handling material scatter – case studies

plastics and composites under dynamic loading

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automotive CAE Grand Challenge 2020
September 29 - 30, 2020
Hanau, Germany

Agenda

- Introduction
- Case study
- Scatter
- foamed plastics
- short and long fiber reinforced plastics
  - stochastic evaluations
  - 3D-DIC
  - micro mechanic approach

CAE GRAND Challenge:
Variation and Scatter in Numerical Experimentation

- General: **Scatter must not dominate product performance!**
- **How to know whether a scatter analysis is required for the considered simulation?**
- **What are the right and necessary inputs for a scatter(uncertainty) analysis?**
  As many as necessary as few as possible
- **How to understand the influence of scatter on simulation results?**
  - data-analysis and datamining
  - Finding and identifying causes and effects to reach an engineering solution to possible issues
- **How to consider possibly available results from physical testing in that context?**
- **How to handle scatter in optimization approaches?**
- **Efficient solvers, data compression and possibly new approaches to data warehousing are necessary to handle the amounts of data produced!**

ENGINEERING

excellence in

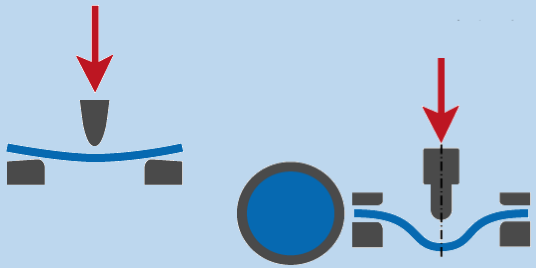
plastics & simulation

testing equipment

lightweight products

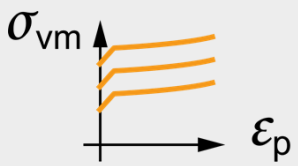
intelligent reliable solutions for plastics, composites, metals, foams, ...

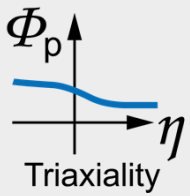
IMPETUS

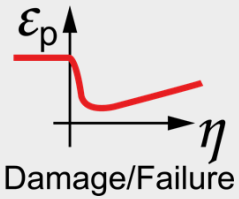


efficient
dynamic testing

VALIMAT

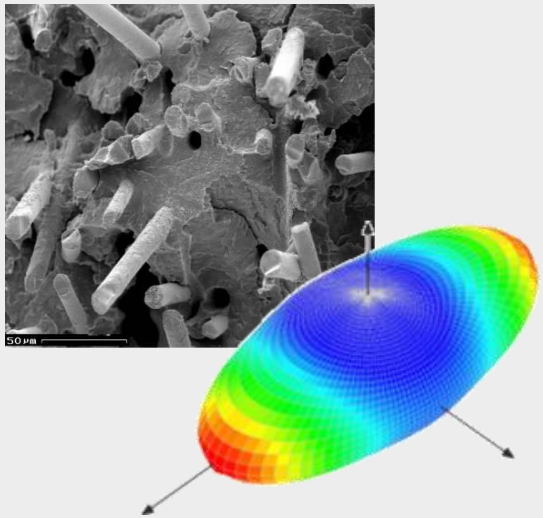






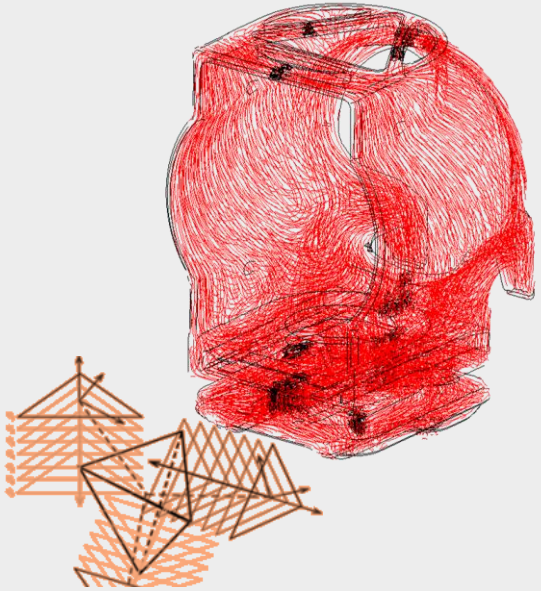
from test to validated
material cards

MICROMEC



3D anisotropic
material cards

FIBERMAP



individual mapping
process information

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

IMPETUS

VALIMAT

MICROMEC

FIBERMAP

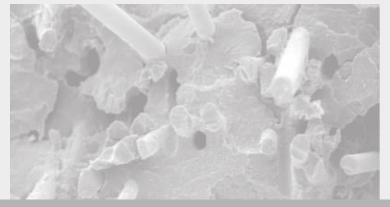
foams

thermoplastics

fiber reinforced plastics (SFRT & LFRT)

composites (carbon)

metals



efficient
dynamic testing

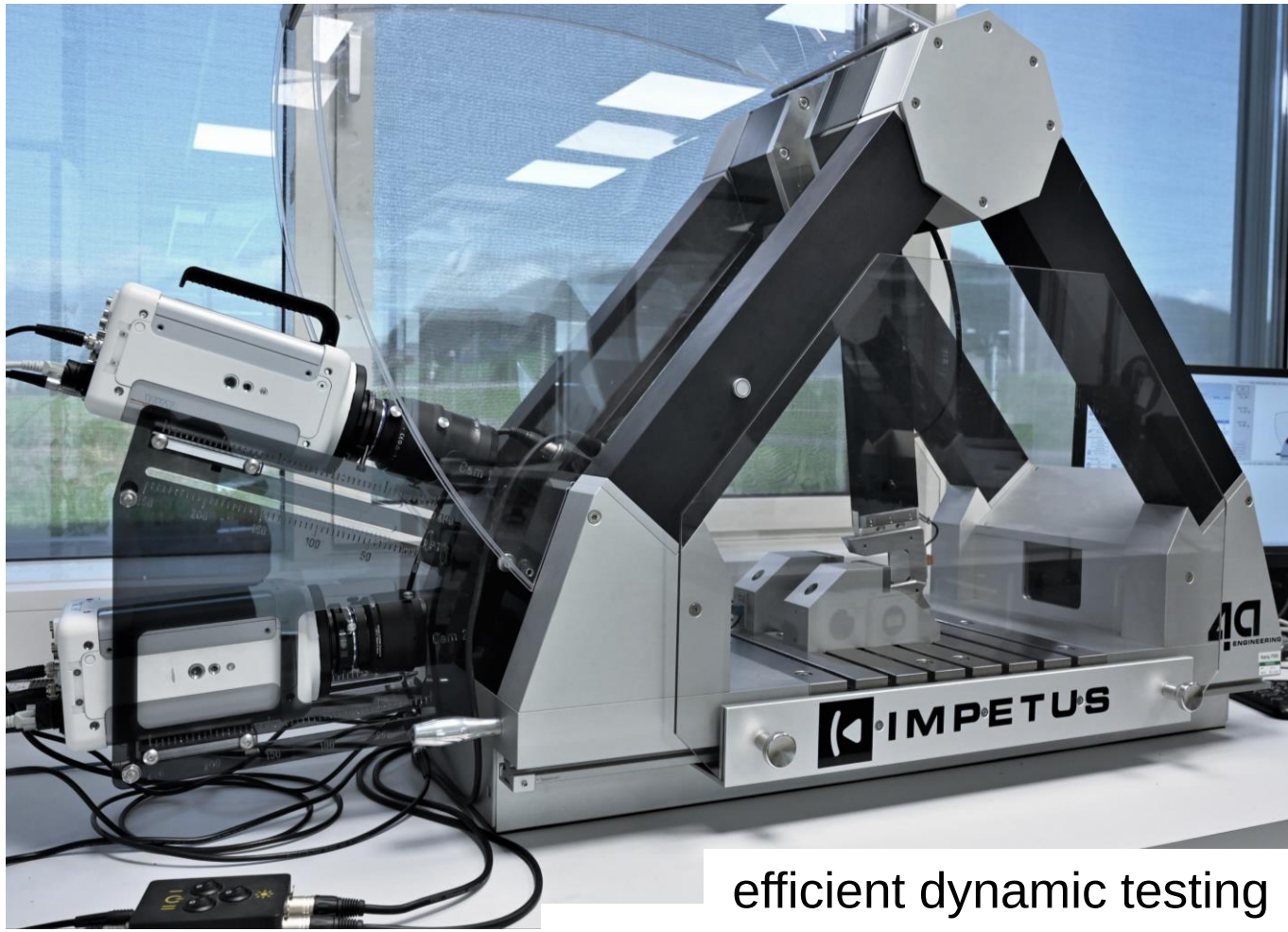
from test to validated
material cards

3D anisotropic
material cards

individual mapping
process information

IMPETUS® - main characteristics

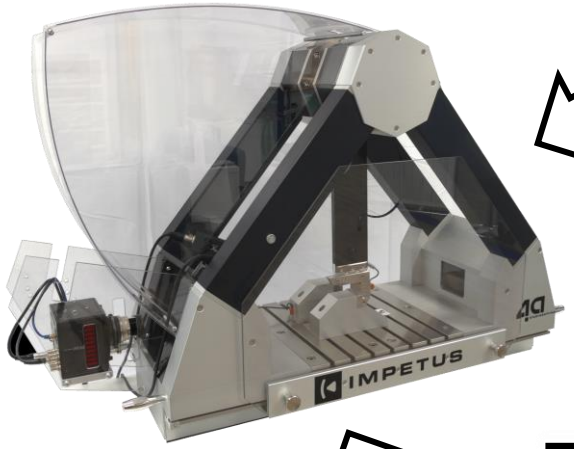
- Desktop testing device
  - ready to use
- Instrumented high speed testing
  - measured → force / displacement
- Impact speed 0.5 – 4.5 m/s
- Maximal energy up to 50 J
- Implemented High speed cameras
  - time sync. recording



efficient dynamic testing

plastics and composites

Measurement technique
used hardware and software



Photron

Time-synchronous data

MERCURY RT

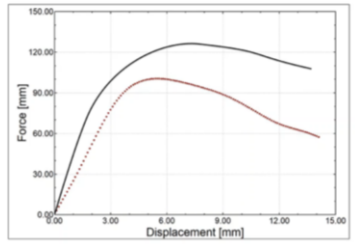
VALIMAT

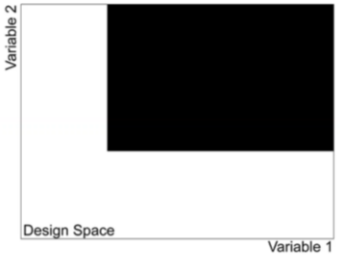
Testresults

- **Predefined camera positions attached to the pendulum**
- **Integrated 5V Trigger output at the IMPETUS® pendulum**
- **digital image correlation evaluation in Mercury**

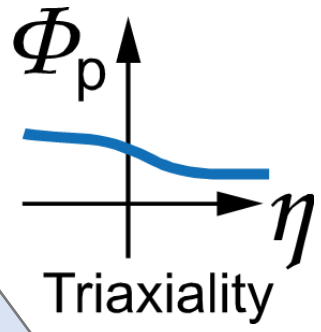
from test to material card

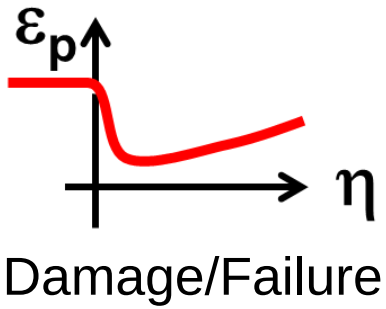
VALIMAT

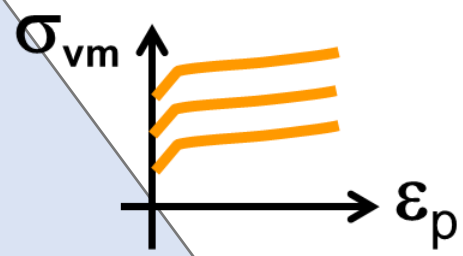


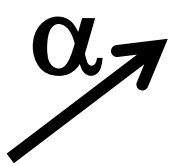


deformation → failure
creep → static → crash
isotropic → anisotropic





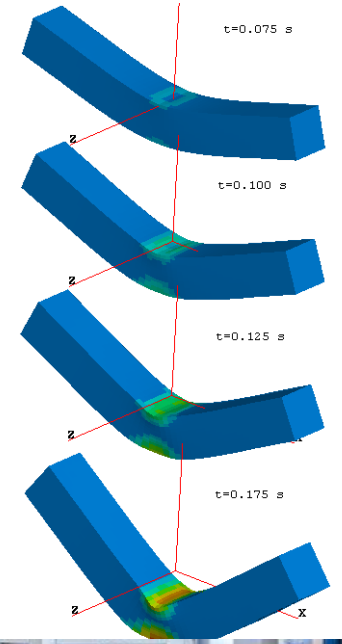




IMPETUS

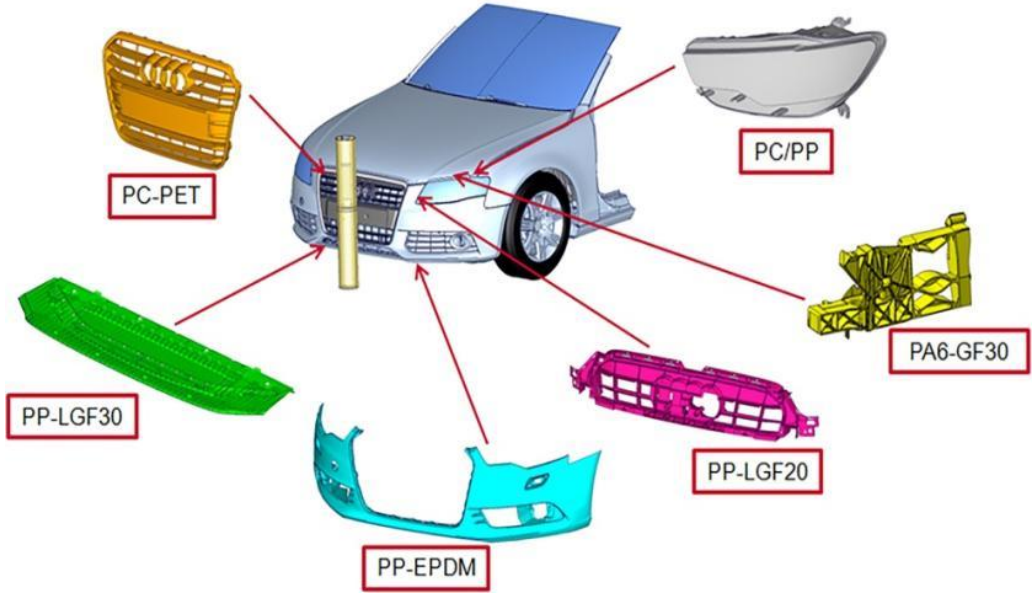
material characterization service

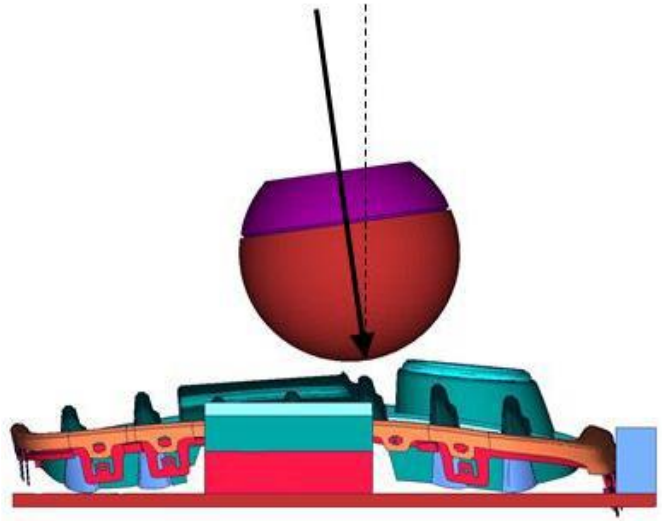
- efficient high-dynamic testing
- dynamic material behaviour
- plastics, foams, composites, …
- **validated material cards ready to use for your crash-simulation**

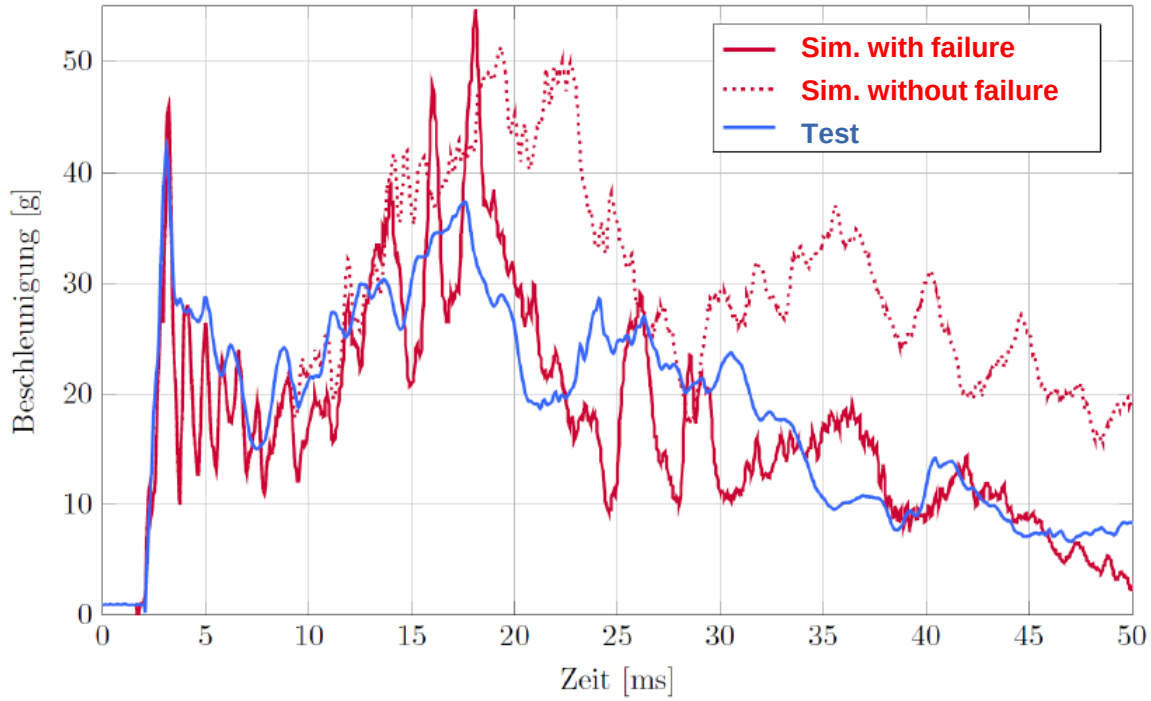


Case study - pedestrian safety

- Low Speed Impact behavior
- Plenty of different plastic grades
- Temperature influence -35°C up to 80°C



