OPEL

CLOSED SIMULATION PROCESS CHAIN FOR SHORT FIBER REINFORCED PLASTIC COMPONENTS WITH LS-DYNA®

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1. OVERVIEW OVER THE PROCESS CHAIN

2. EXPERIMENTAL STUDY

3. MOLDFLOW AND CALIBRATION

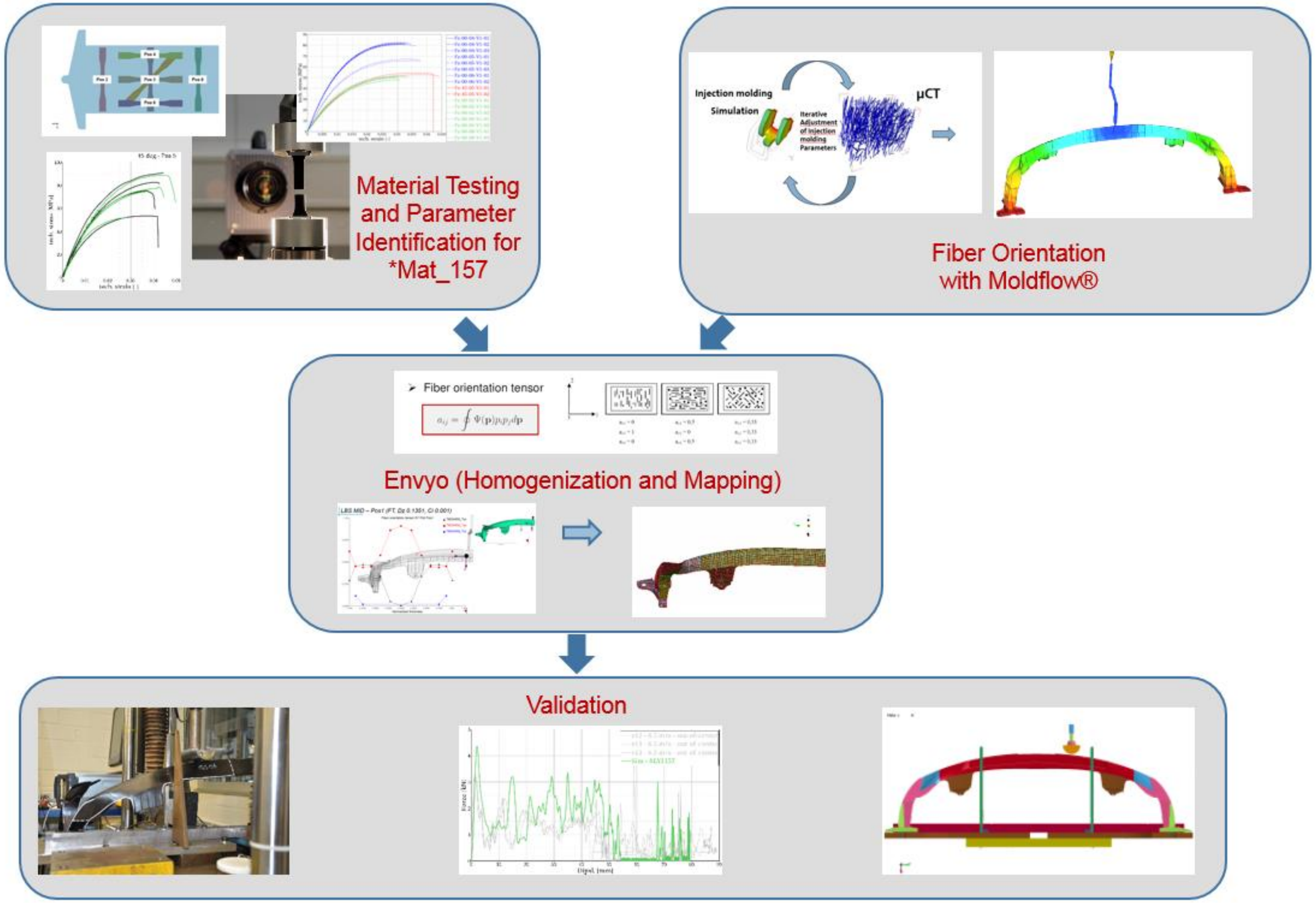
4. *MAT_157 – MATERIAL CALIBRATION AND DATA MAPPING

5. RESULTS

6. OUTLOOK AND CONCLUSION

OVERVIEW OVER THE PROJECT CHAIN

- Process Chain



EXPERIMENTAL STUDY.

- quasi-static and dynamic tensile tests

  5 different positions on a plate

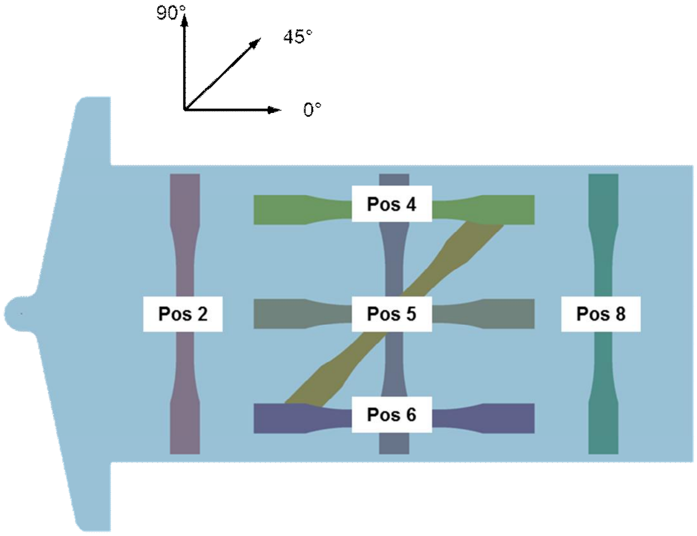
  4 different strain rates

  - 0.03 mm/s
  - 30 mm/s
  - 300 mm/s
  - 3000 mm/s

  3 different directions

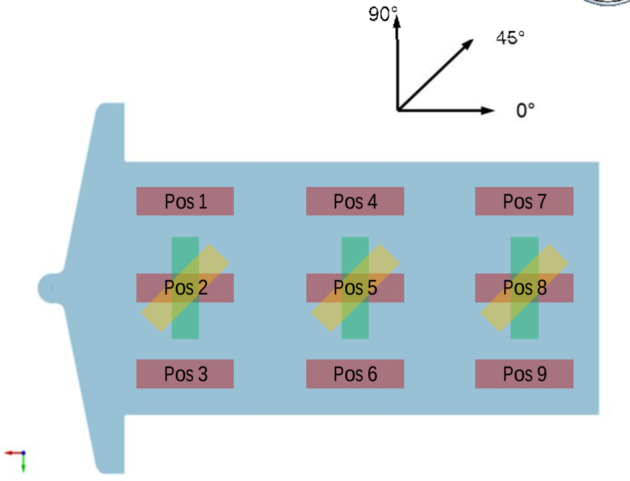
  Fraunhofer EMI

- position 5 from tensile specimen chosen for reverse engineering and material calibration
- other positions used for evaluation purposes



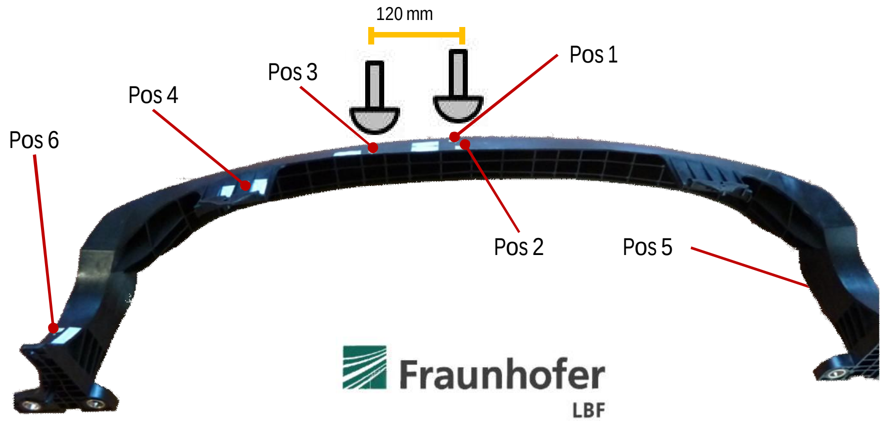
EXPERIMENTAL STUDY

- three point bending tests
  9 different positions
  3 different strain rates
  3 different directions



- qs and dynamic component tests
  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



Fraunhofer LBF

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

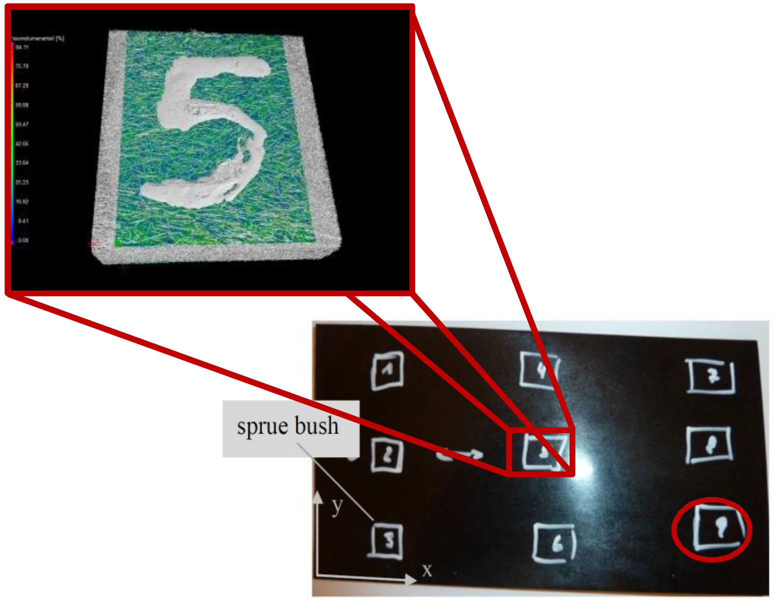


Fig. 1: Positions of specimen for CT-Scan.

