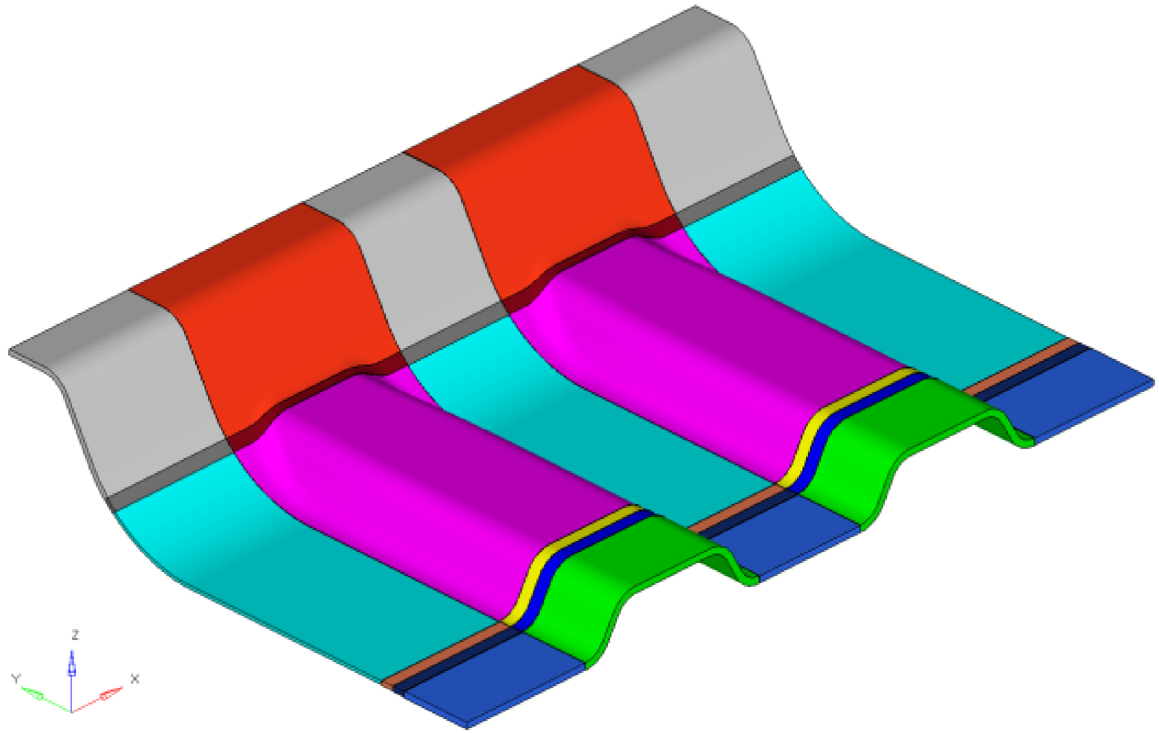

BMBF MAI qfast: design and validation with ULTRASIM® for continuous fiber reinforced parts

Sebastian Ebli, Stefan Glaser, Andreas Wüst

BASF
We create chemistry

Agenda

- Project overview
- ULTRASIM®
- Composite Optimization
- Load cases: comparison experiment to simulation
  - Twisting Load
  - Operating load
  - Impact load
- conclusion

Project MAI qfast

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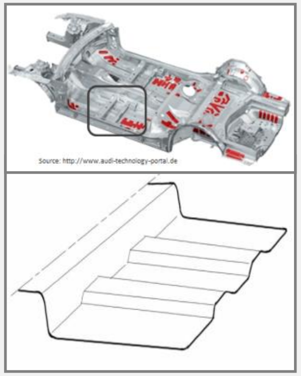
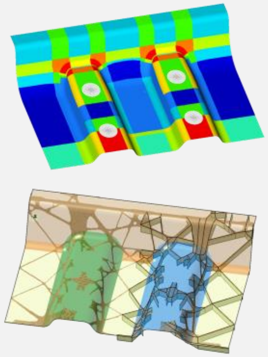
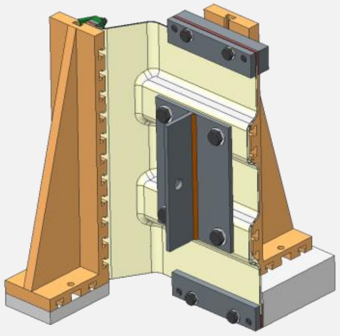
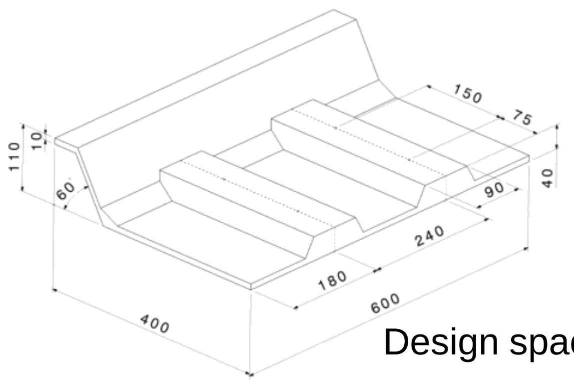
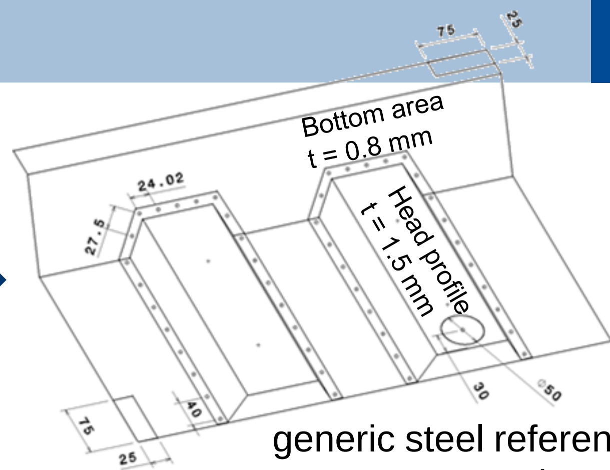
concept	design	manufacturing	simulation/testing
			

duration	2.5 years, 11/2012 – 04/2015
budget	2.146 million €
Material system	carbon fiber with different matrices
partner	AUDI AG, BMW Group, BASF SE, Fraunhofer ICT, (Krauss Maffei – associated partner)
project coordinator	Dr. Julius Rausch, Audi AG

Requirements: load cases

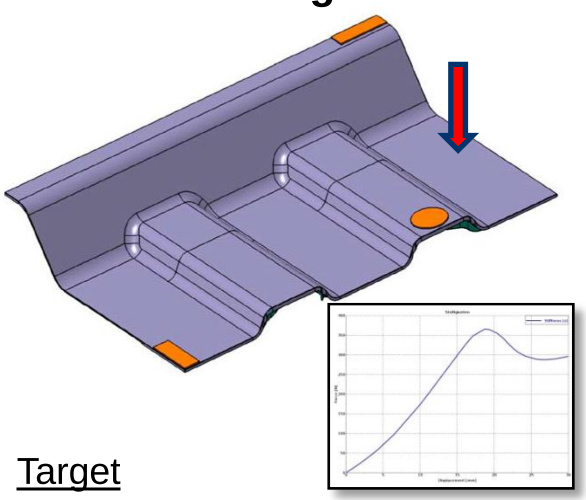


Design space



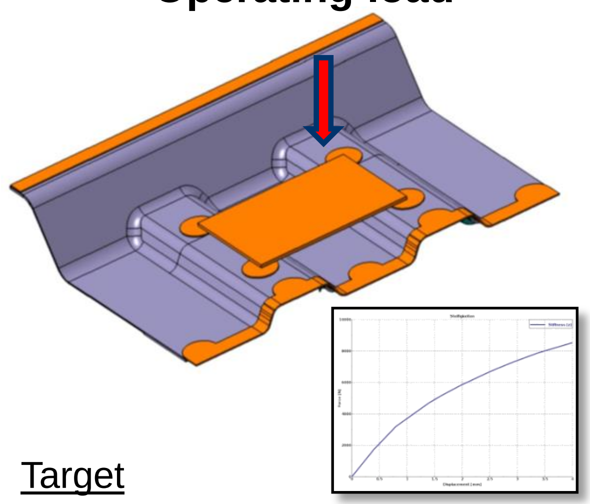
generic steel reference
Mass: 3.27 kg

Twisting load



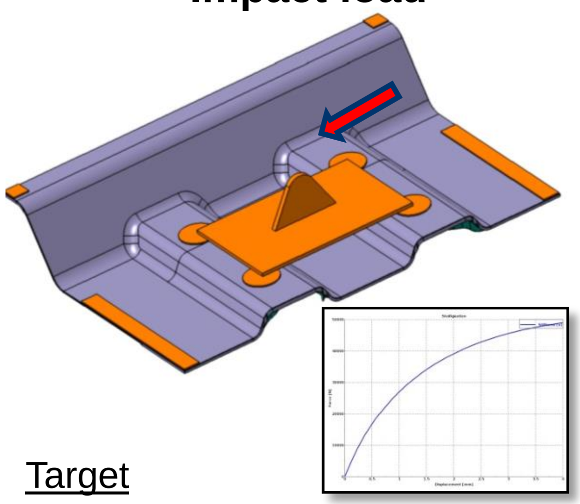
Target
Spring stiffness: 19.5 N/mm
Strength: 366 N

Operating load



Target
Spring stiffness: 5000 N/mm
Strength: 7500 N

Impact load



Target
Spring stiffness: 25000 N/mm
Strength: 25000 N

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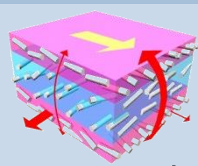
ULTRASIM®

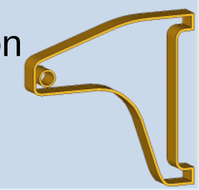
Material modelling - Integrative Simulation

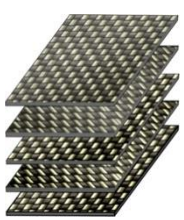
- Anisotropic
- Nonlinear
- Strain-rate sensitive
- Tension-compression asymmetric
- Failure modeling