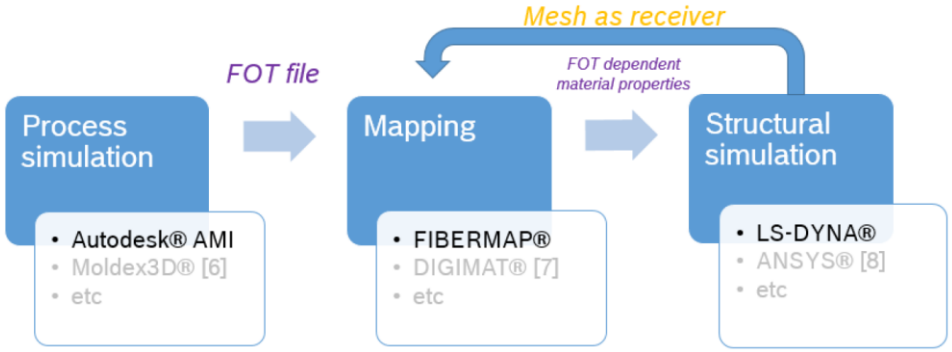




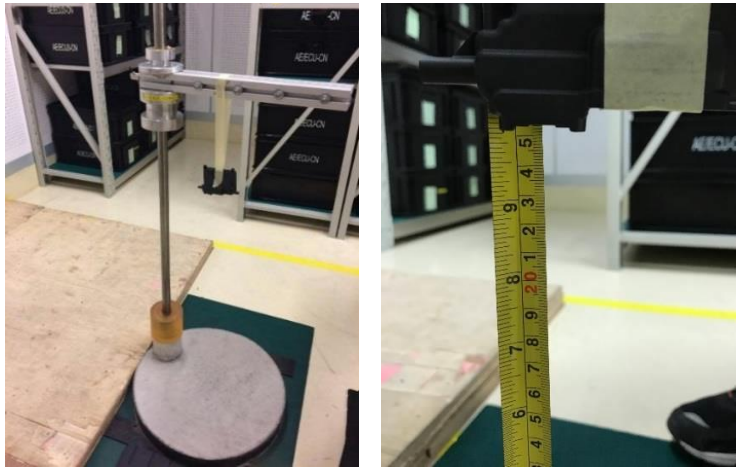
Source: H. Staack, Audi AG: *Anforderungsgerechte Material- und Bruchmodellierung für die Fahrzeugsicherheit*, TT16 Schladming

Case study - Housing Electronic Control Unit

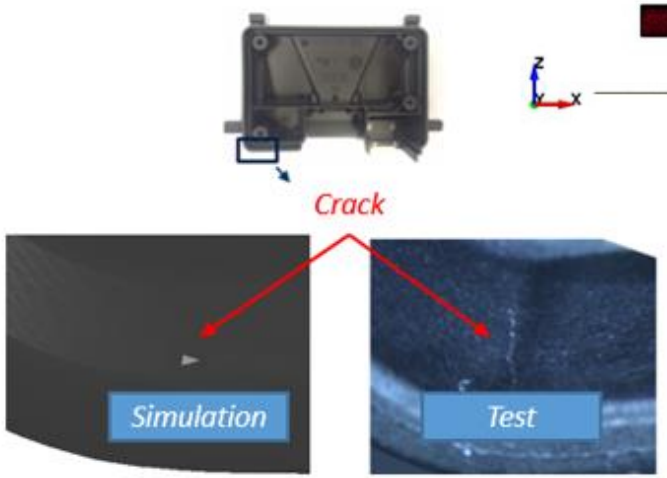
- Integrative Simulation
  Process → Structural Simulation
- Anisotropic material cards
- Prediction on Failure



	Simulation	Test
Pass height (m)	90% H1	H1
Fail height (m)	H1	110% H1



Guided free fall test



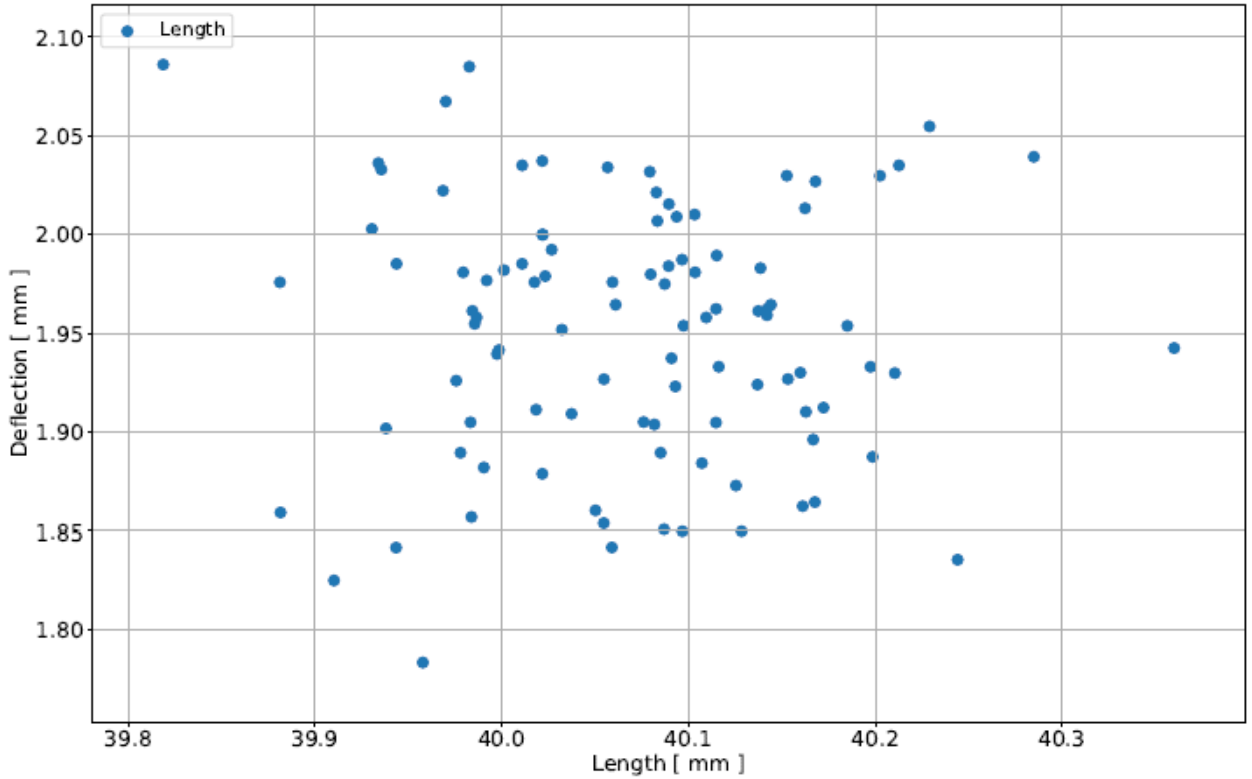
(a) Contact definitions

(b) Meshing of ECU

T. Zhao, D. Papathanassiou (Bosch Automotive Products), High-Dynamic Drop Test Simulation for Fiber Reinforced Plastics in Automotive Electronic Control Units 11th LSDYNA Conference Salzburg

Scatter

- just a lack of information ?
- We don’t understand the relation
  - Knowledge (physics, storage, …)
  - Availability (specimens)
  - Budget (costs & time)
- Reality versus Idealization
  - Process
  - Geometry
  - Material



Source: Sygusch N. (2020) Statistical Analysis. In: Stochastic Approach to Rupture Probability of Short Glass Fiber Reinforced Polypropylene based on Three-Point-Bending Tests

MCS Monte Carlo Simlation
DoE Design of Experiments
Optimization

static &

dynamic

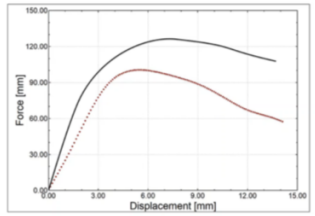
IMPETUS

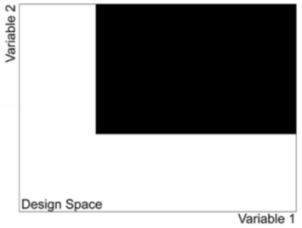
Photron

VALIMAT

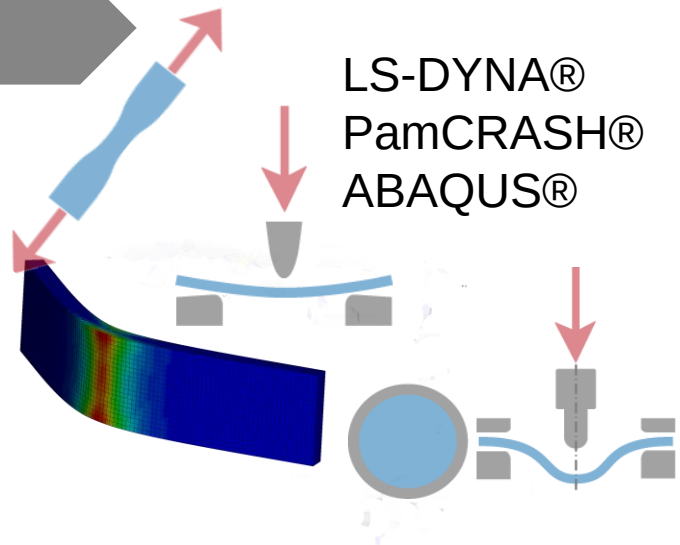
database

LS-OPT

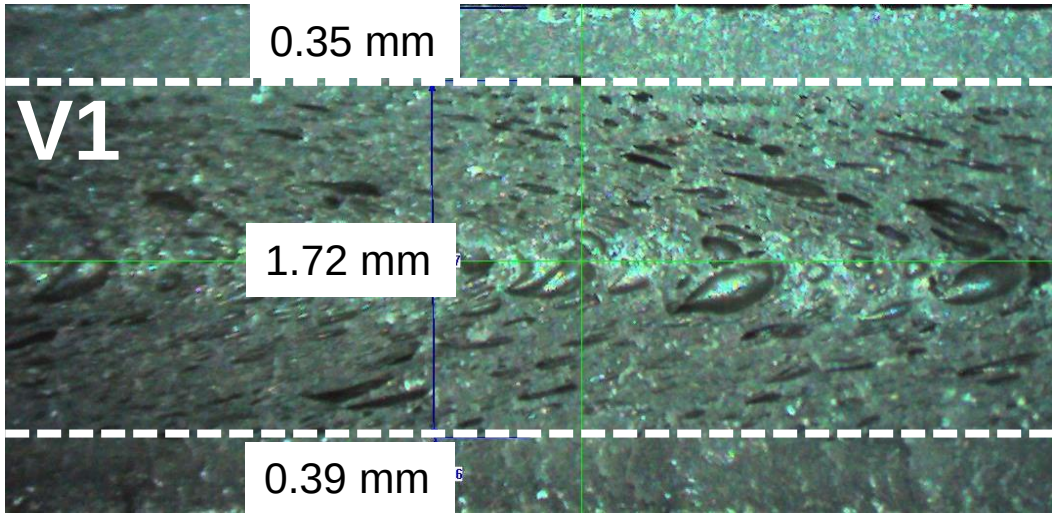




LS-DYNA®
PamCRASH®
ABAQUS®

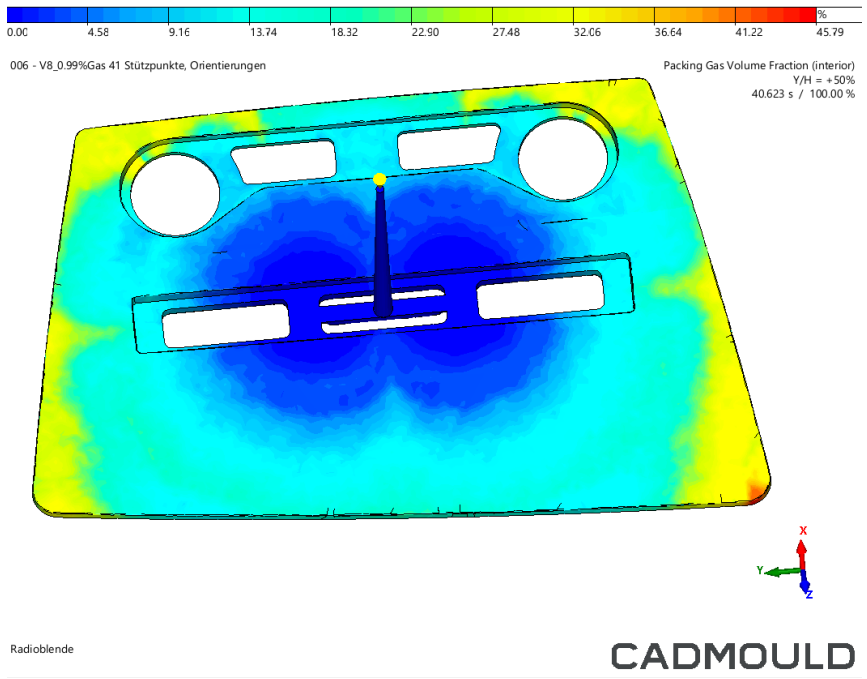


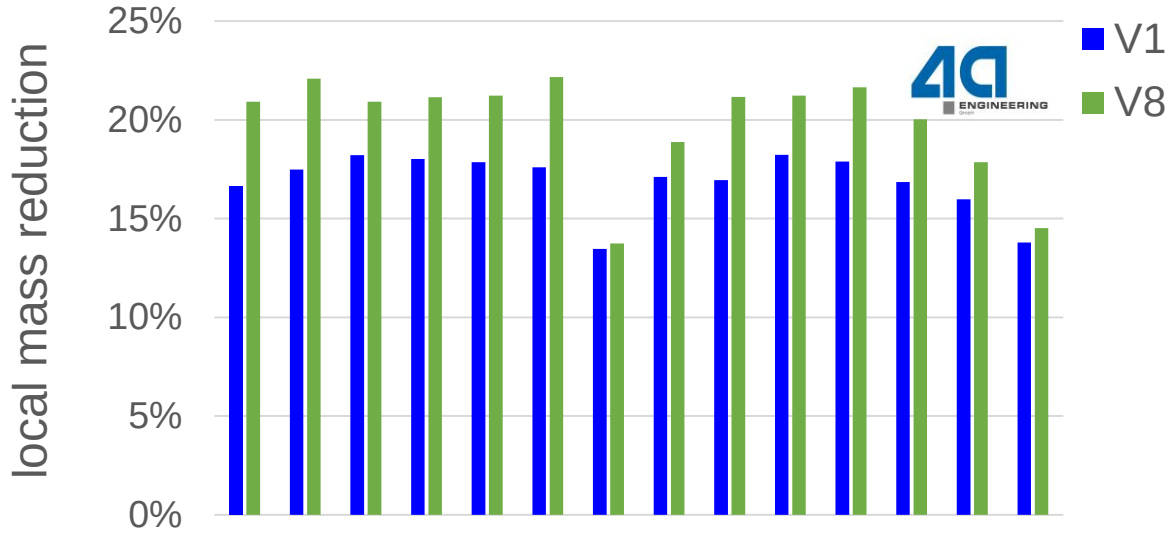
foamed plastics

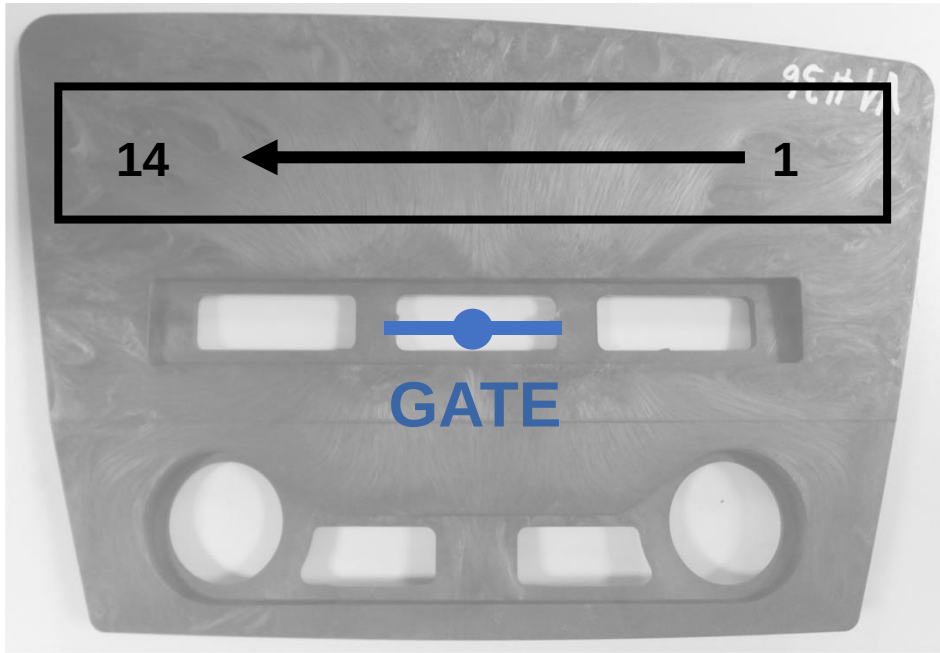


physical foamed plastics

- process induced gas volume
- bubble distribution in
  - location (over thickness)
  - volume
  - size



