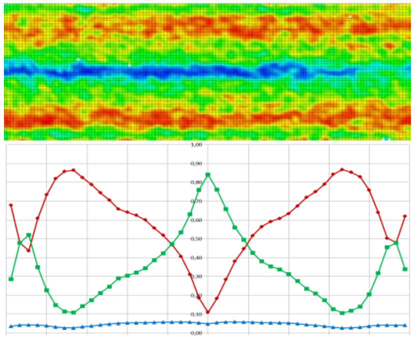
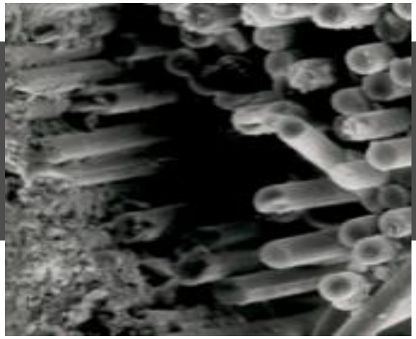
OPEL





Thorough Study of Short Fiber Reinforced Composites: from Micro-CT to Structural Analysis

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23.02.2017

Fachkongress Composite Simulation
Fellbach, GER

Wir leben Autos.

AGENDA

- COMPANY PRESENTATION
- PROCESS CHAIN OVERVIEW
- EXPERIMENTAL STUDY
- MOLDFLOW AND CALIBRATION
- *MAT_157 - MATERIAL CALIBRATION AND DATA MAPPING
- RESULTS
- OUTLOOK AND CONCLUSION

COMPANY PRESENTATION

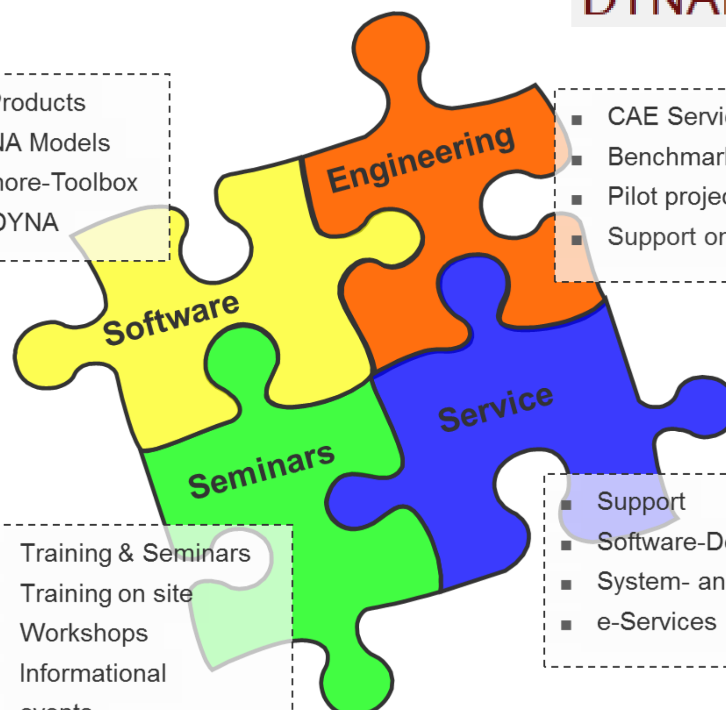
DYNA*more* GmbH
Gesellschaft für
FEM-Ingenieurdienstleistungen

Stuttgart – Berlin - Dresden
Linköping - Gothenburg - Zurich - Torino - Paris

Industriestraße 2
D-70565 Stuttgart

Tel. 07 11 - 45 96 00 - 0
Fax 07 11 - 45 96 00 - 29
e-mail: info@dynamore.de
Internet: www.dynamore.de

- LSTC Products
- LS-DYNA Models
- DYNAmore-Toolbox for LS-DYNA

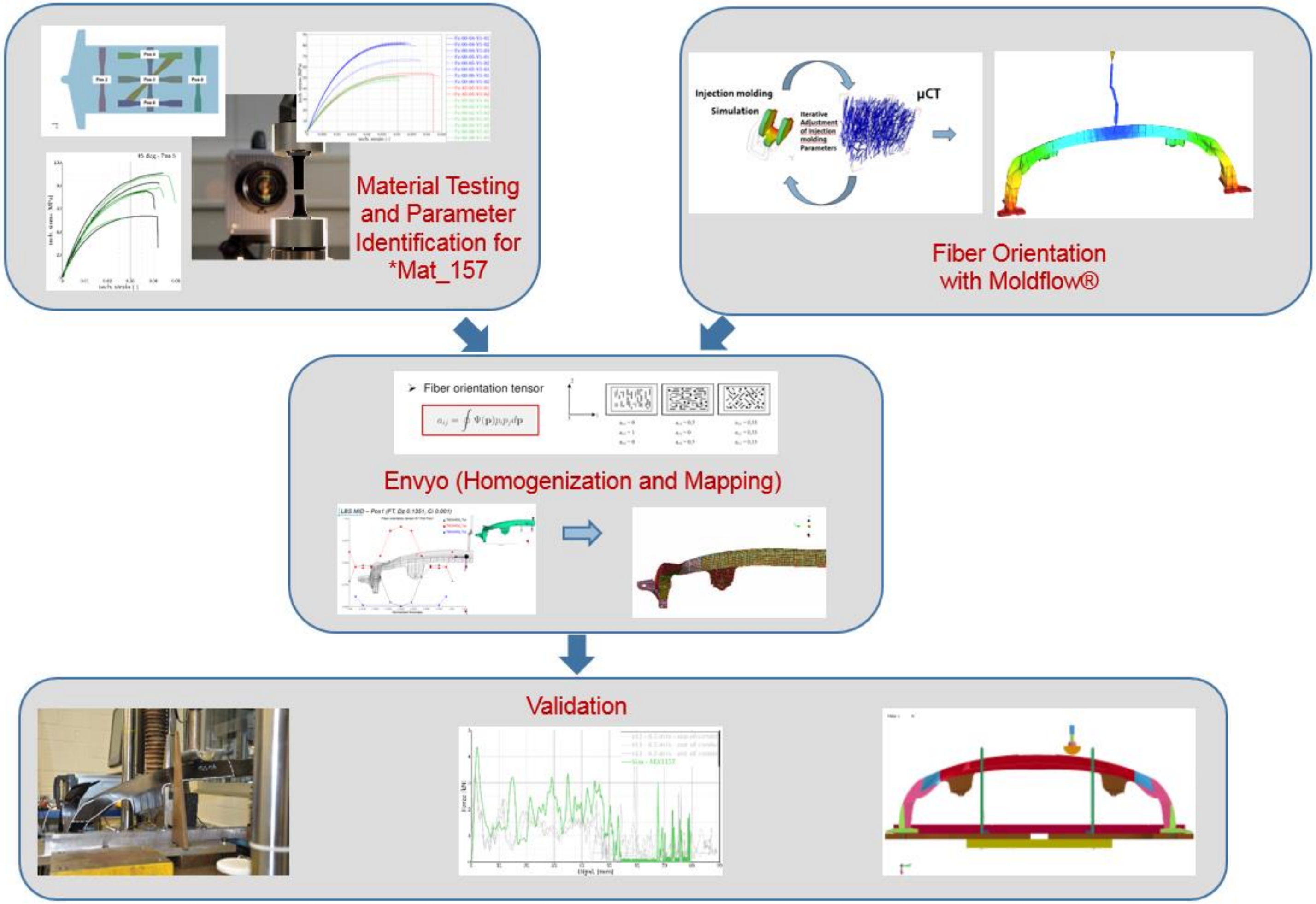


- CAE Services
- Benchmarking
- Pilot projects
- Support on site

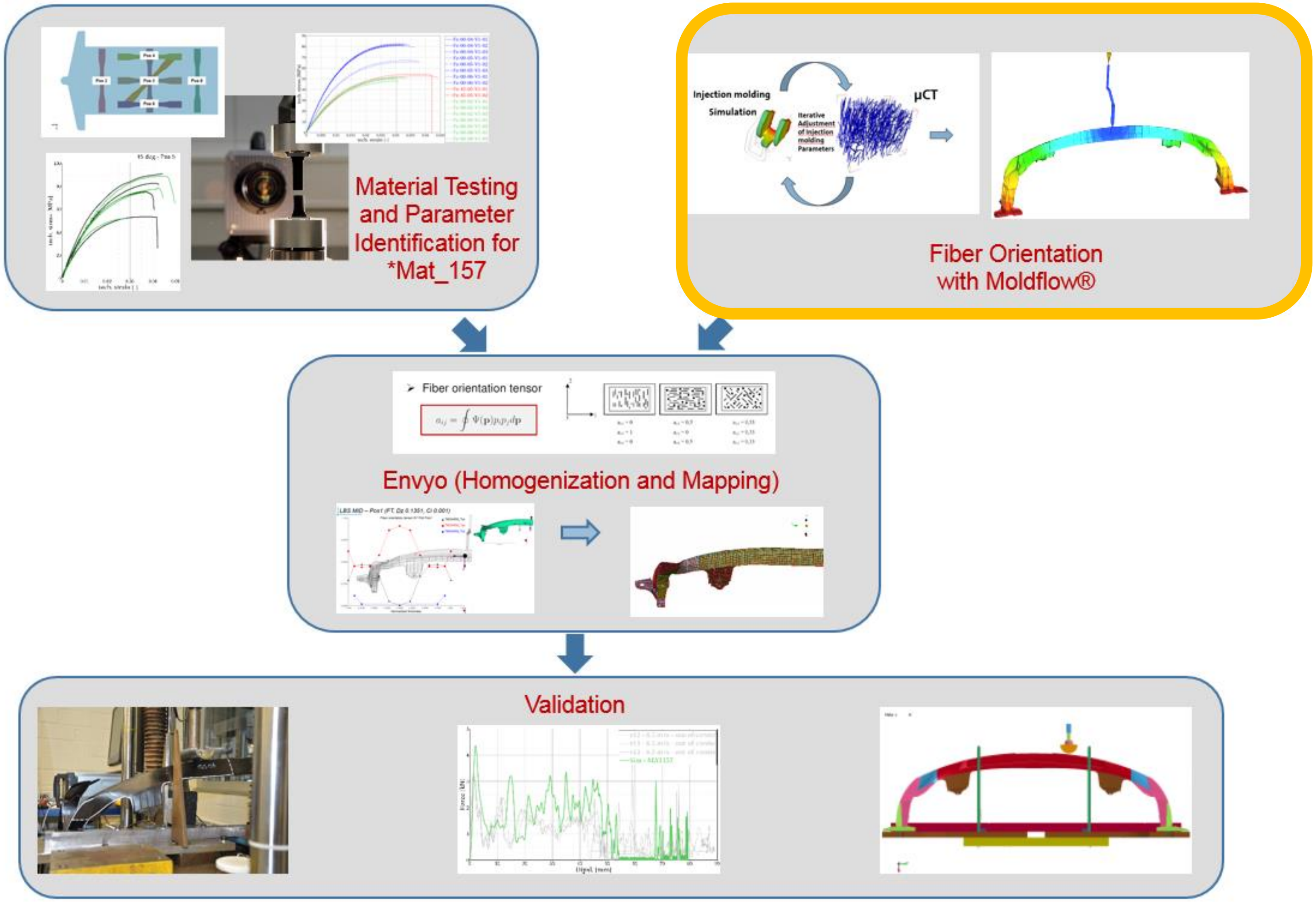
- Training & Seminars
- Training on site
- Workshops
- Informational events

- Support
- Software-Development
- System- and Processintegration
- e-Services

PROCESS CHAIN OVERVIEW



PROCESS CHAIN OVERVIEW



EXPERIMENTAL STUDY

- μ-CT – scan analysis @ 9 different positions on the plate

- μ-CT – scan analysis @ 6 different positions on the component

- position 5 chosen for Moldflow calibration

- evaluation on position 9 on the plate and on the component positions

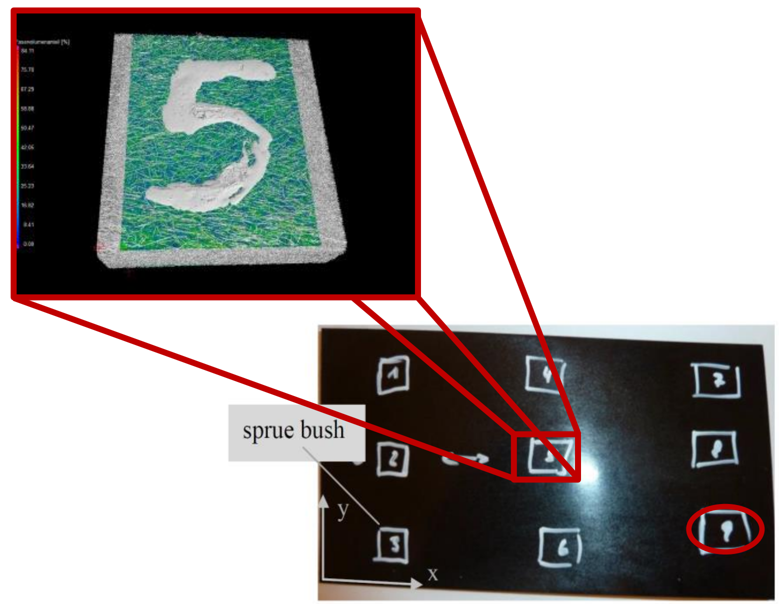
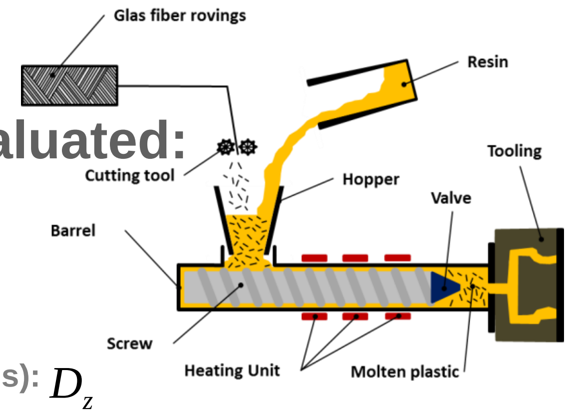


Fig. 1: Positions of specimen for CT-Scan.

