LS-DYNA Forum 2018 Bamberg

Crash Simulation of Fibre Metal Laminates

Crashsimulation von Metall-Faserverbund-Sandwichmaterialien

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Motivation for Fibre Metal Laminates in Body Applications

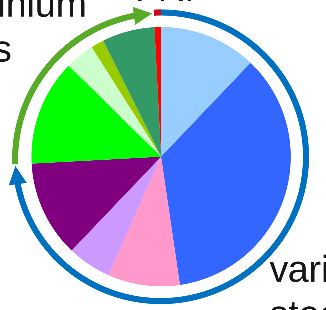
- Lightweight design is considered a key technology for competitiveness in current vehicles [SCH17]
  - … even in electric vehicles with recuperation (~35% of energy consumption is mass-dependent)
- Wide range of requirements in structural applications
  - Low density, high stiffness, high strength coupled with medium/high ductility, good formability, joining, …
- Hybrid materials/"tailored materials" combine different materials with different properties to a "better" one

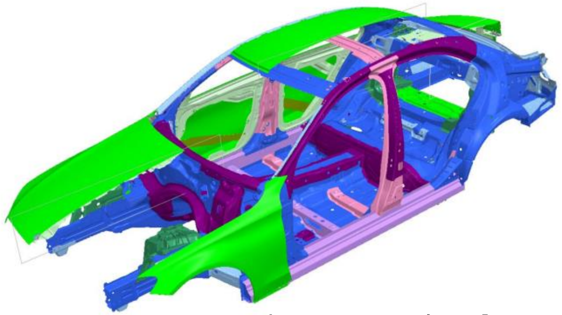
➔ Here: Sandwich materials 2/1 lay-up (Metal/CFRP/Metal)

- Questions:
  - Material choice?
  - Manufacturing? Bonding? Cycle times?
  - Mass reduction in crash applications?
    - Virtual study! Simulation models?

Multi-material design is already present…

… in BIW





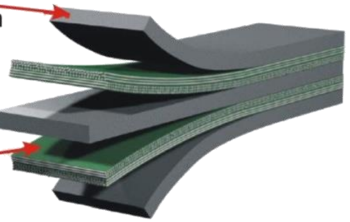
Mercedes-Benz C-Class [EUR14]

… in parts

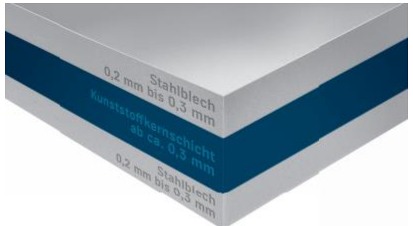
[ICK14]

BMW 7 series [BIM15]

… in materials



GLARE [TUD15]



thyssenkrupp LITECOR® [ATZ14]

Material Choice and Expectations on “Tailored Materials”

- Steel (MHZ340, 0.25 mm): Established body application steel, good overall properties
- Magnesium alloy (AZ31b, 1.0 mm): Available as sheet, low density and good formability
- CFRP (45±5 %, various thickness): highest lightweight potential, good stiffness/strength

SCS

MCM

Qualitative evaluation of (sandwich) material properties relative to each other:

	density	deformation behaviour	spec. energy absorption	spec. bending stiffness	overall part cost
Steel		ductile/buckling			
Magnesium		brittle/crushing			
CFRP		brittle/crushing			
St/CFRP/St					
Mg/CFRP/Mg					

Presented work partly done within:

LEIKA

Funding:

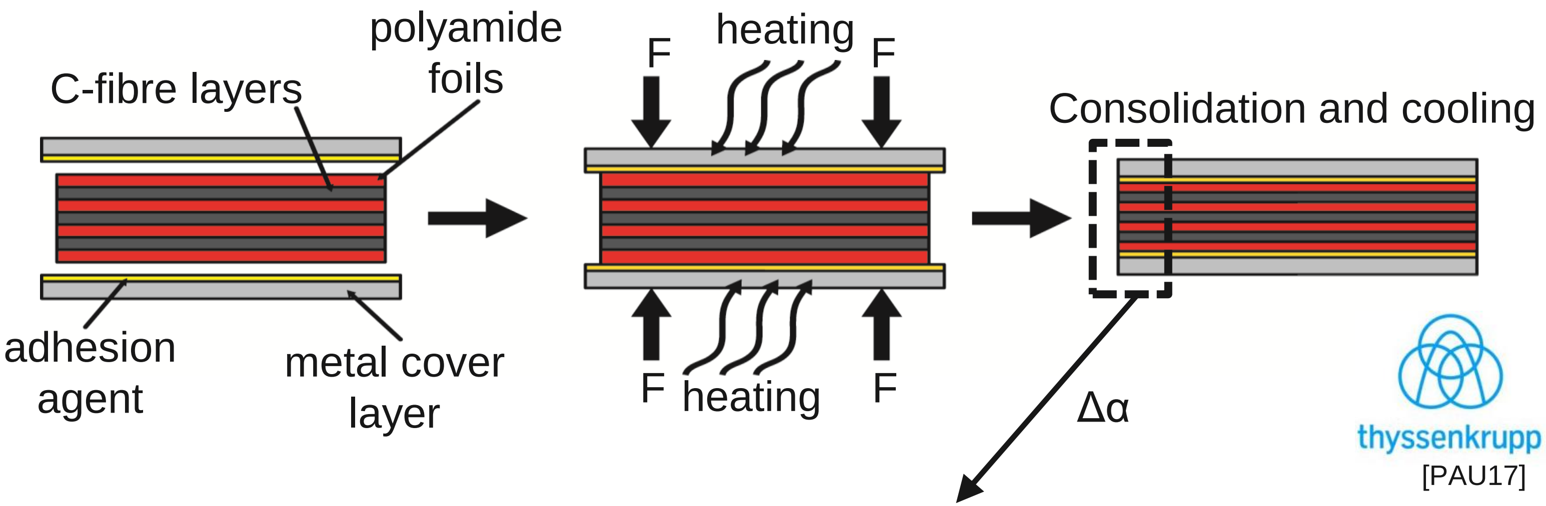
Federal Ministry of Education and Research

FOREL

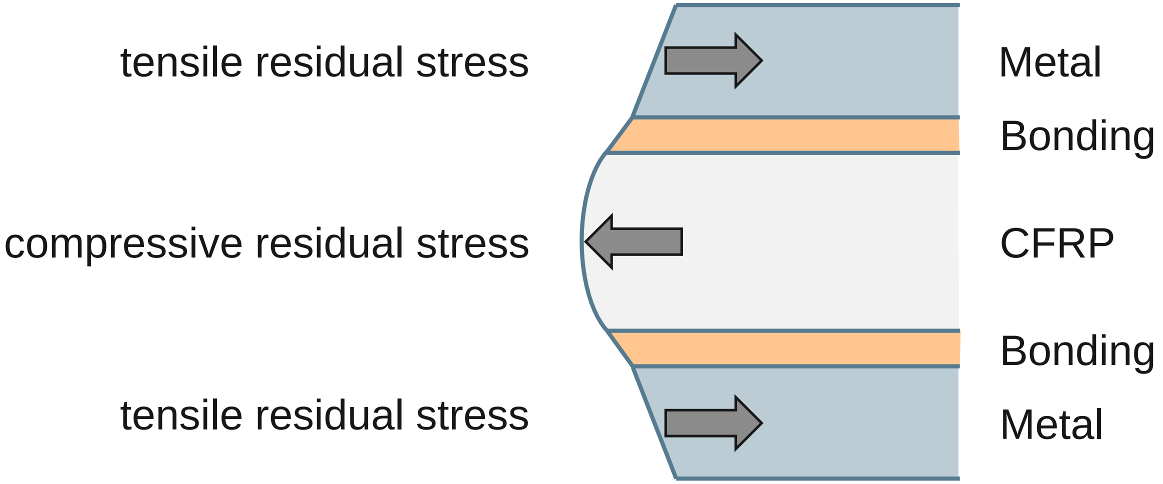
Consortium:

Manufacturing of FML Sheets with Thermoplastic Matrix

- Thermoset matrix (e.g. GLARE)
  - Production of sandwich via autoclave
  - Preforming of metal needed
  - Problem: High cycle times (hours)
- Thermoplastic PA6 matrix (used here):
  - Process developed in LEIKA project
  - Pre-production of sandwich sheets
  - “Standard” hot forming (fast) for part production (mostly bending)
  - Consolidation of CFRP within production process of sandwich
  - Activation of adhesion agent and bonding via temperature/pressure
  - Question: Manufacturing impact on material? Temperature induced stresses, bonding, consolidation, …



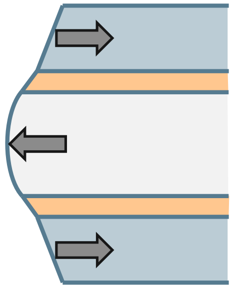
thyssenkrupp
[PAU17]



(symbolic representation)

Additional Boundary Conditions when Modelling these FMLs

Influence of Manufacturing



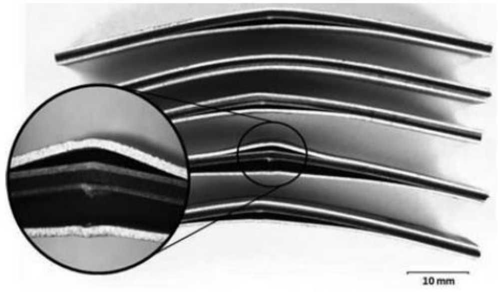
Residual stresses (metal, FRP)

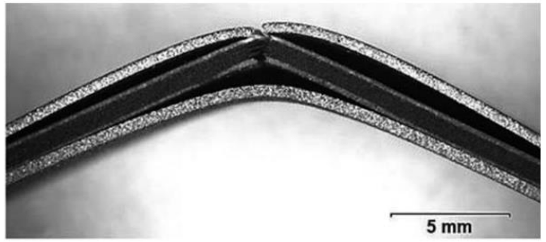
Process parameters (time, temperature, pressure)

Bonding/ adhesion agent

CFRP consolidation

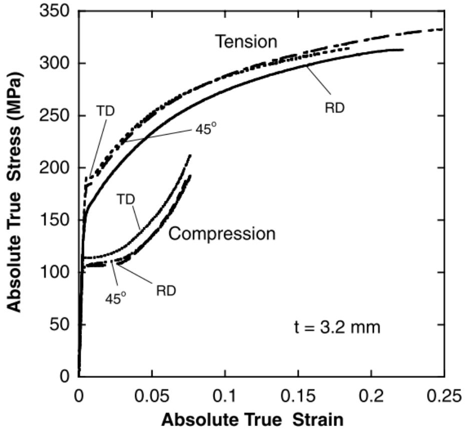
Bonding/Delamination





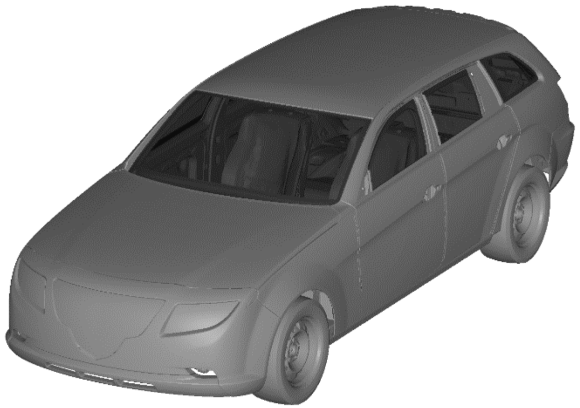
[NES14]

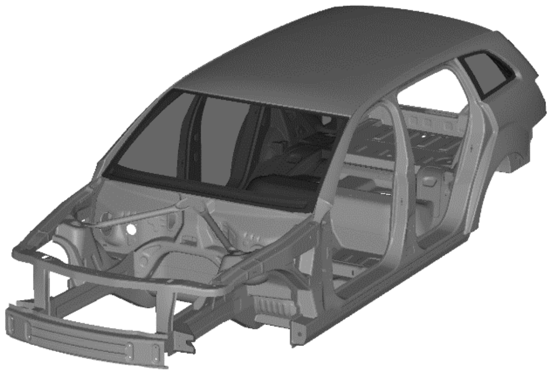
Magnesium AZ31b Anisotropy



[LOU07]