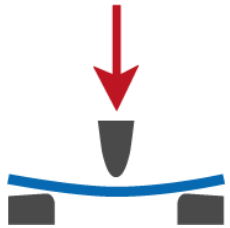


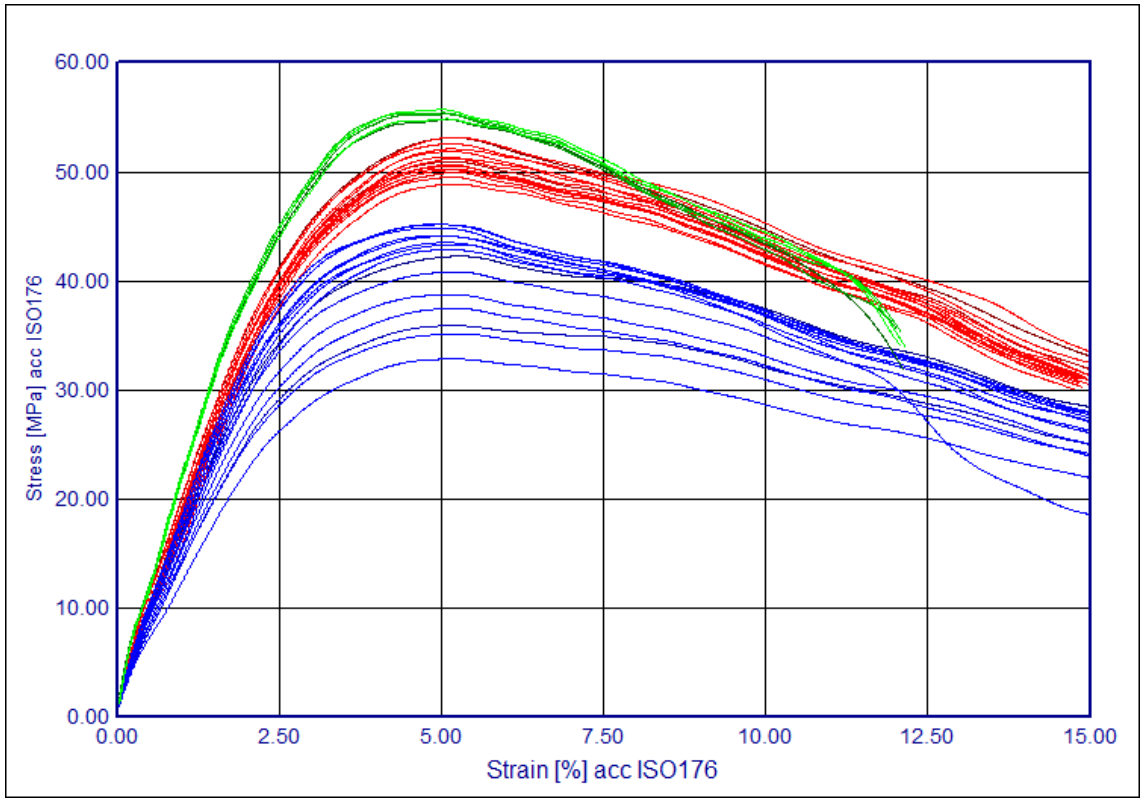


Source: TT2020, VMAP – Virtual material modelling in manufacturing Physical foaming in Injection Moulding

dynamic bending tests

compact plaques
compact part
foamed part -12% mass





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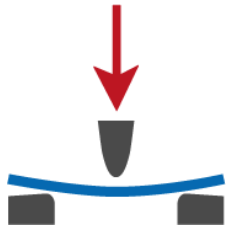
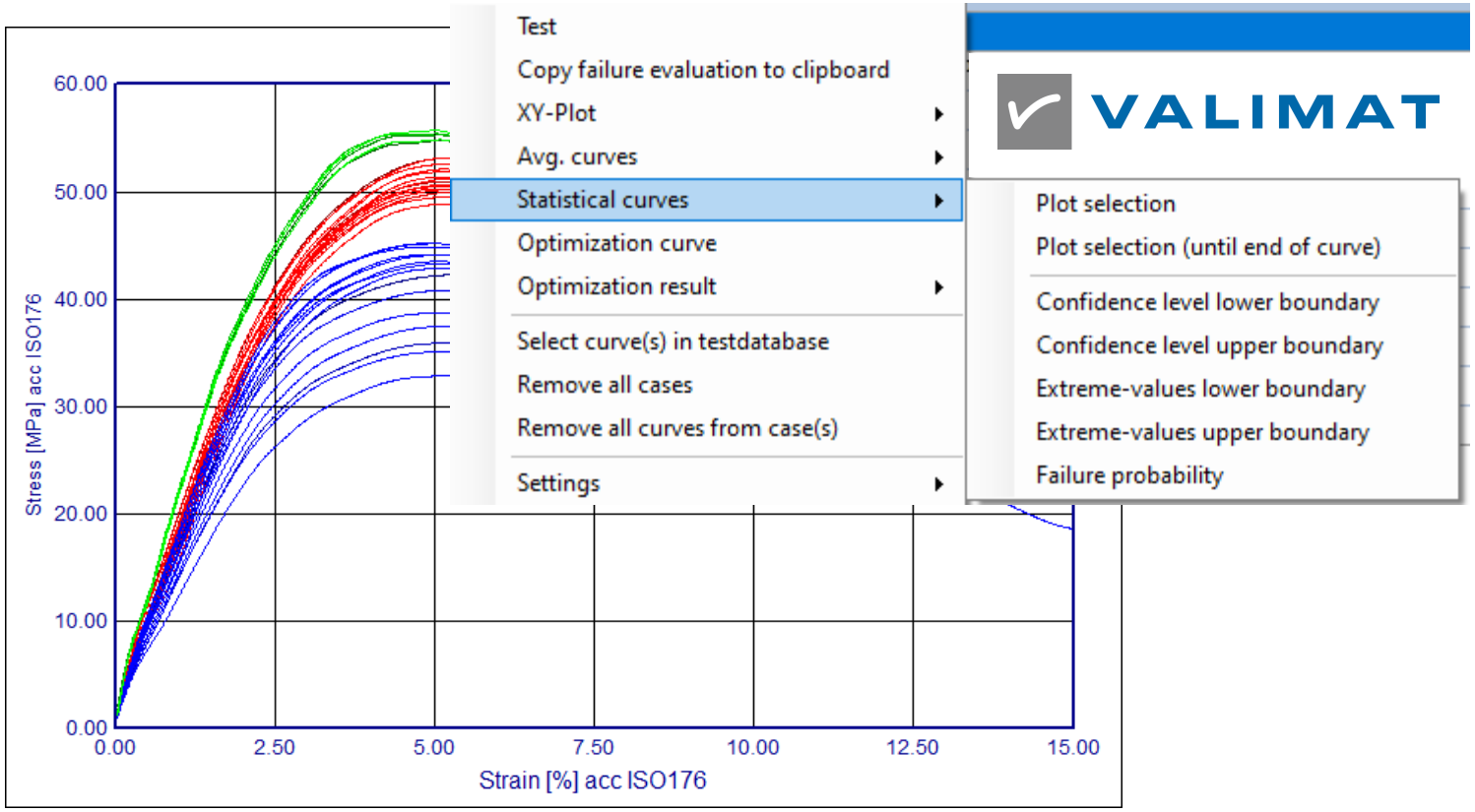
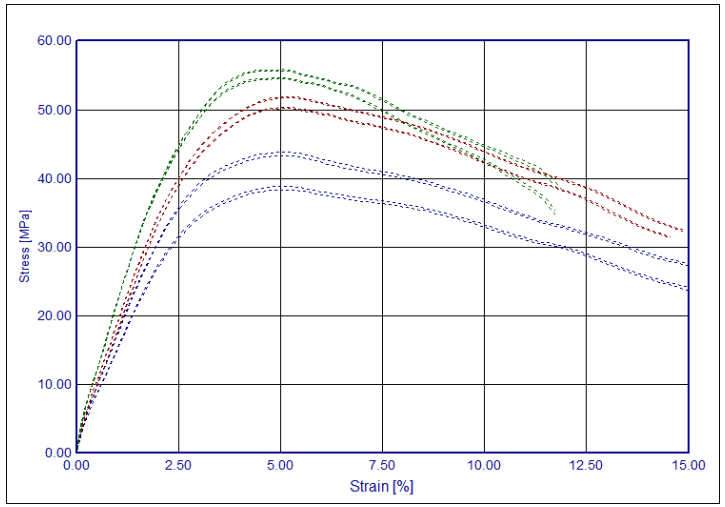
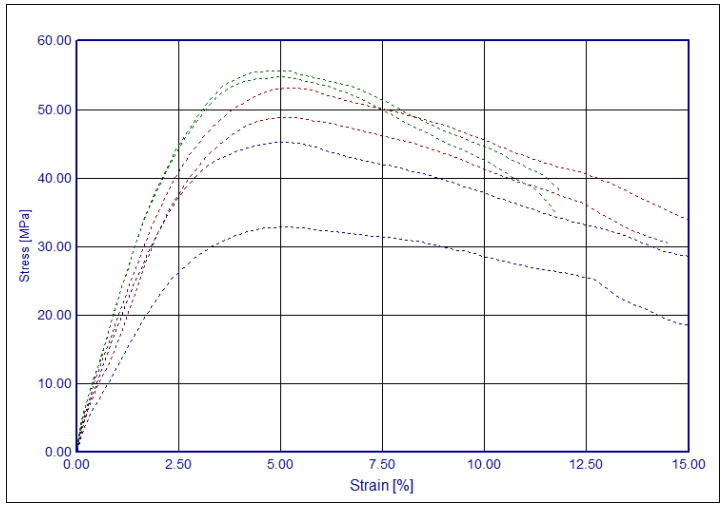




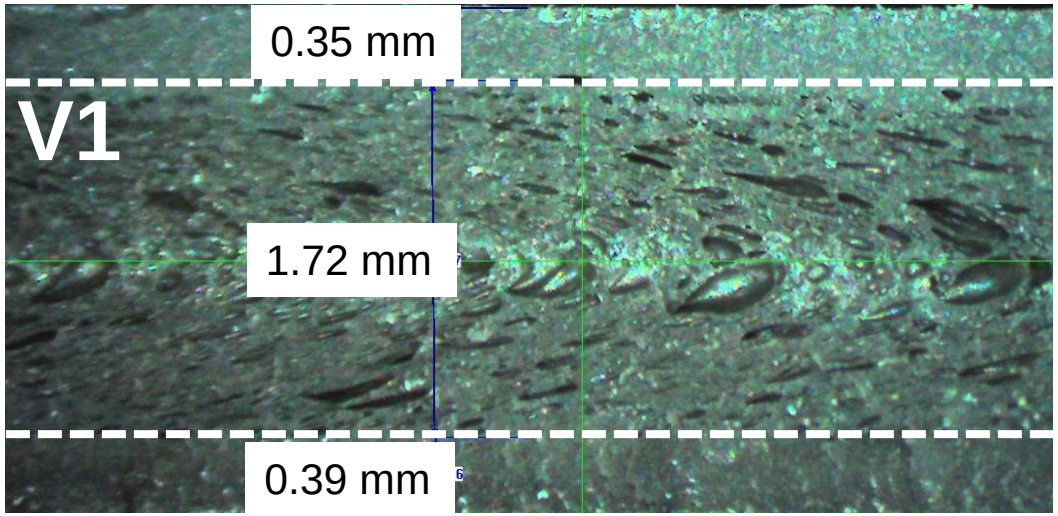




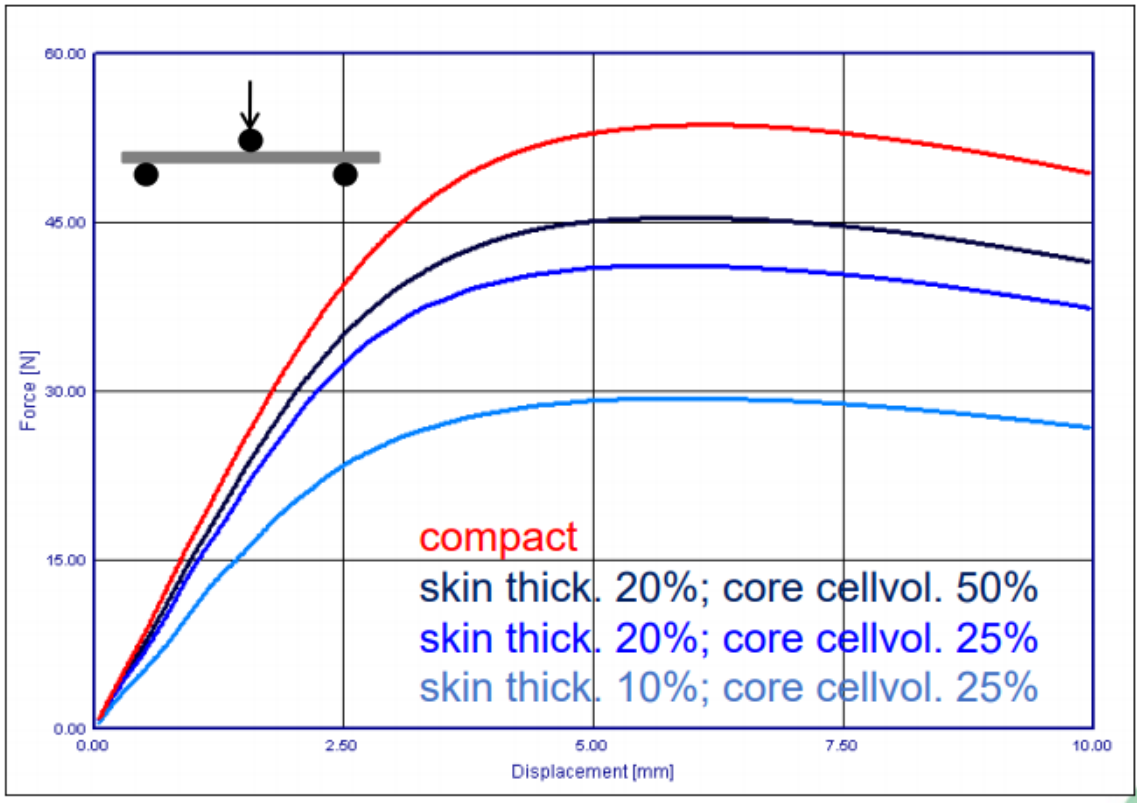
physical foamed plastics

- Using composite model
  - Variation in skin – core thickness
  - Variation in Material properties by scaling

→ **Starting point for a stochastic analysis**



SIMULATION with SKIN-CORE-SKIN



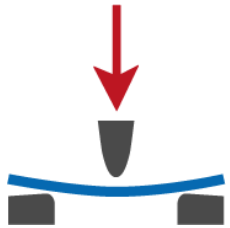
Source: TT2020, VMAP – Virtual material modelling in manufacturing Physical foaming in Injection Moulding