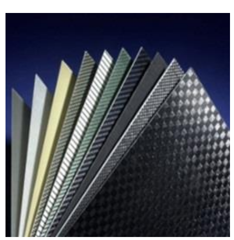


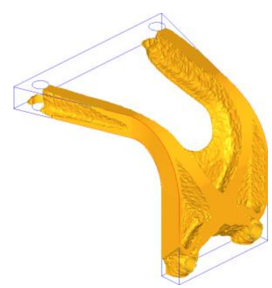
CAE Methods + Mathematical Optimization

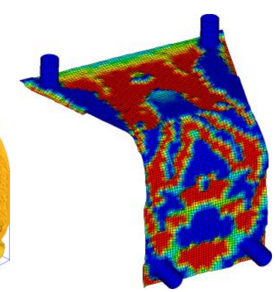
- Process simulation
- Mechanical Simulation
- Mathematical Optimization
  - Parameter
  - Shape
  - Topology
  - Composite

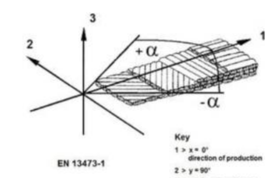


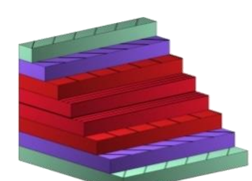












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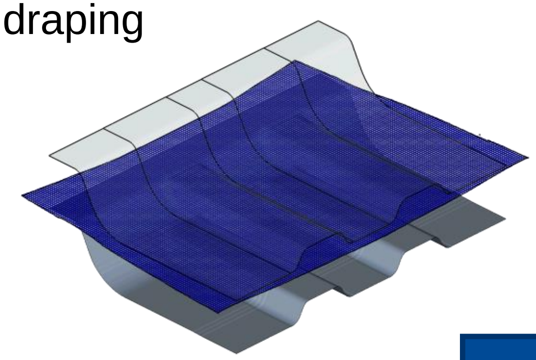
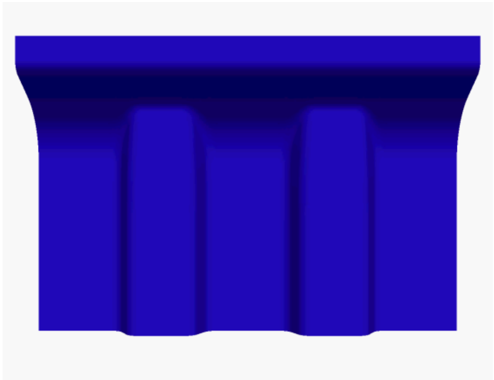
process

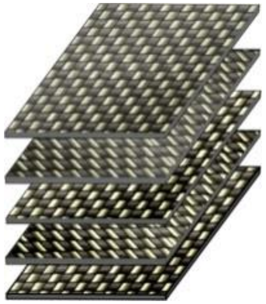
draping



molding

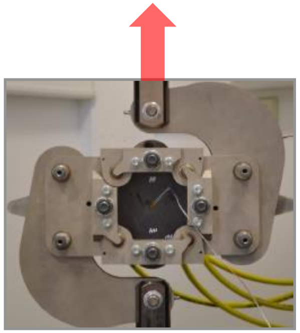


CFRP materialmodel

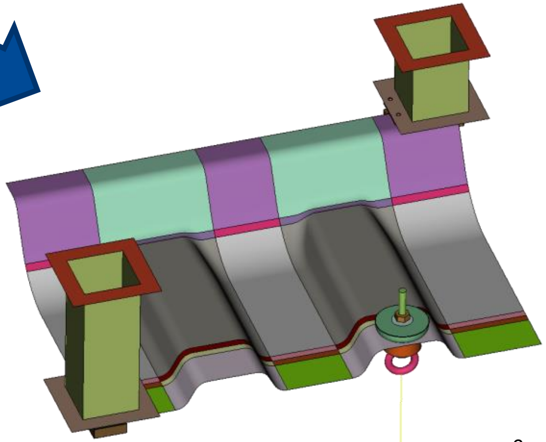


- anisotropic
- nonlinear
- strain-rate sensitive
- tensile-compression asymmetric
- anisotropic failure modelling
- anisotropic degradation
- delamination
- temperature dependent

measurement



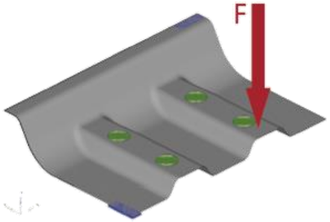
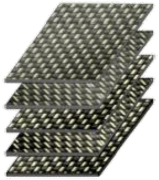
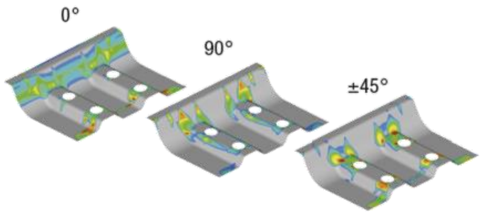
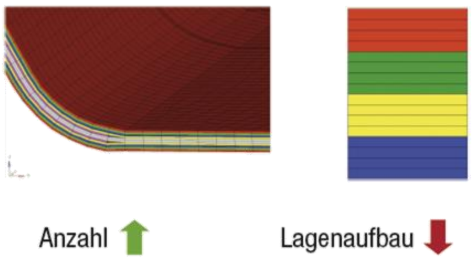
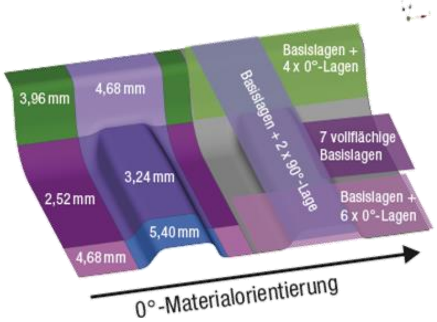
structural analysis



load path driven design of the RTM part

→ non quasi-isotropic layups, no airplane laminate

→ local reinforcements

concept	dimension	layup
		
fiber direction?	**number of plies?**	**stacking order?**
		
thickness distribution for each fiber orientation	**discrete number of single plies**	**best sequence**

Possible results from optimization dependent on setup

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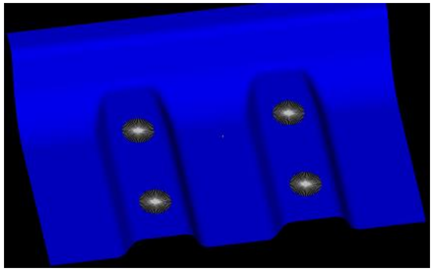
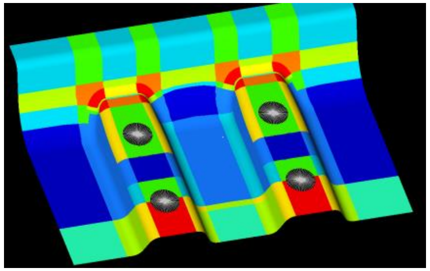
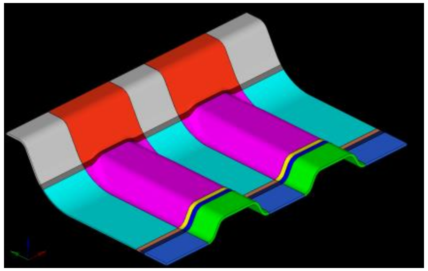
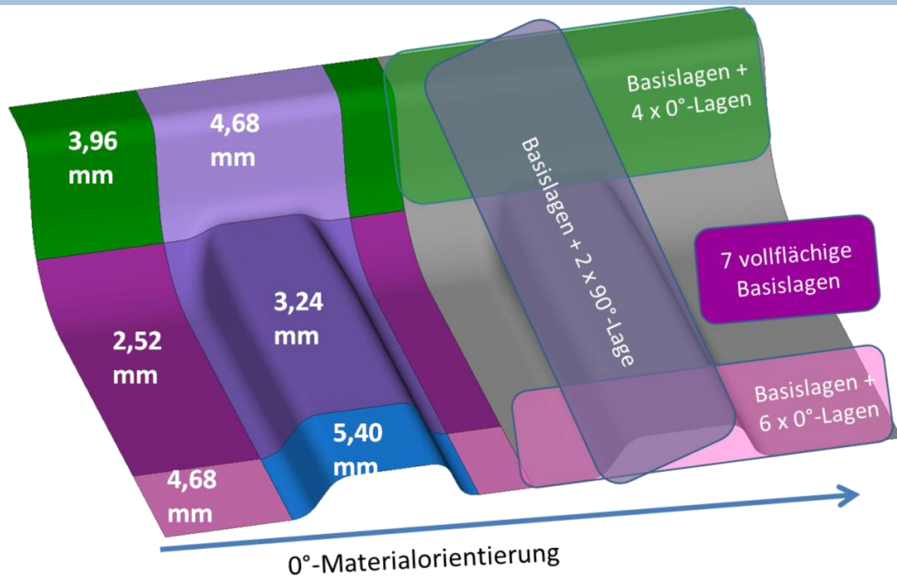
Solution:	„plane“	„pharmacy“	„implementation“
Weight	2.00 kg	1.49 kg	1.60 kg
Number of blanks	13	35 (8 different geometries)	21 (4 different geometries)
Thickness	4.7 mm	1.4 mm – 7.2 mm	2.5 mm – 5.4 mm
Processing (effort)	+	-	o