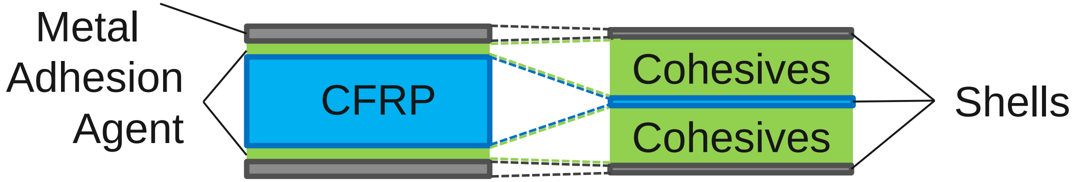
Full Vehicle Crash Simulation





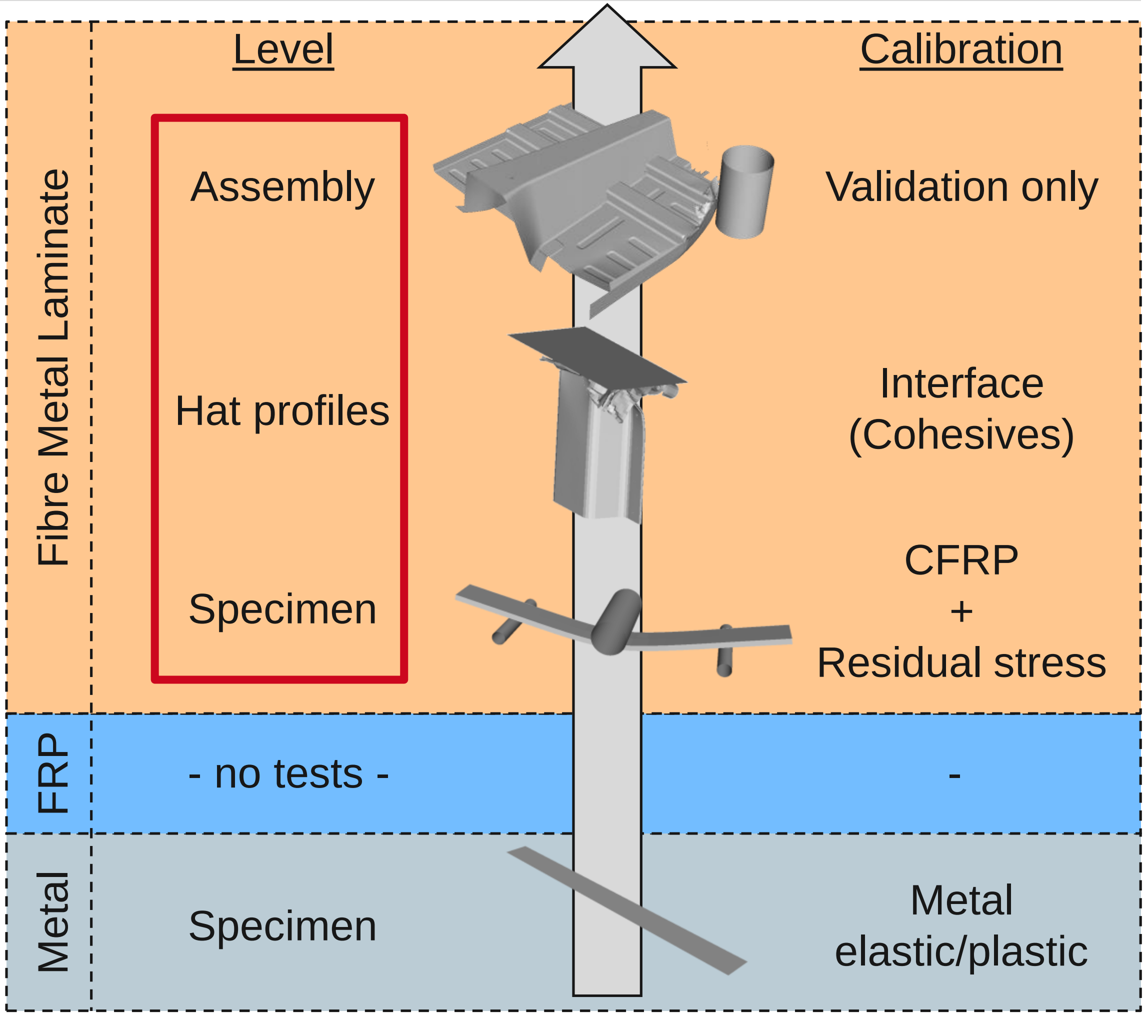
Modelling and Calibration Process for FML in Crash Simulation