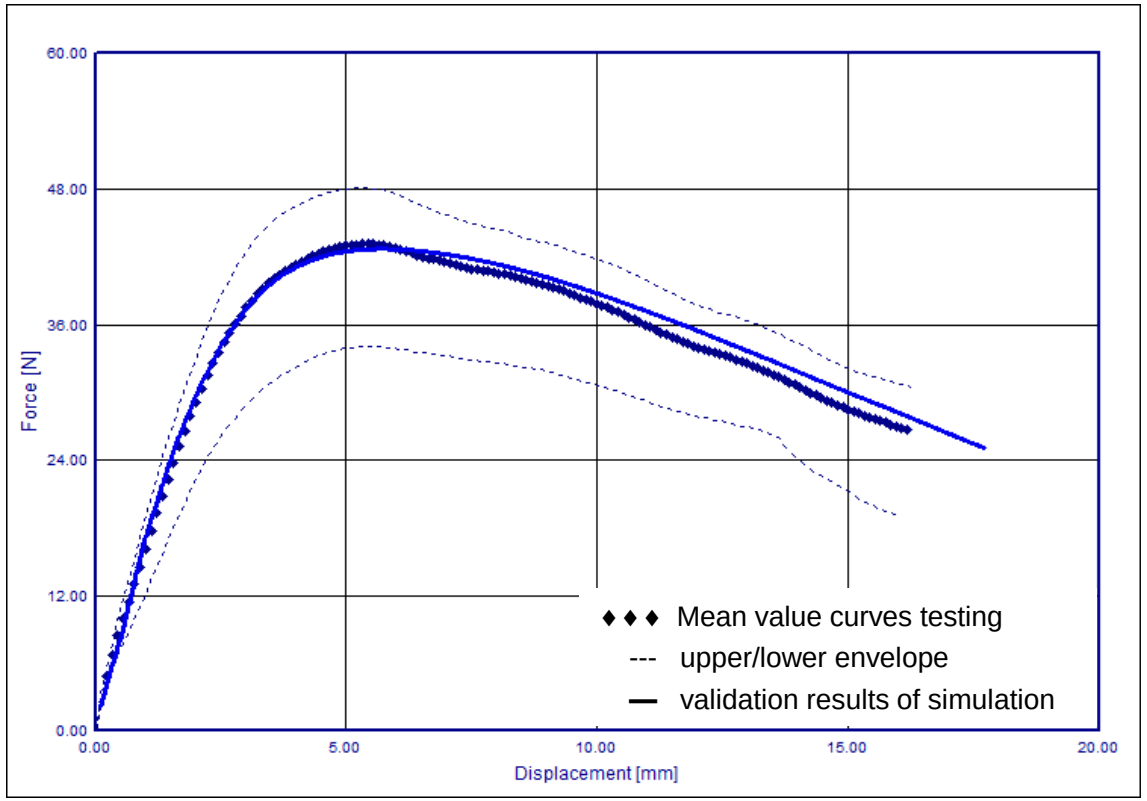
dynamic bending tests

dyn. puncture tests

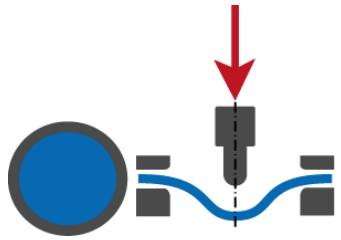
IMPETUS

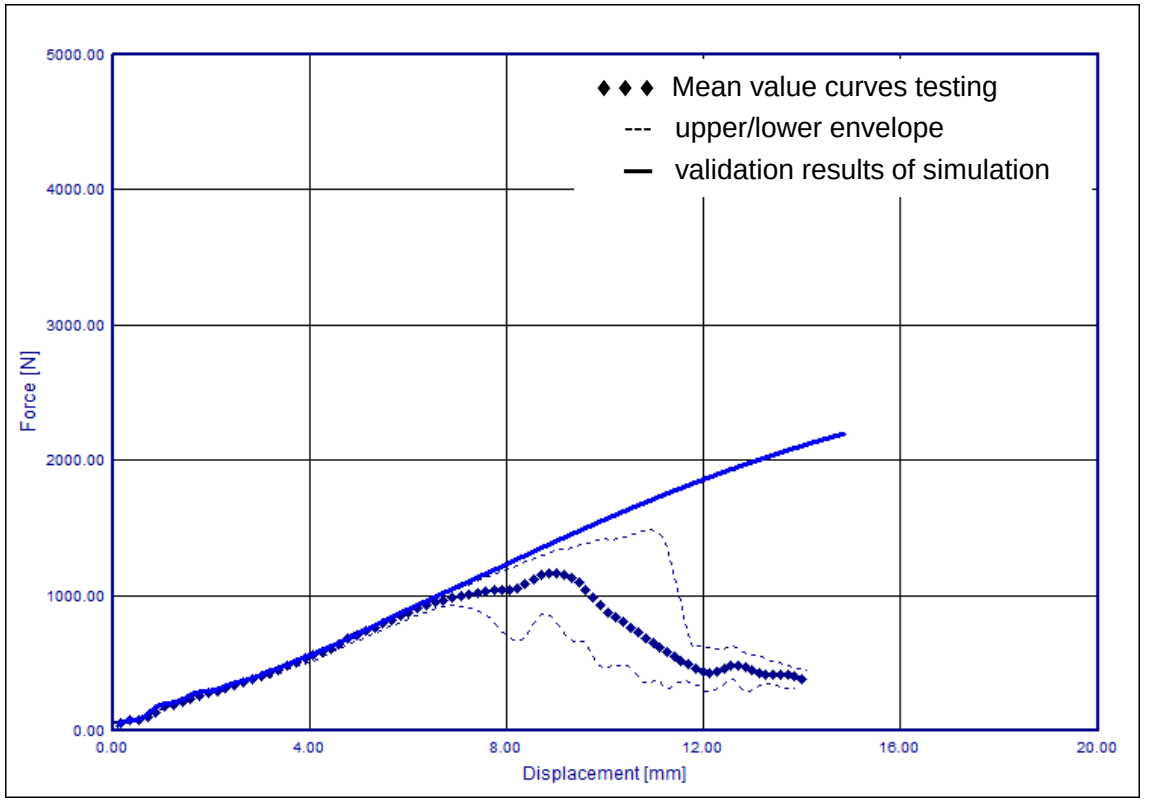
foamed part -12% mass



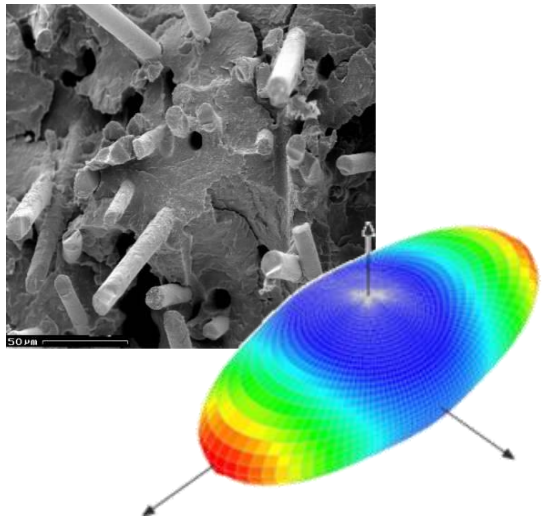


Failure investigation
(in progress – current research)



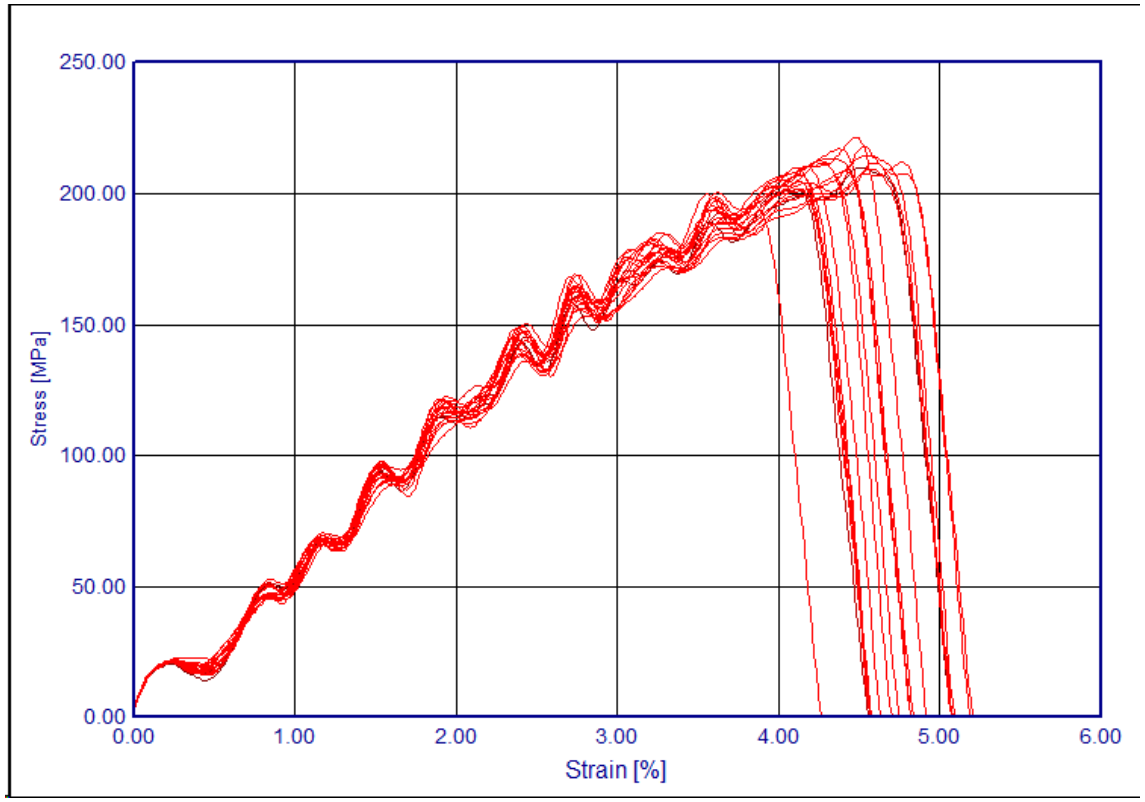


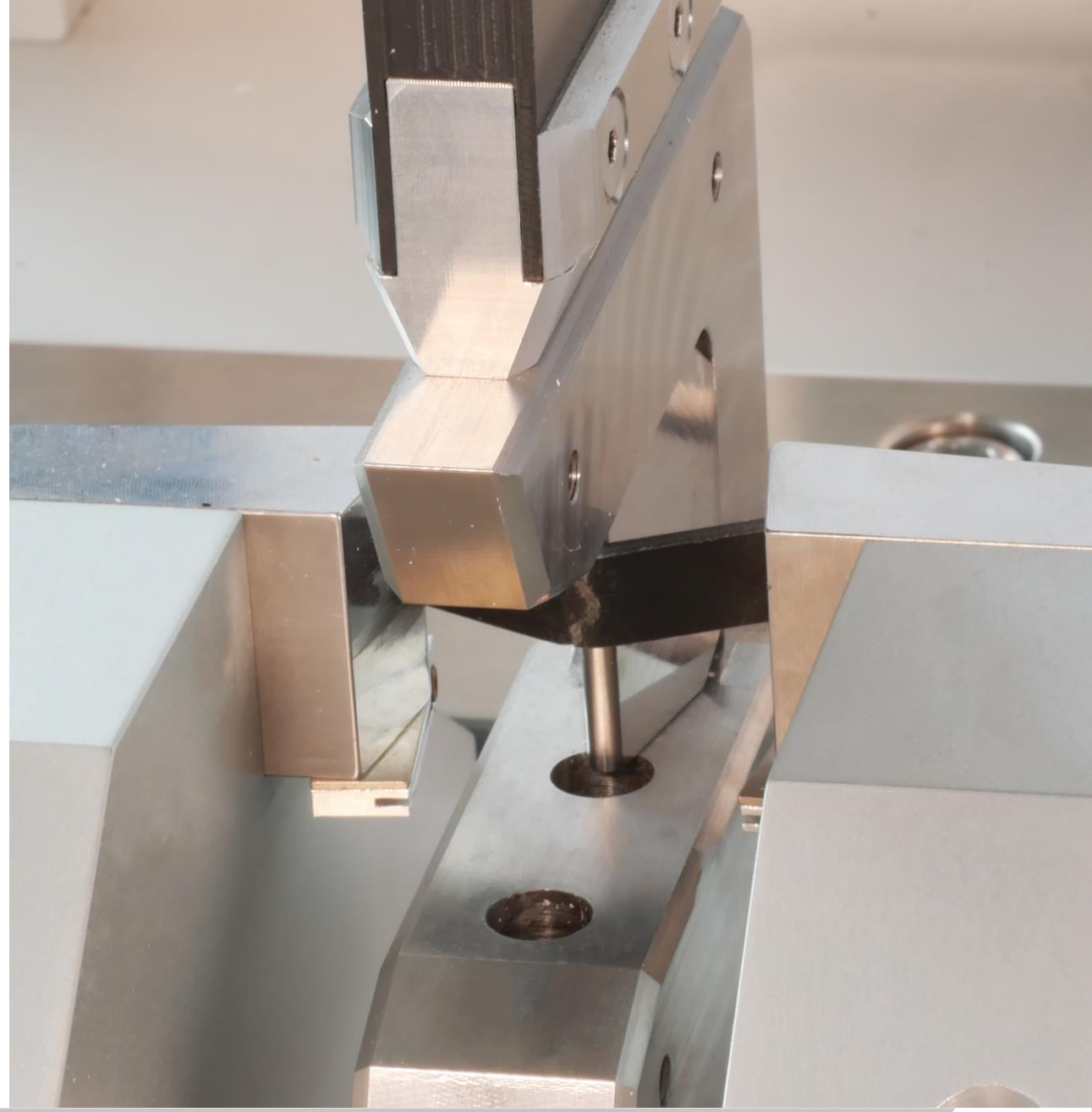
short- and long fiber reinforced plastics



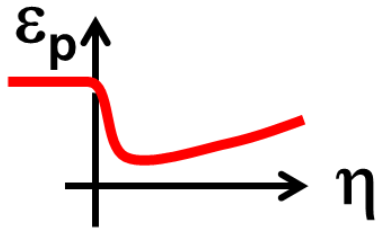
PP-LGF30 exemplary failure evaluation

- injection molded samples
  - 19 tests conducted at 2,5 m/s



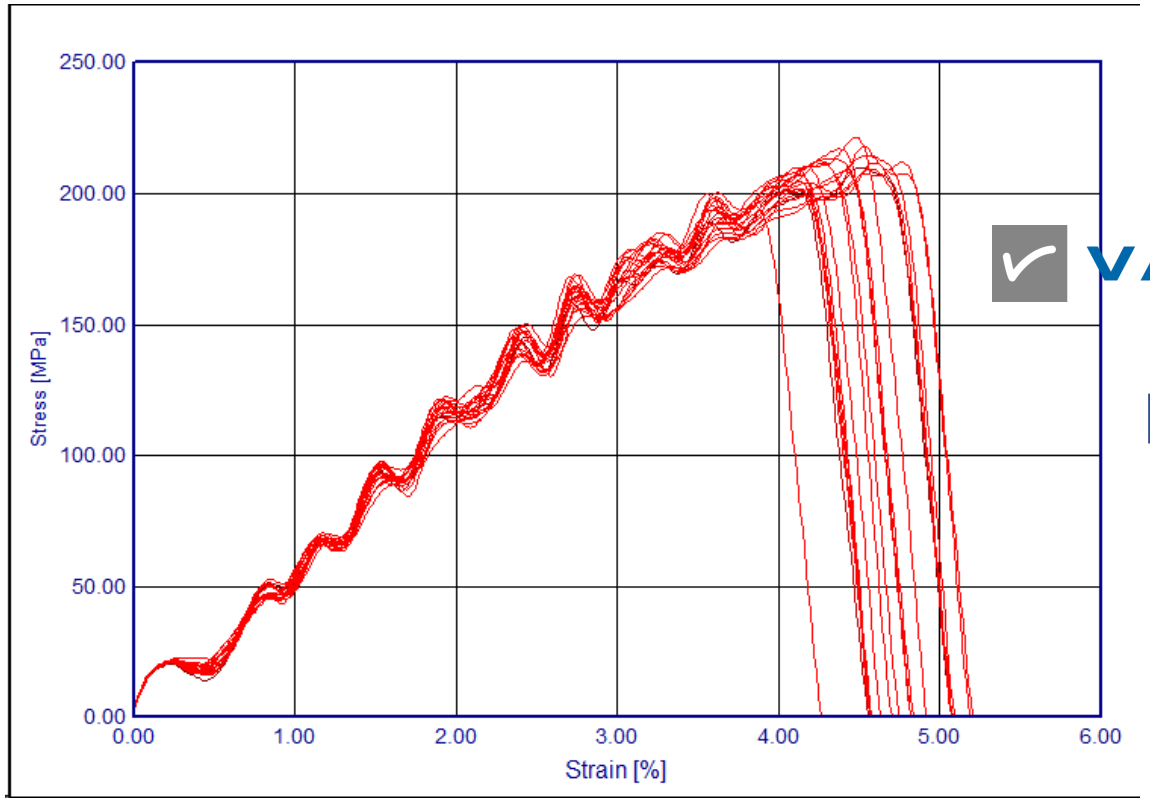


PP-LGF30 exemplary failure evaluation

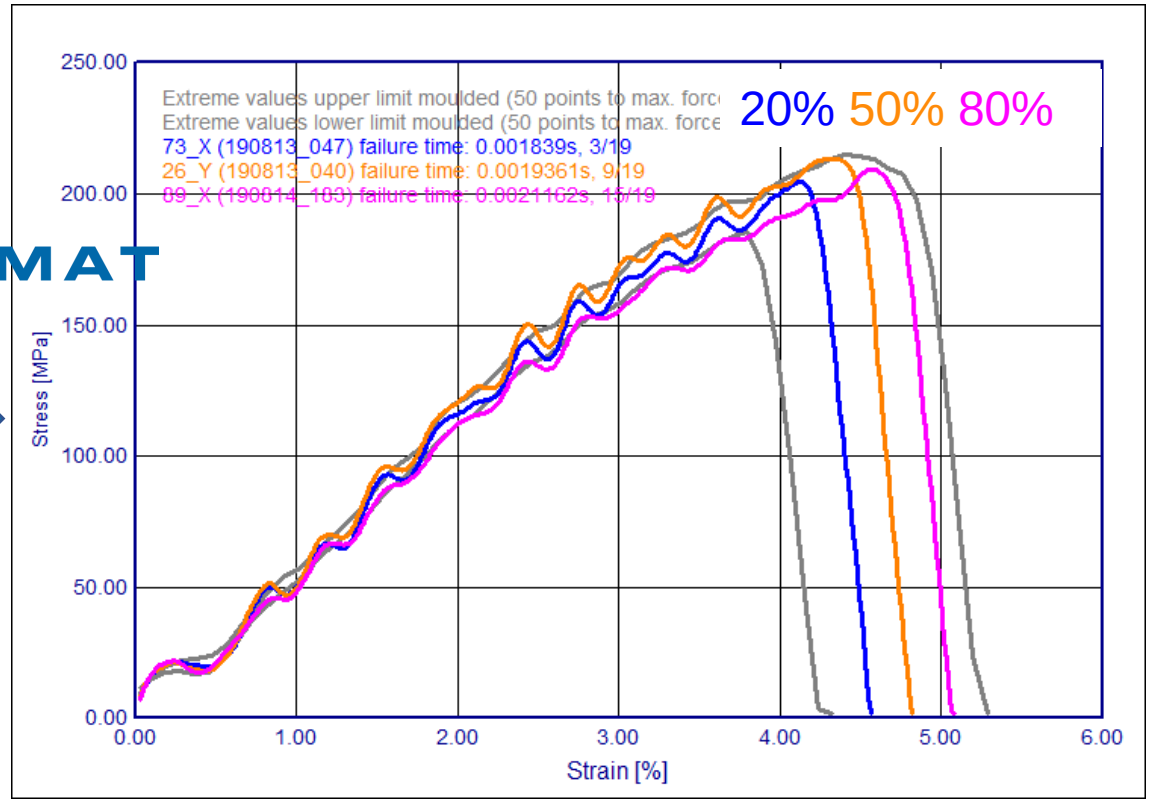


Damage/Failure

VALIMAT® FEATURE:
Directly find the corresponding test for certain failure probability
→ can be used to generate Damage/Failure Criteria