Final design and layup



Manufactured part mass:
1.58 kg

Ground layup
7 complete layer

Layer
+45°
0°
-45°
90°
-45°
0°
+45°

1.26 mm / 1.26 mm

Cross member

Layer
90°
ground 7 layer
90°

1.62 mm / 1.62 mm

tunnel

Layer
0°
0°
ground 7 layer
0°
0°

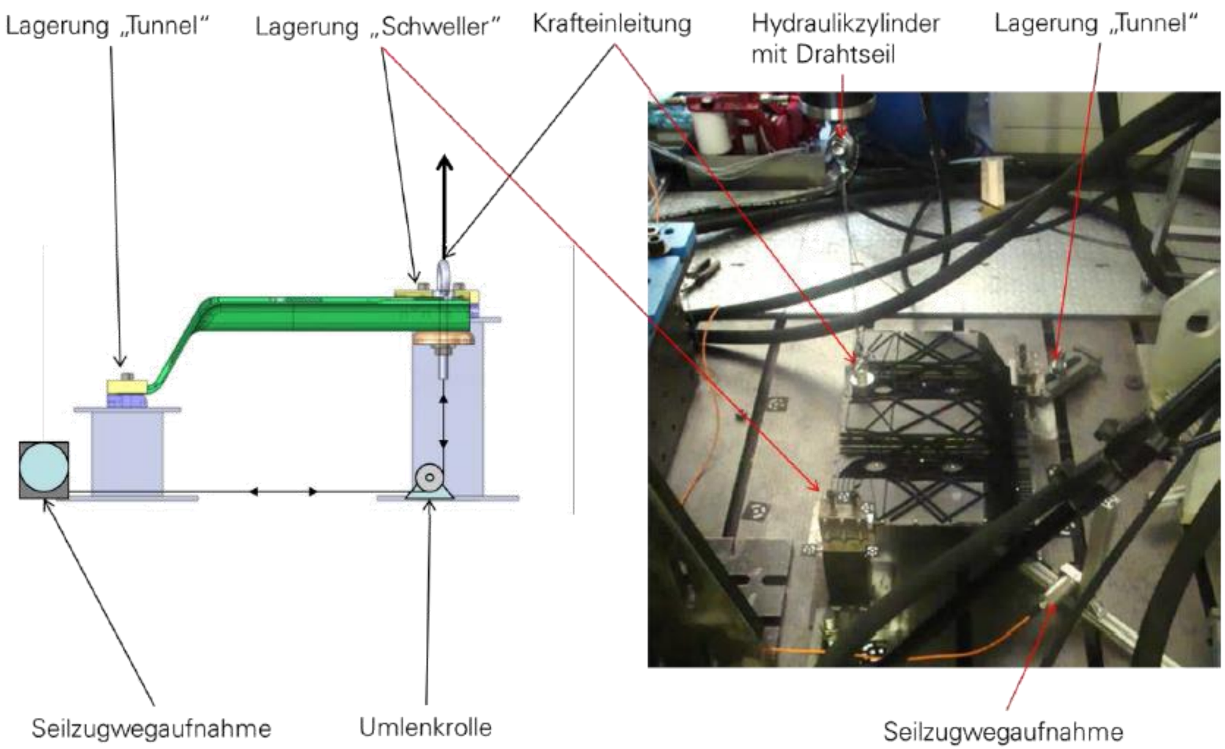
1.98 mm / 1.98 mm

sill

Layer
0°
0°
0°
ground 7 layer
0°
0°
0°

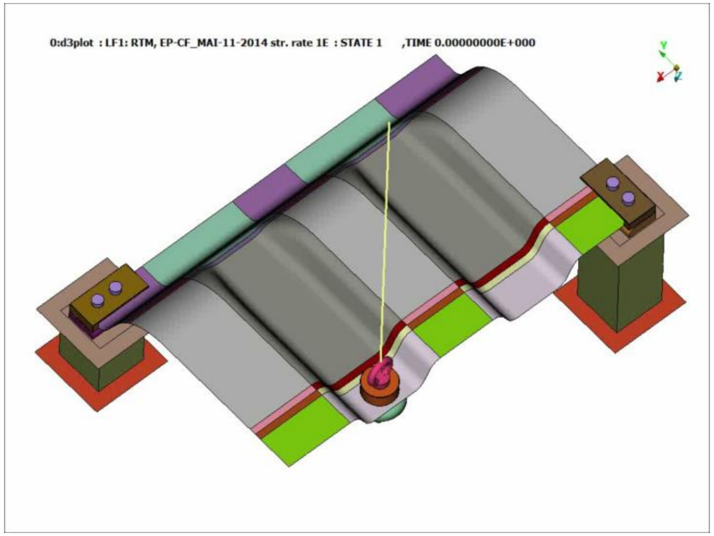
2.34 mm / 2.34 mm

twisting load
targets and test setup



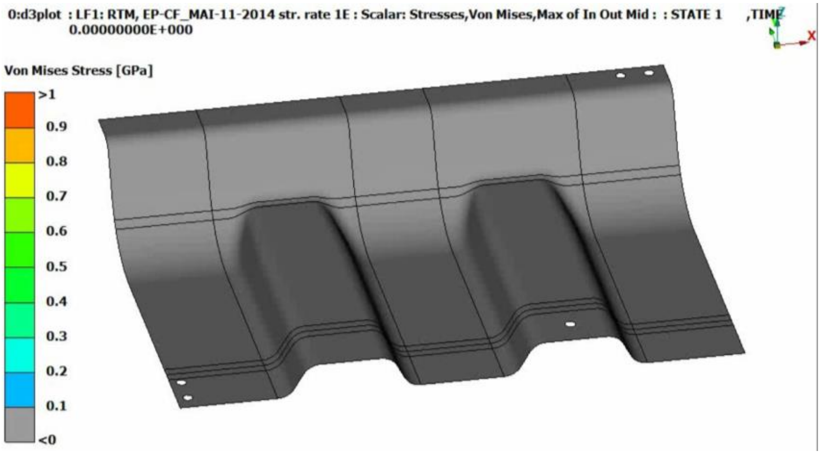
- Quasistatic test
- Targets: Comparions of stiffness
  - between test and simulation
  - For different composite systems under temperature influence
- Maximum 80 mm displacement possible due to test setup

twisting load overview



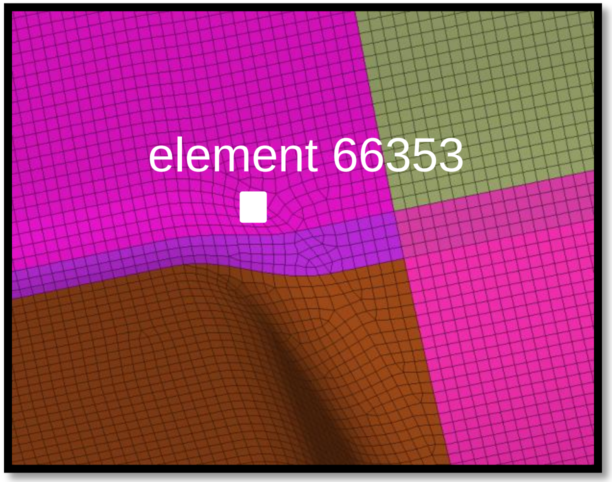
ULTRASIM® global failure

von Mises stress



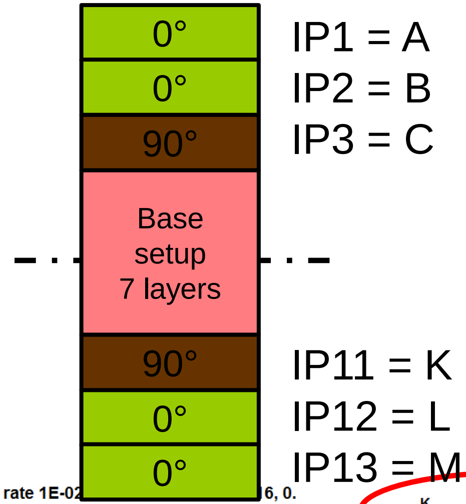
ULTRASIM® delamination

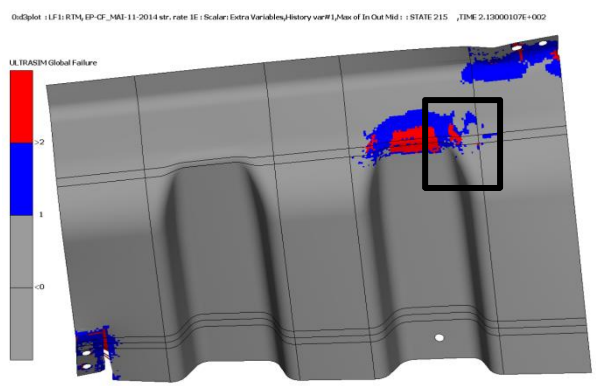
twisting load
extraction of damaged layers

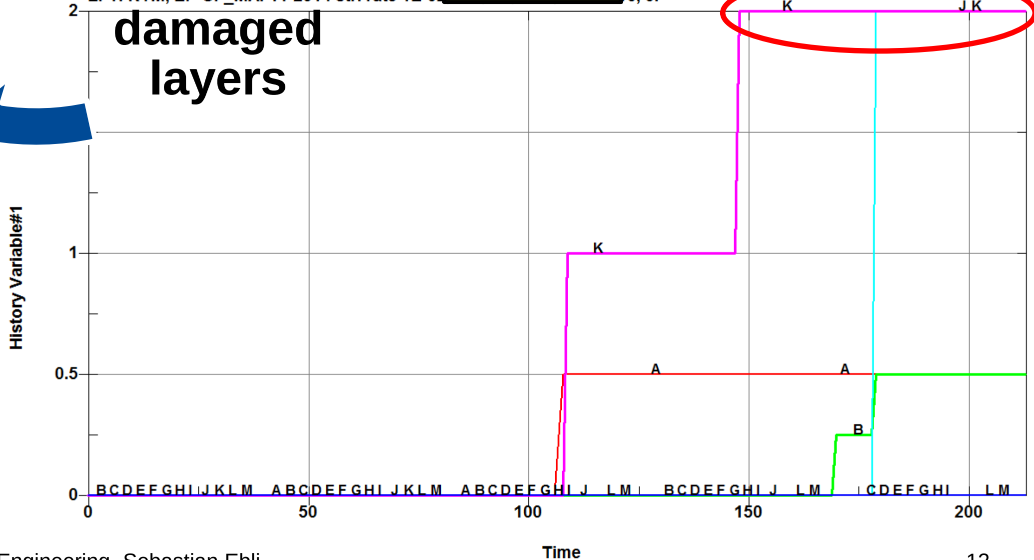


element selection → **layup definition** → **damaged layers** → **critical area** → **element selection**

