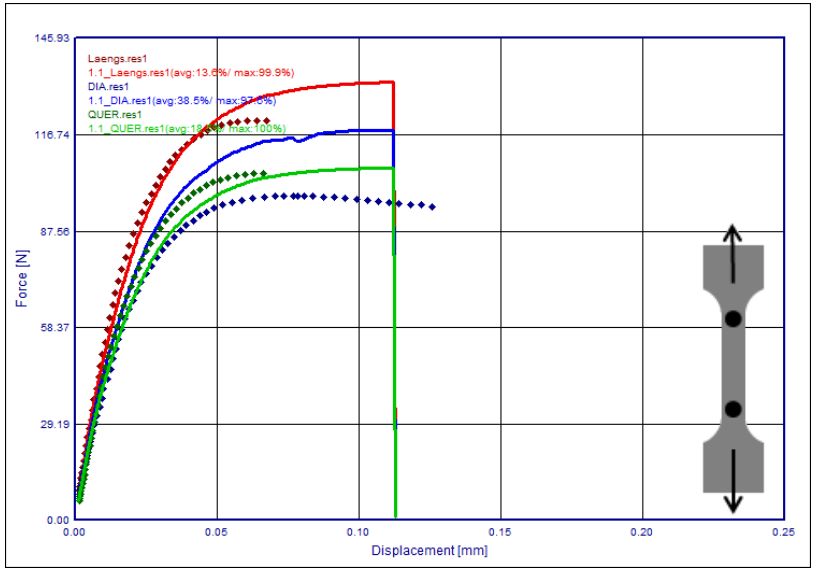
Materialcharakterisierung – Biegeversuche mit VALIMAT



Zugversuch Längs (Pos. D) von 0.01 mm/s – 750 mm/s



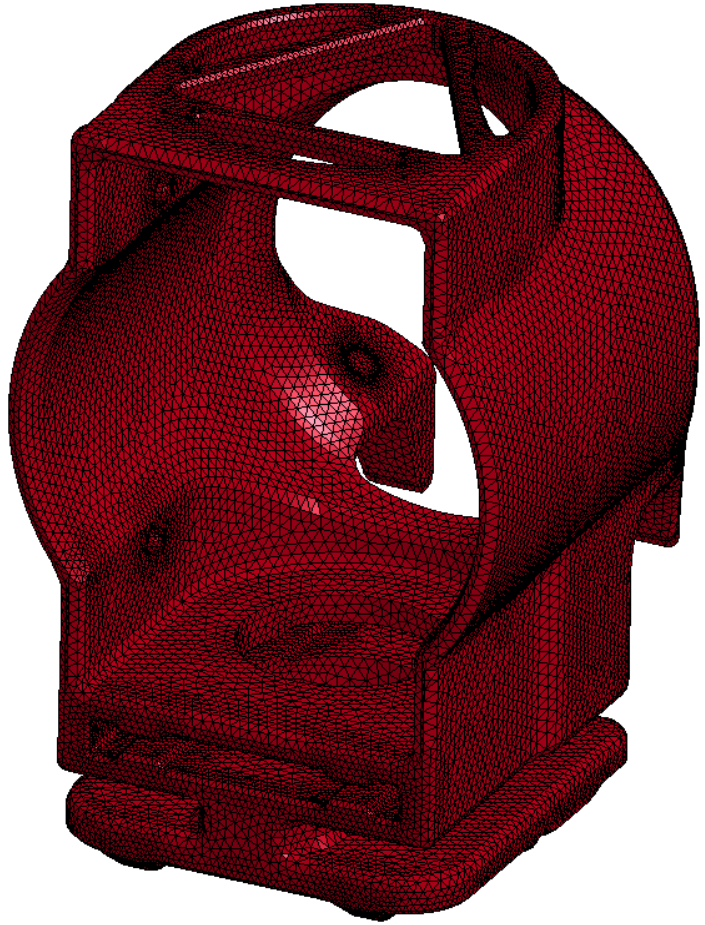
Biegeversuch (Pos. B) 2500 mm/s längs – diagonal – quer



Zugversuch (Pos. D) 100 mm/s längs – diagonal – quer

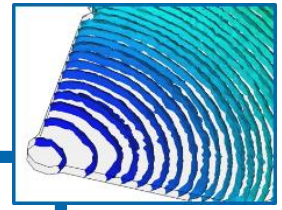
Integrative Simulation – Mapping mit FIBERMAP