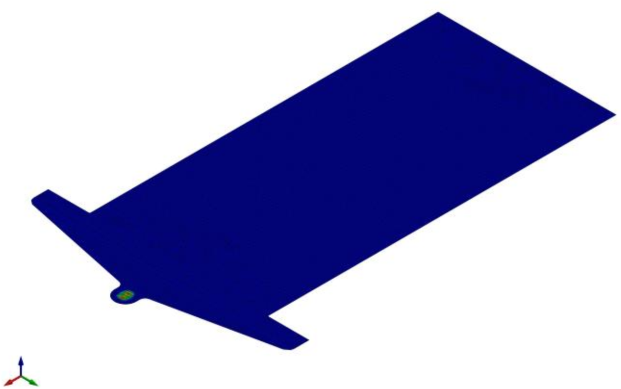
MOLDFLOW ANALYSIS AND CALIBRATION



- two different Moldflow approaches were evaluated:
  - Folgar-Tucker method:
    - varied parameters:
      - fiber interaction coefficient: C_i
      - thickness moment of interaction (for mid-plane problems): D_z

$$\frac{Da_{ij}}{Dt} = -\frac{1}{2}(\omega_{ik}a_{kj} - a_{ik}\omega_{kj}) + \frac{1}{2}\lambda(\dot{\gamma}_{ik}a_{kj} + a_{ik}\dot{\gamma}_{kj} - 2a_{ijkl}\dot{\gamma}_{kl}) + 2C_i\dot{\gamma}[\delta_{ij} - (2+D_z)a_{ij}]$$

  - Reduced Strain Closure (RSC):
    - varied parameters:
      - fiber interaction coefficient: C_i
      - scalar factor κ , Folgar-Tucker method: $\kappa \rightarrow 1$



$$\frac{Da_{ij}}{Dt} = -\frac{1}{2}(\omega_{ik}a_{kj} - a_{ik}\omega_{kj})$$

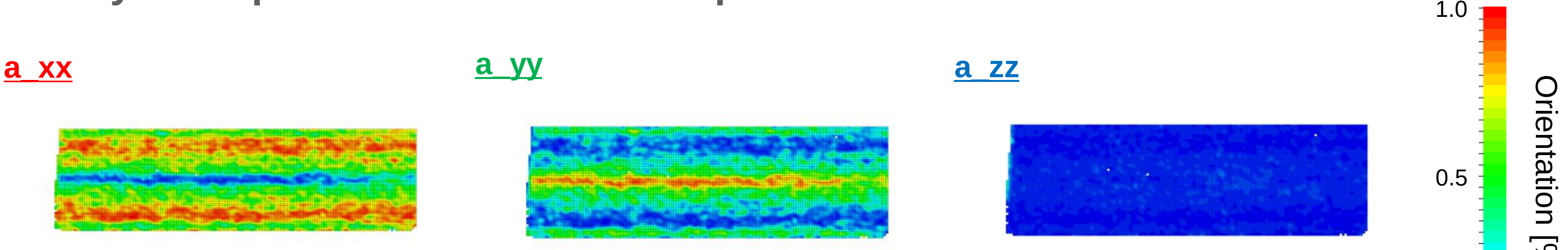
$$+\frac{1}{2}\lambda(\dot{\gamma}_{ik}a_{kj} + a_{ik}\dot{\gamma}_{kj} - 2[a_{ijkl} + (1-\kappa)(L_{ijkl} - M_{ijmn}a_{mnkl}]\dot{\gamma}_{kl})$$

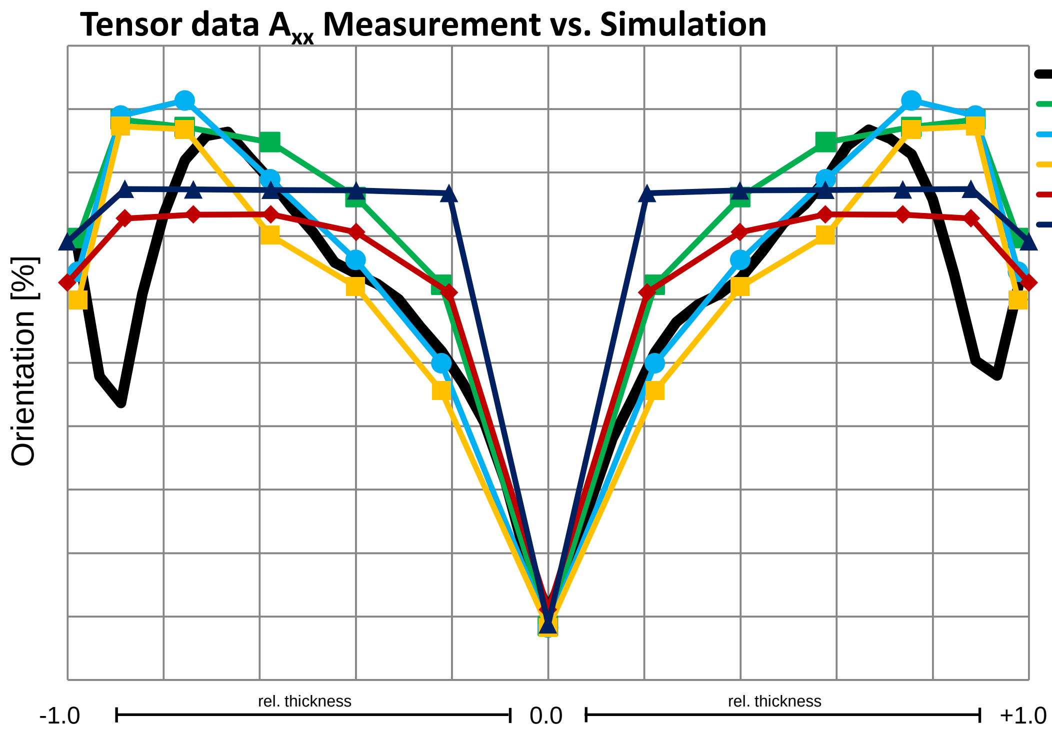
$$+2\kappa C_i\dot{\gamma}(\delta_{ij} - 3a_{ij})$$

PEG Plastics Engineering Group

MOLDFLOW ANALYSIS AND CALIBRATION

- analysis of µ-CT – scan data & comparison with Moldflow – Position 5:





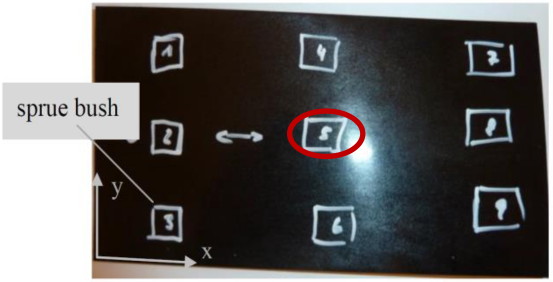
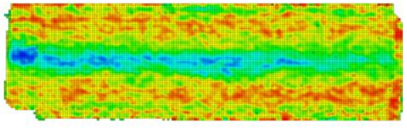


Fig. 1: Positions of specimen for CT-Scan.

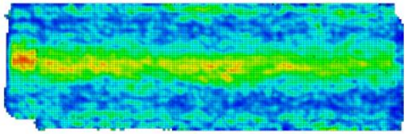
MOLDFLOW ANALYSIS AND CALIBRATION

- analysis of µ-CT – scan data & Moldflow evaluation – Position 9:

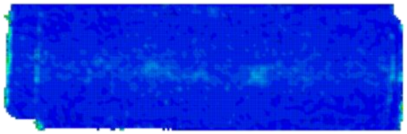
a_xx

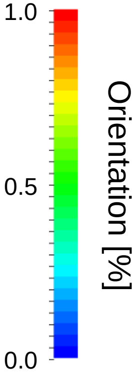


a_yy

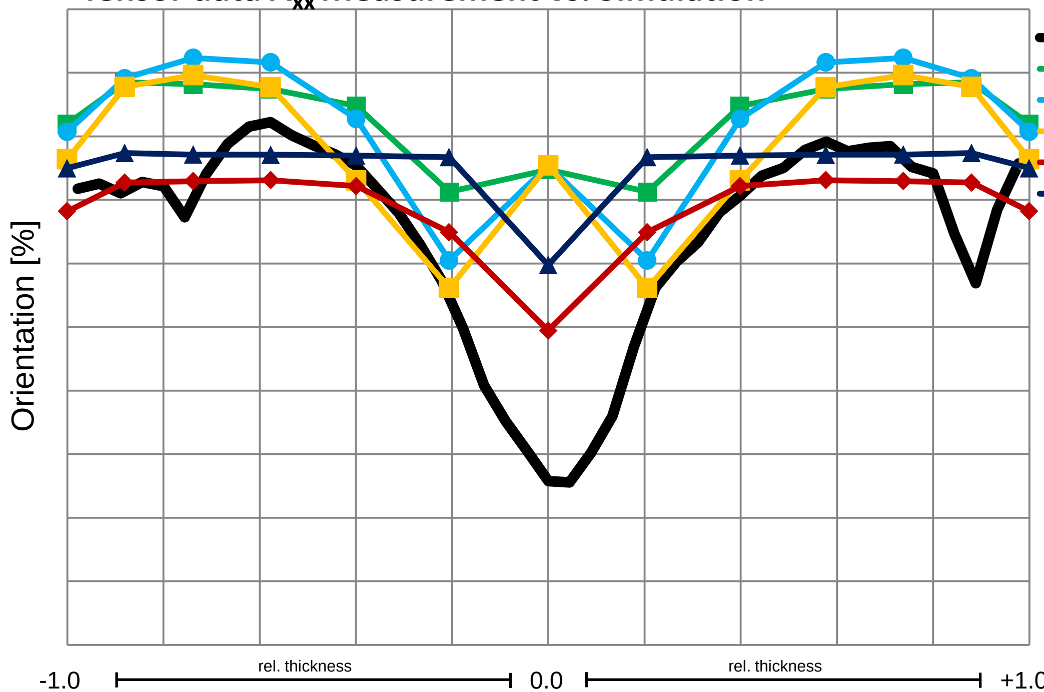


a_zz





Tensor data A_{xx} Measurement vs. Simulation



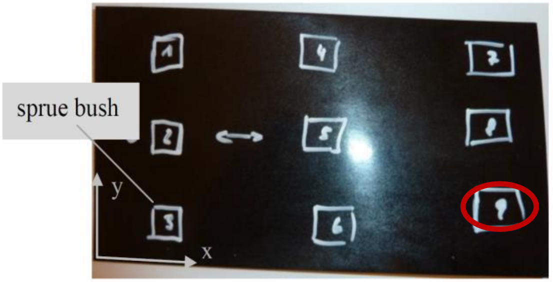
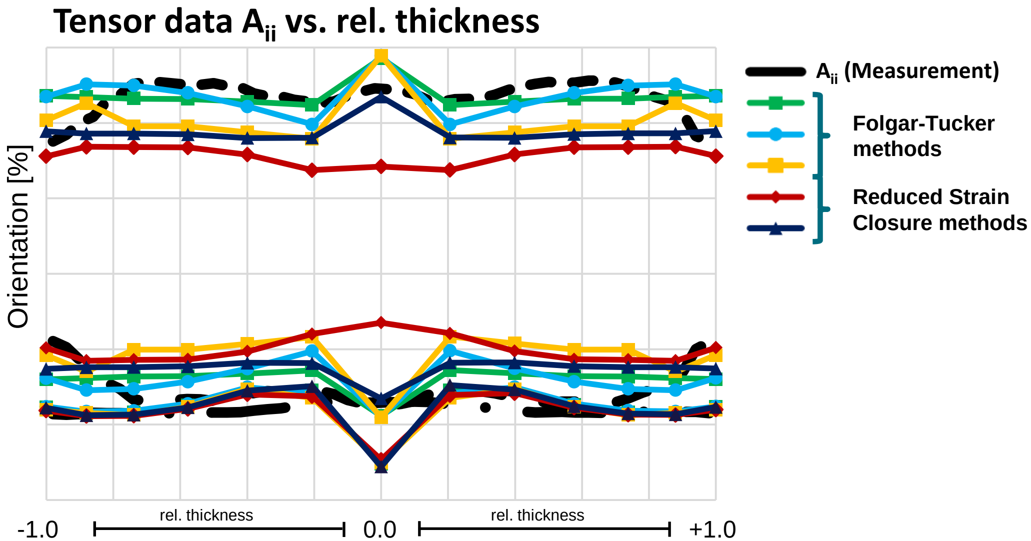


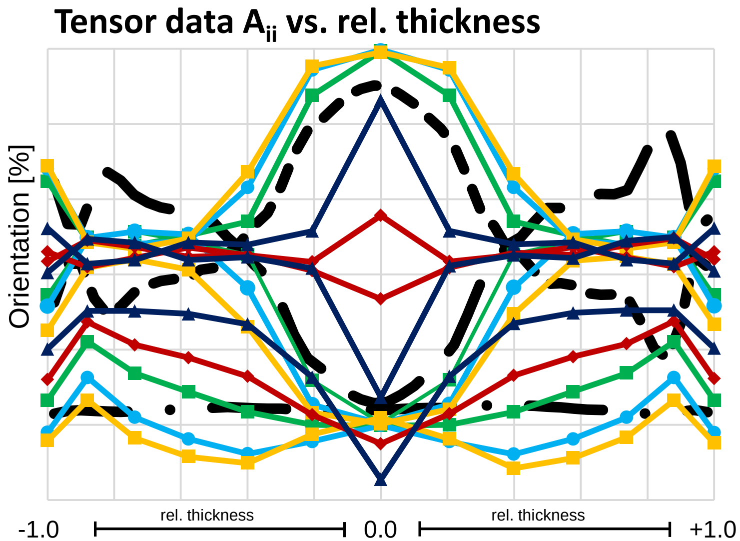
Fig. 1: Positions of specimen for CT-Scan.