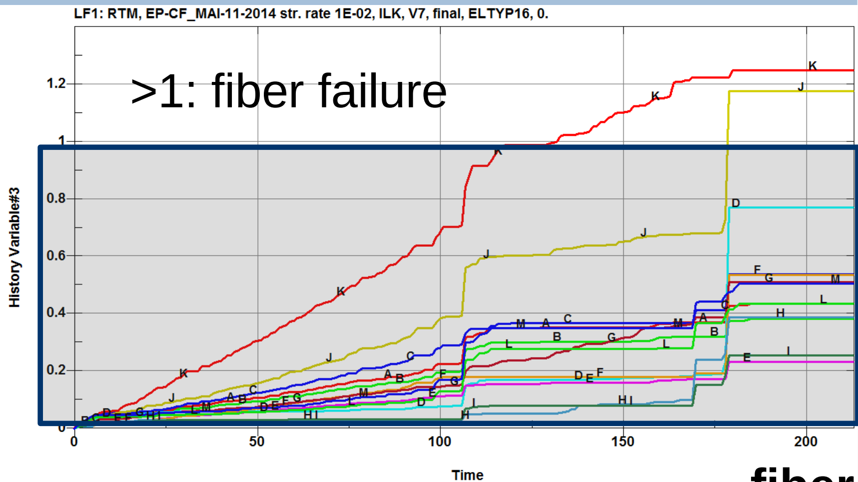
tunnel – cross member

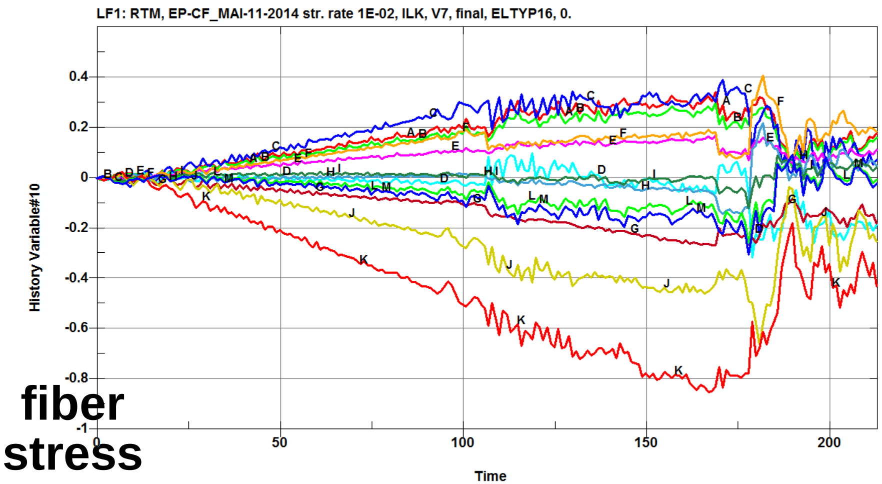






twisting load mode of failure





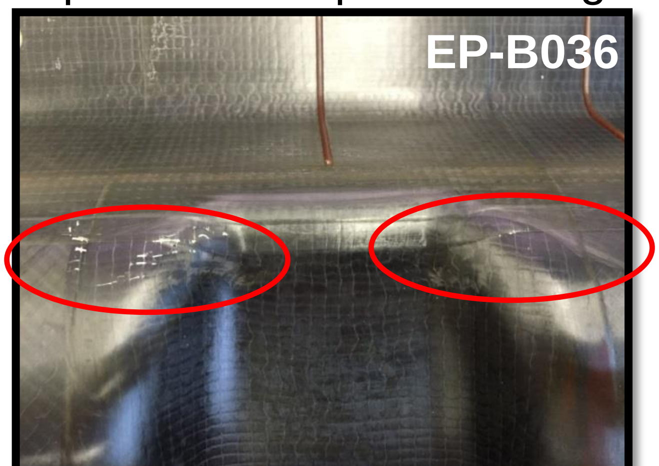
fiber failure

fiber stress (GPa)