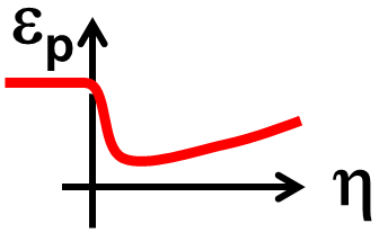


VALIMAT

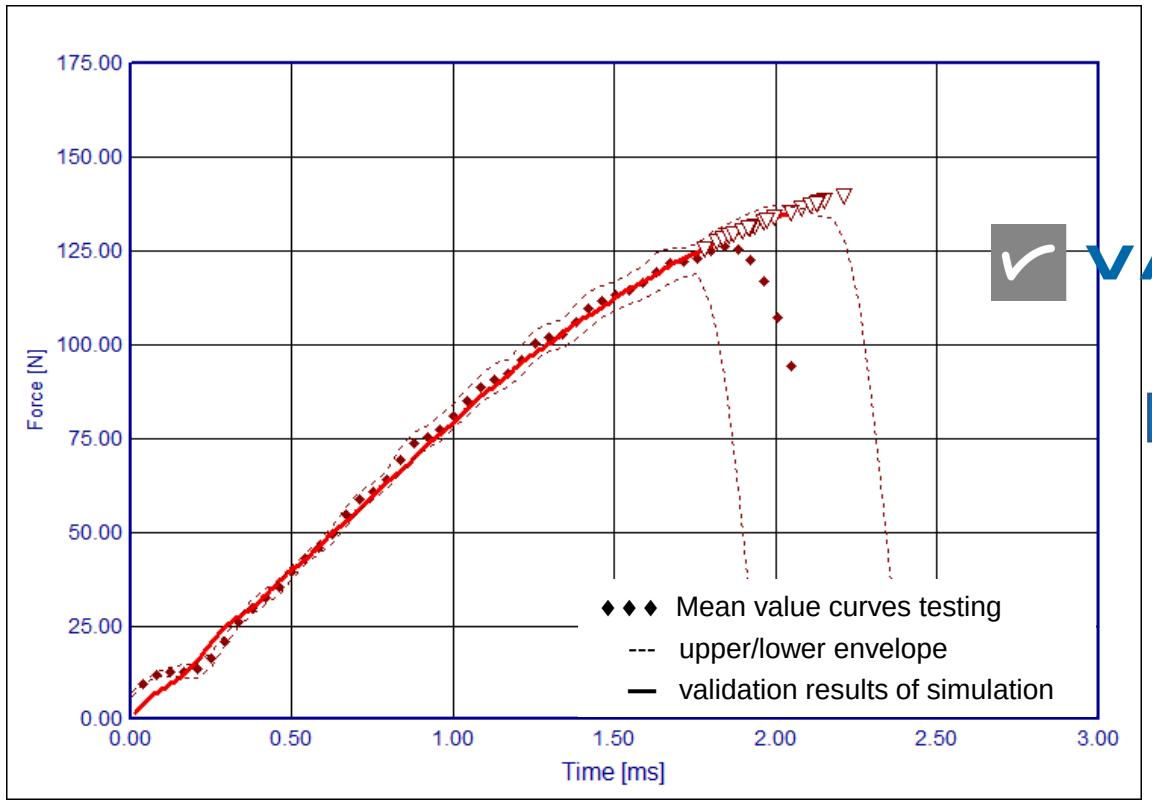


PP-LGF30 exemplary failure evaluation

VALIMAT® FEATURE:
Visualize failure points in simulation
Export to Clipboard for further evaluation Excel, R, …



Damage/Failure



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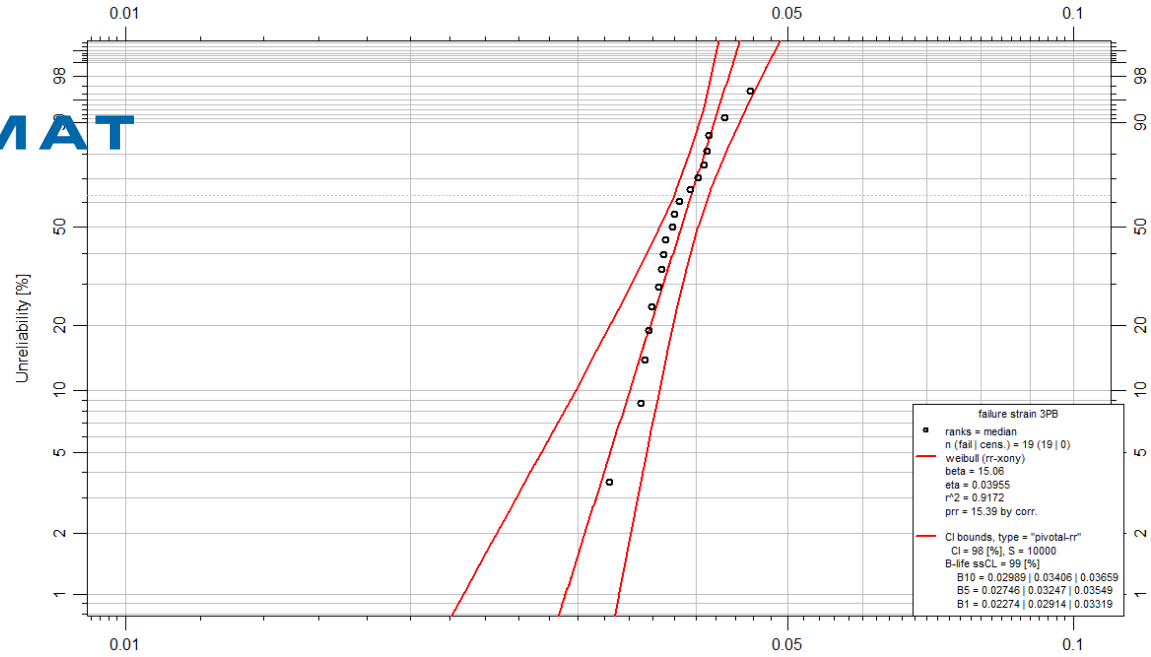
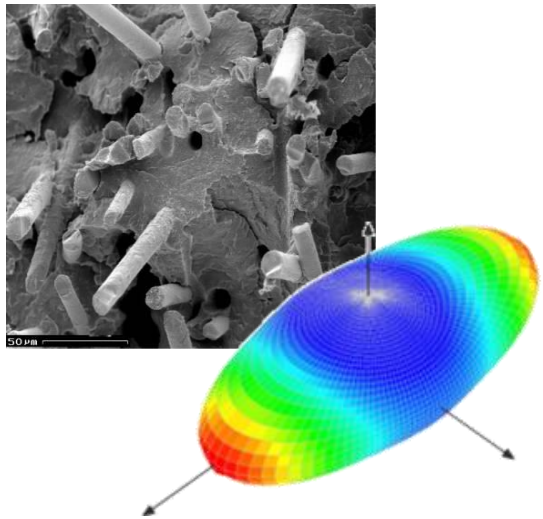


short fiber reinforced plastics constitutive approach *MAT_157



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

short fiber reinforced plastics – Stochastic Approach to Rupture Probability

done by Sygusch N. (2020)

- Material: PPGF30
- 3 point bending test
  - static and dynamic
  - 30 tests for different orientation
- Simulation with LS-DYNA
  - deformation: *MAT_157
    orthotropic elastic visco plastic
  - failure: *MAT_ADD_EROSION
    maximum principal strain
- Investigations on
  - failure: deterministic versus probability
  - Influences: Monte Carlo Simulation

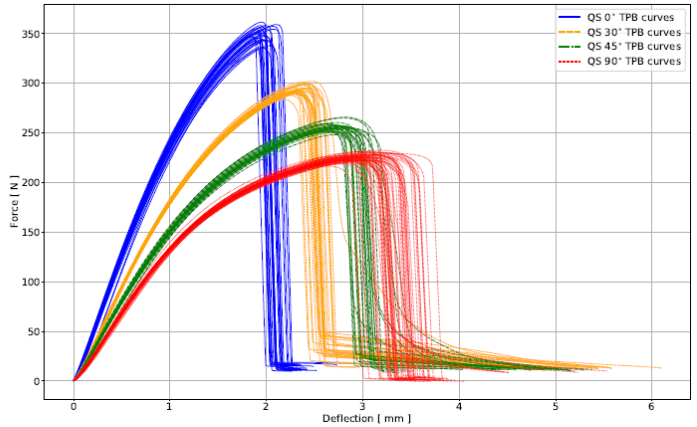


Figure A.19 Quasistatic three point bending force deflection curves

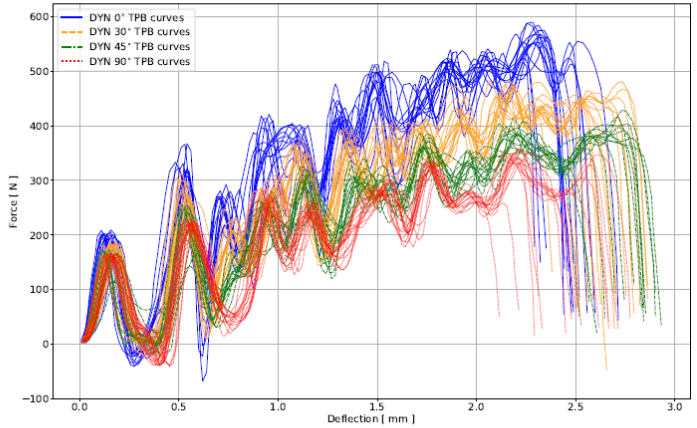
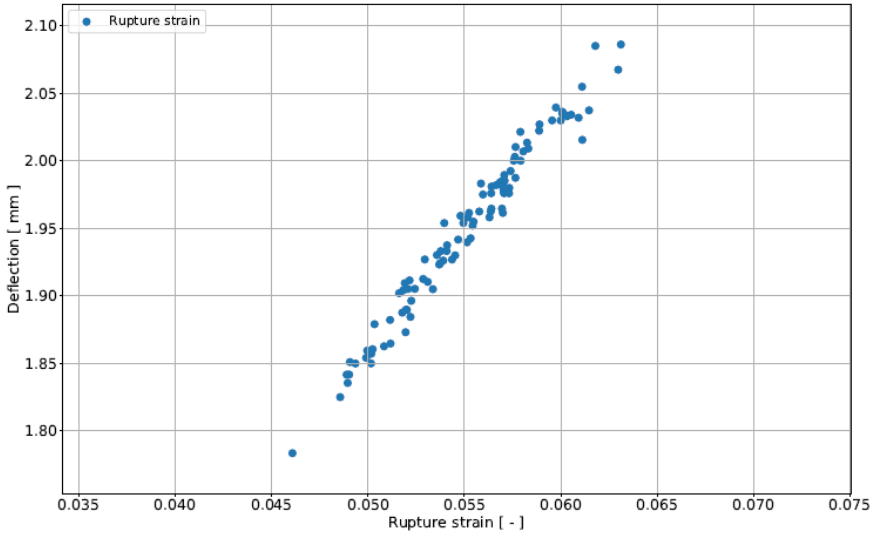


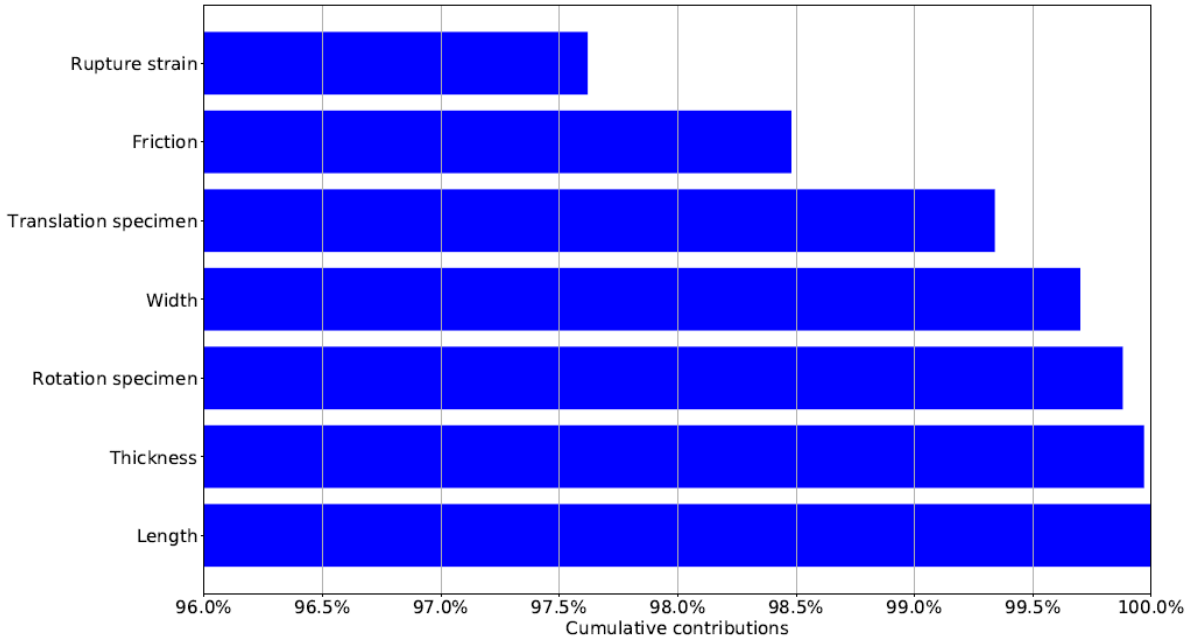
Figure A.20 Non filtered 4 ms^{-1} impact velocity three point bending force deflection curves

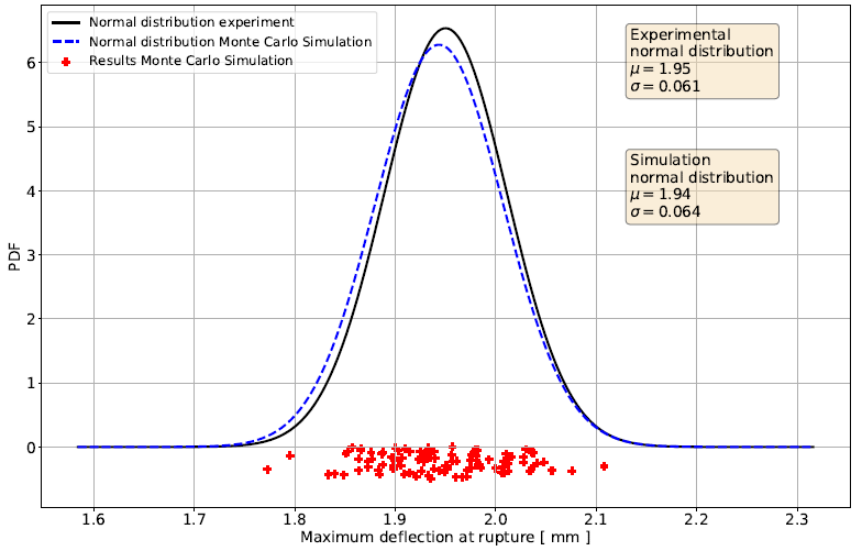
Source: Sygusch N. (2020) Statistical Analysis. In: Stochastic Approach to Rupture Probability of Short Glass Fiber Reinforced Polypropylene based on Three-Point-Bending Tests

Monte Carlo Simulation – 3PB max. deflection

Parameter	Expected value μ	Standard deviation σ
Specimen length	40.09 mm	0.093 mm
Specimen width	10.02 mm	0.15 mm
Specimen thickness	3.17 mm	0.007 mm
Translation specimen	0.0 mm	1.0 mm
Rotation specimen	0.0°	1.0°
Friction	0.3	0.05
Rupture strain	0.055	0.00363

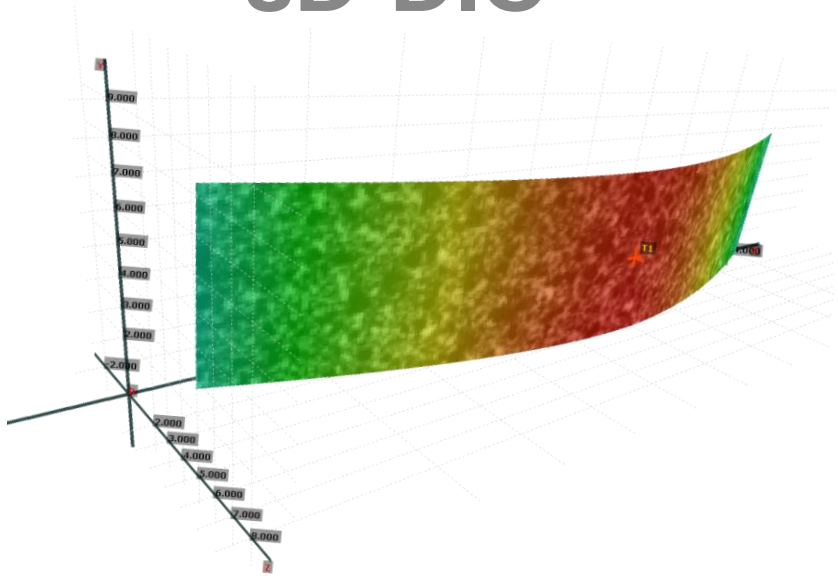






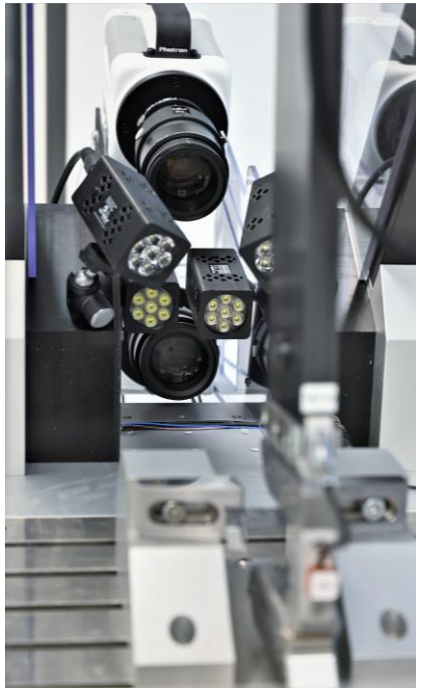
Source: Sygusch N. (2020) Statistical Analysis. In: Stochastic Approach to Rupture Probability of Short Glass Fiber Reinforced Polypropylene based on Three-Point-Bending Tests