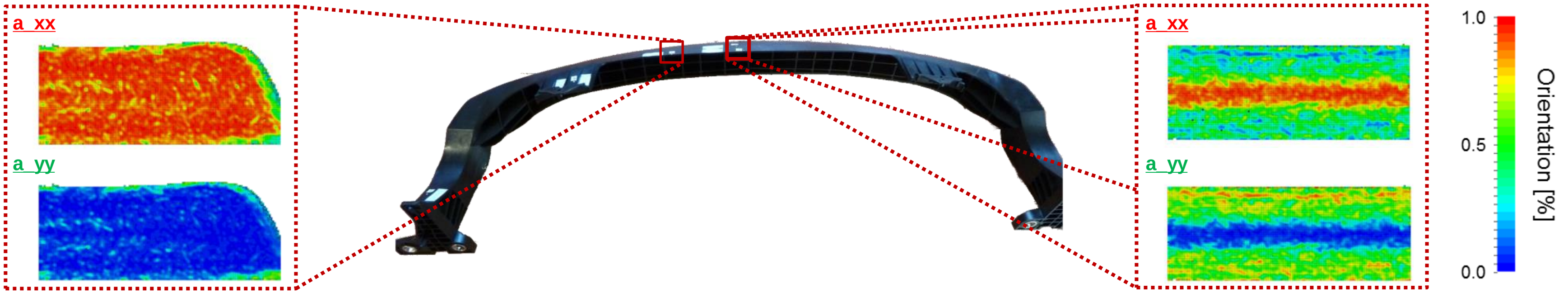
MOLDFLOW ANALYSIS AND CALIBRATION

- analysis of µ-CT – scan data & comparison with Moldflow:
  - component position 3 :

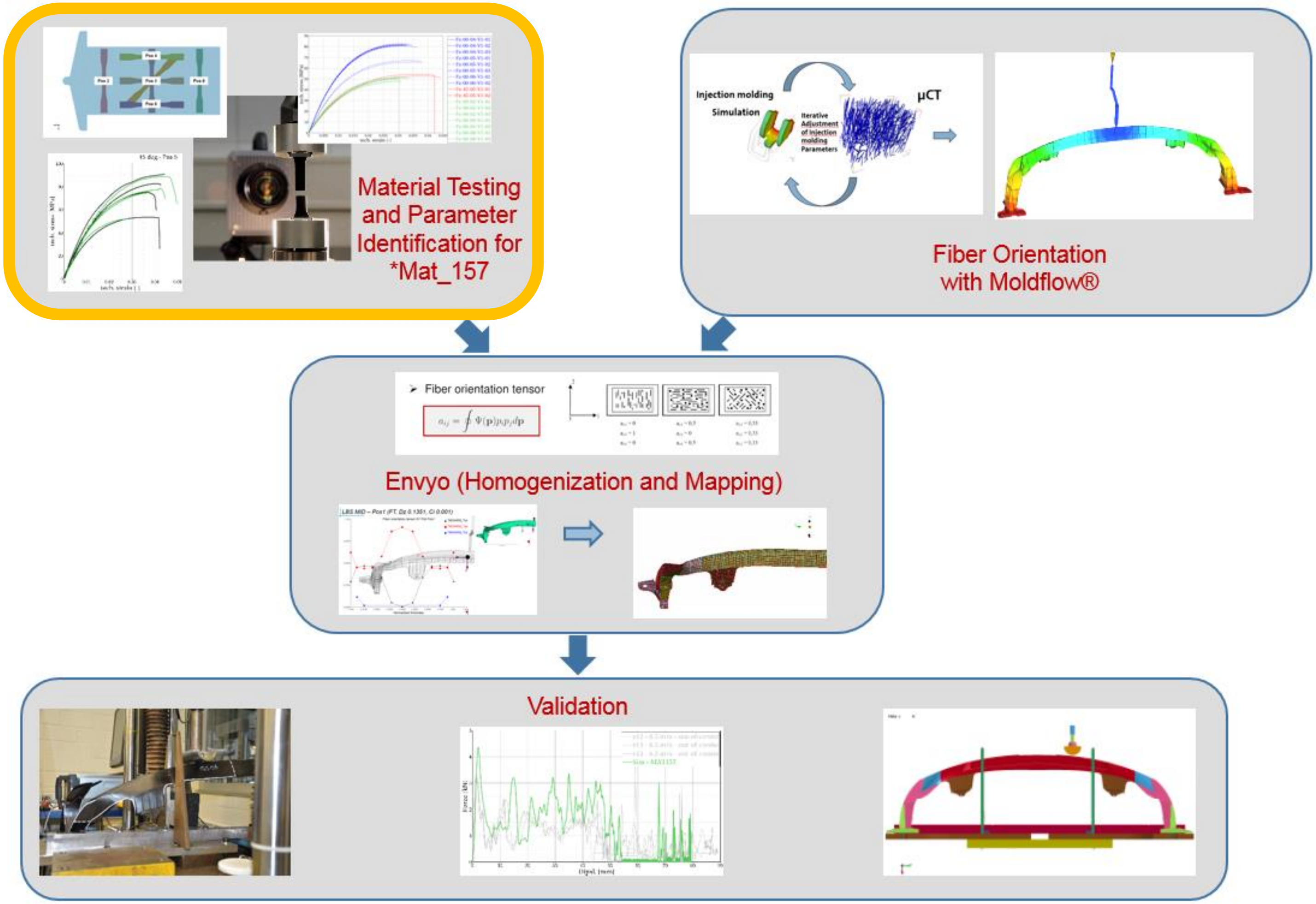
component position 1:







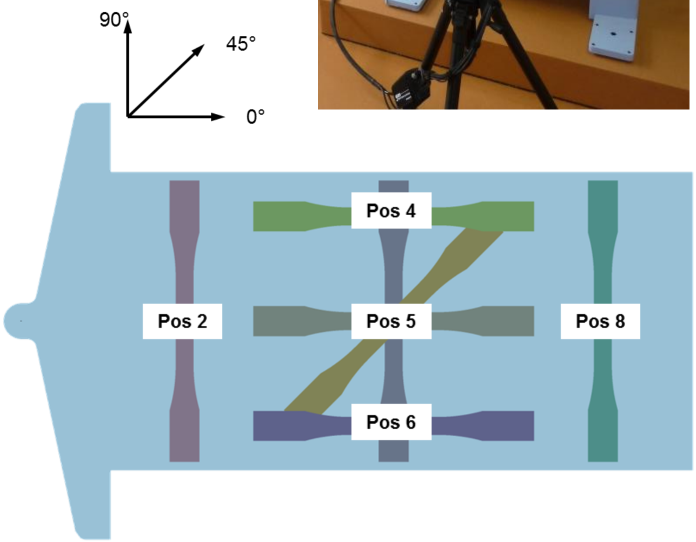
PROCESS CHAIN OVERVIEW



EXPERIMENTAL STUDY

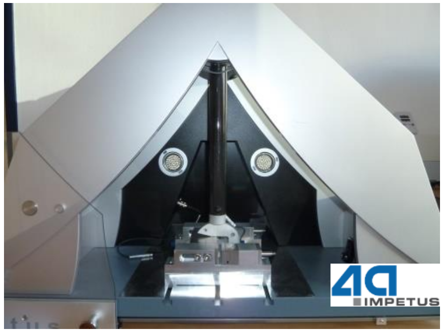
- quasi-static (qs) and dynamic tensile tests
  - 5 different positions on a plate
  - 4 different strain rates:
    - 0.03 mm/s
    - 30 mm/s
    - 300 mm/s
    - 3000 mm/s

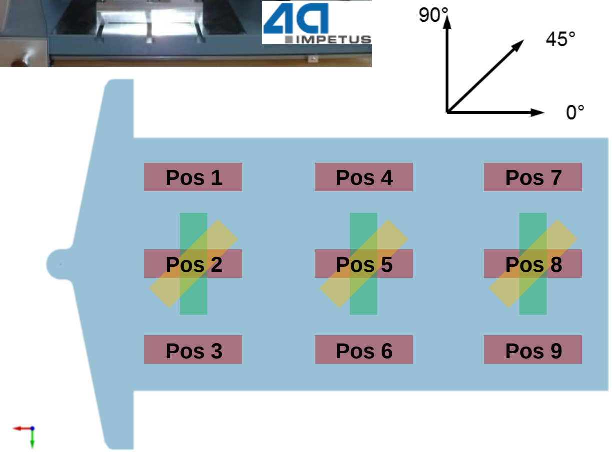
    Fraunhofer EMI
  - 3 different directions
- position 5 from tensile specimen chosen for reverse engineering and material calibration
- other positions used for evaluation purposes

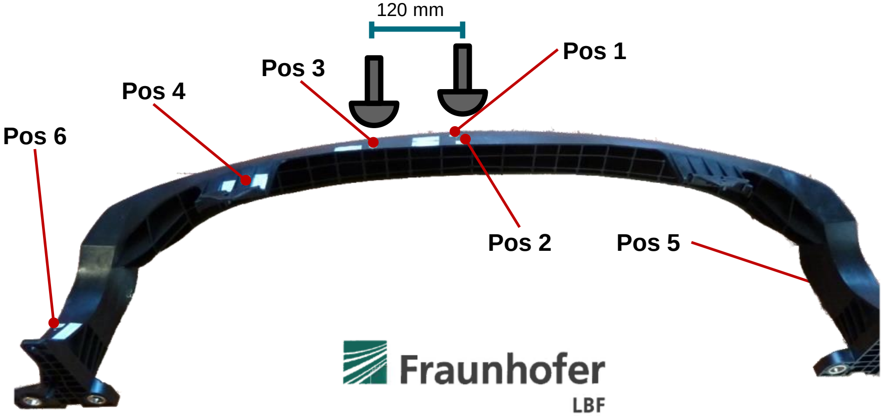


EXPERIMENTAL STUDY

- <u>three point bending tests</u>
  - 9 different positions
  - 3 different strain rates
  - 3 different directions
- qs and dynamic <u>component tests</u>
  - 5 different impact velocities
  - 2 different impact positions
- bending tests and component crushing used for validation
  - accuracy, calculation time, testing and modeling requirements for calibration