Modelling Approach

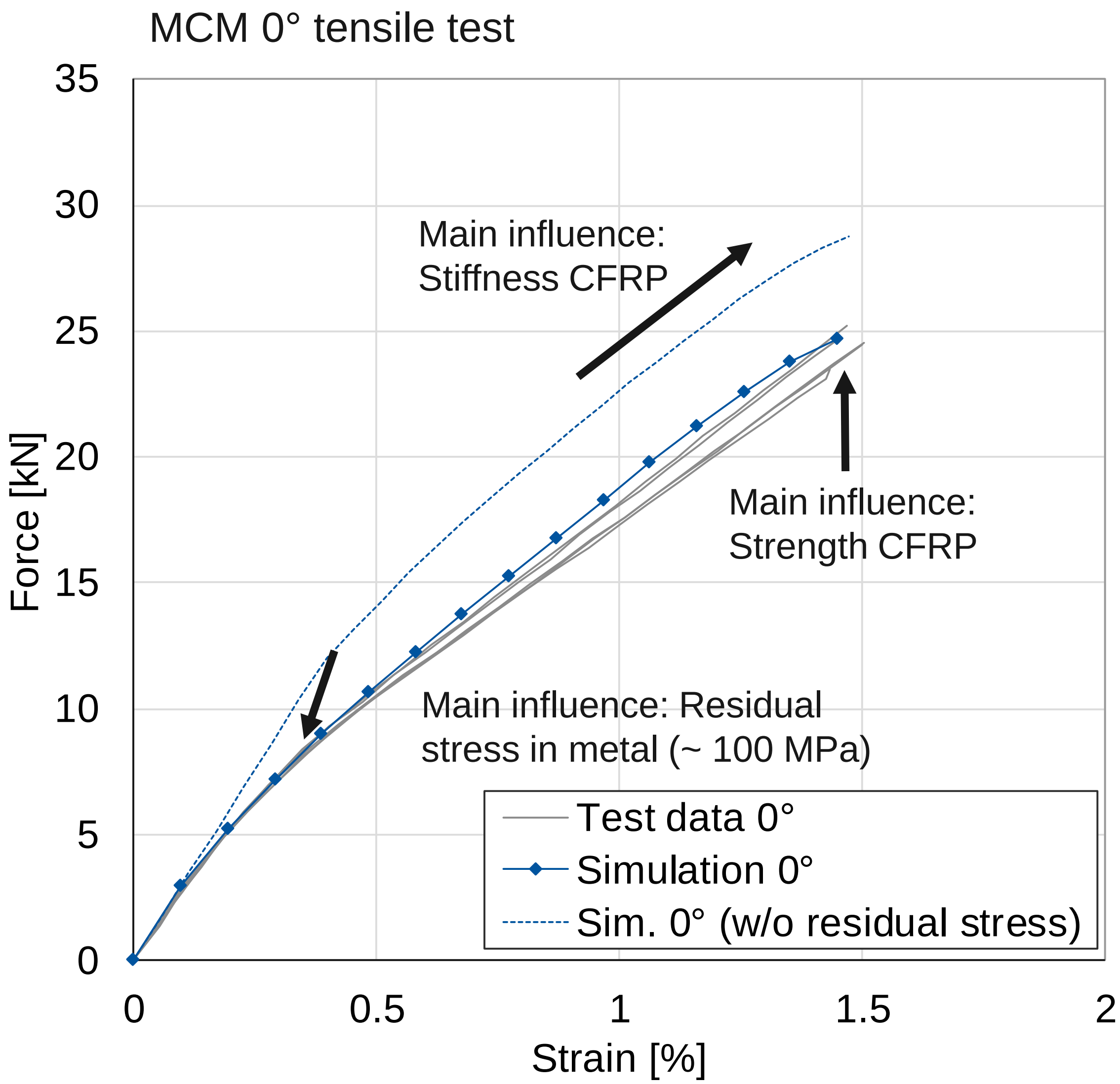


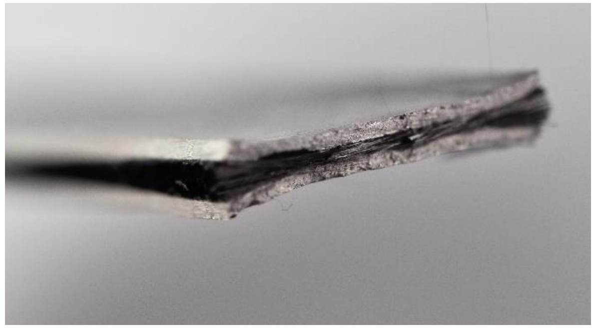
- Stacked shell modelling using cohesive elements (ELFORM 20) and shells (ELFORM 8 with physical hourglass control), element size of ~5 mm
- Metals (Steel and Mg): MAT_124
  - LC input for tension and compression (needed for proper Mg modelling and residual stresses)
  - Strain rate depended plasticity (Steel)
  - Simplifications: No anisotropy or advanced failure
- CFRP (lay-up of UD tapes): MAT_58
  - Sufficient representation, distinct failure
- Cohesive zones: MAT_138 (or CONTACT_TIEBREAK)
  - no increased time step size, few parameters
- Disclaimer for test data: Prototype material made in laboratory environment