MOLDFLOW ANALYSIS AND CALIBRATION

- two different Moldflow approaches were evaluated:

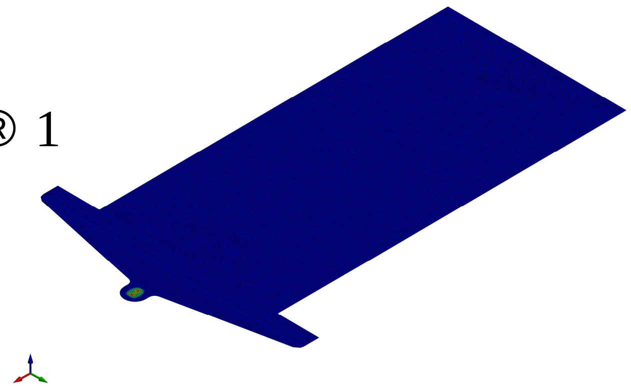
  Folgar-Tucker method:

  - 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: $\kappa \rightarrow 1$

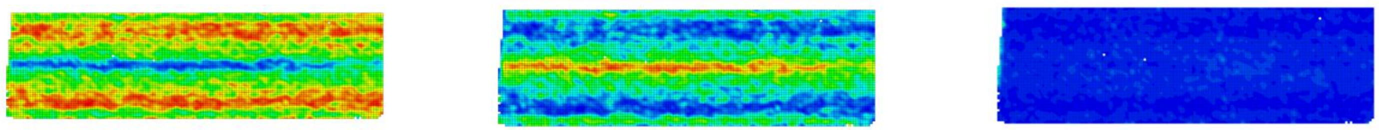


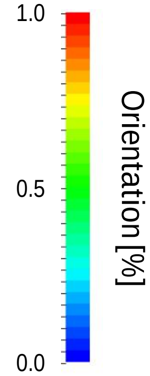
$$\frac{Da_{ij}}{Dt} = -\frac{1}{2}(\omega_{ik} a_{kj} - a_{ik}\omega_{kj})$$
$$+\frac{1}{2}\lambda(\dot{\gamma}_{ik} a_{kj} + a_{ik}\dot{\gamma}_{kj} - 2[a_{ijkl} + (1-\kappa)(L_{ijkl} - M_{ijmn}a_{mnkl})]\dot{\gamma}_{kl})$$
$$+2\kappa C_i\dot{\gamma}(\delta_{ij} - 3a_{ij})$$

MOLDFLOW ANALYSIS AND CALIBRATION

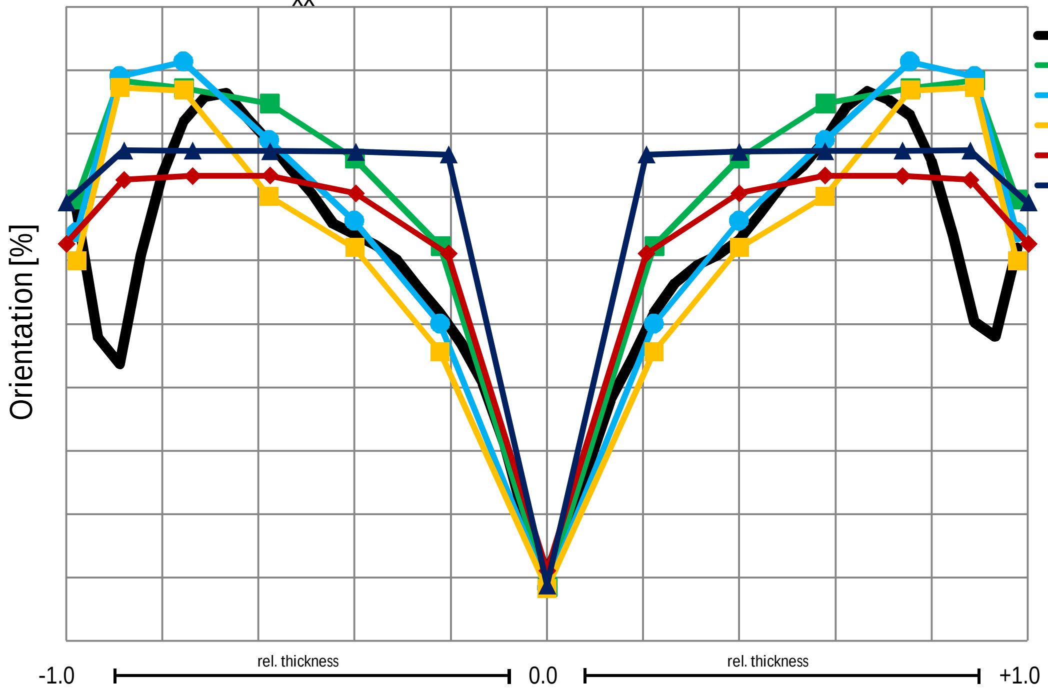
- analysis of µ-CT – scan data & comparison with Moldflow – Position 5:

a_xx a_yy a_zz





Tensor data A_{xx} Measurement vs. Simulation



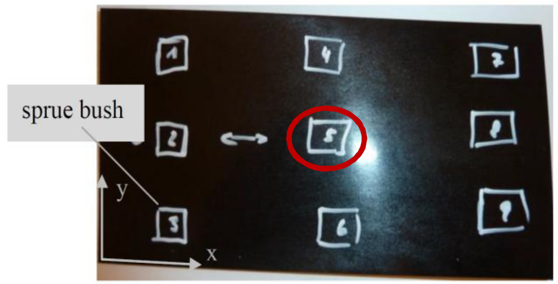
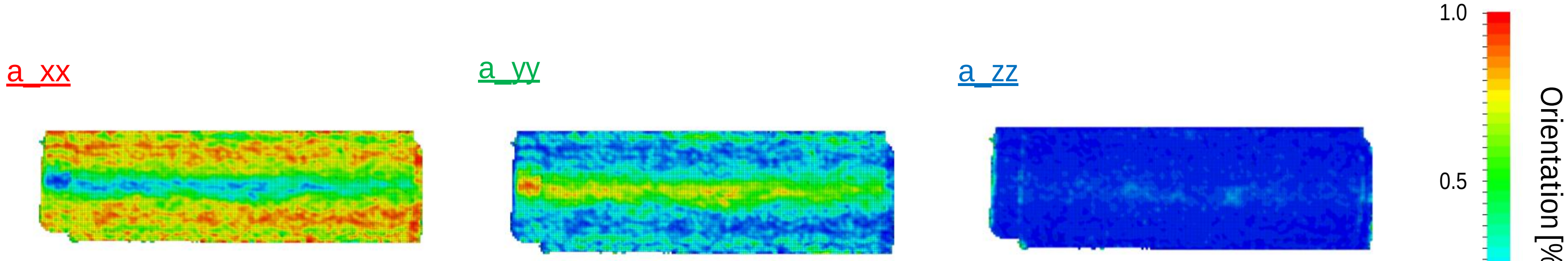


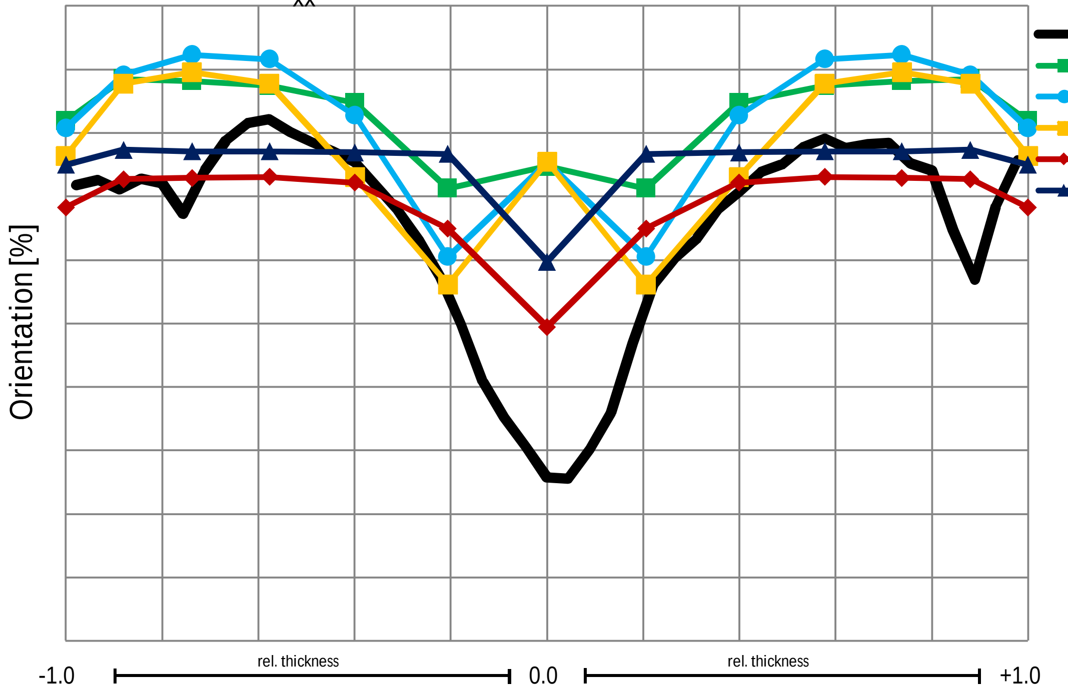
Fig. 1: Positions of specimen for CT-Scan.