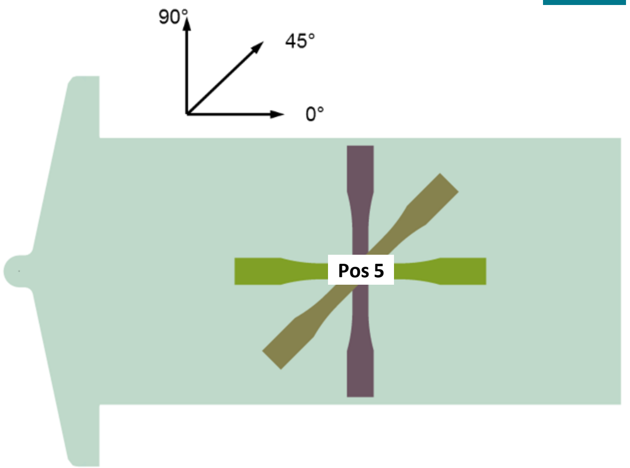


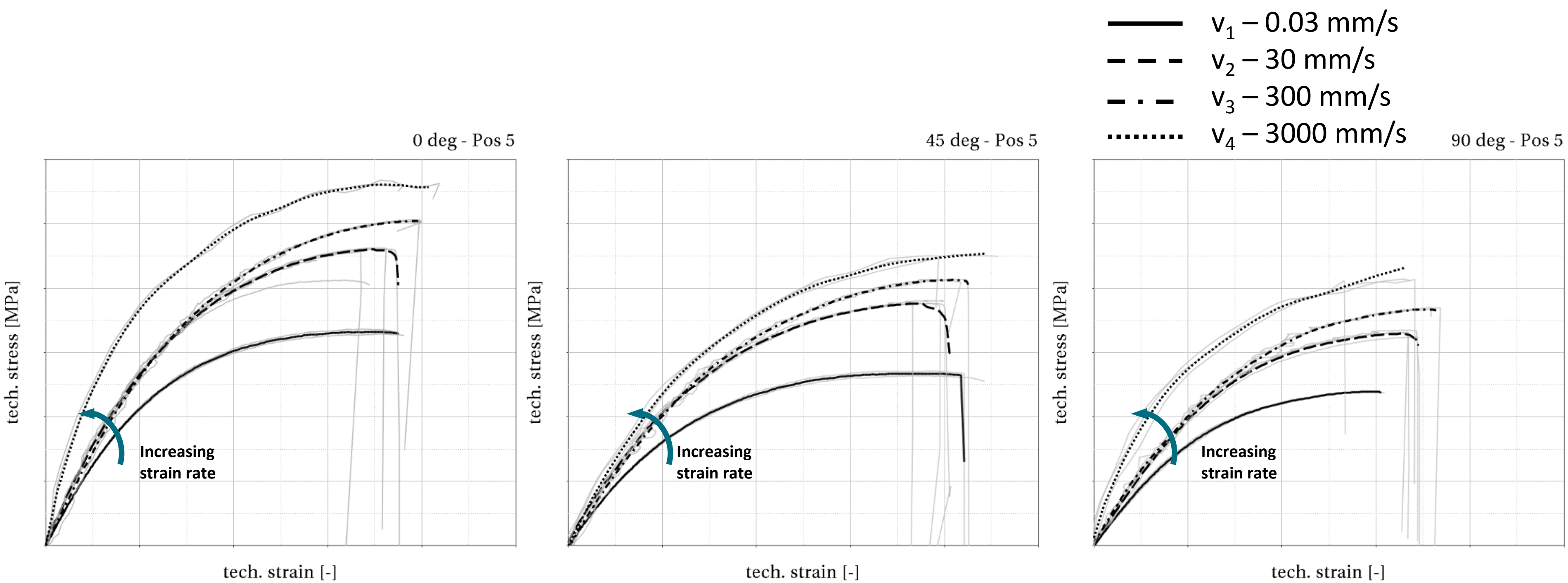




*MAT_157 MATERIAL CALIBRATION

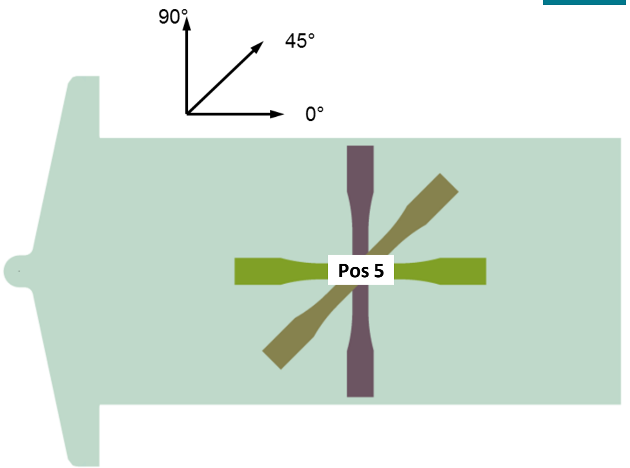
- **Experimental results – tensile specimen position 5**
  - **a high degree of visco-elasticity is observed**

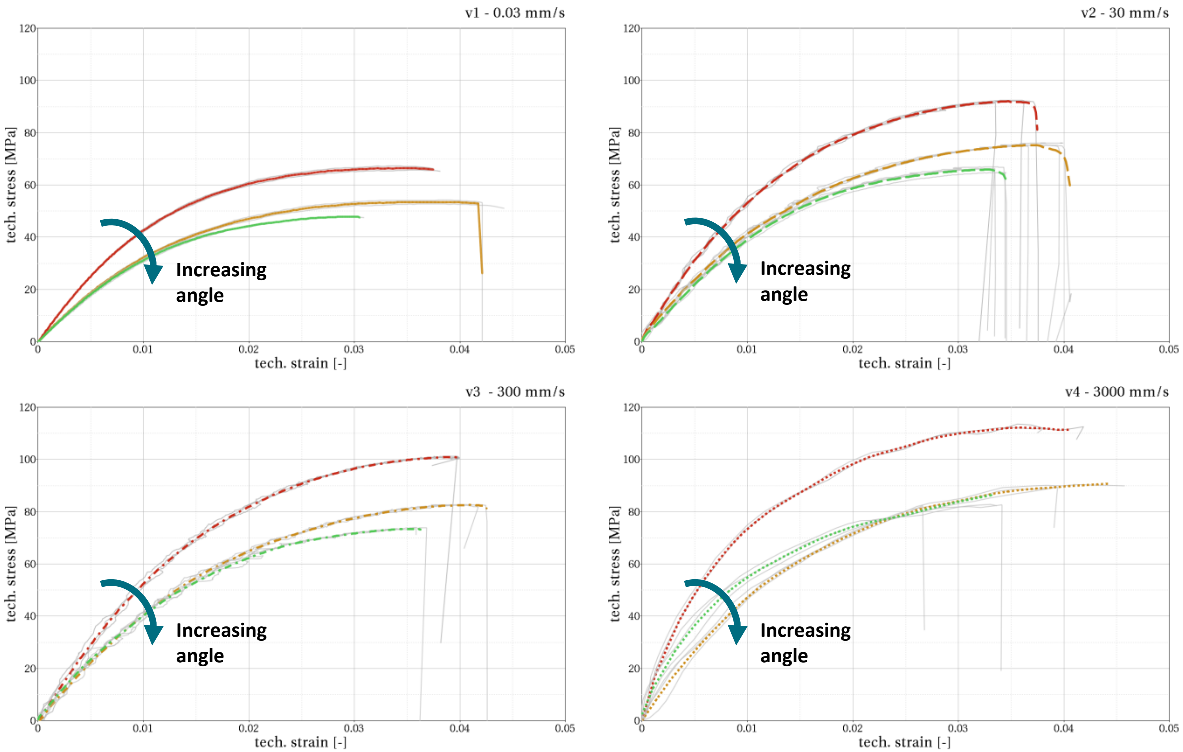




*MAT_157 MATERIAL CALIBRATION

- **Experimental results – tensile specimen position 5**
  - **a high degree of visco-elasticity is observed**
  - **intersection 45° and 90° curve at highest strain rate**





0 deg
45 deg
90 deg

*MAT_157 MATERIAL CALIBRATION

- *MAT_ANISOTROPIC_ELASIC_PLASTIC (*MAT_157)

CARD 1	mid	ro	sigy	lcss	qr1	cr1	qr2	cr2
CARD 2	c11	c12	c13	c14	c15	c16	c22	c23
CARD 3	c24	c25	c26	c33	c34	c35	c36	c44
CARD 4	c45	c46	c55	c56	c66	r00	r45	r90
CARD 5	s11	s22	s33	s12	aopt	vp		macf
CARD 6	xp	yp	zp	a1	a2	a3		
CARD 7	v1	v2	v3	d1	d2	d3	beta	ihis

- IHIS = a_3 x 8 + a_2 x 4 + a_1 x 2 + a_0 , $a_i \in 0, 1$
- AOPT = 0, initialize orientation and stiffness tensor using history variables using *INITIAL_STRESS_SHELL
- No damage and failure model included -> use of *MAT_ADD_EROSION

*MAT_157 MATERIAL CALIBRATION

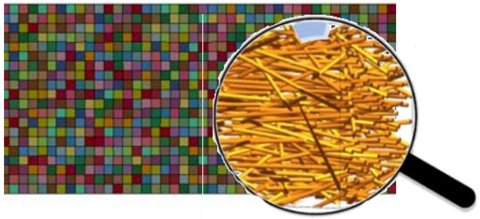
- *INITIAL_STRESS_SHELL

CARD 1	eid	nplane	nthick	nhisv	ntensor	large	nthint	nthhsv
CARD 2	t	sigxx	sigyy	sigzz	sigxy	sigyz	sigzx	eps
CARD 3	hisv1= q_1	hisv2= q_2	#3= C_{11}	#4= C_{12}	#5= C_{13}	#6= C_{14}	#7= C_{15}	#8= C_{16}
CARD 4	#9= C_{22}	#10= C_{23}	#11= C_{24}	#12= C_{25}	#13= C_{26}	#14= C_{33}	#15= C_{34}	#16= C_{35}
CARD 5	#17= C_{36}	#18= C_{44}	#19= C_{45}	#20= C_{46}	#21= C_{55}	#22= C_{56}	#23= C_{66}	#24=TBID

- example for shells , IHIS=11 ($a_3 = 1$, $a_1 = 1$, $a_0 = 1$)
  → NHISV=2+21+1=24

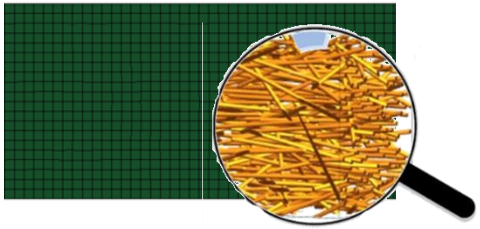
flag	description	variables	number
a_0	material directions	q_1, q_2	2
a_1	anisotropic elastic stiffness	C_{ij}	21
a_2	anisotropic plasticity	r_{00}, r_{45}, r_{90}	3
a_3	hardening curve	LCSS	1

In material card



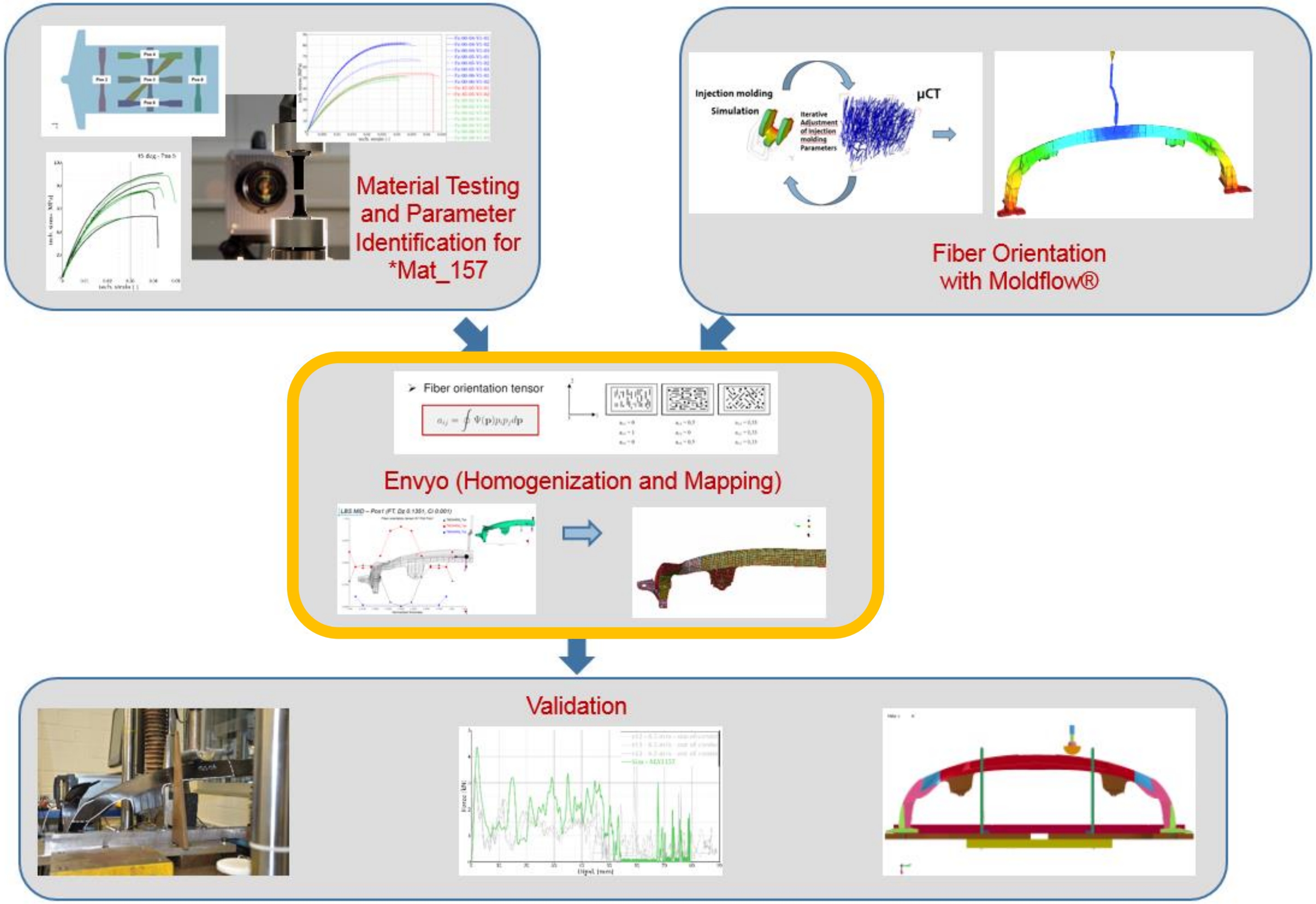
Needs individual part definition for every element

With *INITIAL_STRESS_SOLID



Only one part definition for whole component.