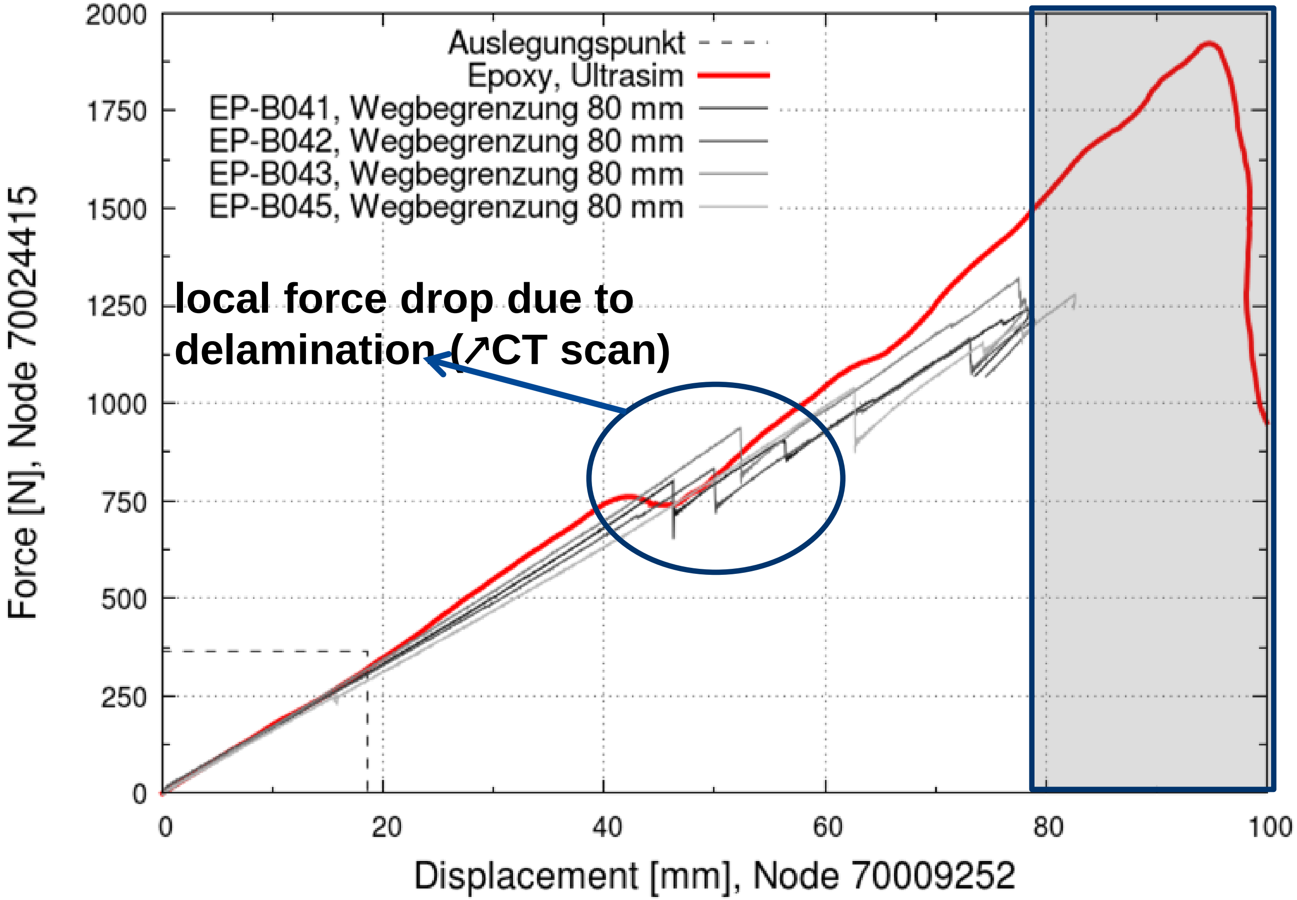
part damage

failure mode of layer J (45°) and K (90°): **compression**

optical and haptical damage

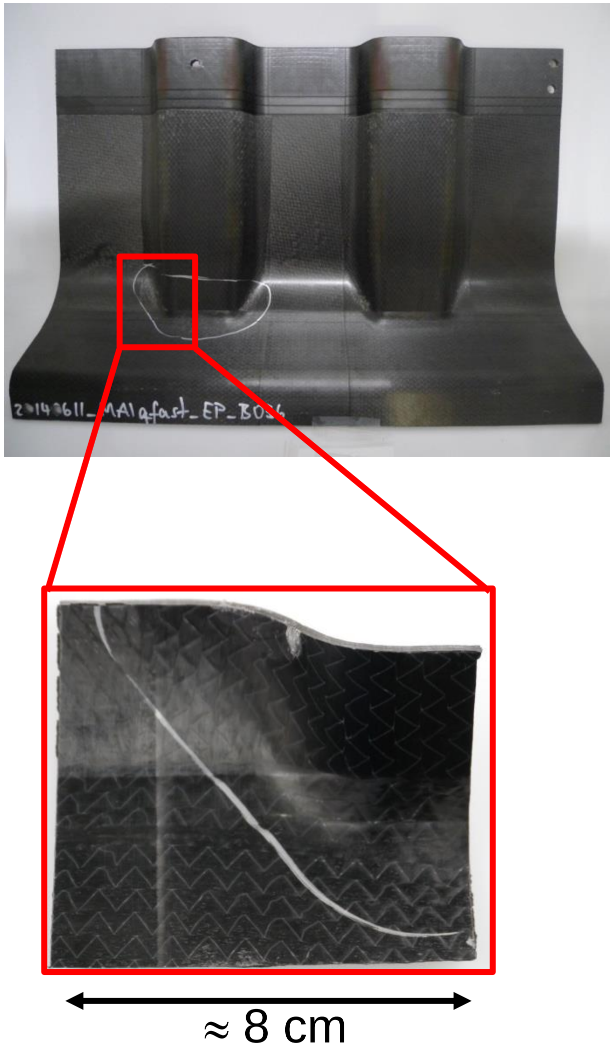


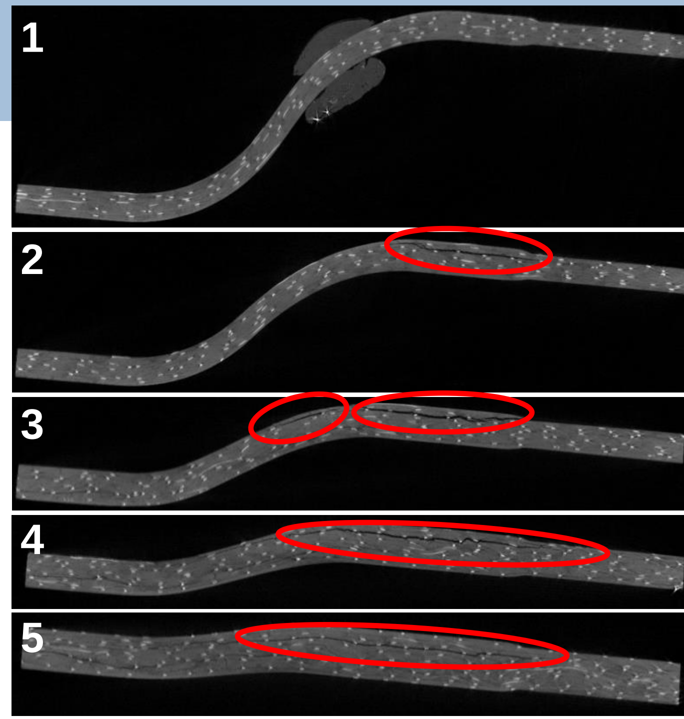
twisting load
force-displacement curve

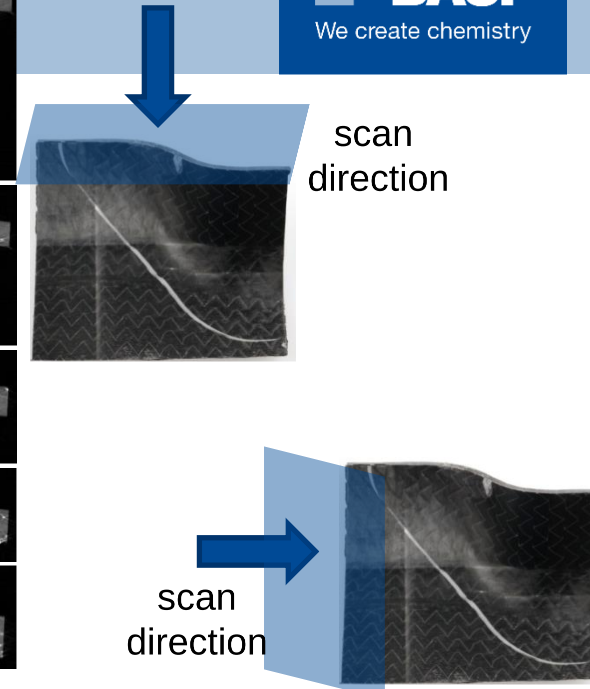


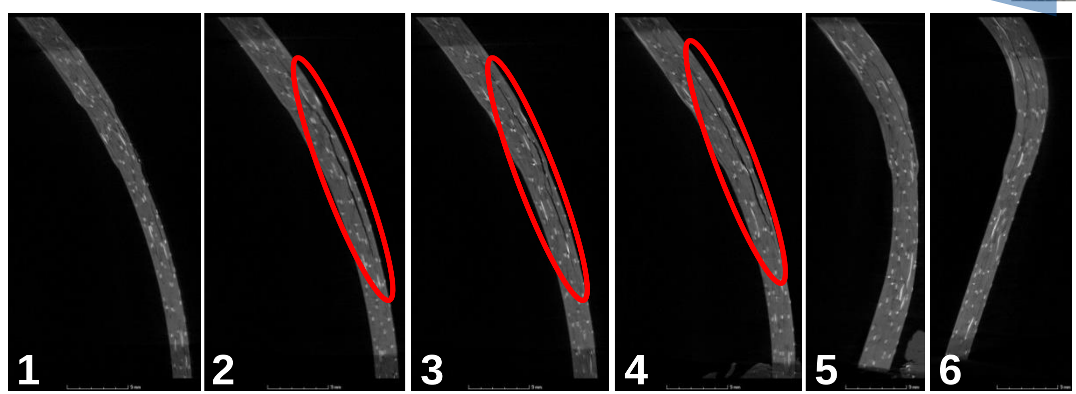
- Initial stiffness target 19.5 N/mm nearly fulfilled
- strength target overfulfilled
- perfect match between simulation and experiment

CT scan of critical area twisting load



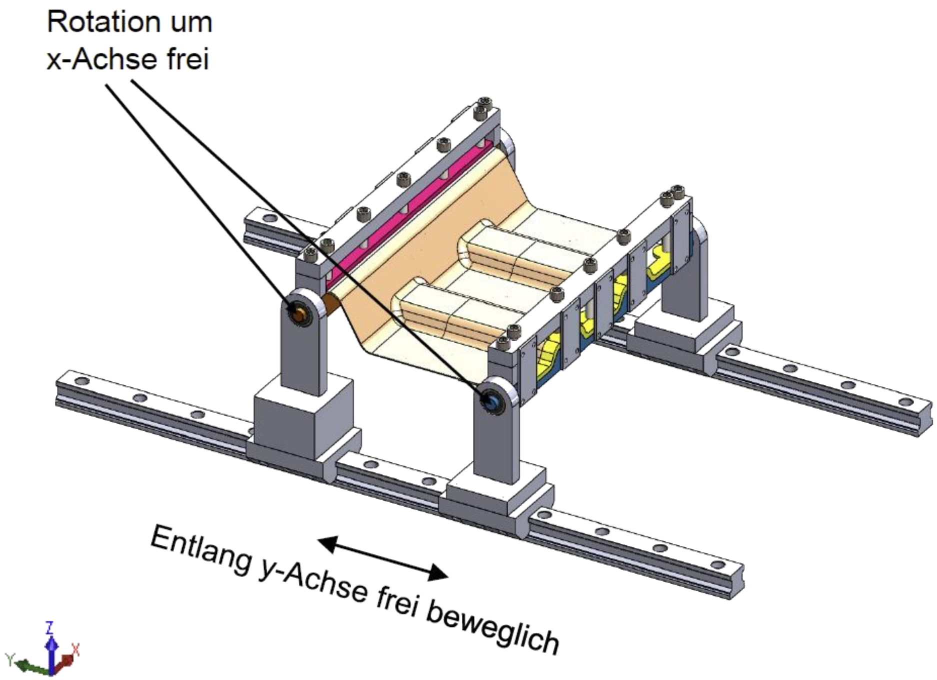


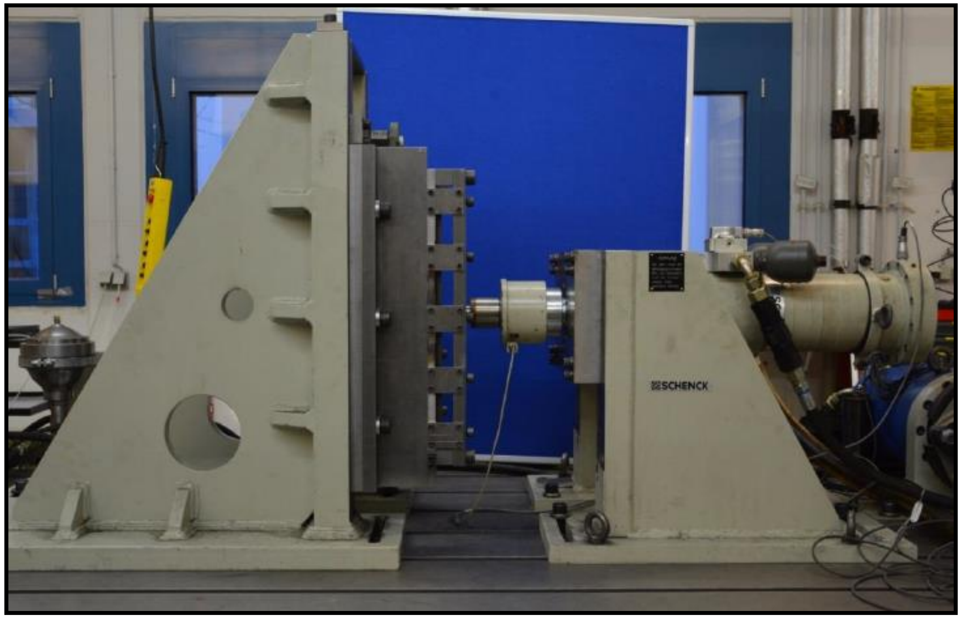




delamination in both directions visible.

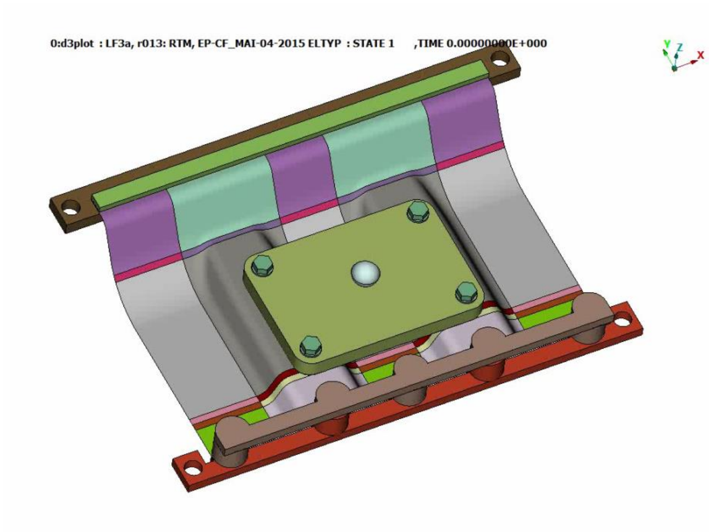
operating load test setup



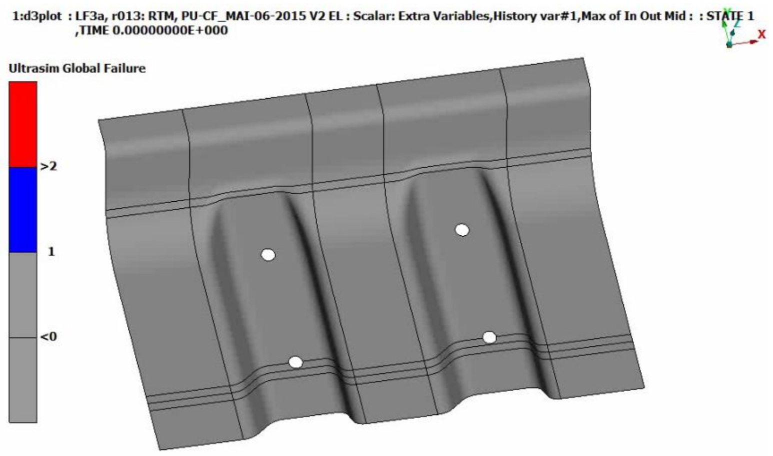


- Quasistatic and cycle load test for comparison
- Simulation done for quasistatic load