3D-DIC



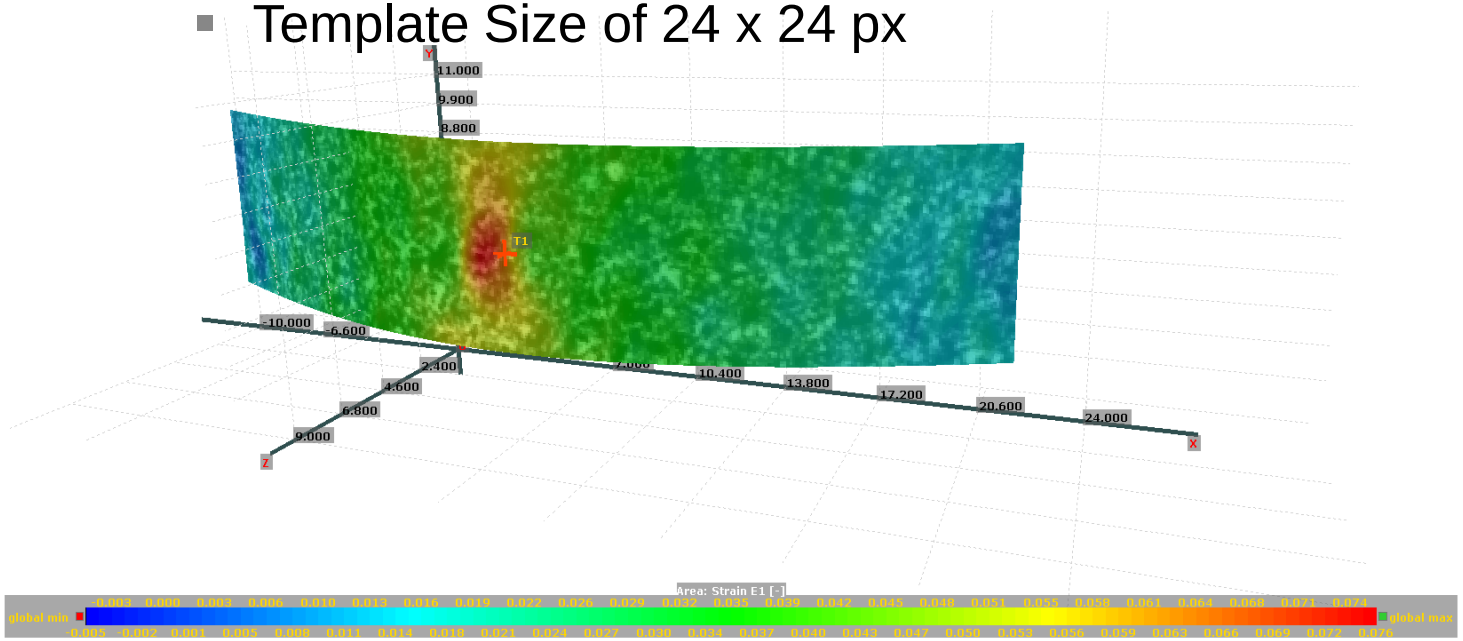
IMPETUS® - 3D DIC Setup

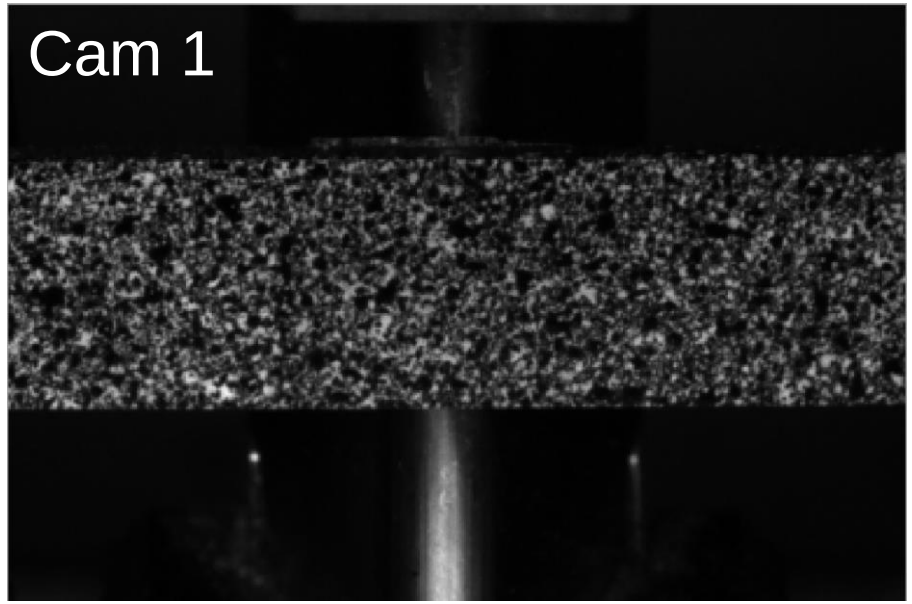
- 3PB Test setup
  - 2 x Photron FASTCAM NOVA S9
  - Camera 1 from above tilt angle 20°
  - Camera 2 from below tilt angle -5°

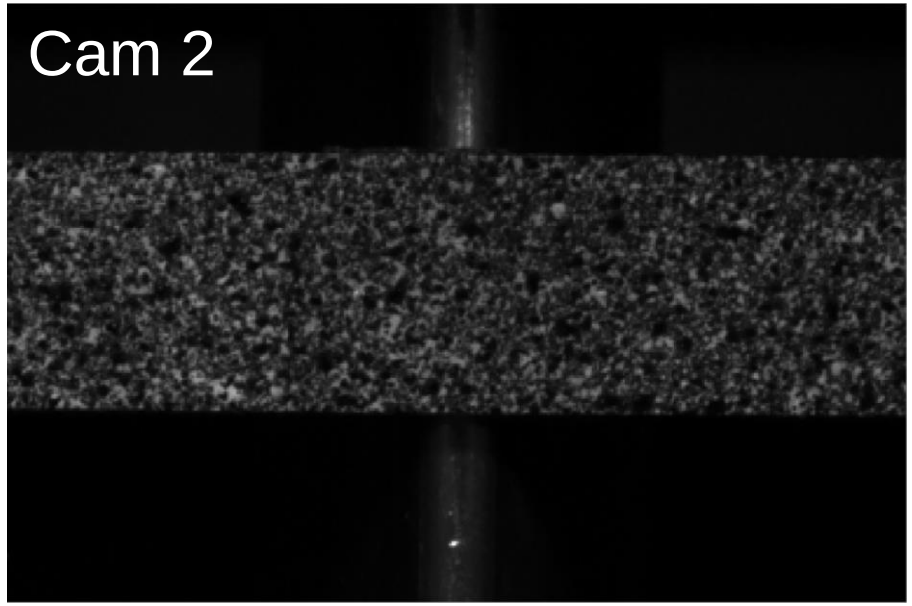


IMPETUS® - 3D DIC Setup

- DIC settings
  - Resolution of 384x256 px
  - Recorded frame rate of 15.000 fps
  - Strain measuring with a Full-Field Area
    - True Strain E1maximum
    - Template Size of 24 x 24 px

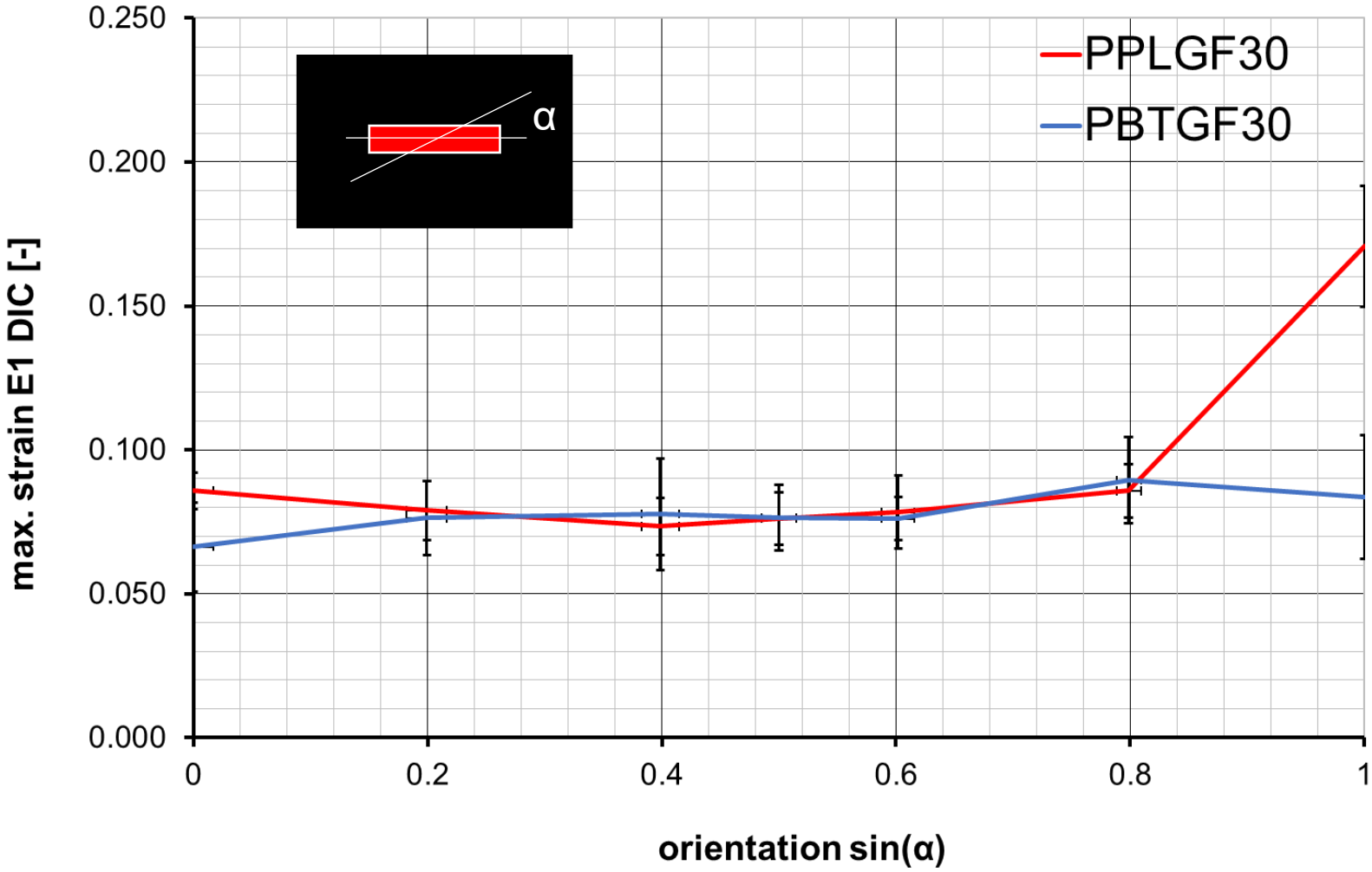


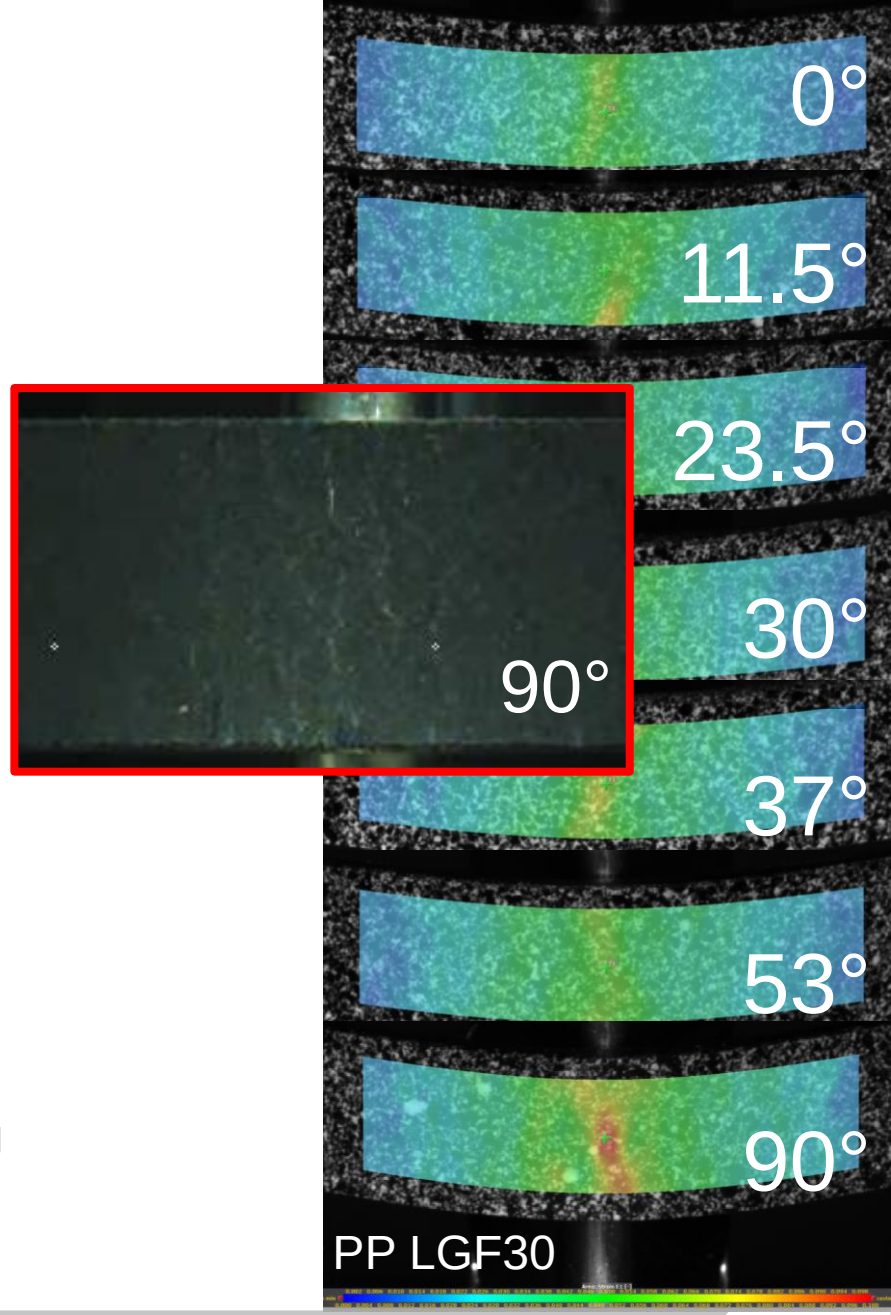




Source: P Reithofer, failure criteria SFRT and LFRT

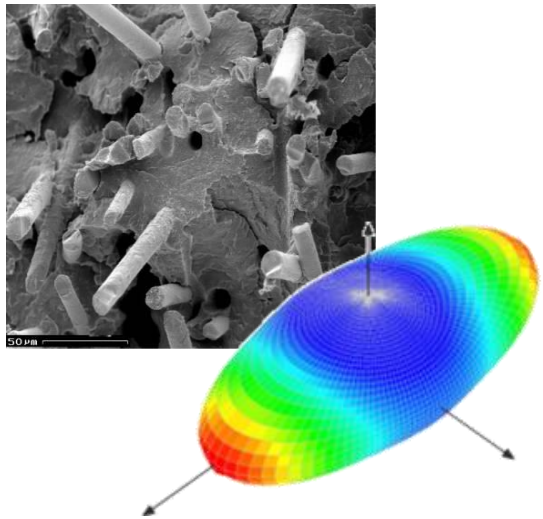
first results





Source: P Reithofer, failure criteria SFRT and LFRT

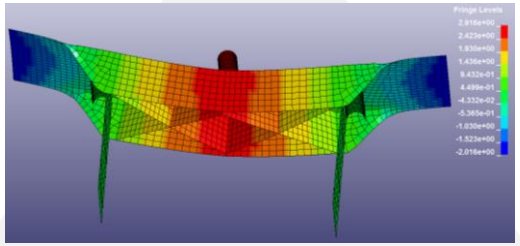
short fiber reinforced plastics micro scale - *MAT_215