PROCESS CHAIN OVERVIEW

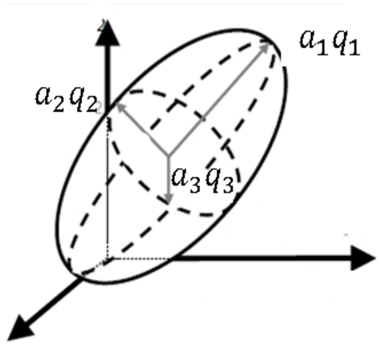


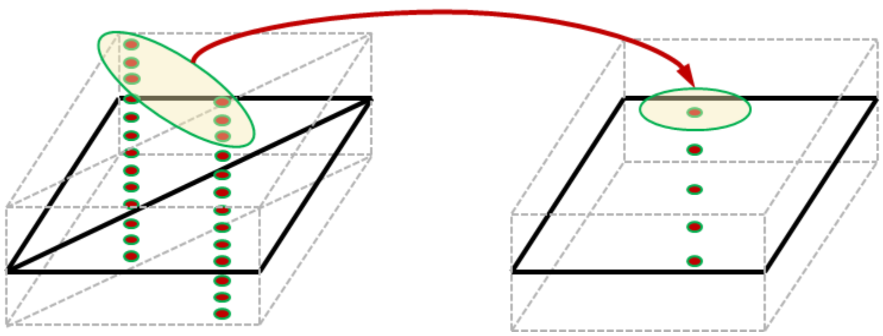
*MAT_157 MATERIAL CALIBRATION

- Data mapping using Envyo®:
  - Input:
    - unit systems for mesh transformation and scaling
    - source and target files, moldfow® *.xml - file
    - fiber and matrix elastic properties
    - target thickness, element type and number of through-thickness integration points
    - geometrical parameters (inclusion shape, aspect ratio)

fiber-orientation tensor 2nd order $\boldsymbol{a}$:

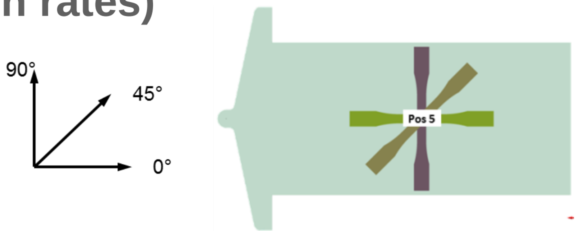
- eigenvectors q_i (main fiber directions)
- eigenvalues a_i (orientation probablity)



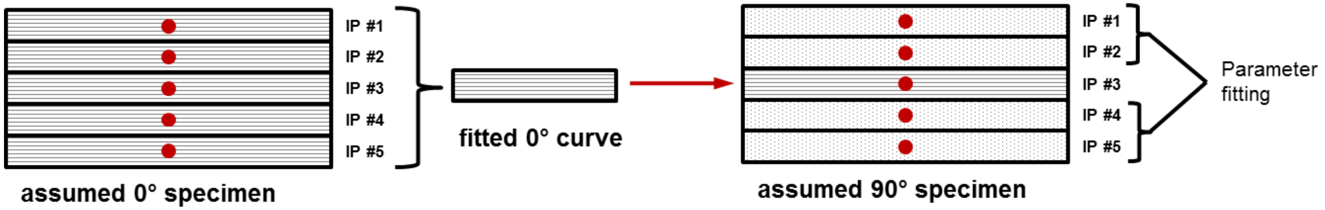


*MAT_157 MATERIAL CALIBRATION

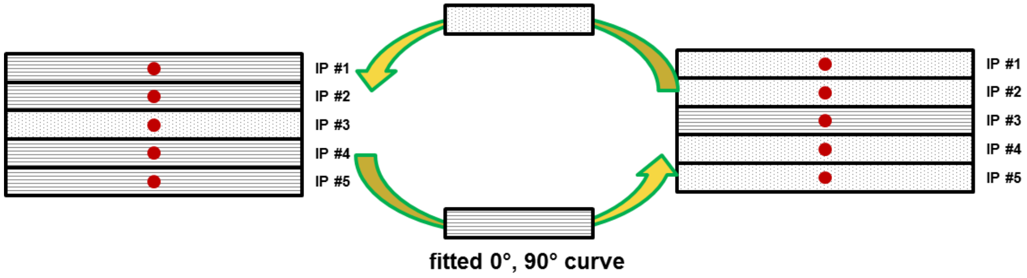
- Evaluate stiffness parameters of mapping input on experimental data (multi-directions at multiple strain rates)



- Derive plasticity curve for 0° specimen ignoring the skin-core effect and use it for the 90° specimen as an input.

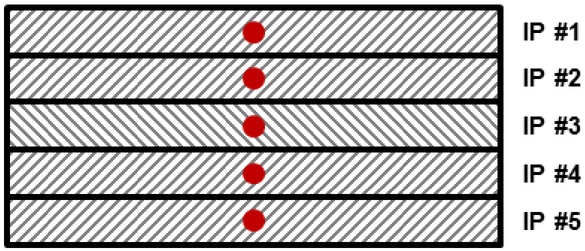


- Perform reverse engineering until results are satisfactory.

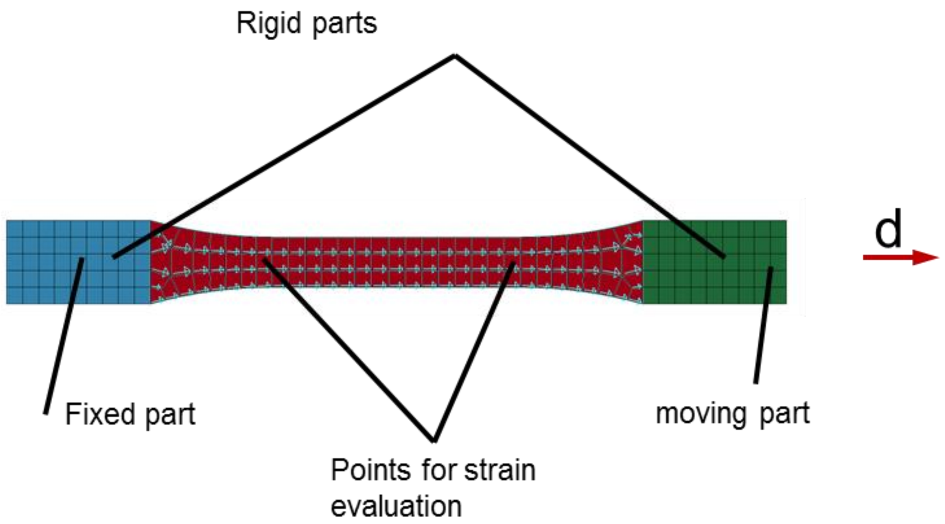


*MAT_157 MATERIAL CALIBRATION

- Repeat for multiple strain rates.

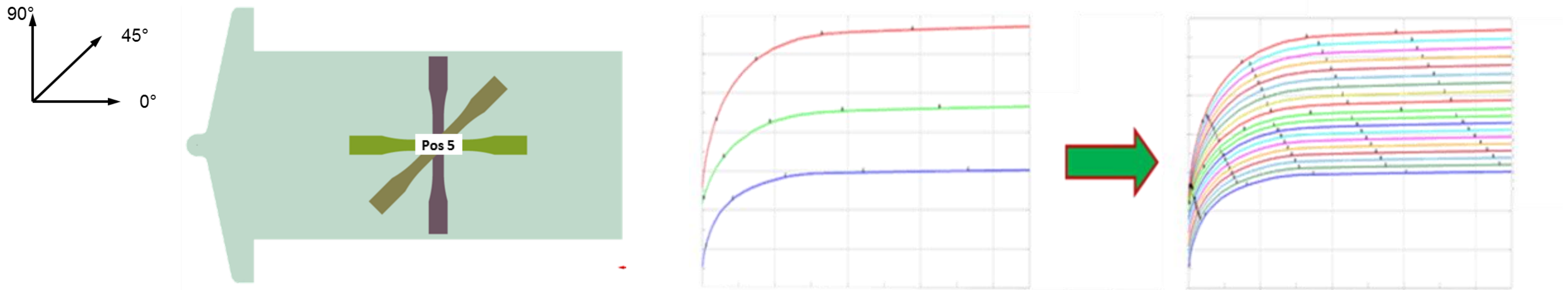


- Fit 45° curve independently.
- For proper data mapping, plasticity curves may not intersect.
- Finally, perform parameter fitting for damage and failure using *MAT_ADD_EROSION.
  - 0° failure is stress based
  - 90° failure is strain based
  - Evaluate on 45° results

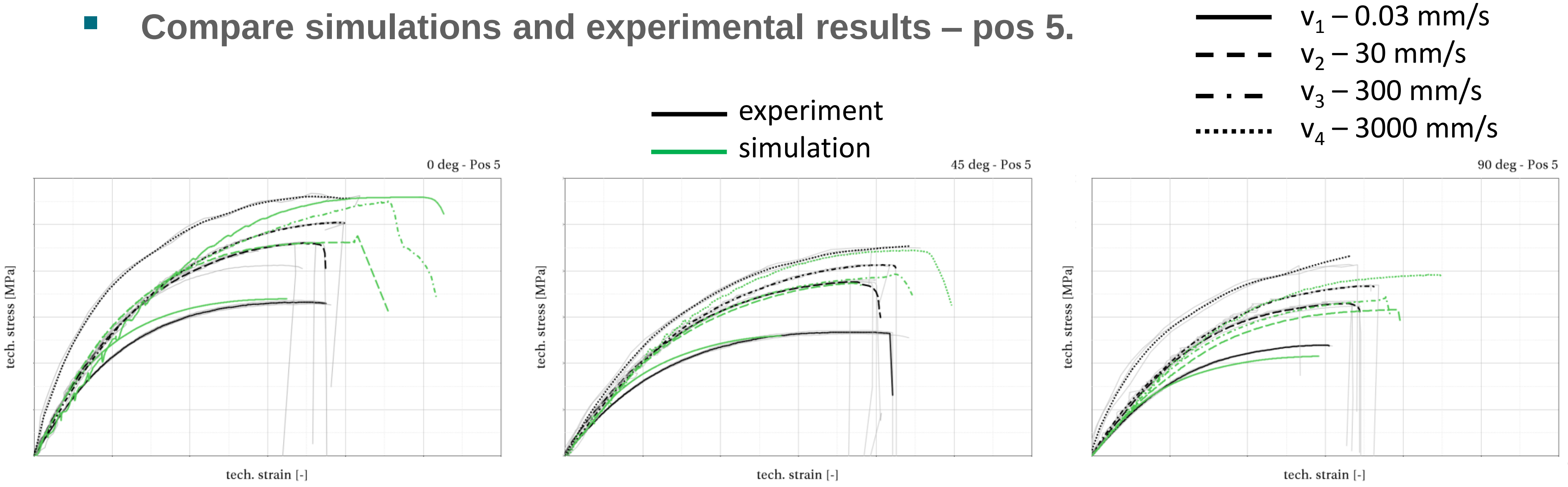


*MAT_157 MATERIAL CALIBRATION

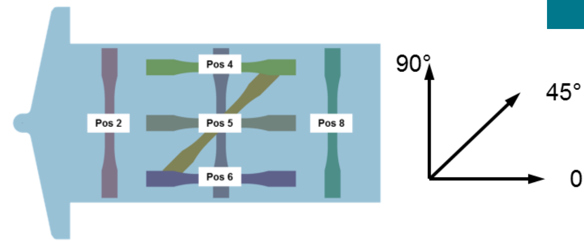
- Estimate remaining plasticity curves using linear interpolation.



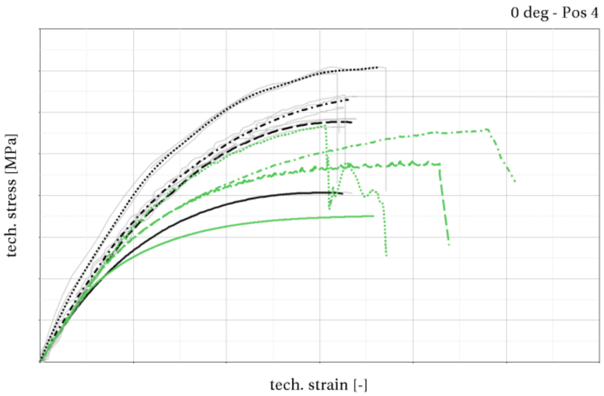
- Compare simulations and experimental results – pos 5.