MOLDFLOW ANALYSIS AND CALIBRATION

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



Tensor data A_{xx} Measurement vs. Simulation



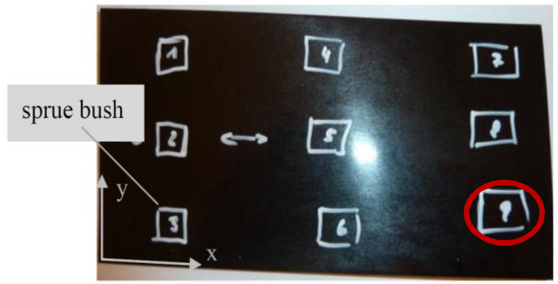
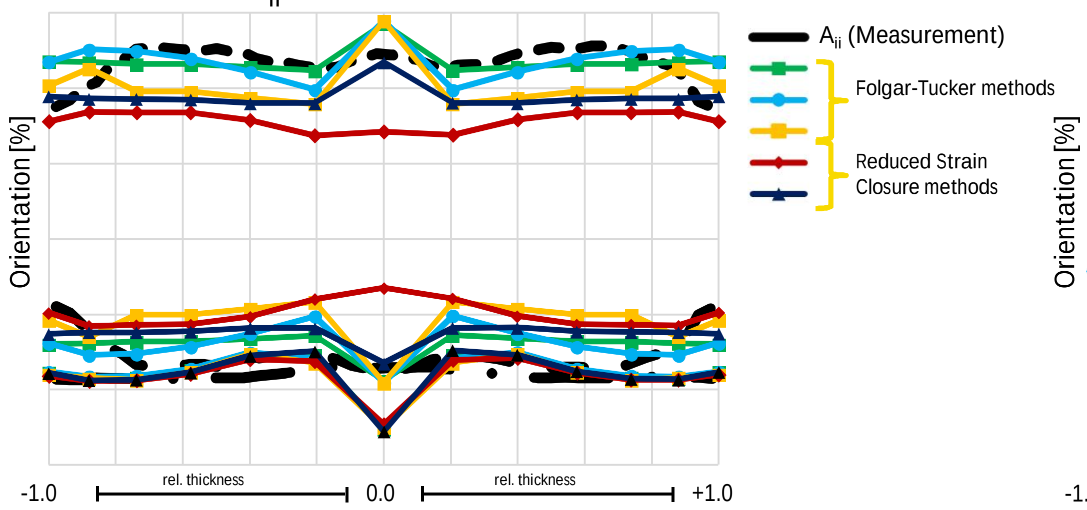


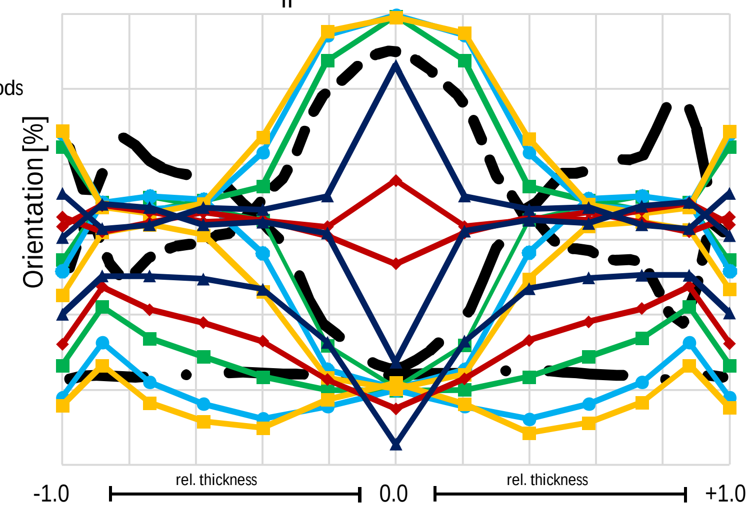
Fig. 1: Positions of specimen for CT-Scan.

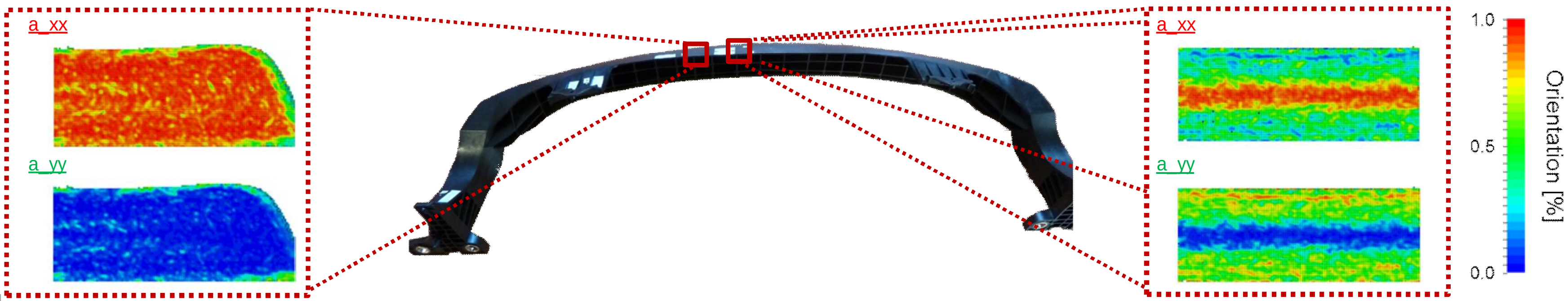
MOLDFLOW ANALYSIS AND CALIBRATION

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

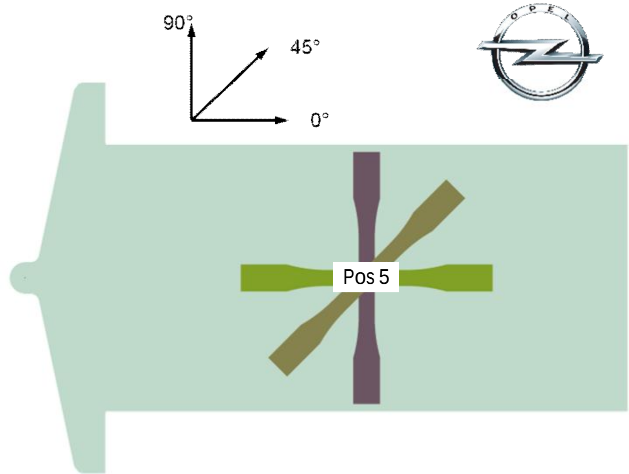
component position 3 | component position 1