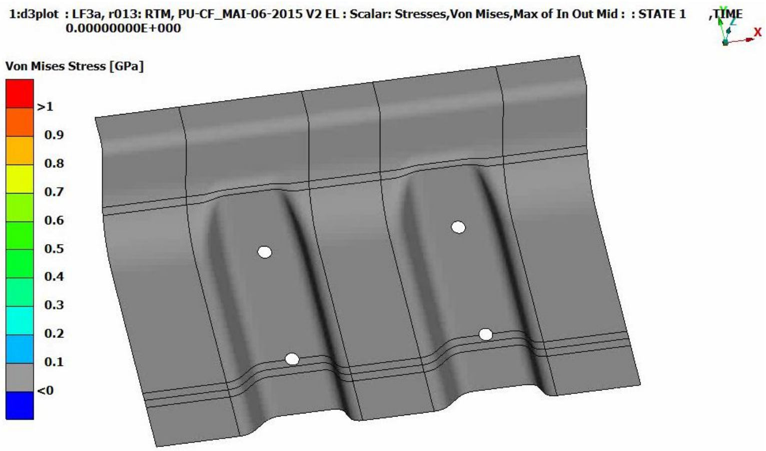
operating load overview



ULTRASIM® global failure

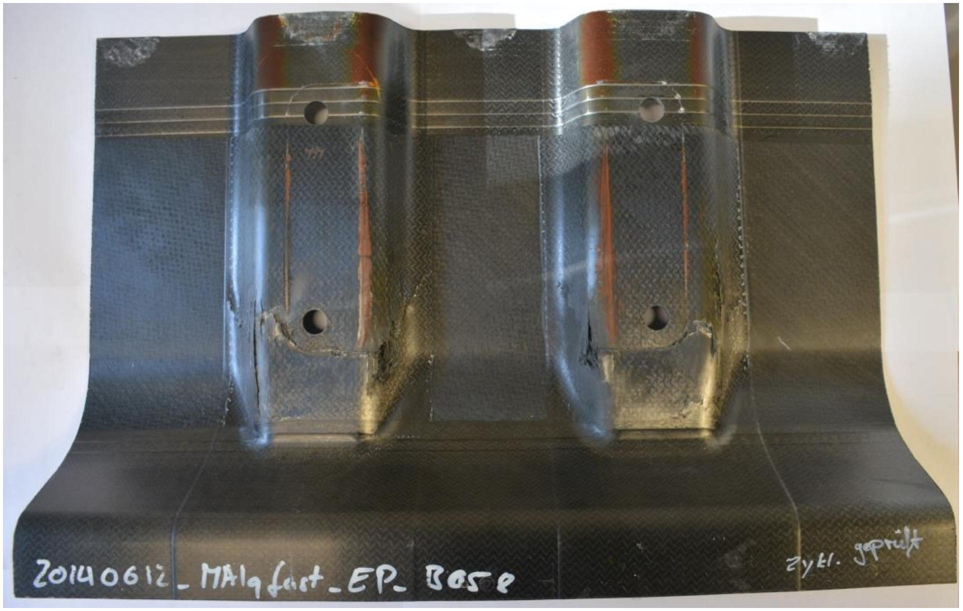


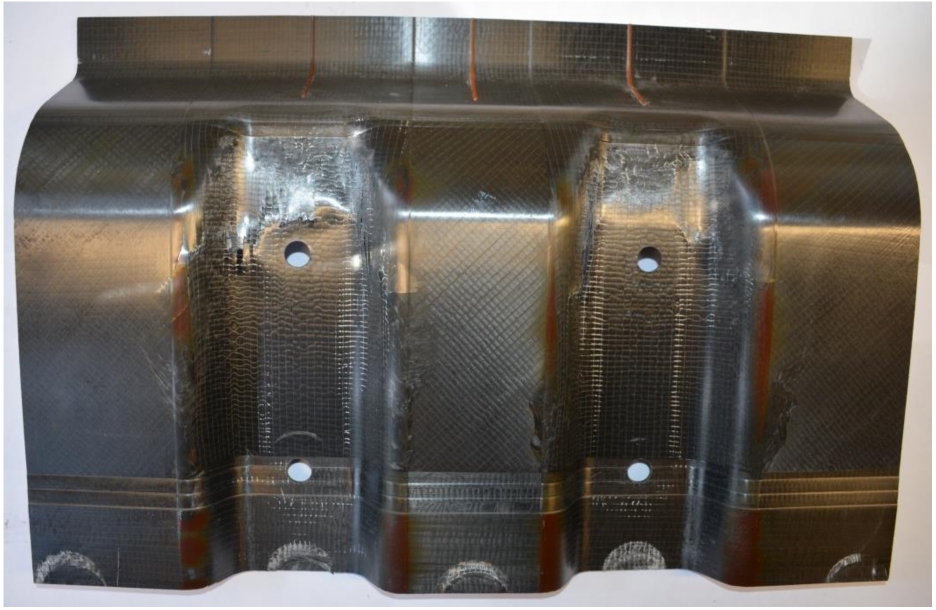
von Mises stress



ULTRASIM® delamination

operating load
damaged, failed parts



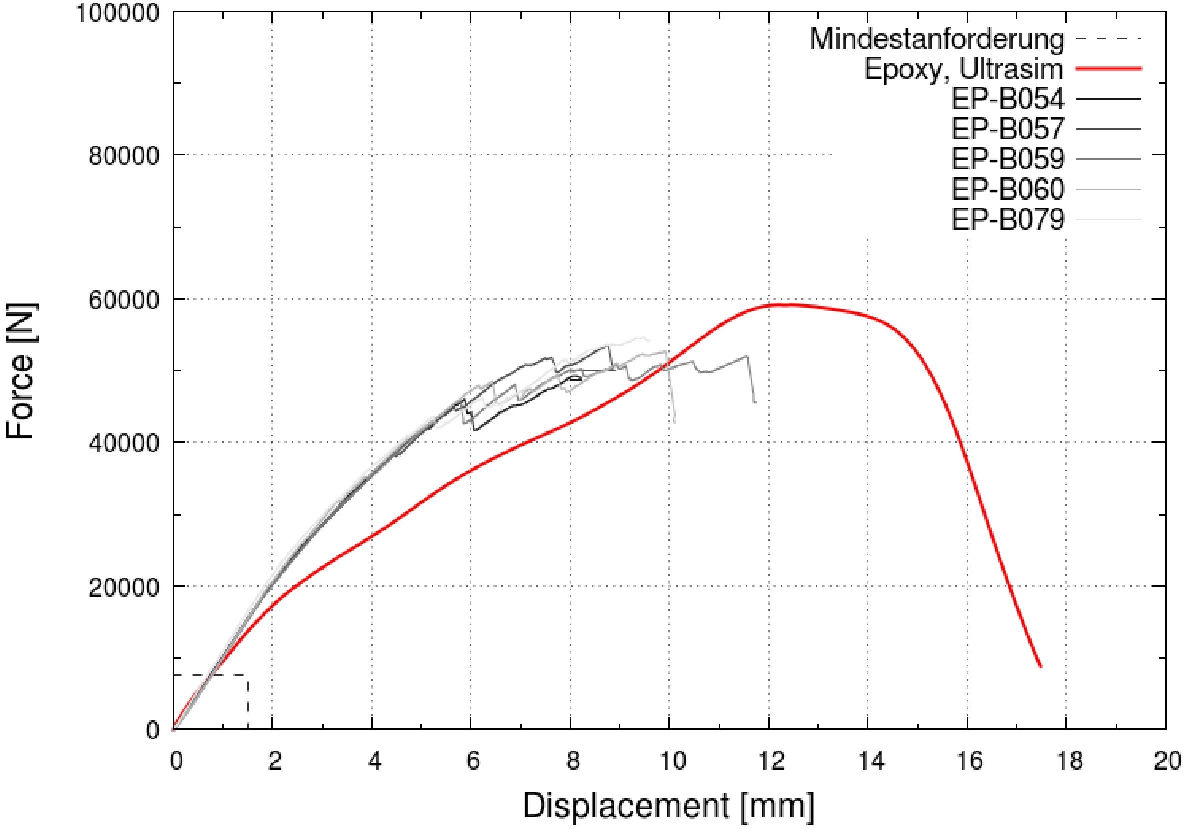


Cycle load

- part EP-B058
- Compression force -1 to -30 kN

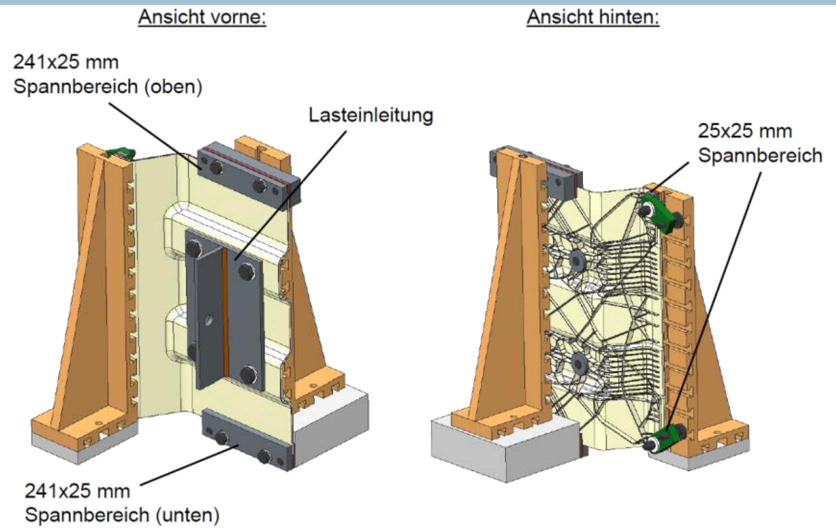
→ 4000 cycle till stiffness drop of 25%
→ Outer layers failed