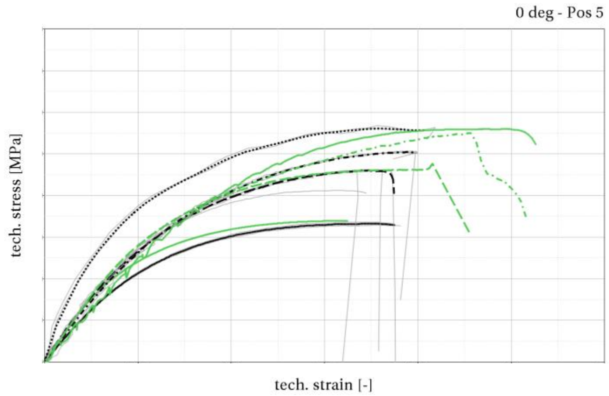


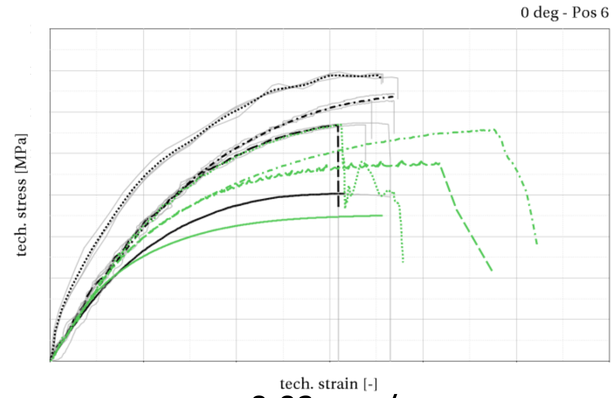
RESULTS TENSILE SPECIMEN



- 0° results, pos. 4, pos. 5 & pos. 6

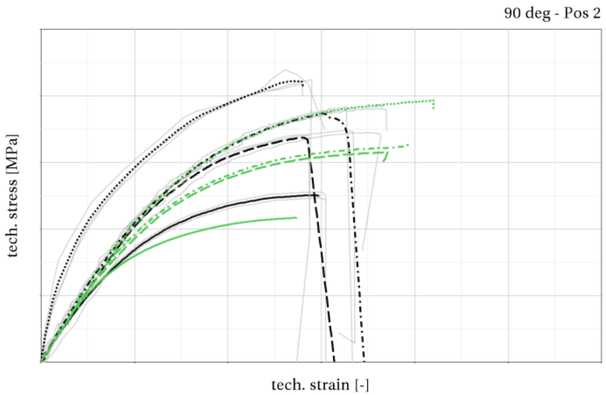


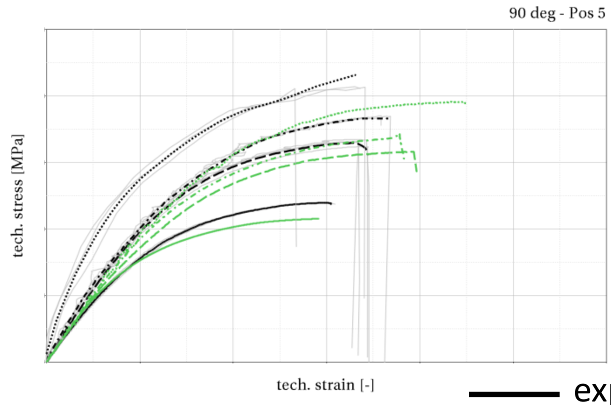


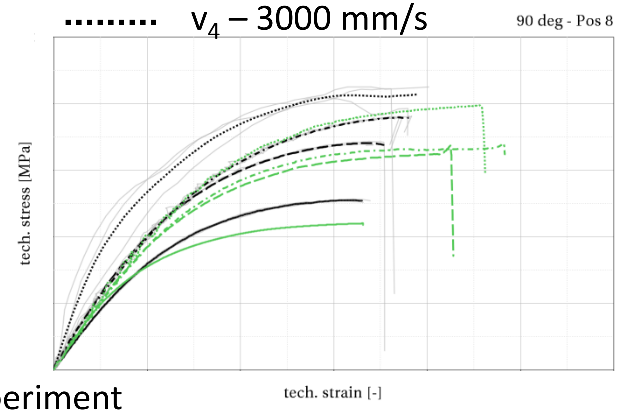


- 90° results, pos. 2, pos. 5 & pos. 8

v_1 – 0.03 mm/s
v_2 – 30 mm/s
v_3 – 300 mm/s
v_4 – 3000 mm/s



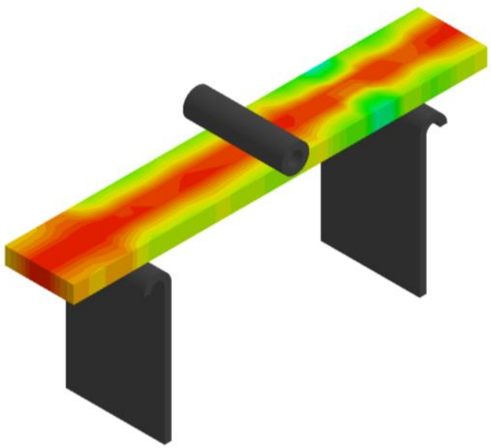


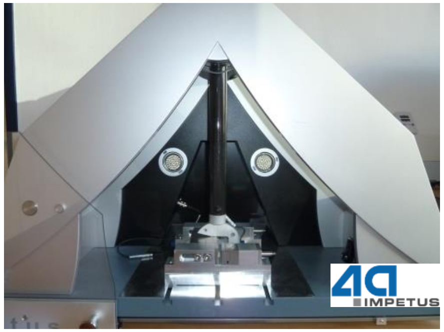


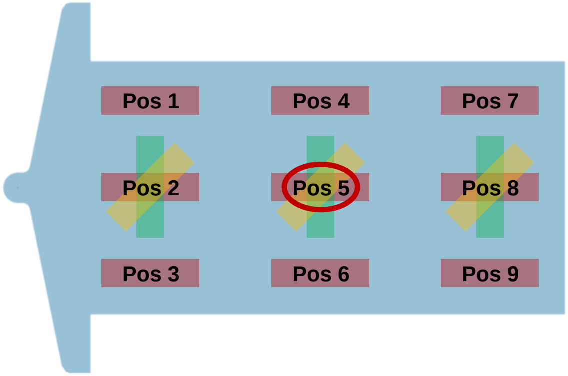
experiment
simulation

RESULTS TENSILE SPECIMEN

- Evaluate on three-point bending tests

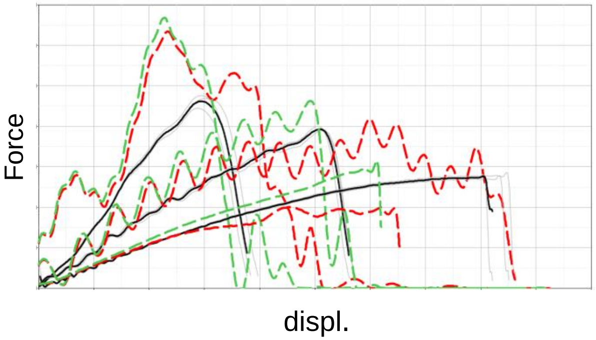




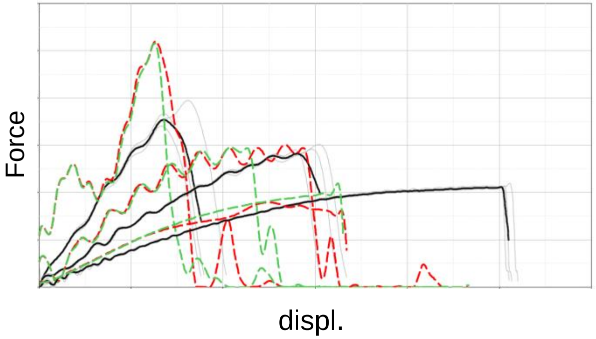