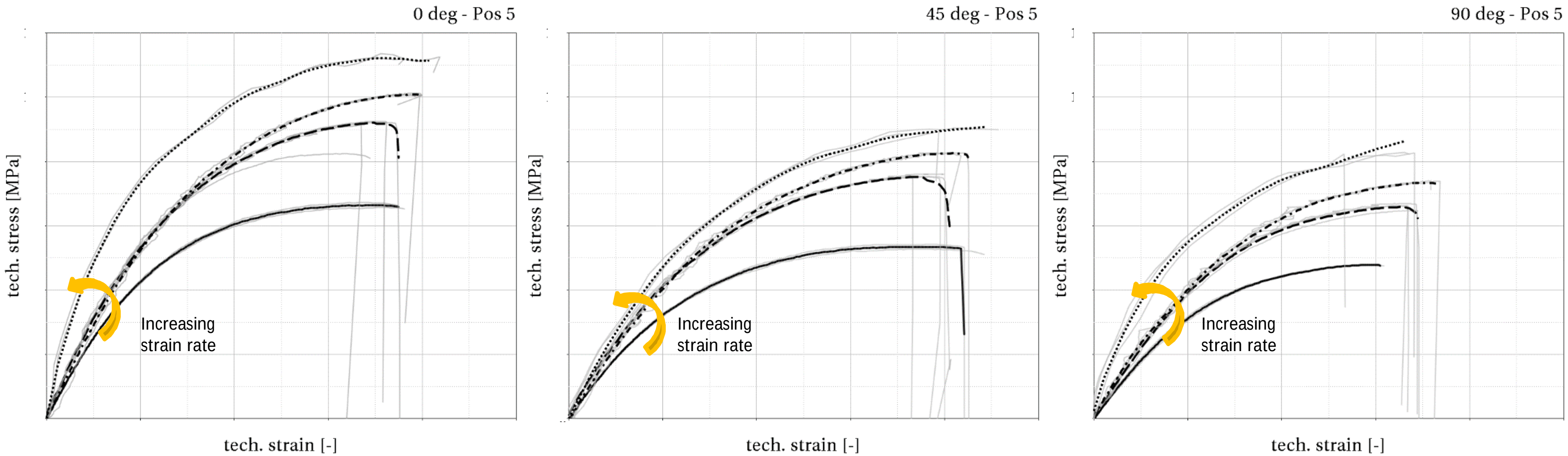




*MAT_157 – MATERIAL CALIBRATION

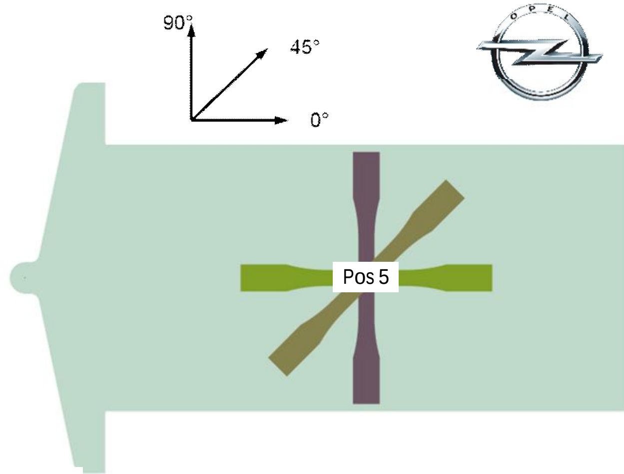


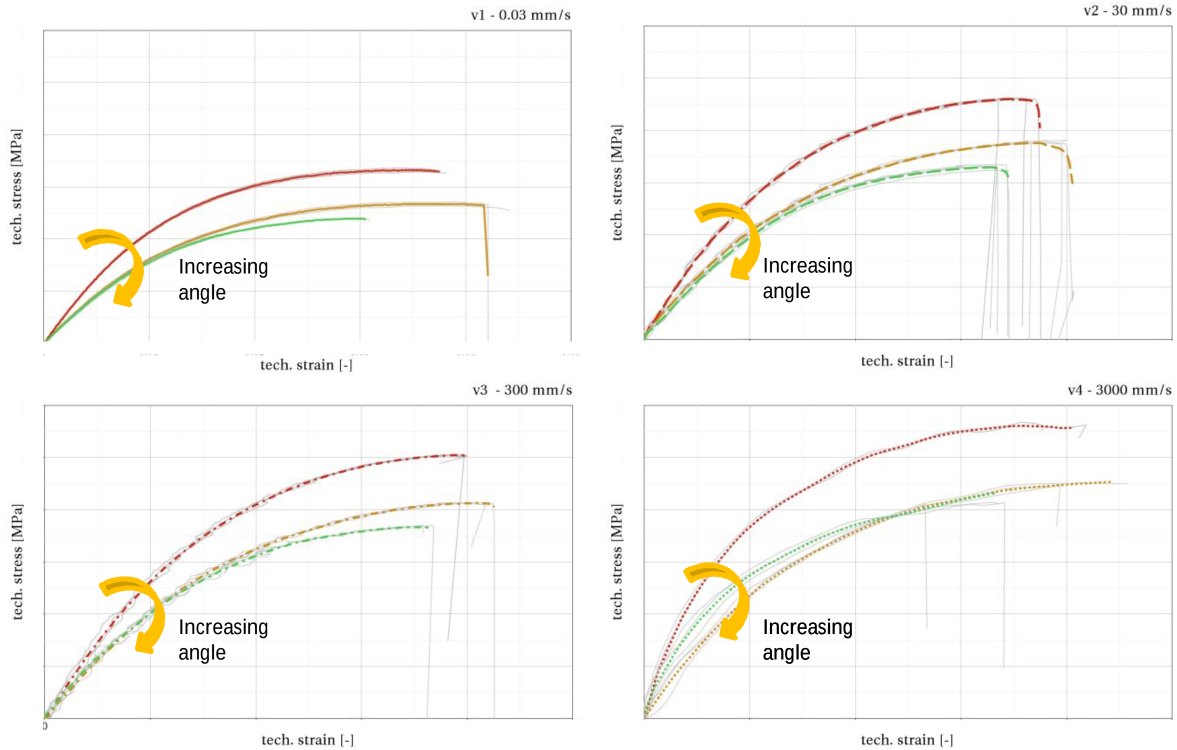
- Experimental results – tensile specimen position 5
  a high degree of visco-elasticity is observed



*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

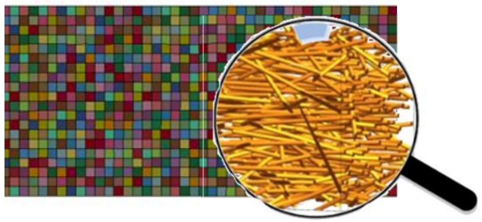
CARD 1	eid	nplane	nthick	nhisv	ntensor	large	nthint	nthhsv
CARD 2	t	sigxx	sigyy	sigzz	sigxy	sigyz	sigzx	eps
CARD 3	hisv1= q_1	hisv2= q_2	#3= C_{11}	#4= C_{12}	#5= C_{13}	#6= C_{14}	#7= C_{15}	#8= C_{16}
CARD 4	#9= C_{22}	#10= C_{23}	#11= C_{24}	#12= C_{25}	#13= C_{26}	#14= C_{33}	#15= C_{34}	#16= C_{35}
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 ($a_3 = 1$, $a_1 = 1$, $a_0 = 1$)

à 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.

*MAT_157 – MATERIAL CALIBRATION

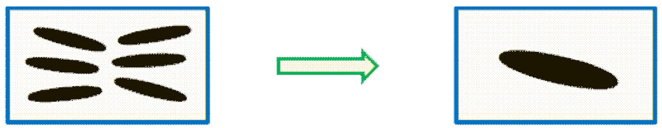
- Data mapping using Envyo®:

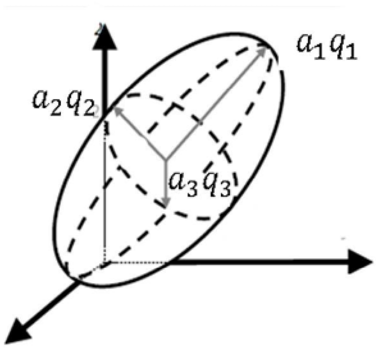
  Input:

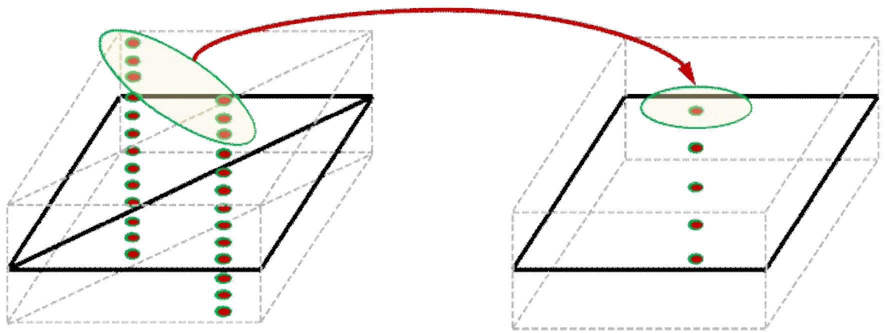
  - unit systems for mesh transformation and scaling
  - source and target files, moldflow® *.xml - file
  - fiber and matrix elastic properties
  - target thickness, element type and number of through-thickness integration points
  - geometrical parameters (inclusion shape, aspect ratio)

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

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

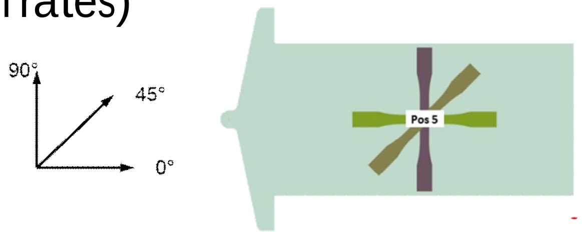




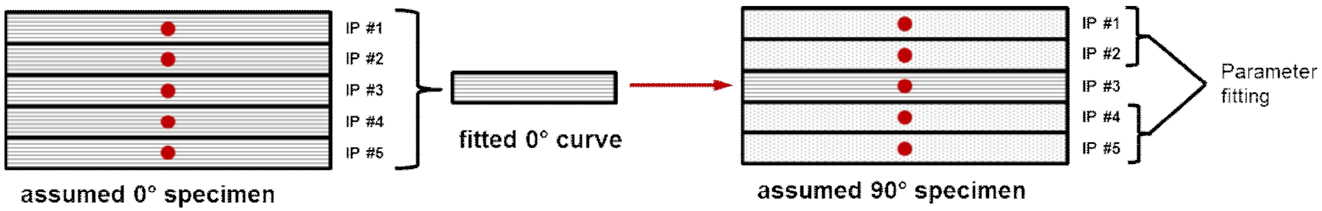


*MAT_157 – MATERIAL CALIBRATION

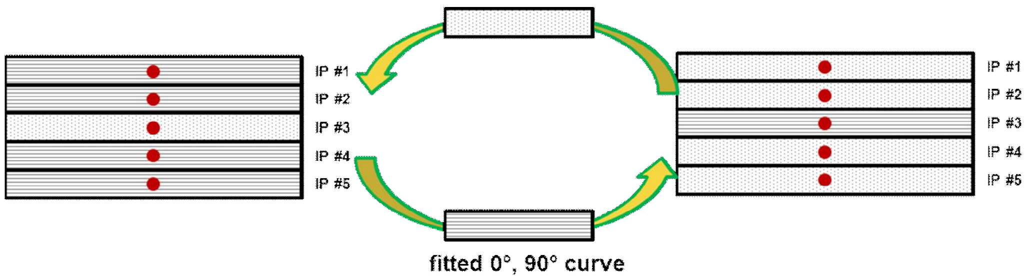
- Evaluate stiffness parameters of mapping input on experimental data (multi-directions at multiple strain rates)



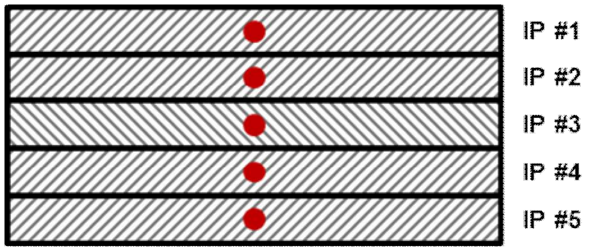
- Derive plasticity curve for 0° specimen ignoring the skin-core effect and use it for the 90° specimen as an input.