- Bauteil:
  - Kunststoff-Manschette
- Material:
  - PA 6 GF30
- Spritzguss-Simulation
  - Moldex3D
- Struktur-Simulation:
  - LS-Dyna
  - Solid-Elemente (Typ 10)
  - 0.5 mm Elementgröße
  - *MAT_215 (*MAT_4A_MICROMEC)
- Mapping von
  - Bindenaht
  - Faserorientierung



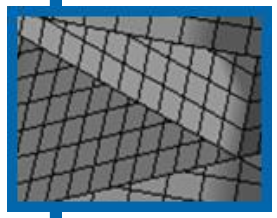
Integrative Simulation – Mapping mit FIBERMAP - Vorgehensweise

process simulation result



CADMOULD 3D-F SIMULATION | Moldex3D MOLDING INNOVATION | MOLDFLOW

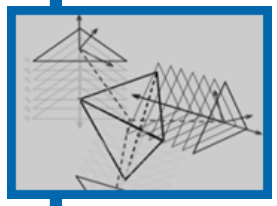
structural mesh

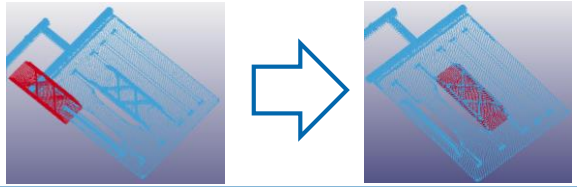


LSTC Livermore Software Technology Corp. LS-DYNA® | SIMULIA

shell
solid

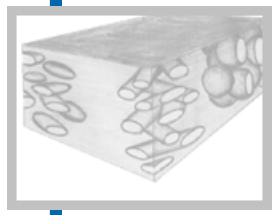
mapping settings





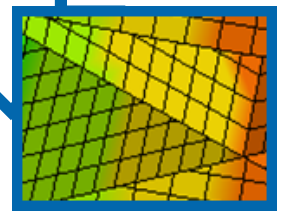
Transformation mapping (KD-Tree)

material card definition



orthotropic
elastic
visco plastic

structural output



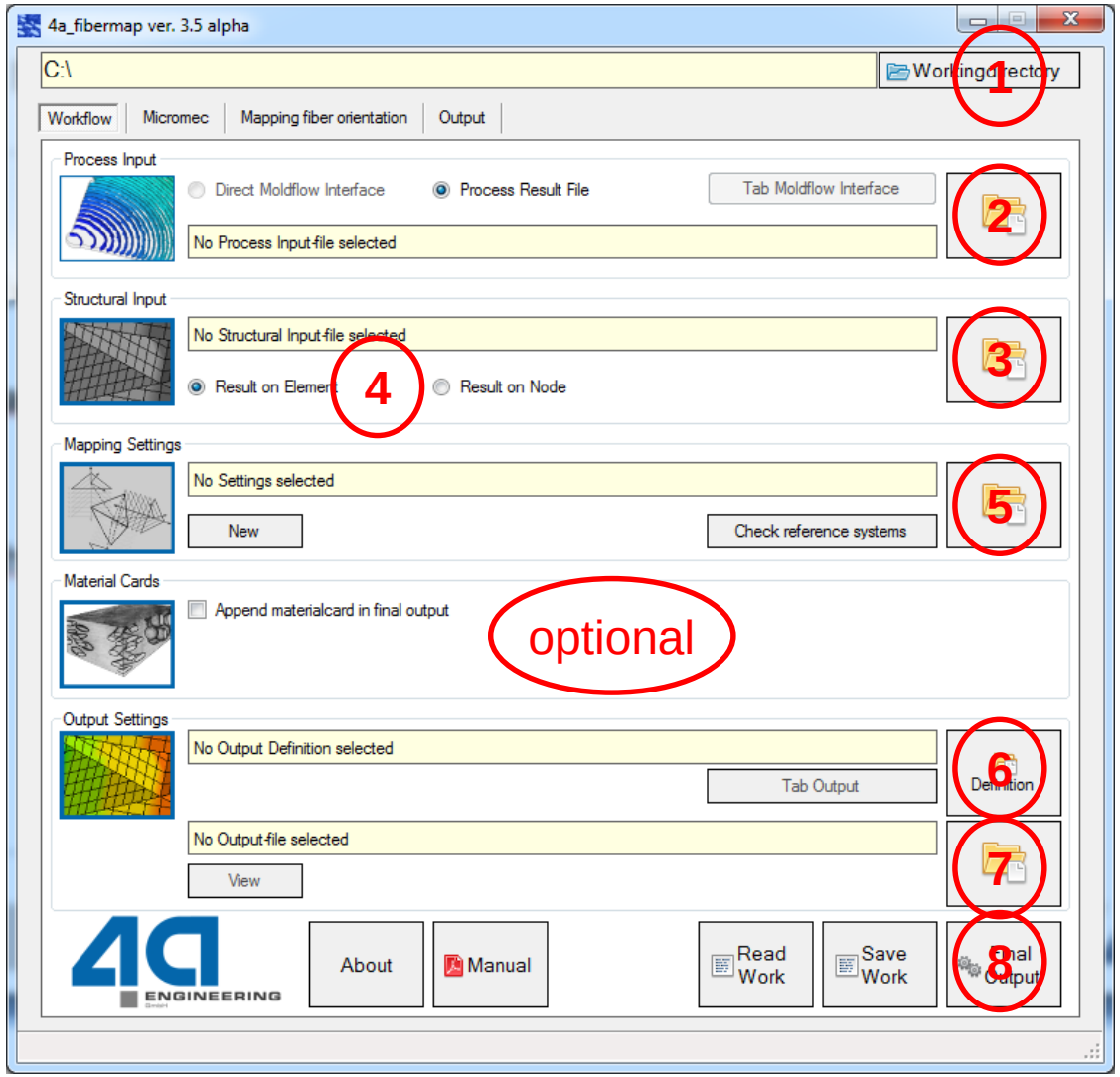
LSTC Livermore Software Technology Corp. LS-DYNA® | SIMULIA | ANSYS | Virtual Performance Solution | MSC Nastran