Experiment
*MAT_157 – simulation - ETYP 16
*MAT_157 – simulation - ETYP 2

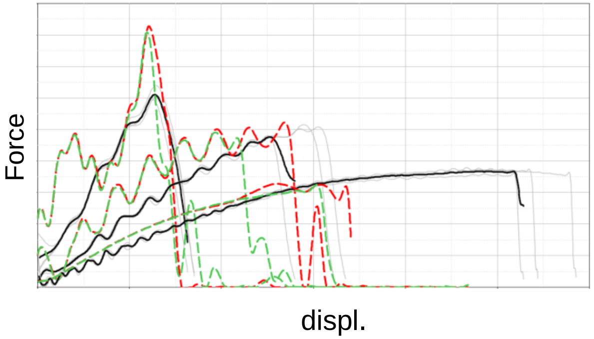
0 deg



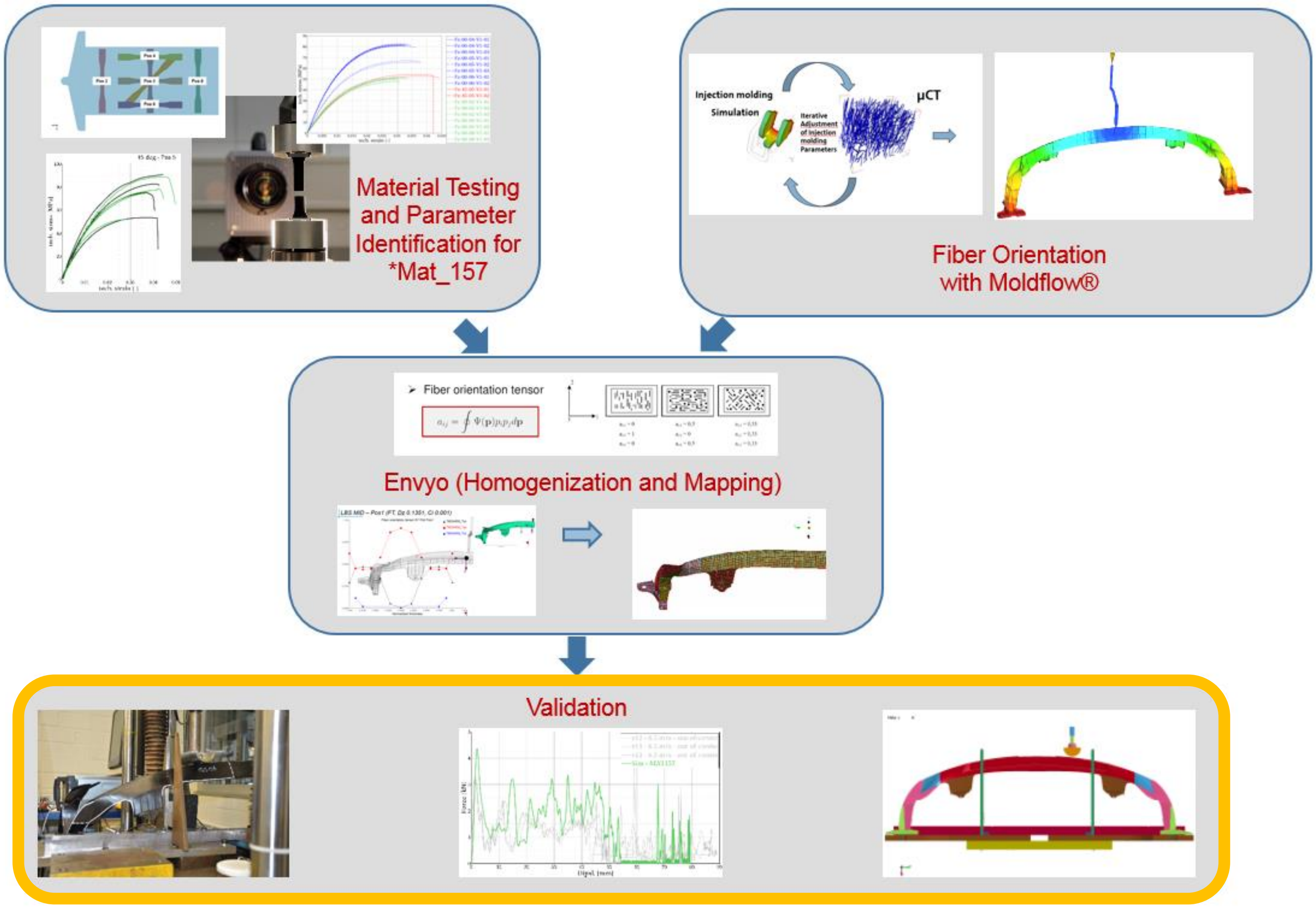
45 deg



90 deg

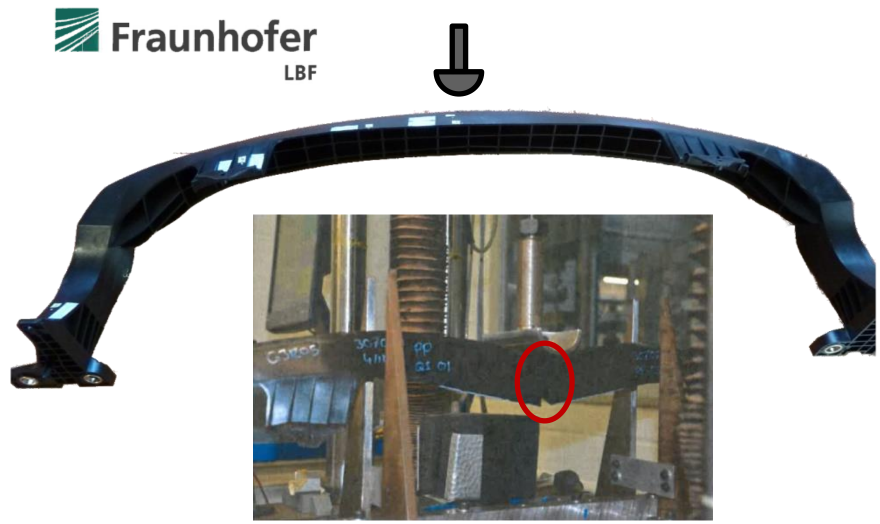


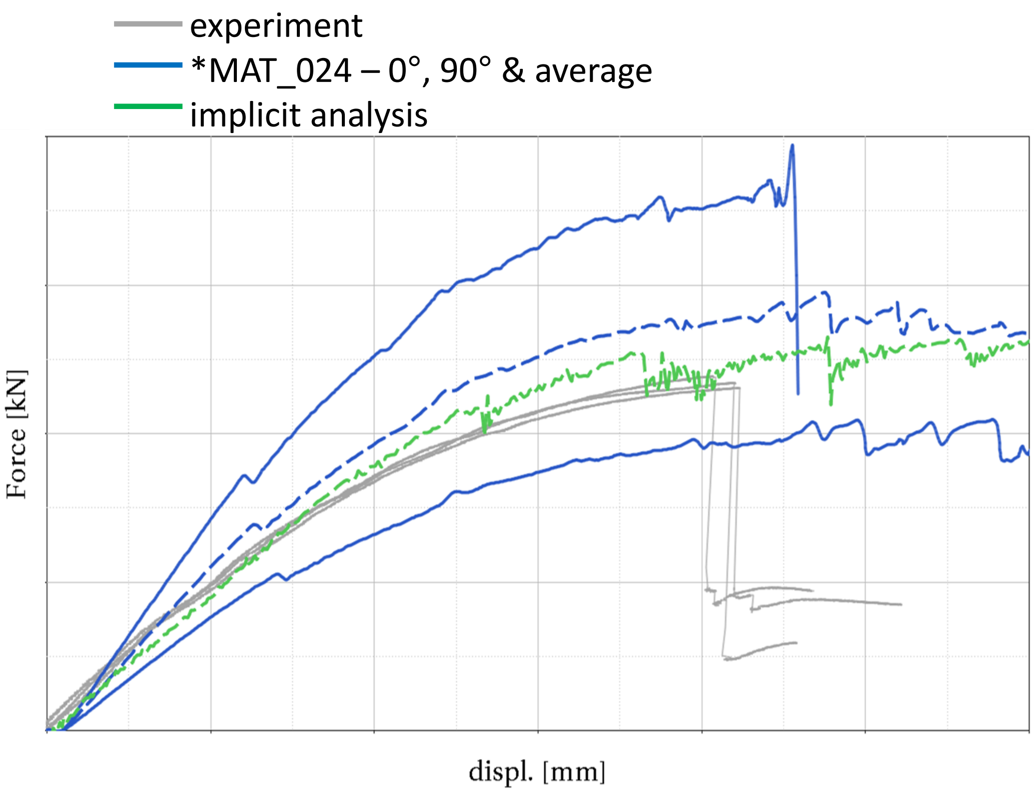
PROCESS CHAIN OVERVIEW

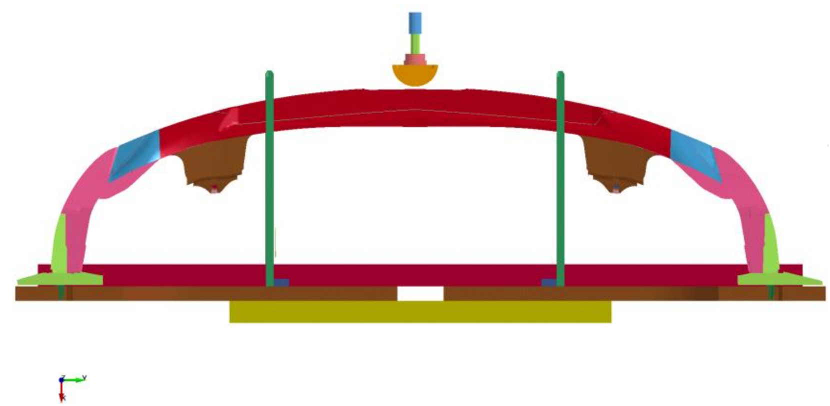


RESULTS COMPONENT

- qs – center position
  - breakage under the impactor
  - failure turned off for simulation

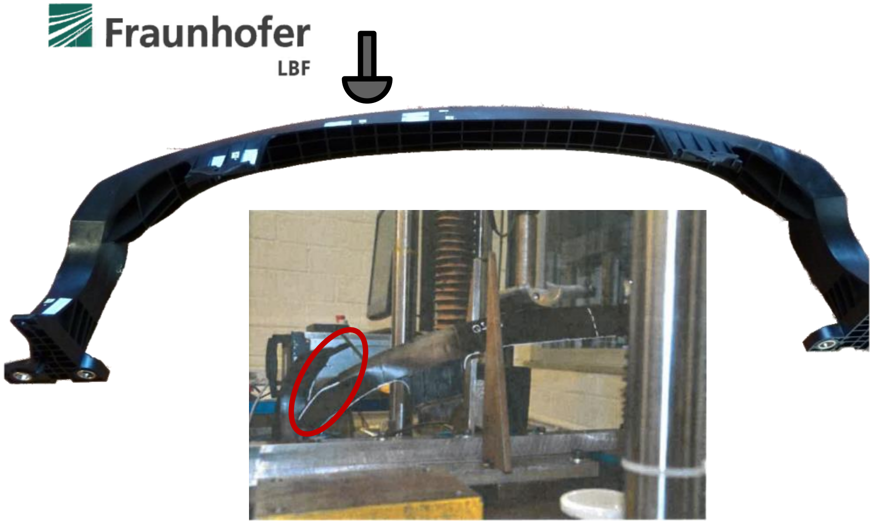


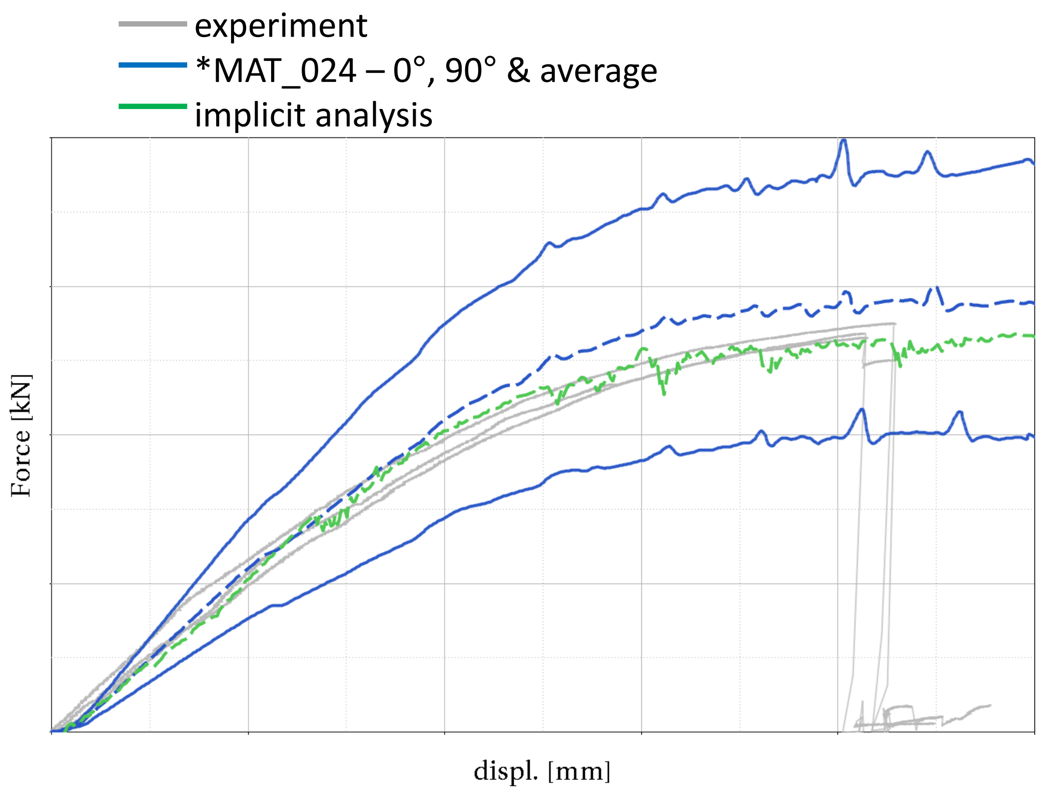


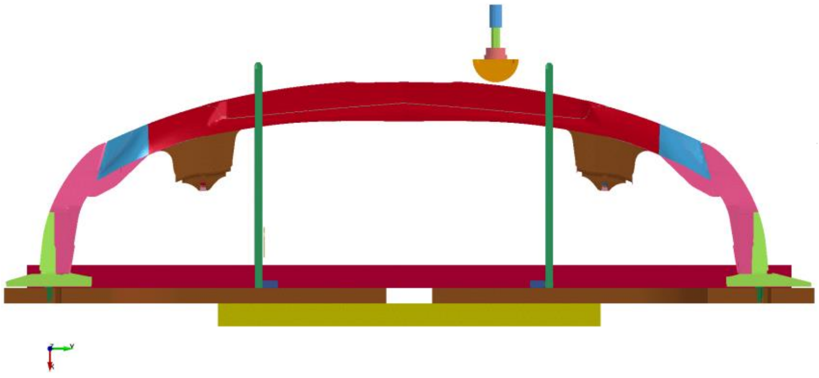


RESULTS COMPONENT

- qs – out-of-center position
  - breakage on the outside
  - failure turned off for simulation