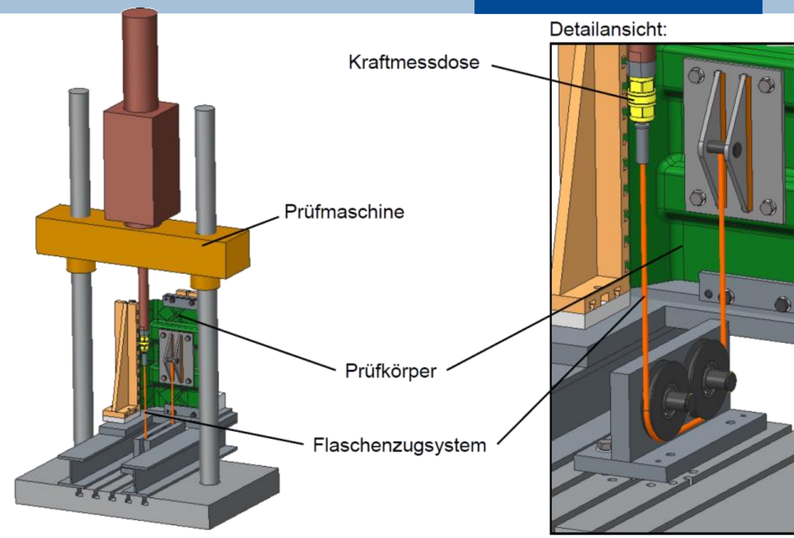
operating load
force-displacement curve

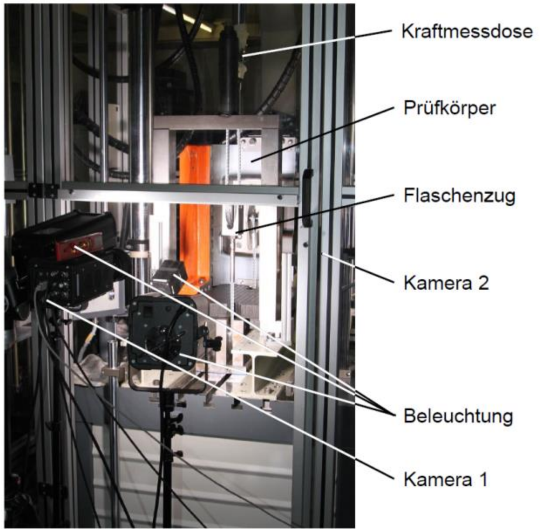


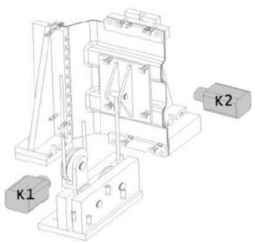
- stiffness and strength target overfulfilled
- < 2mm: good correlation
- 2 – 11 mm: stiffness under predicted due to delamination
- > 11 mm: force plateau as in experiment

impact load test setup

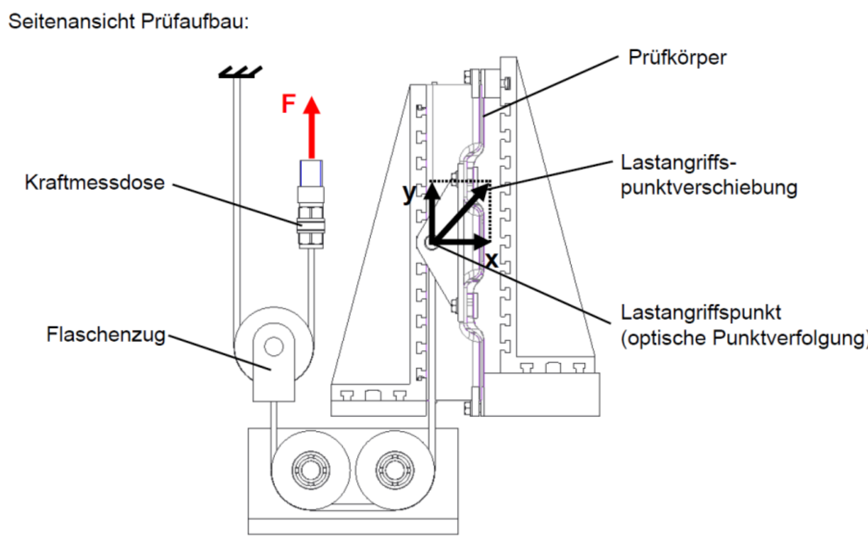




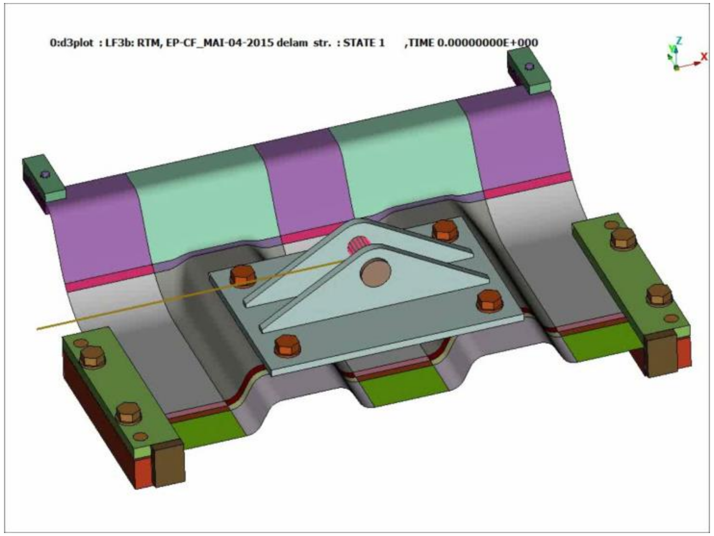




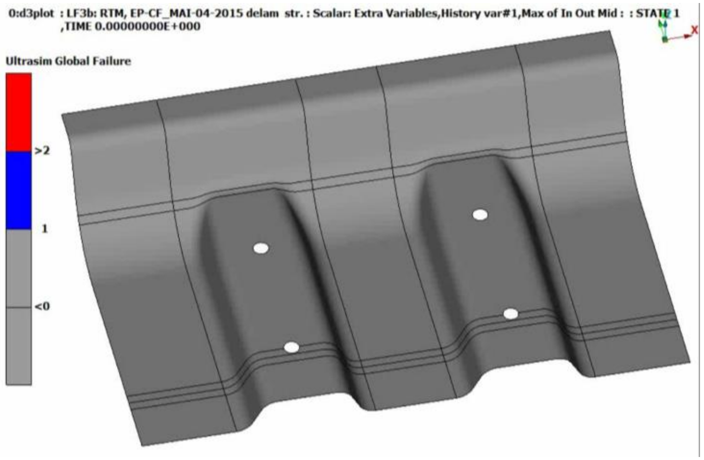
- Static tests
- Dynamic tests



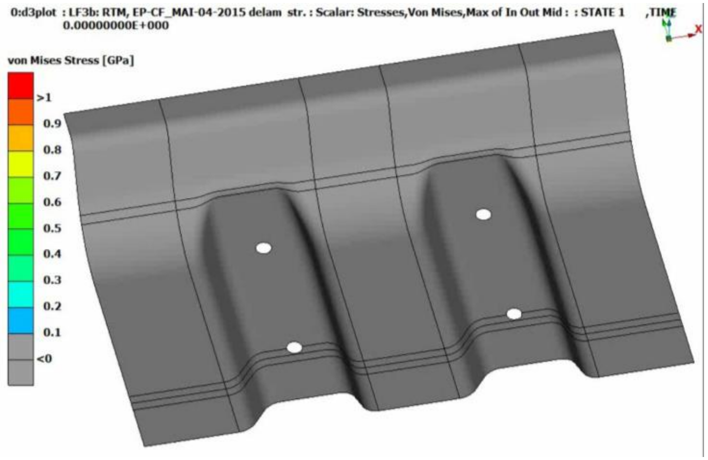
impact load overview



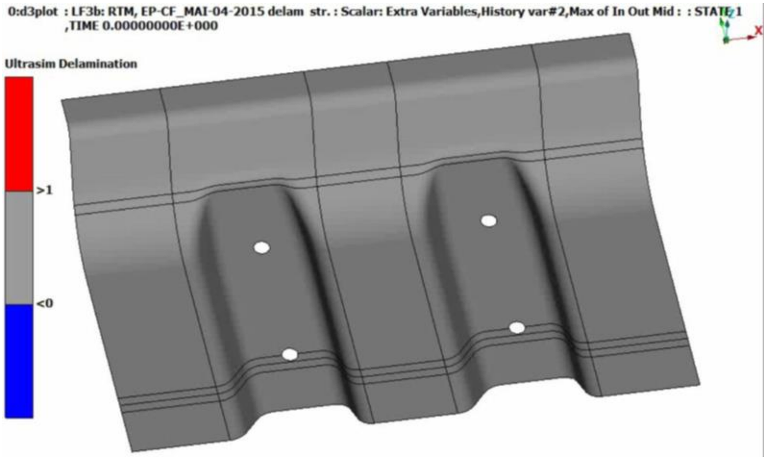
ULTRASIM® global failure



von Mises stress



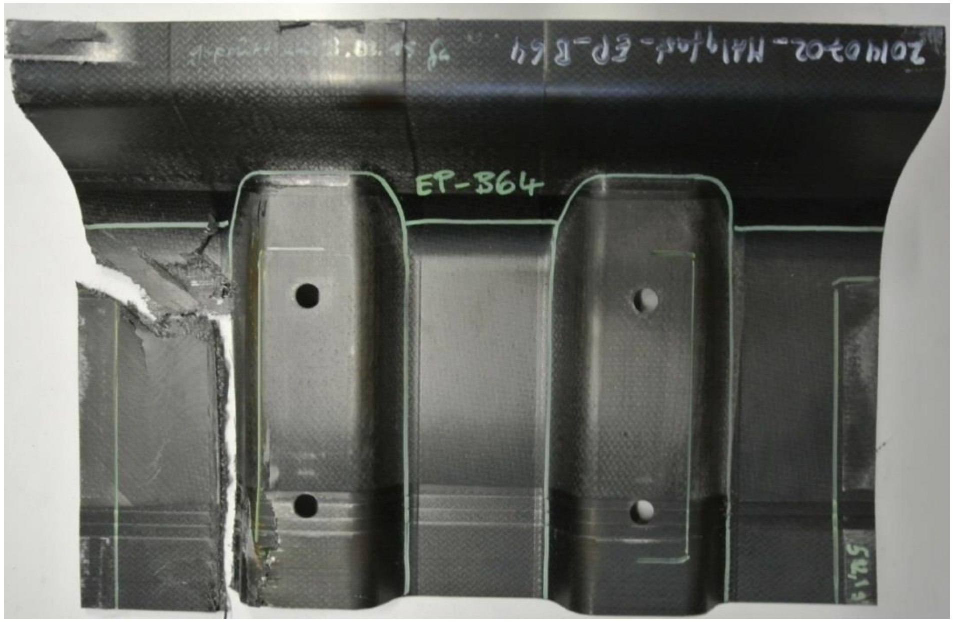
ULTRASIM® delamination



impact load
damaged, failed parts

quasistatisch (EP-B70)

dynamisch (EP-B64)