Template based ASCII output

Integrative Simulation – Mapping mit FIBERMAP - Vorgehensweise

- **Mapping mit FIBERMAP (Workflow)**:

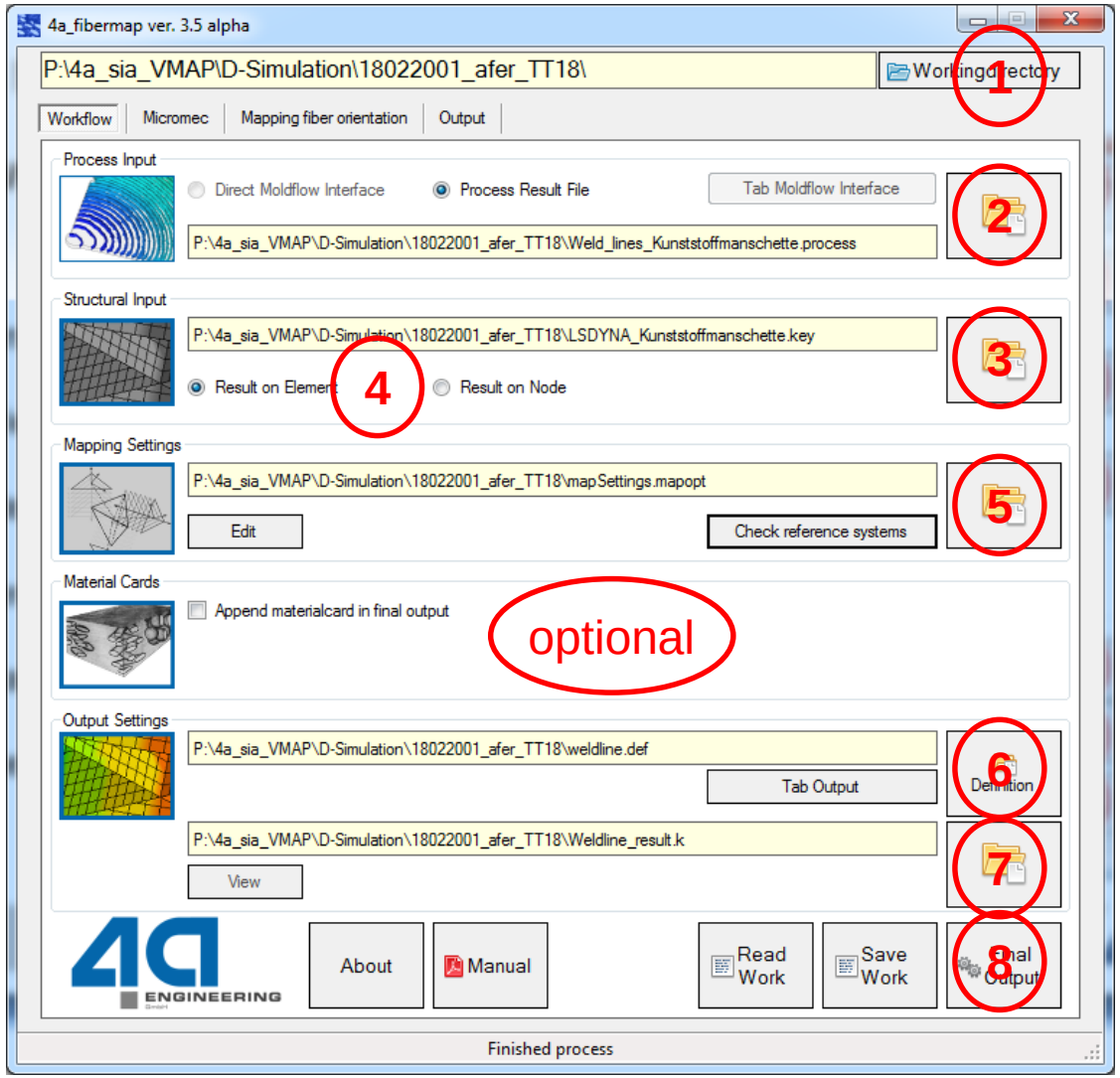
1. Arbeitsverzeichnis angeben
2. Spritzgusssimulations-Ergebnis angeben
3. Struktursimulations-Geometrie angeben
4. Ergebnisse auf Element/Knoten schreiben
5. Settings für Mapping einstellen
6. Mapping-Ergebnis-Template angeben
7. Mapping-Ergebnis-Dateinamen angeben
8. Mapping starten