- Perform reverse engineering until results are satisfactory.



*MAT_157 – MATERIAL CALIBRATION

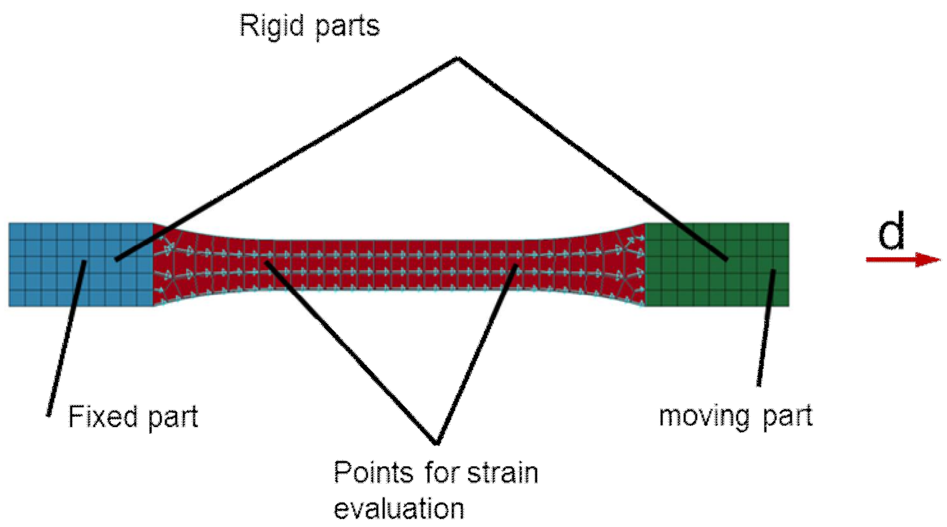


- Repeat for multiple strain rates.

- Fit 45° curve independently.

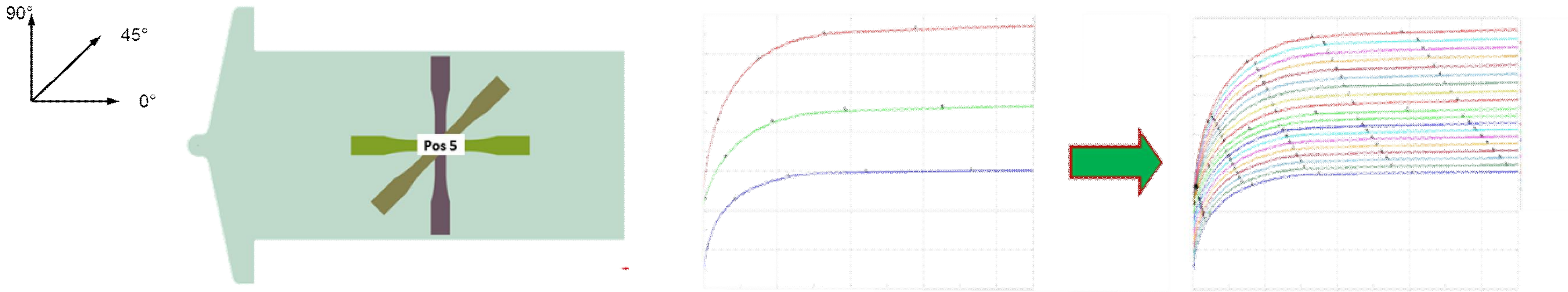
- For proper data mapping, plasticity curves may not intersect.

- 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



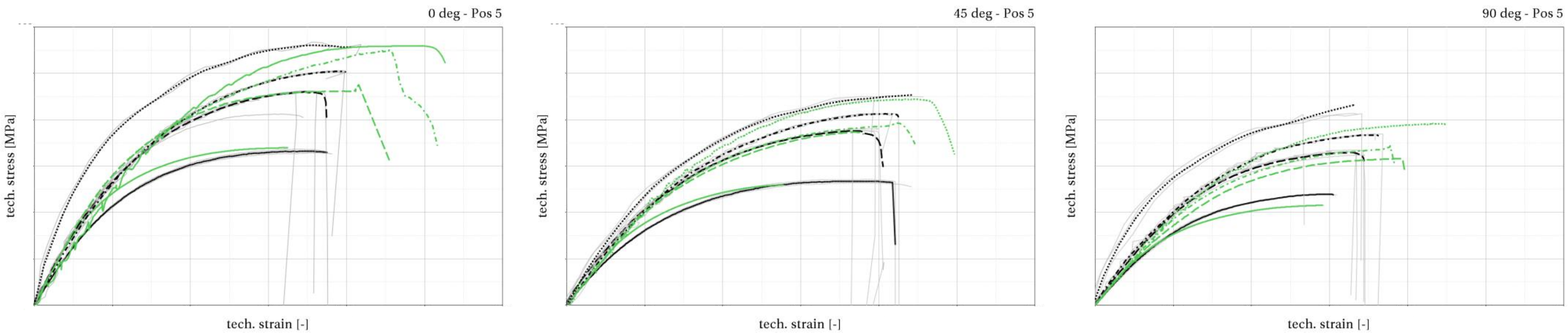
*MAT_157 – MATERIAL CALIBRATION

- Estimate remaining plasticity curves using linear interpolation.



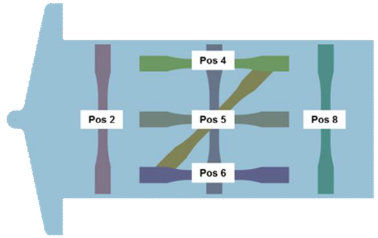
- Compare simulations and experimental results – pos 5.

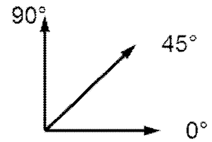
v_1 – 0.03 mm/s
v_2 – 30 mm/s
v_3 – 300 mm/s
v_4 – 3000 mm/s