impact load
effect on part

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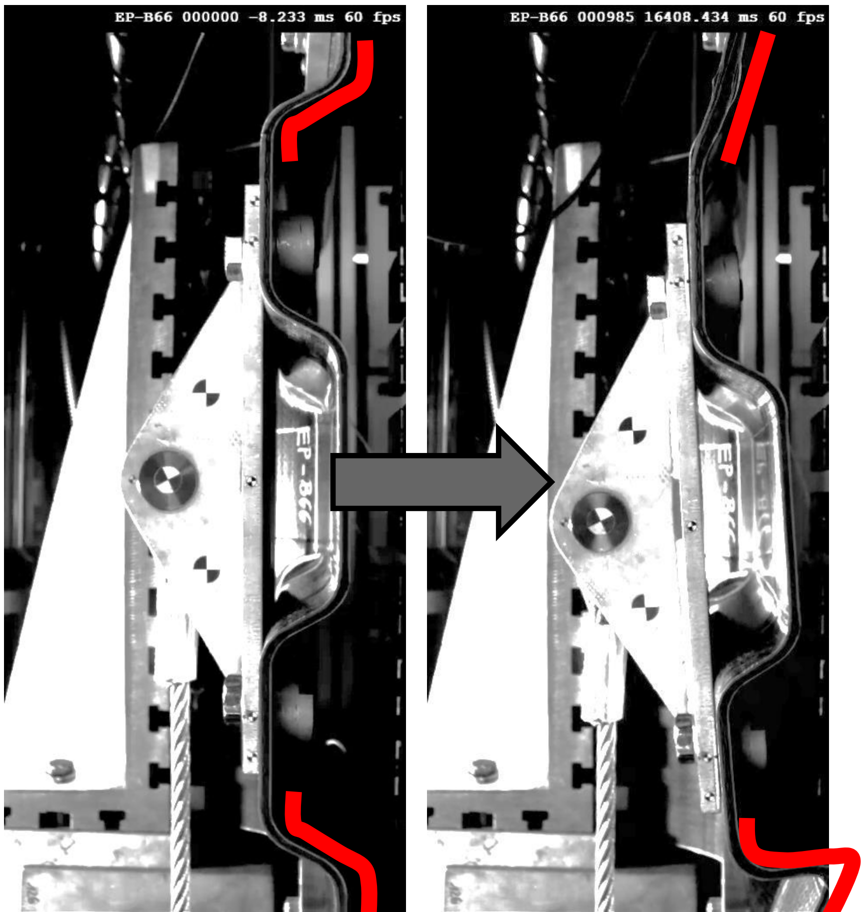
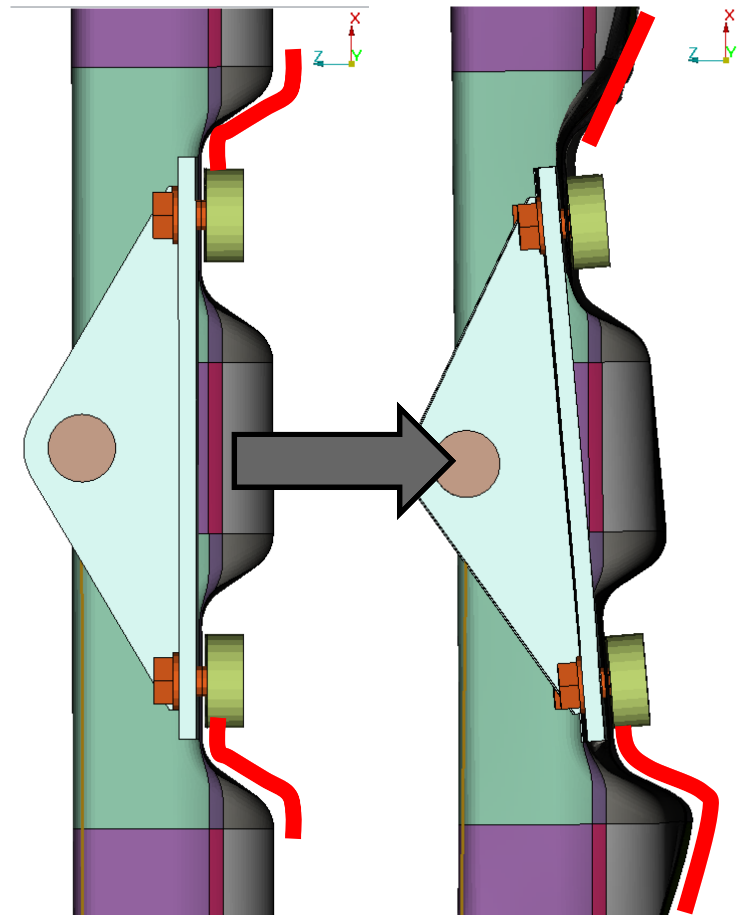
experiment

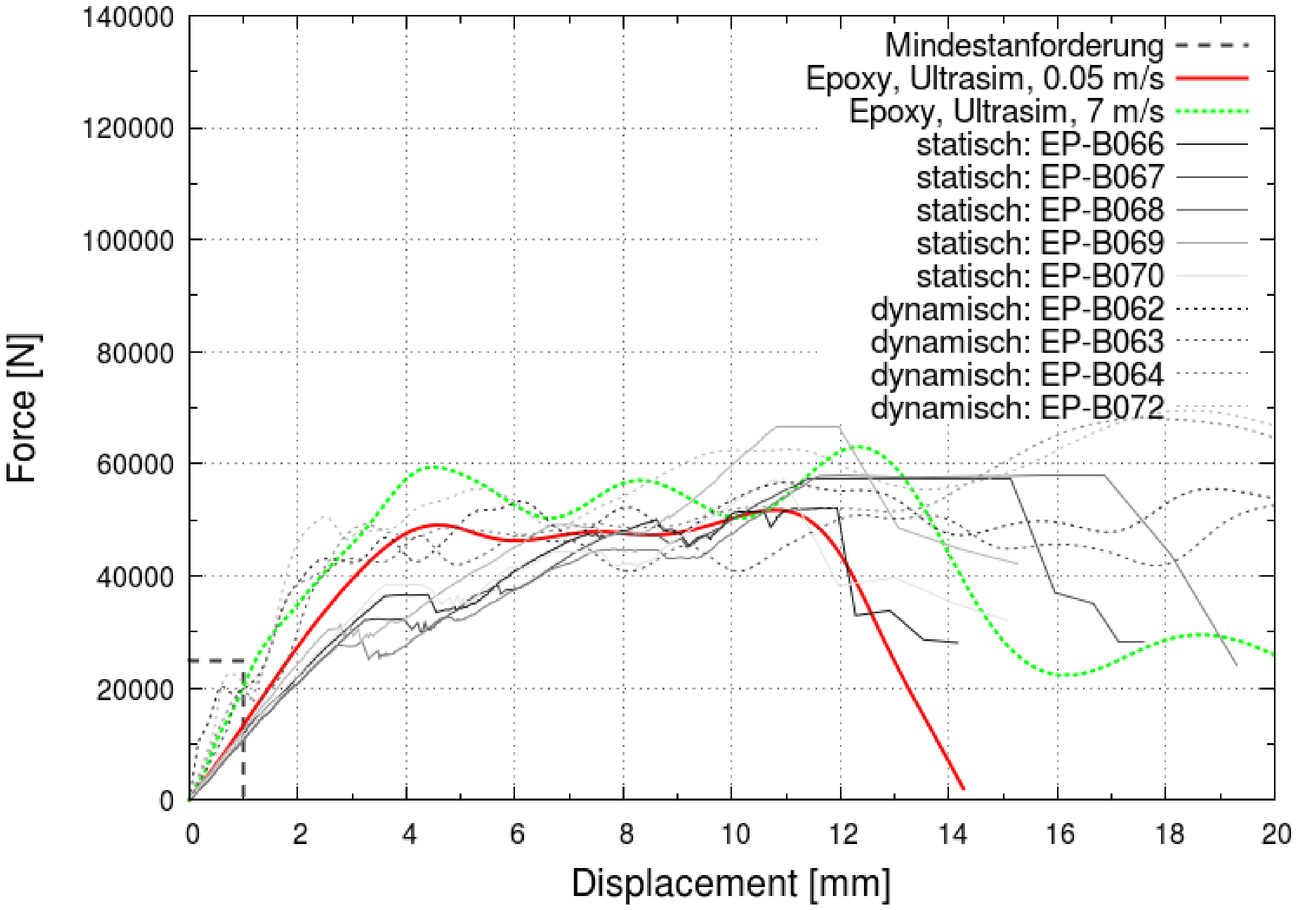


simulation



delamination in the radius of the cross member coincides with simulation results.

impact load
force-displacement curve



- load case was performed with different velocities in experiment
- strain-rate effect of different velocities is visible in simulated curves

summary and conclusion

- simulation describes mechanical behavior in a very good way
- weight saving is 50% to generic steel reference
- Test setup with a high impact on results
- influence on part performance
  - design with and without ribs
  - best use of continuous fibers by anisotropic design
  - best design by optimization methods
- material model
  - Homogenization for **fast** calculation time
  - considering behavior and failure modes of CFRP

  → detailed analysis of failure mechanism possbile for a better understanding

Thanks. Any Questions?

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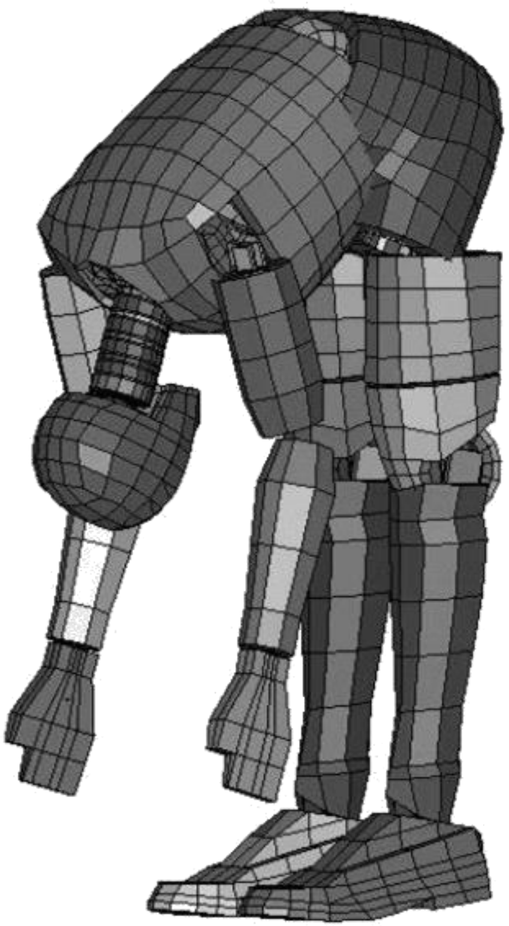

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