Integrative Simulation – Mapping mit FIBERMAP - Vorgehensweise

- **Mapping mit FIBERMAP (Workflow)**:

1. Arbeitsverzeichnis angeben
2. Spritzgusssimulations-Ergebnis angeben
3. Struktursimulations-Geometrie angeben
4. Ergebnisse auf Element/Knoten schreiben
5. Settings für Mapping einstellen
6. Mapping-Ergebnis-Template angeben
7. Mapping-Ergebnis-Dateinamen angeben
8. Mapping starten

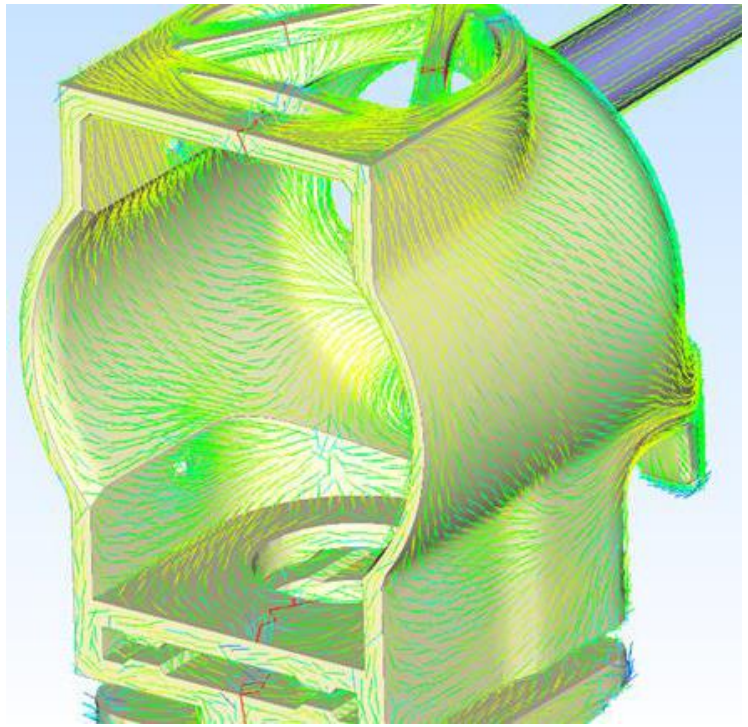


Integrative Simulation – Mapping mit FIBERMAP - Bindenaht

- **Ergebnis**:
  - Elemente mit Bindenaht → Part_ID 2 (blau)

Integrative Simulation – Mapping mit FIBERMAP - Faserorientierung

- Analoge Vorgehensweise für die **Faserorientierung**
- Unterschiede:
  - Anderes Spritzgusssimulations-Ergebnis
  - Anderes Mapping-Ergebnis-Template
- Ergebnis:



Vgl:
Visualisierung
Moldex3D

Integrative Simulation – Mapping mit FIBERMAP - Features

- Spritzguss-Simulation:
  - CADMOULD 3D-F SIMULATION, Moldex3D MOLDING INNOVATION, MOLDFLOW
  - 2D, 2.5D, 3D
- Struktursimulation:
  - LSTC Livermore Software Technology Corp. LS-DYNA®, SIMULIA, Virtual Performance Solution
  - Schale, Solid
- Ergebnisse:
  - Faserorientierung , Bindenaht, Druck, Temperatur, …
- Ausgabe:
  - Über Vorlagen (Templates)
  - **„Was auch immer der User möchte“**