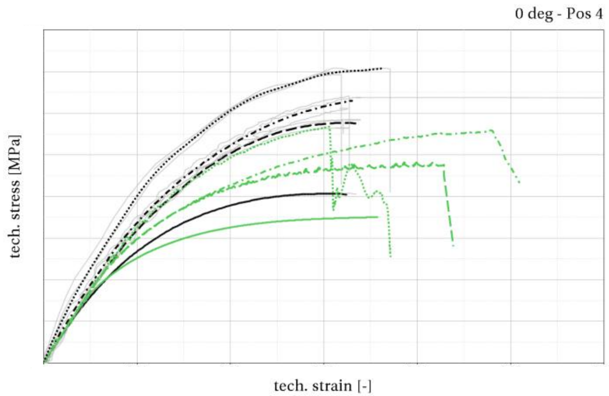
experiment
*Mat157 simulation

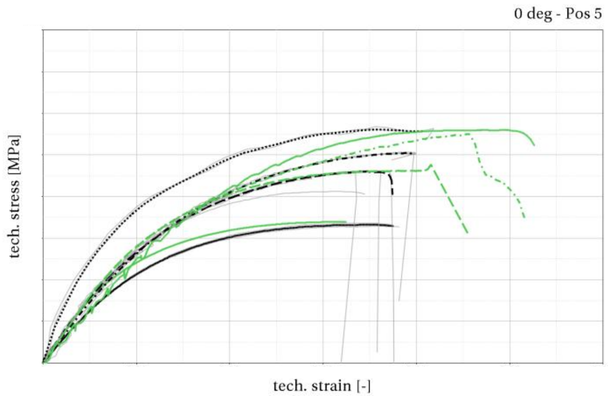
RESULTS TENSILE SPECIMEN

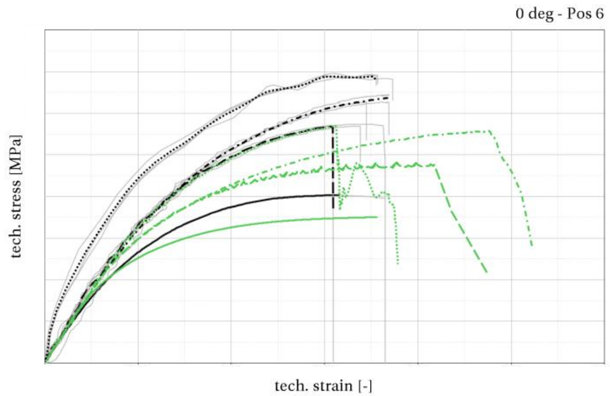




- 0° results, pos. 4, pos. 5 & pos. 6

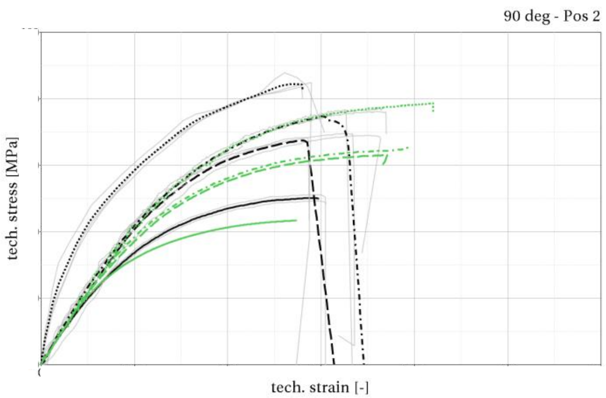


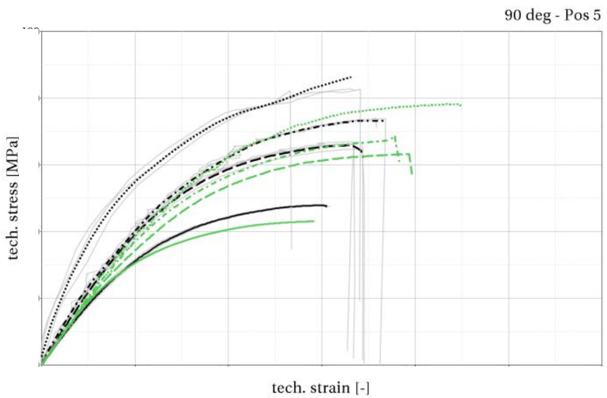


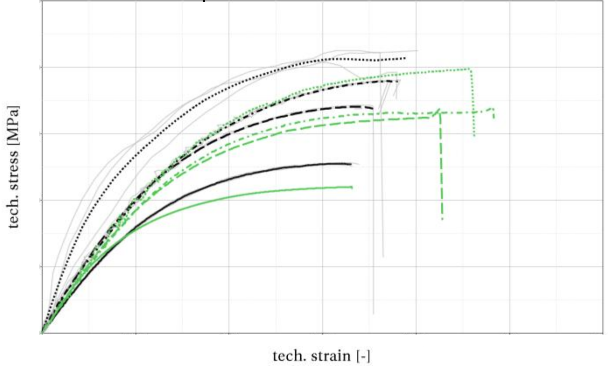


v_1 – 0.03 mm/s
v_2 – 30 mm/s
v_3 – 300 mm/s
v_4 – 3000 mm/s

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



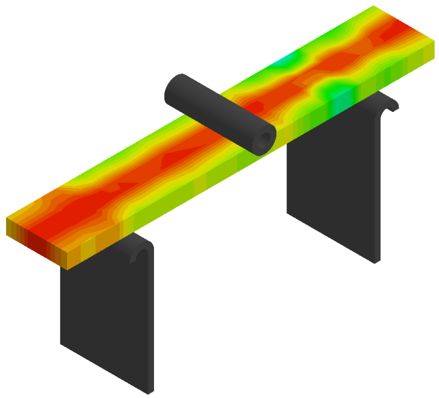


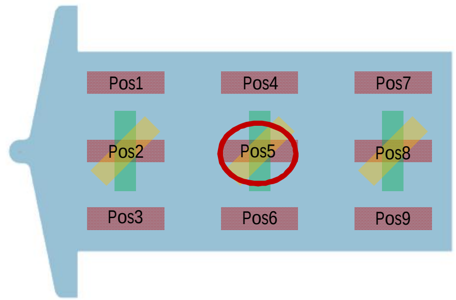


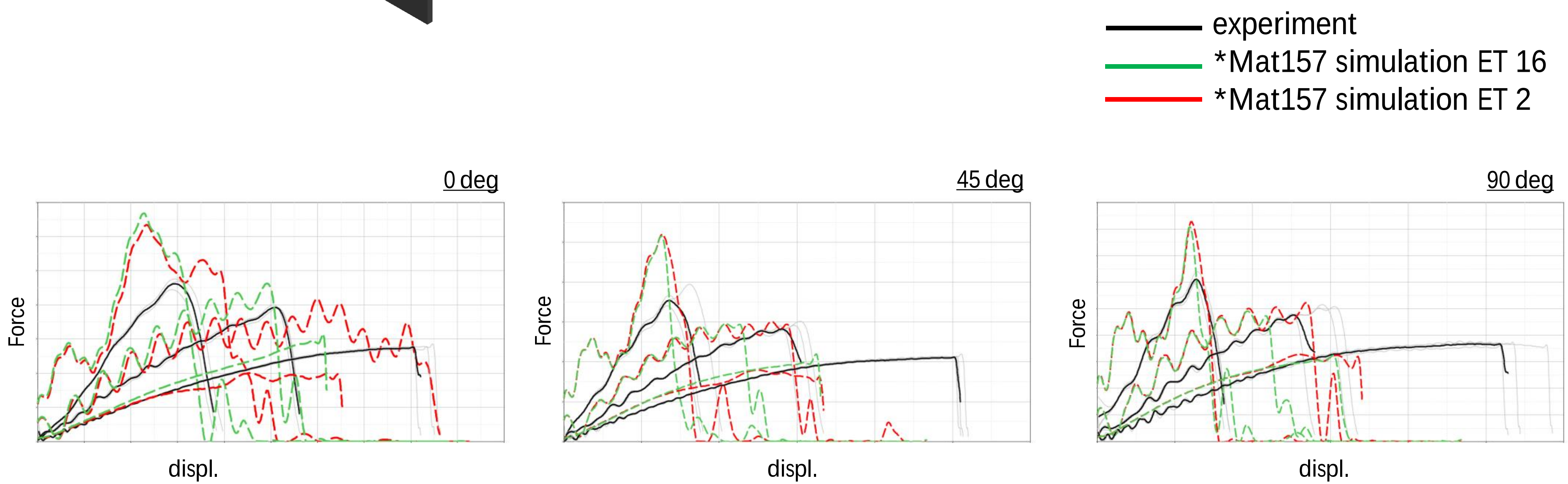
experiment
*Mat_157 simulation

RESULTS TENSILE SPECIMEN