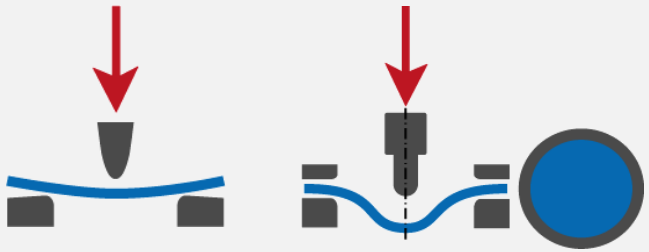


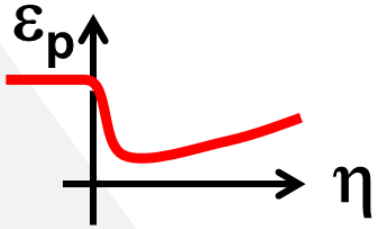
$$\overline{\sigma}^{C} = \varphi\overline{\sigma}^{F} + (1-\varphi)\overline{\sigma}^{M}$$

from test to material card

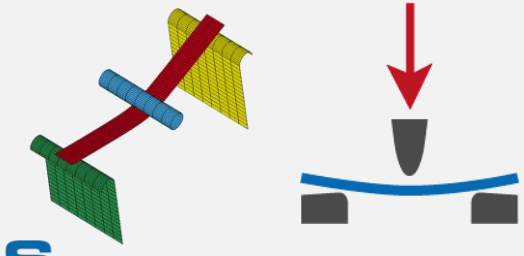
VALIMAT



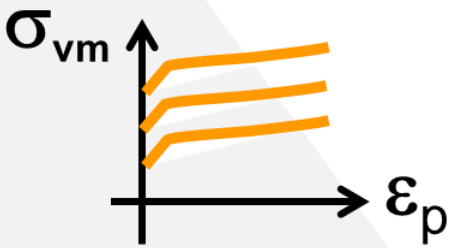




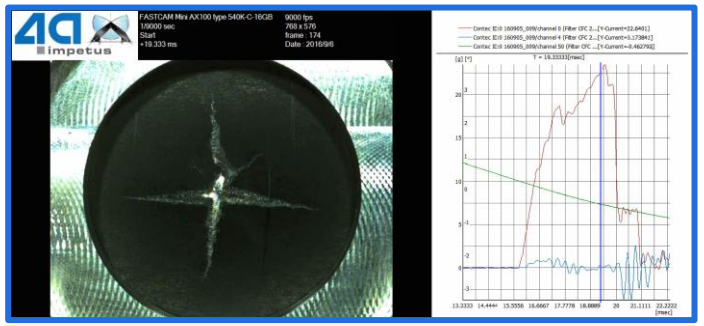
Damage/Failure

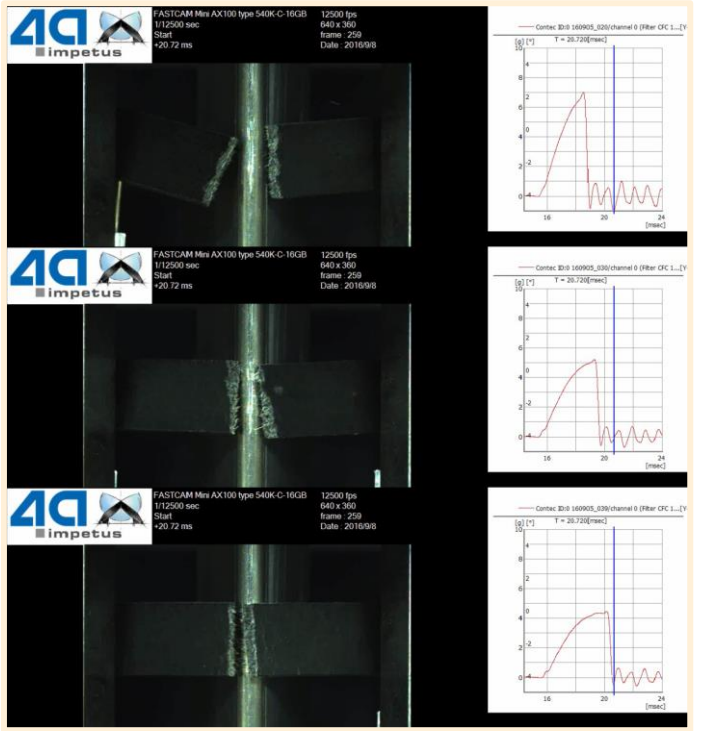


Anisotropic



Hardening





Source: P Reithofer, failure criteria SFRT and LFRT

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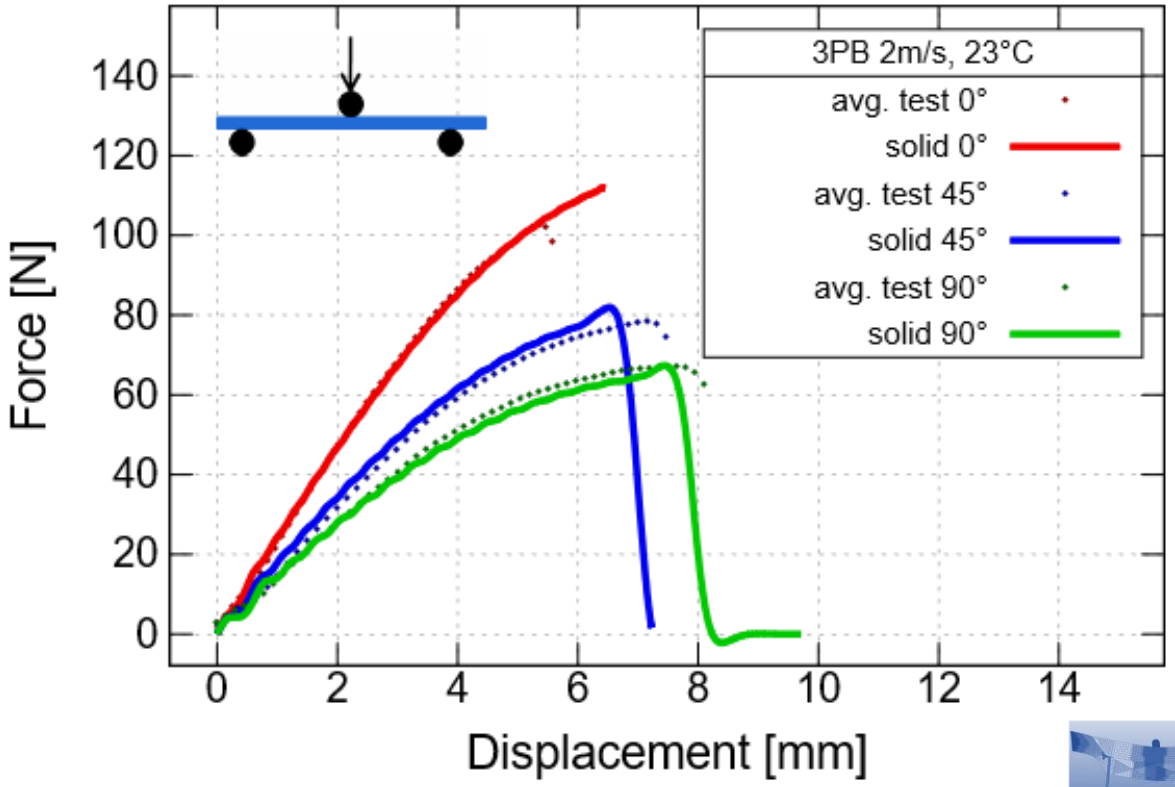
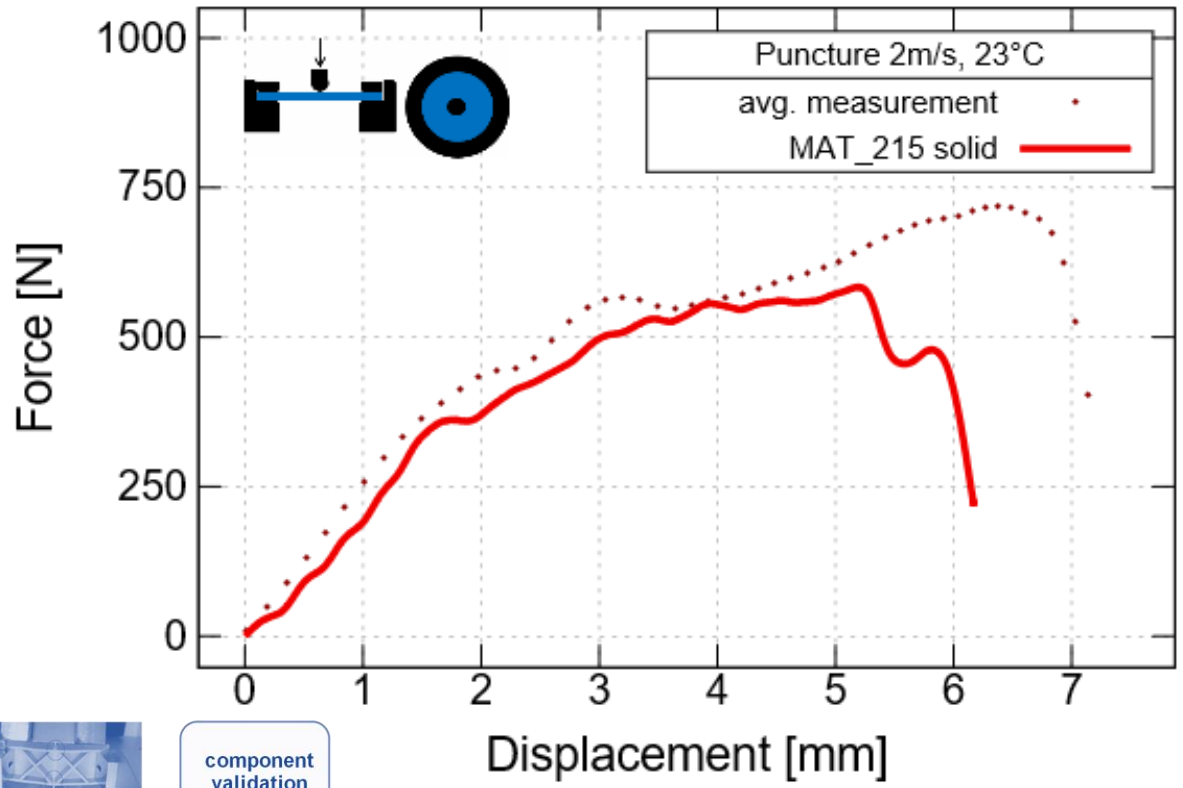
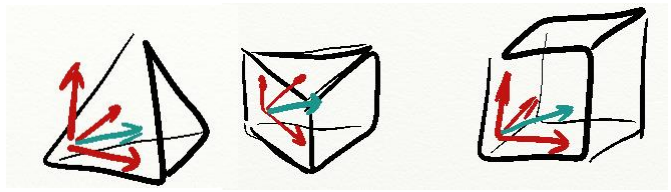
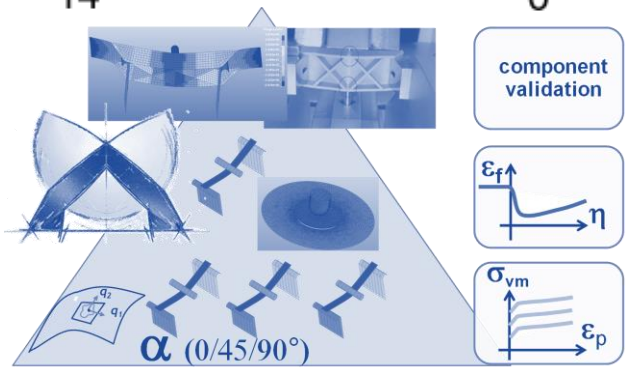
From test to material card – PP LGF30 *MAT_215





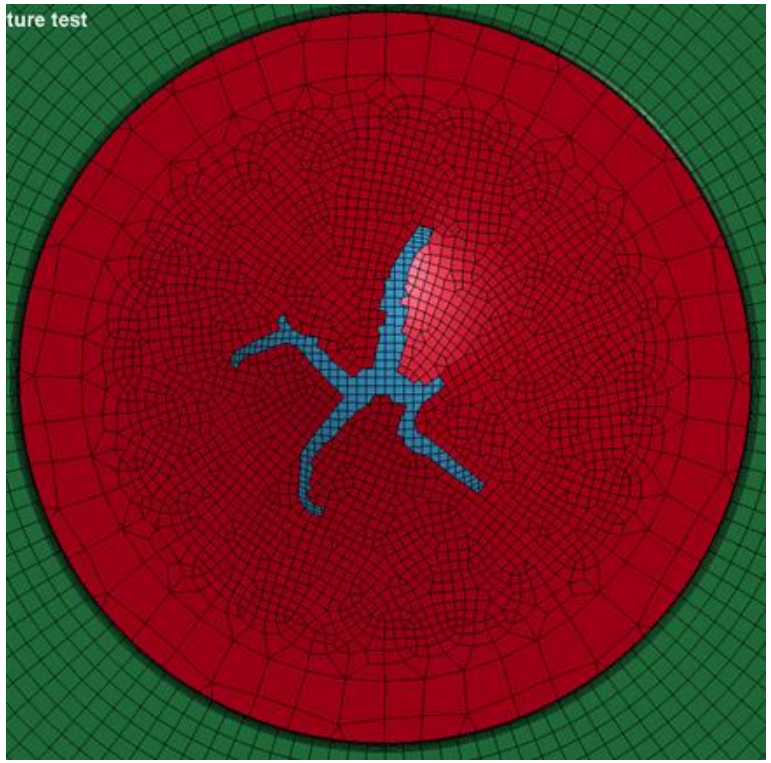


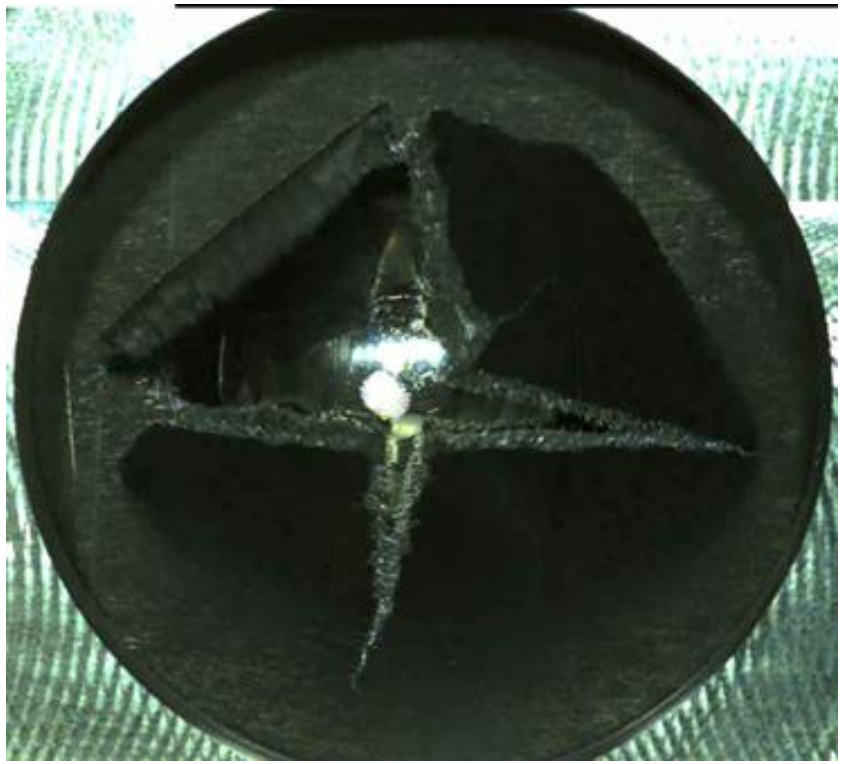


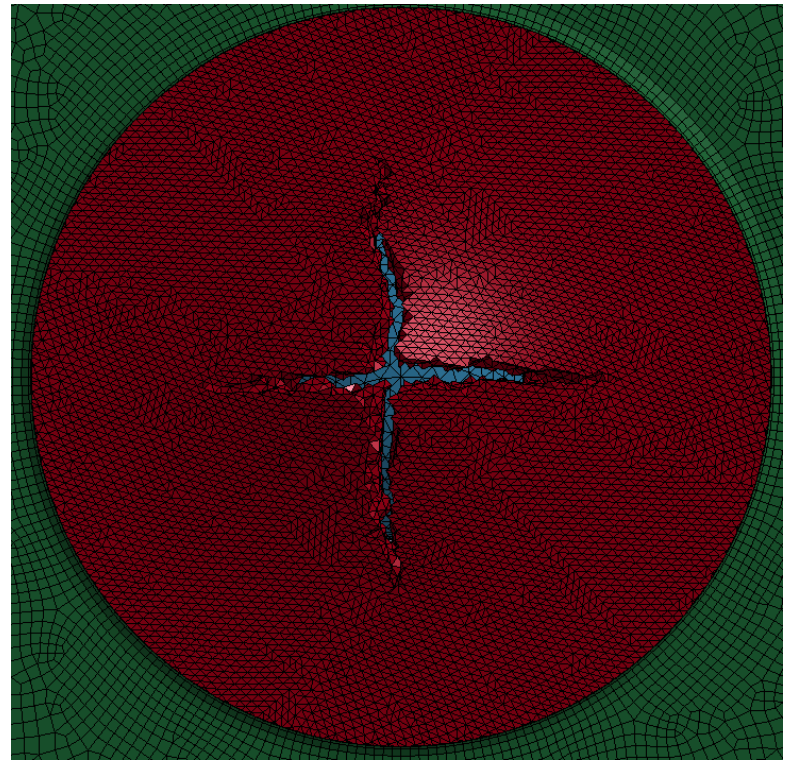
···· averaged test curves
— result of simulation

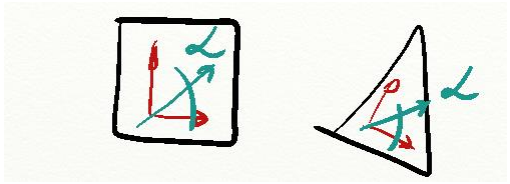
Source: P Reithofer, failure criteria SFRT and LFRT

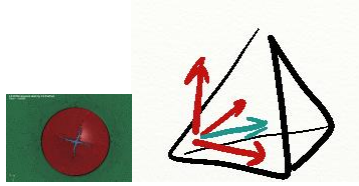
From test to material card – PP LGF30 *MAT_215