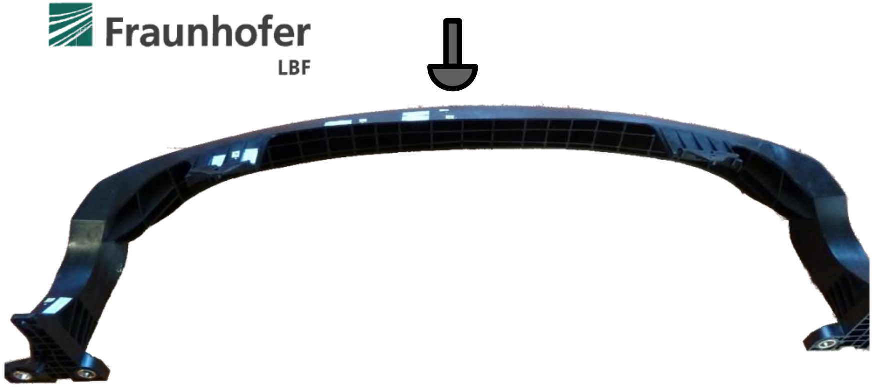




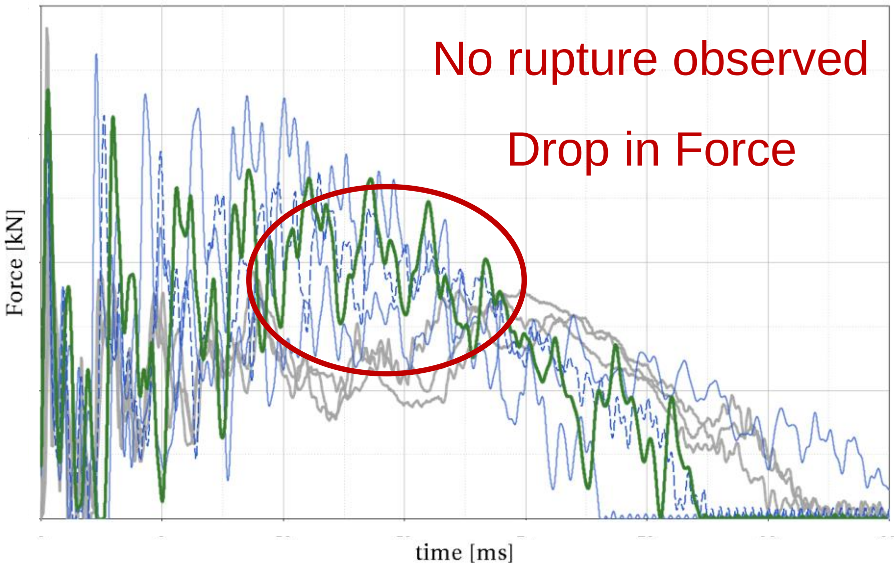


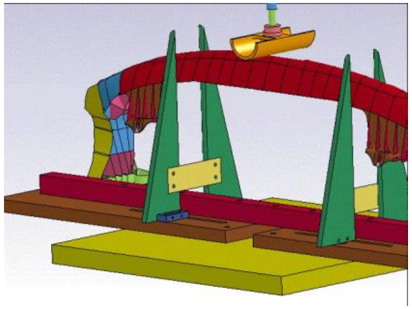
RESULTS COMPONENT

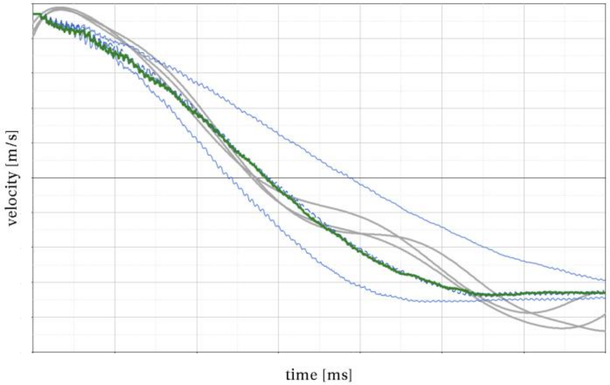
Fraunhofer LBF

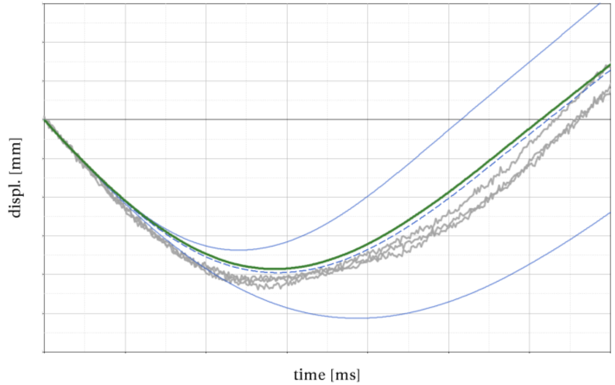


- 5.5 – center position





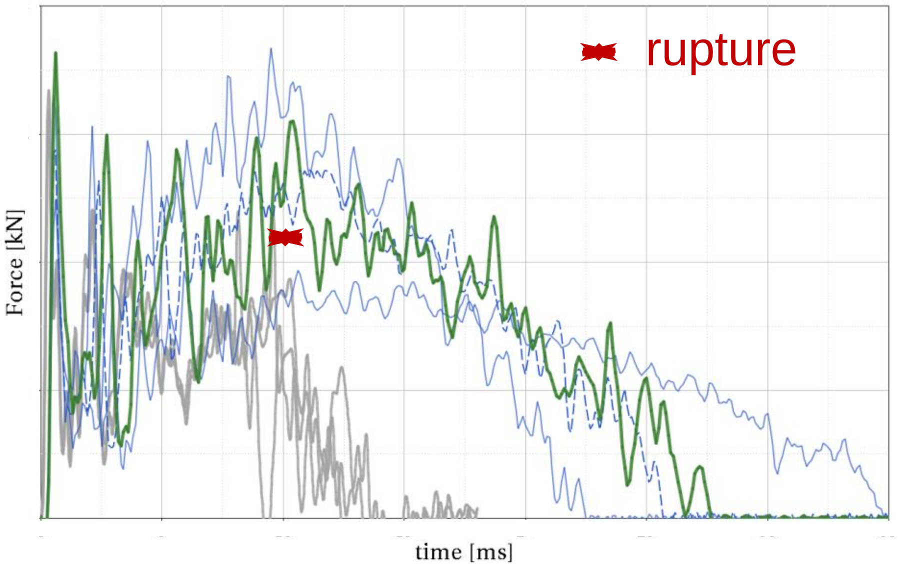


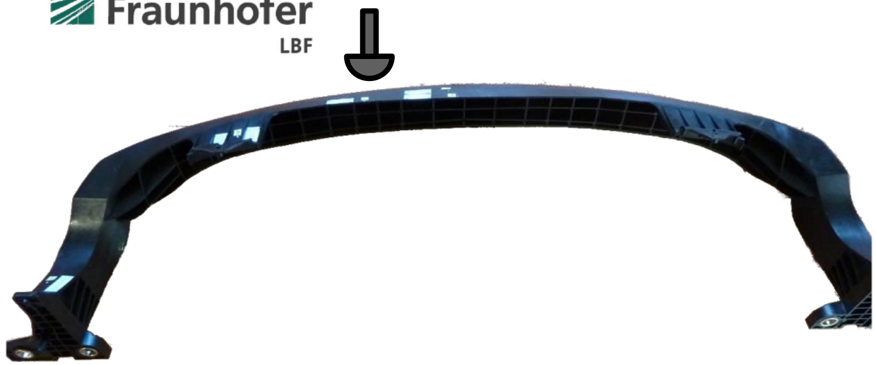


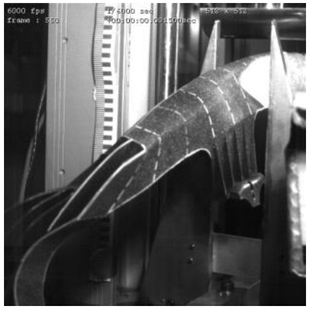
- experiment
- *MAT_024 – 0°, 90° & average
- Simulation

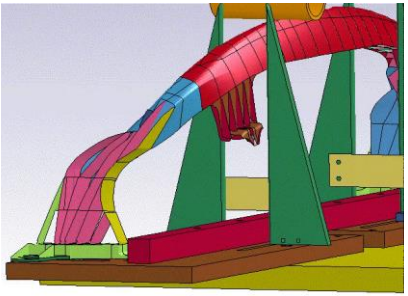
RESULTS COMPONENT

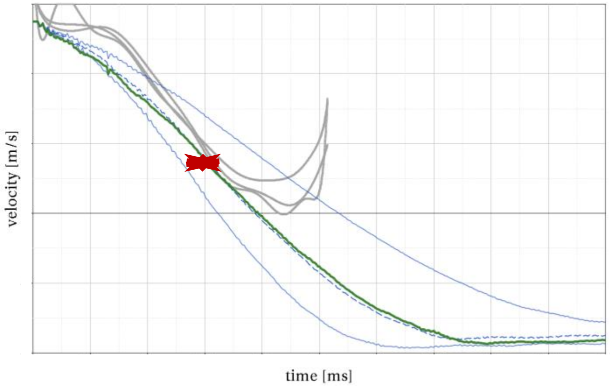
- 6.5 – out-of-center position

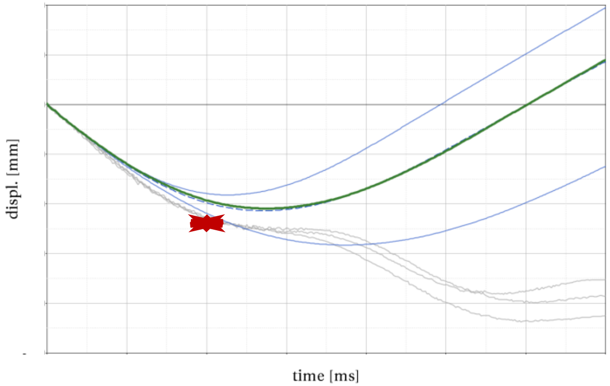












experiment
*MAT_024 – 0°, 90° & average
Simulation

CONCLUSION AND OUTLOOK

- A method to consider anisotropy induced through an injection molding process in fiber reinforced plastic components has been introduced.
- Results from Moldflow® simulations can be used for homogenization and calibration of the material model *MAT_157 in LS-DYNA, using the mapping software Envyo ®.
- The developed strategy has been evaluated of dumpbell specimen and on component level, with satisfying results for stiffness, displacement and velocity output.
- Further investigation will be made, using the newly introduced anisotropic failure criteria Tsai-Wu and Tsai-Hill within the *MAT_157 material model.

CONCLUSION AND OUTLOOK

- *MAT_ANISOTROPIC_ELASIC_PLASTIC (*MAT_157)

CARD 1	mid	ro	sigy	**lcss**	qr1	cr1	qr2	cr2
CARD 2	c11	c12	c13	c14	c15	c16	c22	c23
CARD 3	c24	c25	c26	c33	c34	c35	c36	c44
CARD 4	c45	c46	c55	c56	c66	r00	r45	r90
CARD 5	s11	s22	s33	s12	aopt	vp		macf
CARD 6	xp	yp	zp	a1	a2	a3		**EXTRA**
CARD 7	v1	v2	v3	d1	d2	d3	beta	ihis
CARD 8	**XT**	**XC**	**YT**	**YC**	**SXY**	**FF12**		**NCFAIL**
CARD 9	**ZT**	**ZC**	**SYZ**	**SZX**	**FF23**	**FF31**		

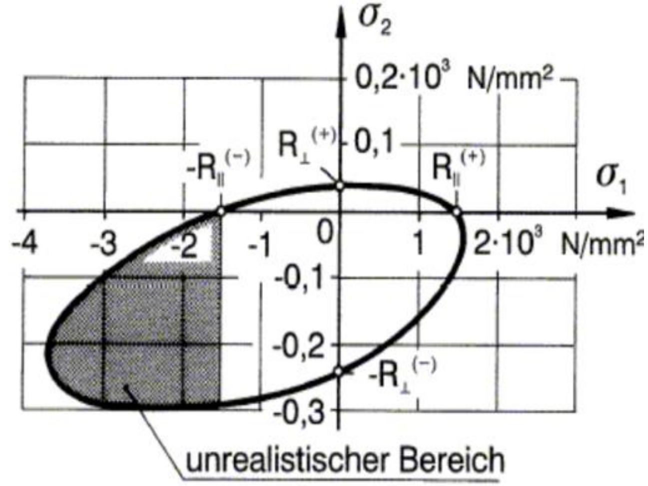
- EXTRA = 1 / 2 – triggers the usage of the Tsai-Wu or Tsai-Hill failure criterion
- Failure stresses can be defined strain rate dependent

CONCLUSION AND OUTLOOK

- EXTRA = 1 - Tsai-Wu failure criterion

$$\left(\frac{1}{XT}-\frac{1}{XC}\right)\sigma_{aa}+\left(\frac{1}{YT}-\frac{1}{YC}\right)\sigma_{bb}+\left(\frac{1}{ZT}-\frac{1}{ZC}\right)\sigma_{cc}$$
$$+\frac{1}{XT\cdot XC}\sigma_{aa}{}^{2}+\frac{1}{YT\cdot YC}\sigma_{bb}{}^{2}+\frac{1}{ZT\cdot ZC}\sigma_{cc}{}^{2}+\frac{1}{SXY^{2}}\sigma_{ab}{}^{2}+\frac{1}{SYZ^{2}}\sigma_{bc}{}^{2}+\frac{1}{SZX^{2}}\sigma_{ca}{}^{2}$$
$$+2\cdot F_{12}\cdot\sigma_{aa}\cdot\sigma_{bb}+2\cdot F_{23}\cdot\sigma_{bb}\cdot\sigma_{cc}+2\cdot F_{31}\cdot\sigma_{cc}\cdot\sigma_{aa}<1$$

with: $F_{12}=FF12\cdot\sqrt{\frac{1}{XT\cdot XC\cdot YT\cdot YC}}$, $F_{23}=FF23\cdot\sqrt{\frac{1}{YT\cdot YC\cdot ZT\cdot ZC}}$, $F_{23}=FF23\cdot\sqrt{\frac{1}{YT\cdot YC\cdot ZT\cdot ZC}}$



CONCLUSION AND OUTLOOK

- EXTRA = 2 - Tsai-Hill failure criterion

$$(G+H)\cdot\sigma_{aa}^{2}+(F+H)\cdot\sigma_{bb}^{2}+(F+G)\cdot\sigma_{cc}^{2}-2H\sigma_{aa}\sigma_{bb}-2F\sigma_{bb}\sigma_{cc}-2G\sigma_{cc}\sigma_{aa}$$
$$+2N\sigma_{ab}^{2}+2L\sigma_{bc}^{2}+2M\sigma_{ca}^{2}<1$$

with: $G+H=\frac{1}{X_i^2}$, $F+H=\frac{1}{Y_i^2}$, $F+G=\frac{1}{Z_i^2}$, $2N=\frac{1}{SXY^2}$, $2L=\frac{1}{SYZ^2}$, $2M=\frac{1}{SZX^2}$

$$H=0.5\cdot\left(\frac{1}{X_i^2}+\frac{1}{Y_i^2}-\frac{1}{Z_i^2}\right),\quad F=0.5\cdot\left(\frac{1}{Y_i^2}+\frac{1}{Z_i^2}-\frac{1}{X_i^2}\right),\quad G=0.5\cdot\left(\frac{1}{X_i^2}+\frac{1}{Z_i^2}-\frac{1}{Y_i^2}\right)$$

$$X_i=\begin{cases}XT & if \quad \sigma_{aa}>0\\ XC & if \quad \sigma_{aa}<0\end{cases},\quad Y_i=\begin{cases}YT & if \quad \sigma_{bb}>0\\ YC & if \quad \sigma_{bb}<0\end{cases},\quad Z_i=\begin{cases}ZT & if \quad \sigma_{cc}>0\\ ZC & if \quad \sigma_{cc}<0\end{cases}$$