- Evaluate on three-point bending tests

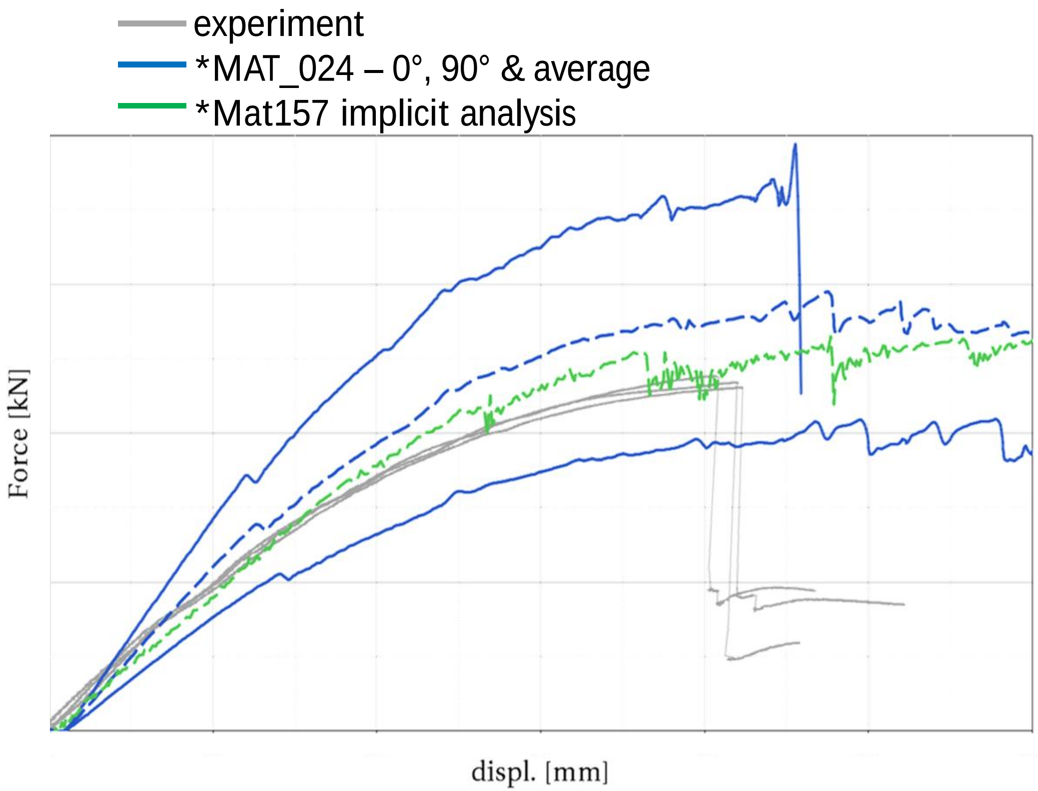


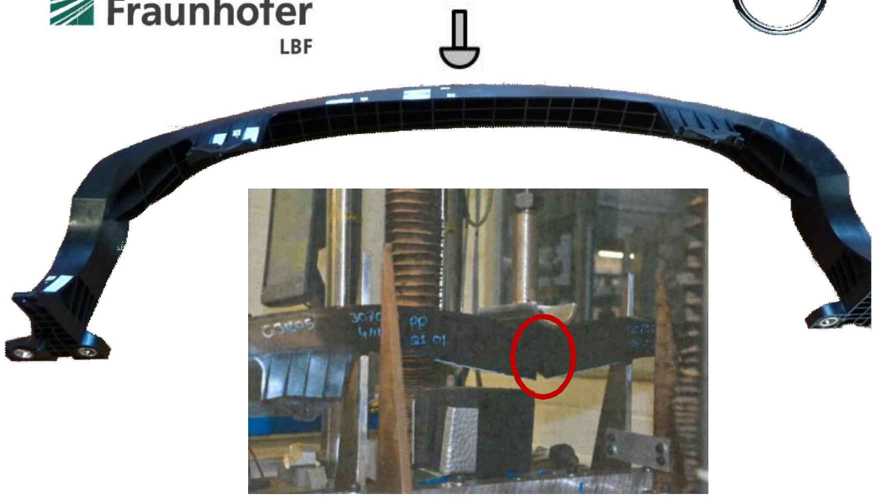


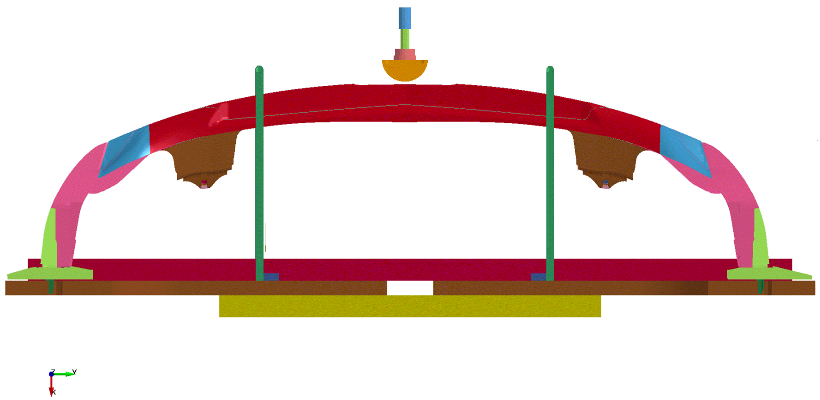


RESULTS COMPONENT

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





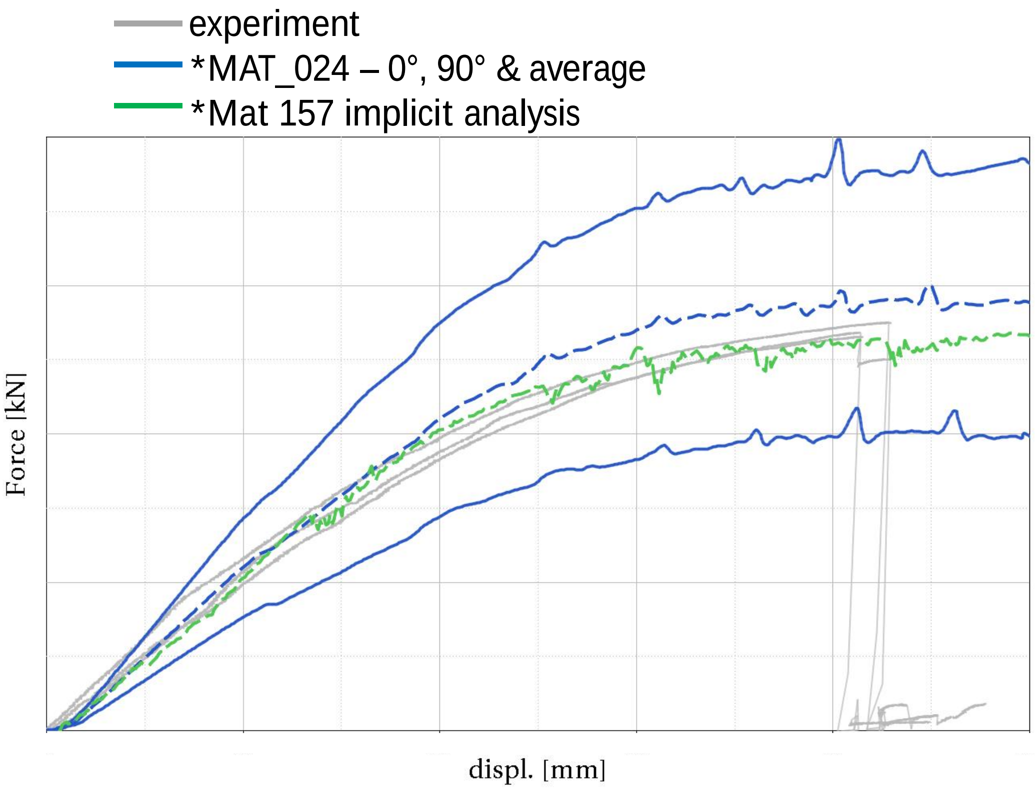


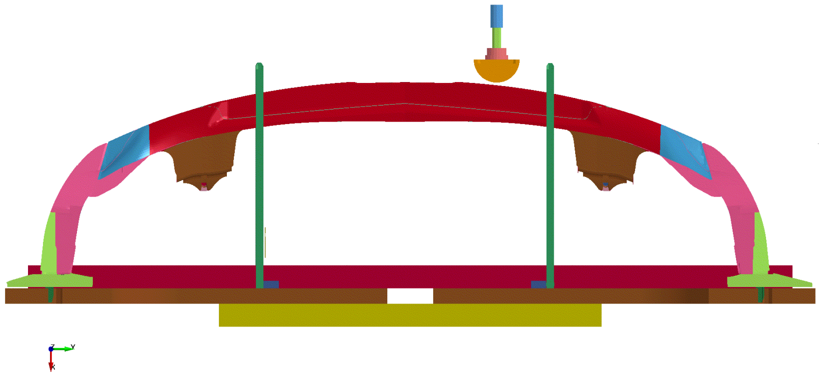
RESULTS COMPONENT

- qs – out-of-center position

breakage on the outside

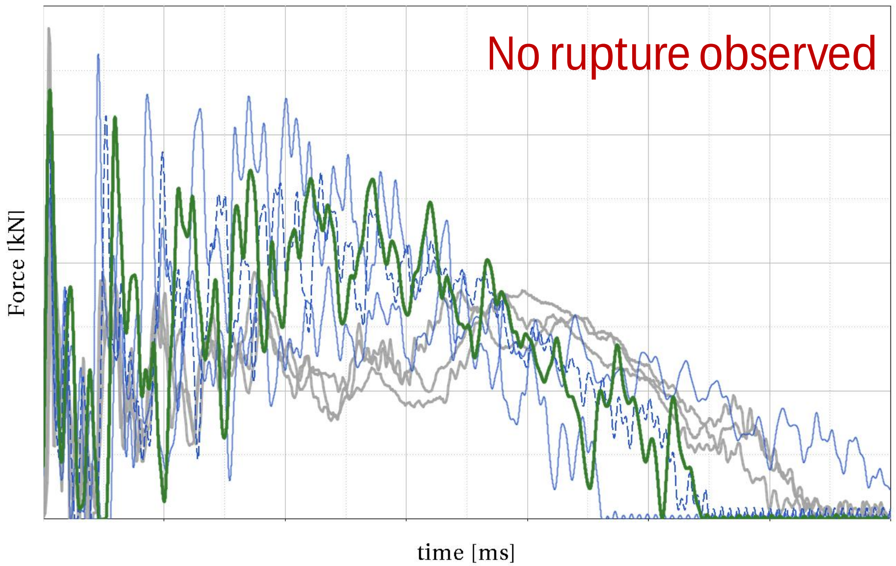
failure turned off for simulation

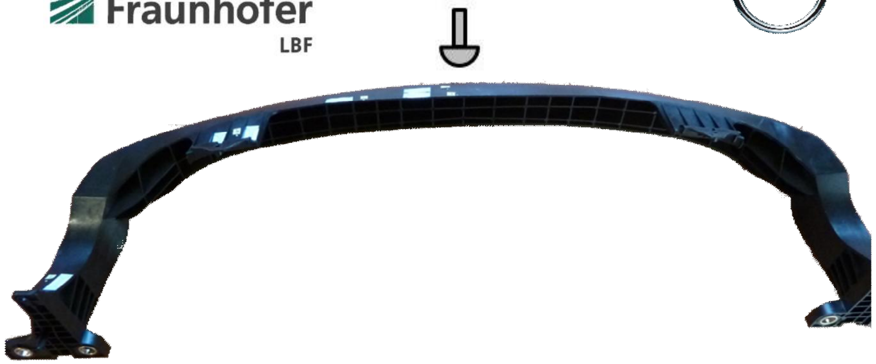


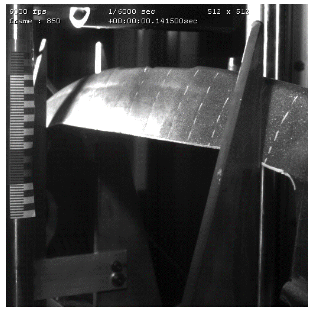


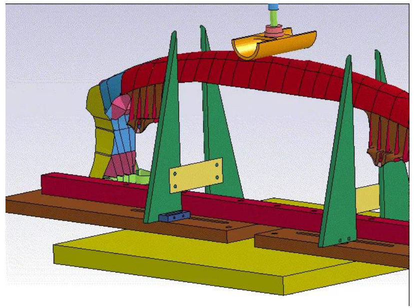
RESULTS COMPONENT