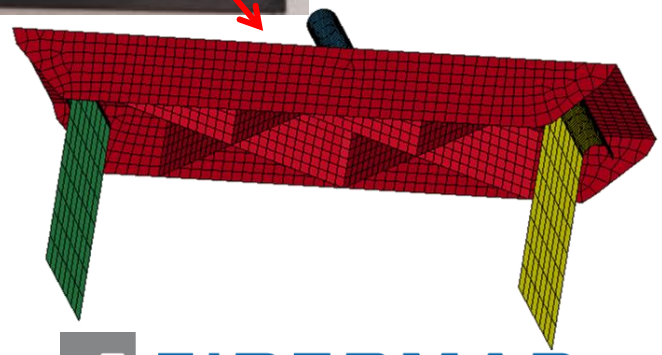


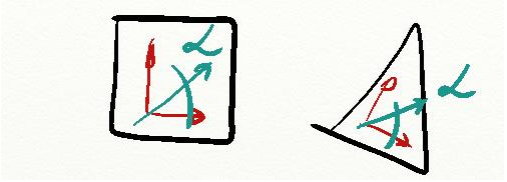


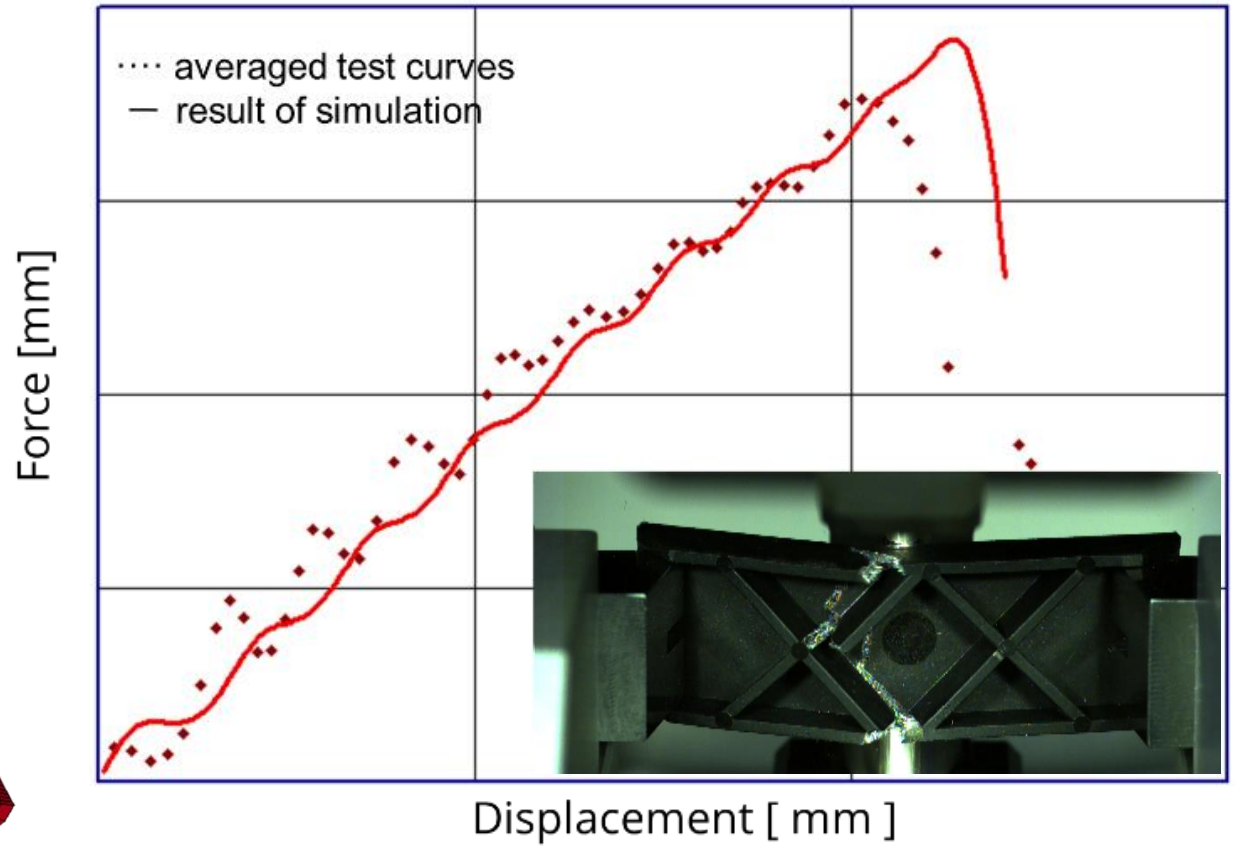


Source: P Reithofer, failure criteria SFRT and LFRT

from test to material card – PP LGF30 *MAT_215







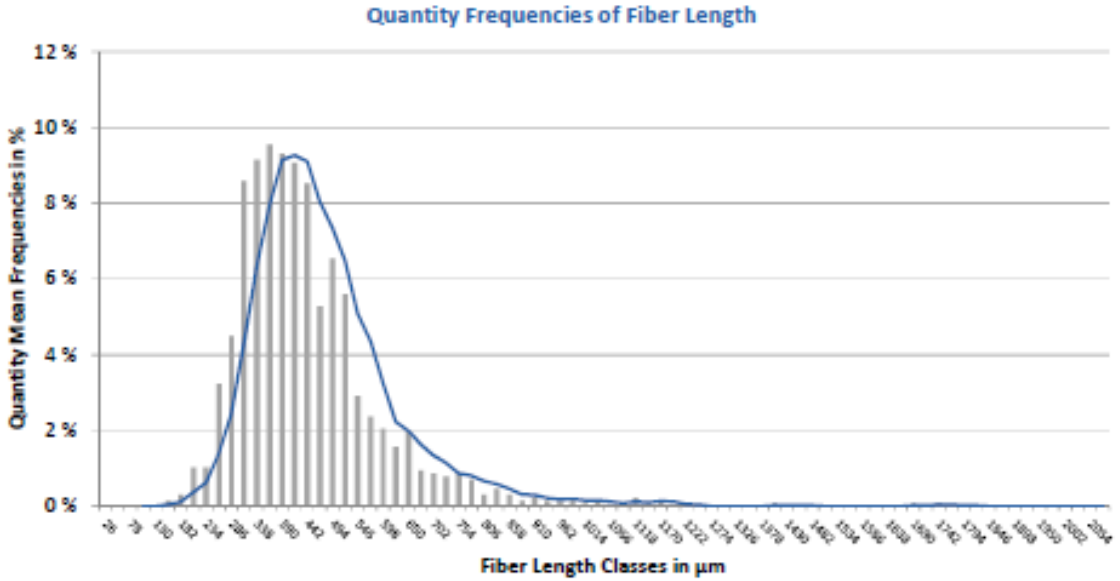
FIBERMAP

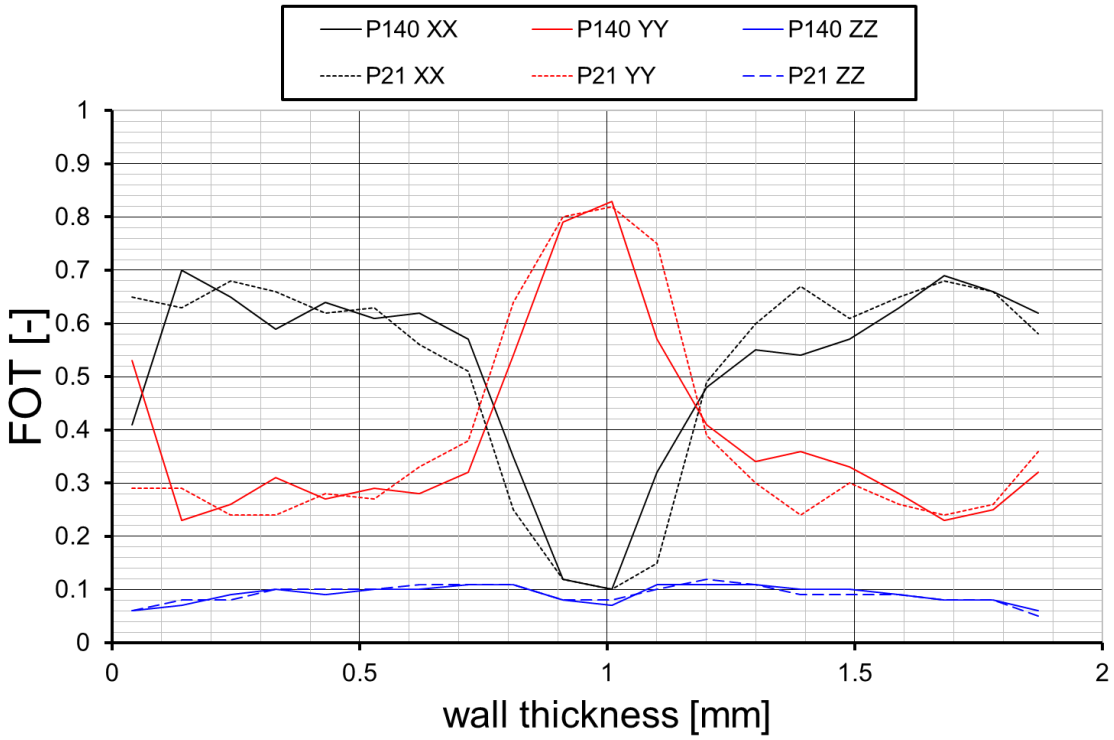
Source: P Reithofer, failure criteria SFRT and LFRT

short & long fiber reinforced plastics

- process induced due different shear and elongational flow
- fiber distribution
  - content (delivery)
  - location (probability) → FOT
  - length (fiber brakeage)

material	sample	ash [%]	vol. ave. Length [mm]	l/d [-]
PA6-sGF30	A1-54	29.9	0.44	36.7
PA6-sGF30	A2-51	29.8	0.46	38.3
PP-LGF30	B1-21	29.8	1.00	50.0
PP-LGF30	B2-30	29.5	0.98	49.0
PBT-sGF30	C1-80	29.6	0.43	35.8
PBT-sGF30	C2-182	29.6	0.44	36.7





Source: P Reithofer, failure criteria SFRT and LFRT

*MAT_215 KEYWORD (more see Summer-School-Day7.pdf)

CARD 1: General Options / Parameter

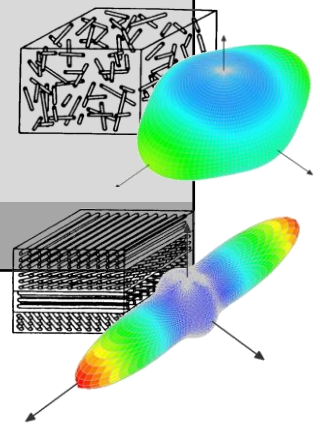
CARD 2-3: Element orientation*

analog to LSDYNA standard anisotropic material cards

MONTE CARLO SIMULATION

CARD 4: Composite Buildup*

Card 4	1	2	3	4	5	6	7	8
	FVF		FL	FD		A11	A22	
PP GF30	-0.3		200.0	10.0		0.7	0.25	
PP LGF50	-0.5		1000.0	20.0		0.65	0.30	
PA6 GF45	-0.45		250.0	10.0		0.8	0.15	
Carbon UD	0.6		10000.0	10.0		1.0	0.0	

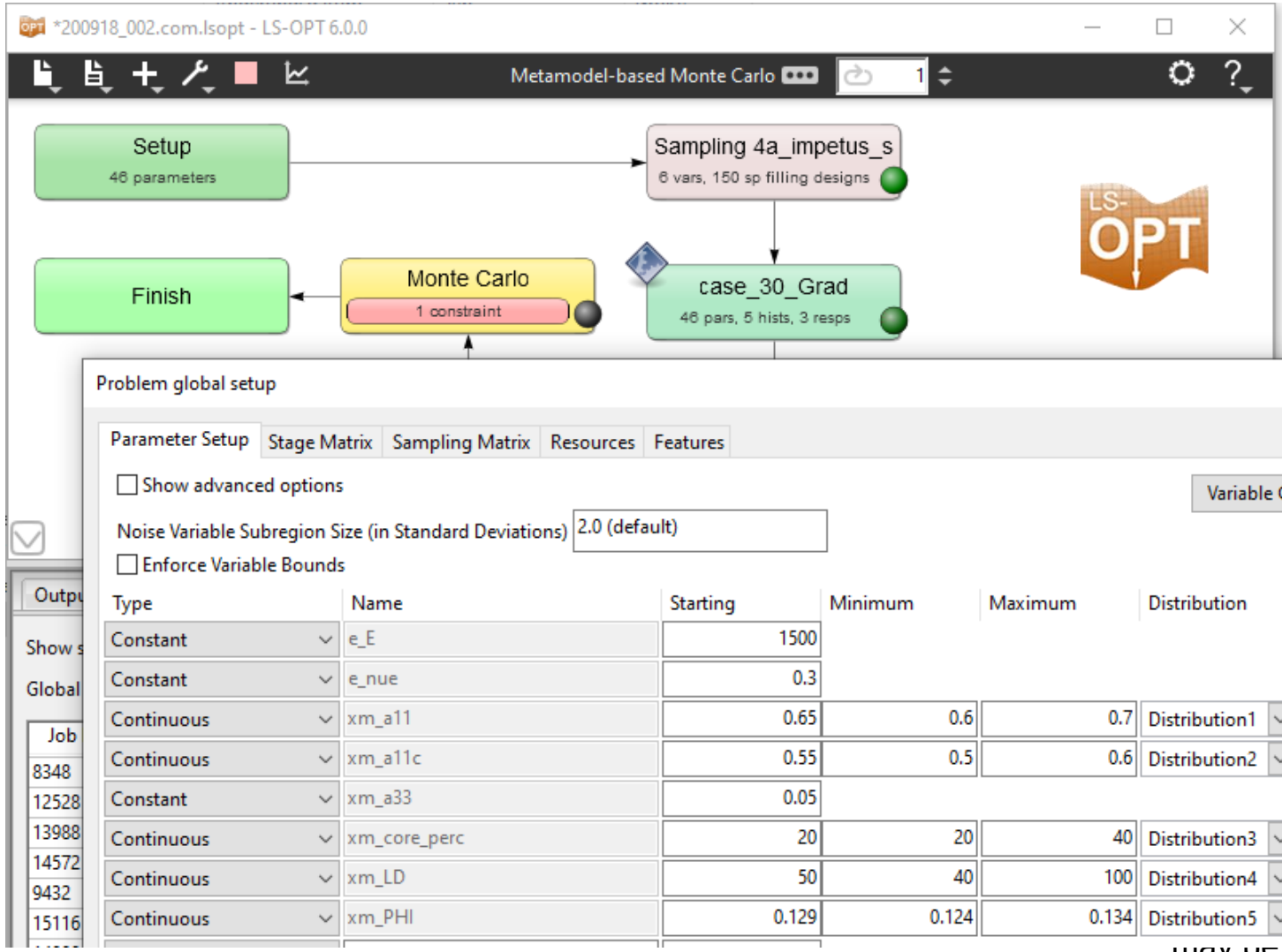


FVF > 0: fiber volume fraction → Composite
FVF < 0: fiber mass fraction → SFRT/LFRT

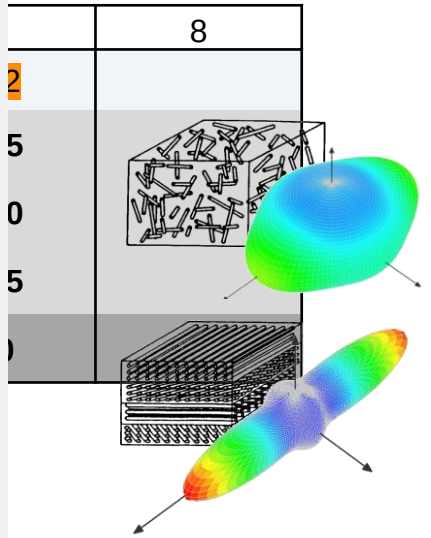
*may be overwritten by
*INITIAL_STRESS_SHELL/SOLID

exemplary values without any warranty

*MAT_215 KEYWORD (more see Summer-School-Day7.pdf)



LO SIMULATION



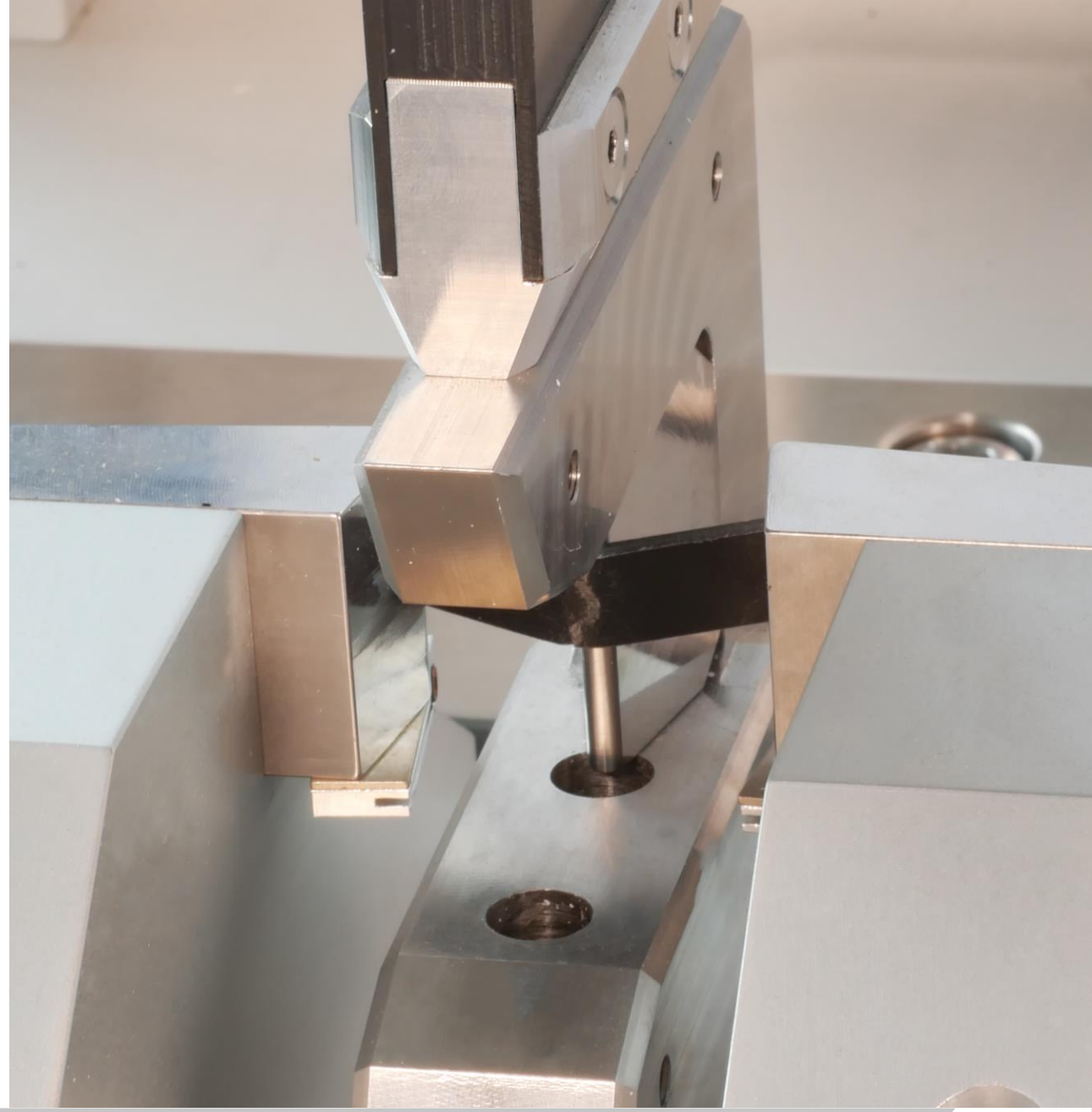
may be overwritten by
*INITIAL_STRESS_SHELL/SOLID

exemplary values without any warranty

Summary

- exemplary depiction of main influences
  - Foamed Plastics
  - SFRP & LFRP
- Features of VALIMAT®
  - Statistics
  - Setting up MCS with LS-Opt
- IMPETUS® offers
  - Efficient testing
    including 3D strain measurement
- Micro Mechanical Models offer new opportunities for MCS

→ All together good starting point



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YouTube CHANNEL