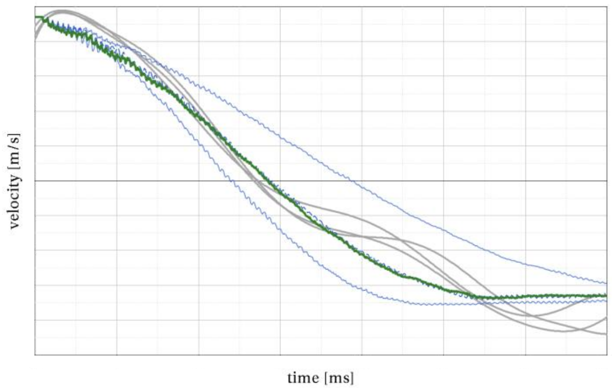
- 5.5 – center position

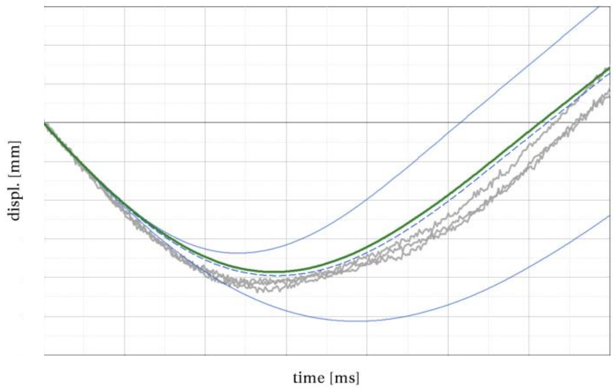








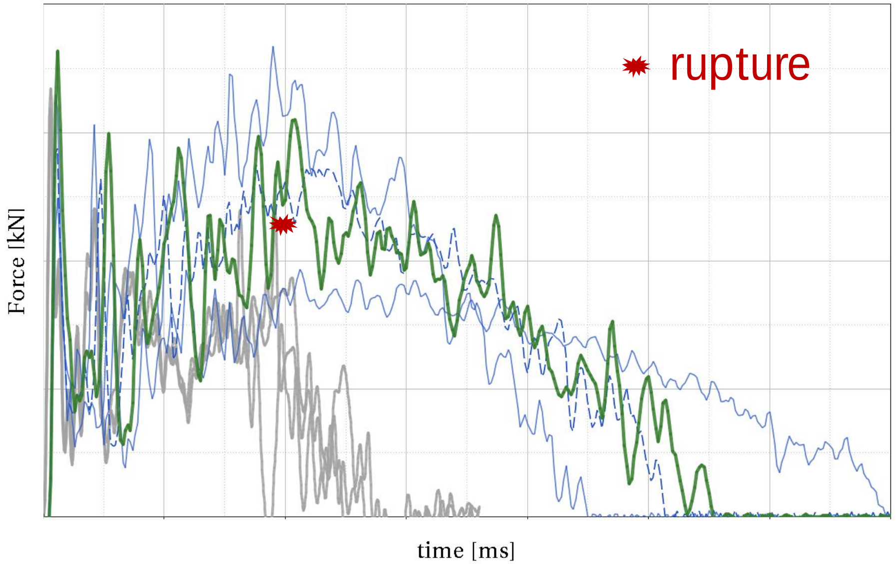


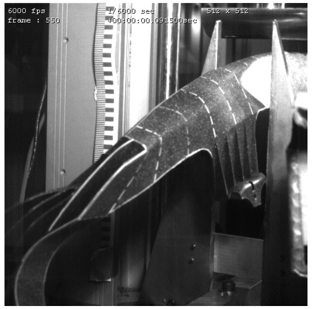


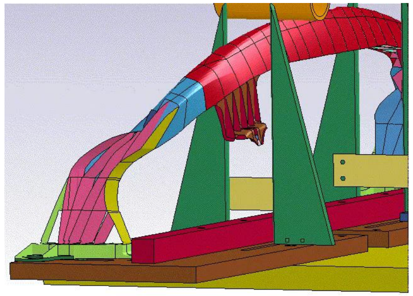
experiment
*MAT_024 – 0°, 90° & average
*Mat_157 simulation

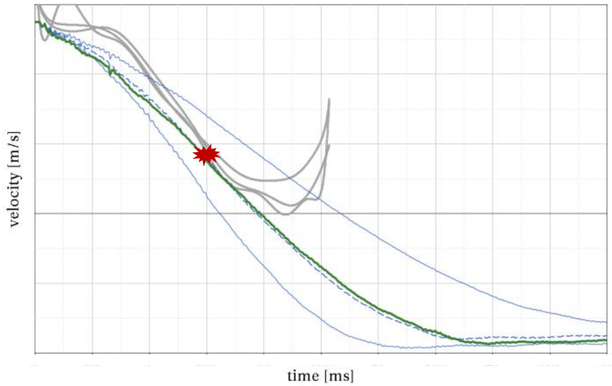
RESULTS COMPONENT

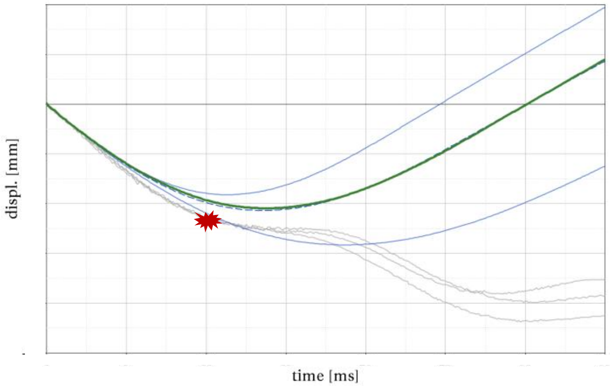
- 6.5 – out-of-center position











experiment
*MAT_024 – 0°, 90° & average
*Mat_157 simulation

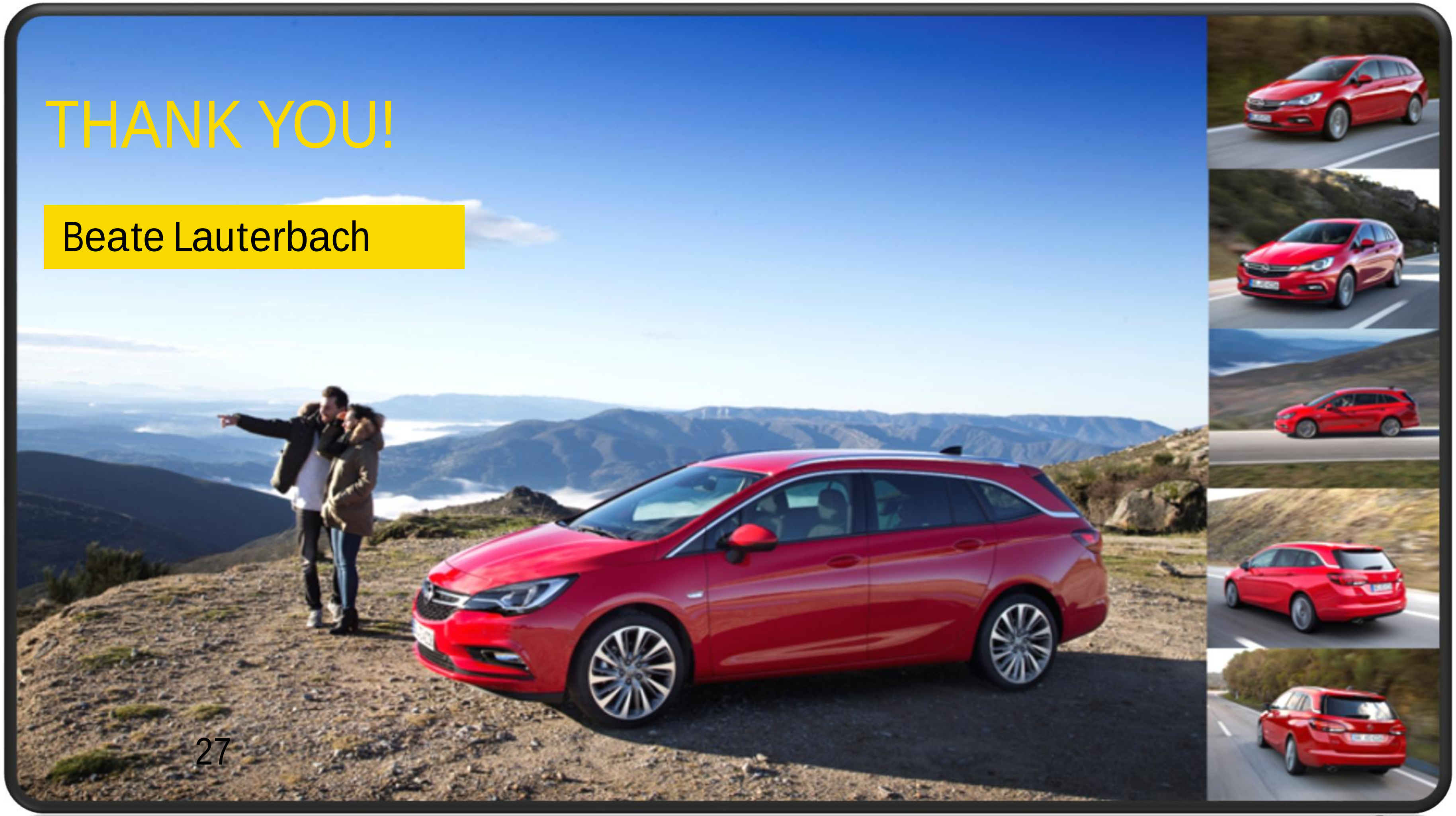
CONCLUSION AND OUTLOOK

- 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.


THANK YOU!
Beate Lauterbach