Calibration/Validation Process

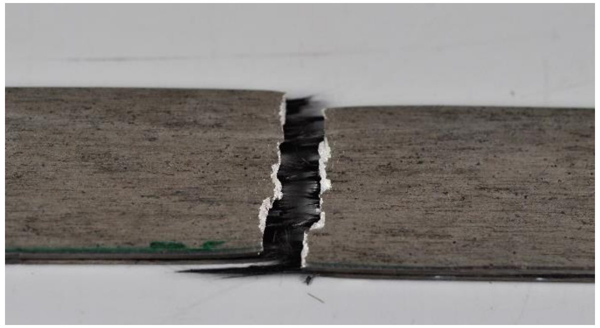


Calibration of FML on Specimen Level: Tensile Tests





MCM 90° tensile test



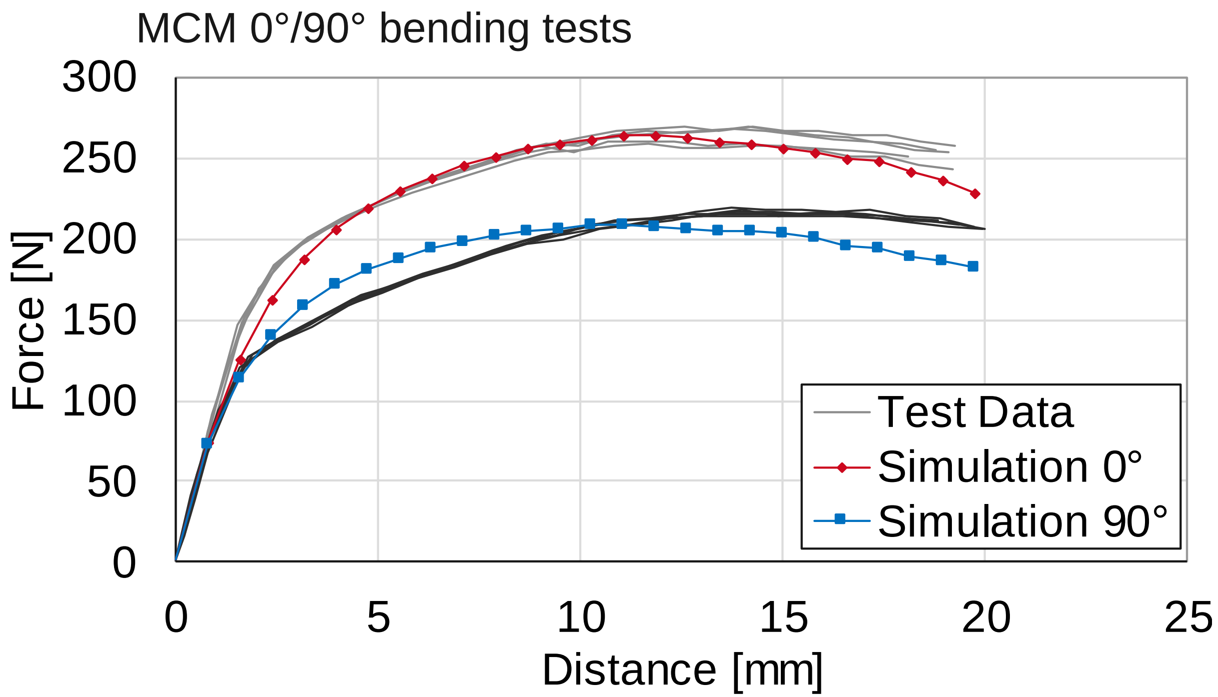
MCM 0° tensile test

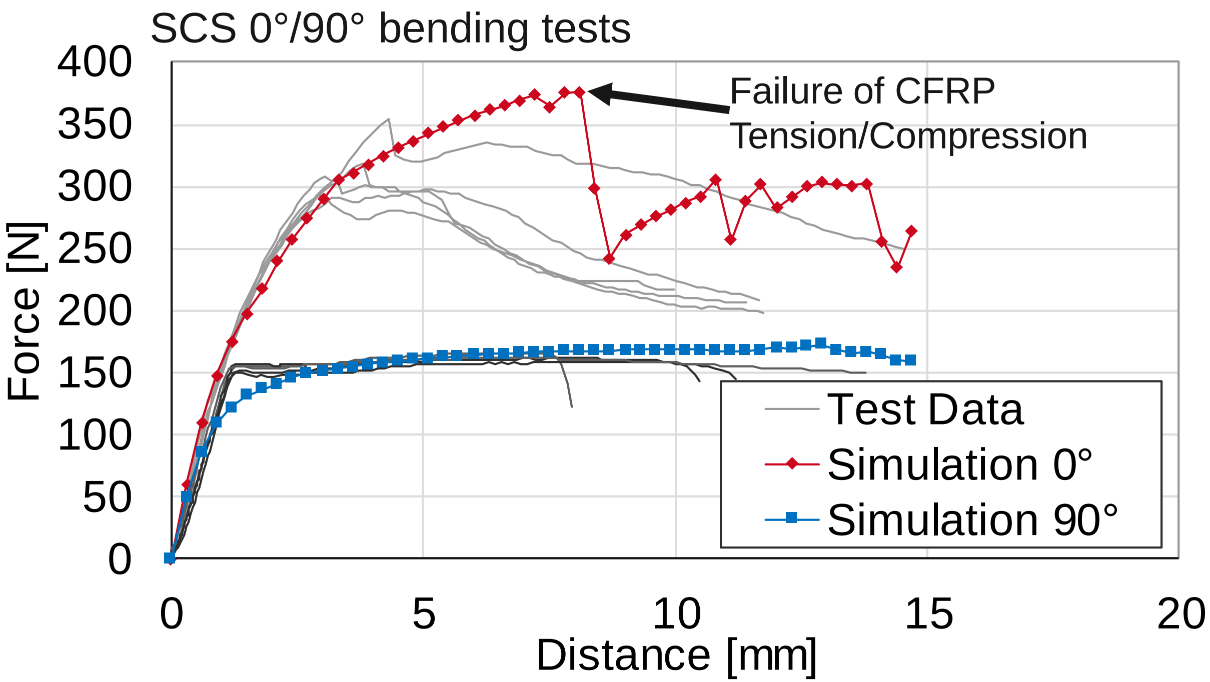
- Mg AZ31b 1,0 mm / CFRP 45 vol% 0.7 mm (total: 2.7 mm)
- Failure strength 25 kN equivalent to 455 MPa averaged stress
- Failure strain of 1.5% comparable to CFRP max. strain
- CFRP (MCM) Young's Modulus: 100 GPa (0°) slightly lower than expected, 10 GPa (90°) much higher than calculated

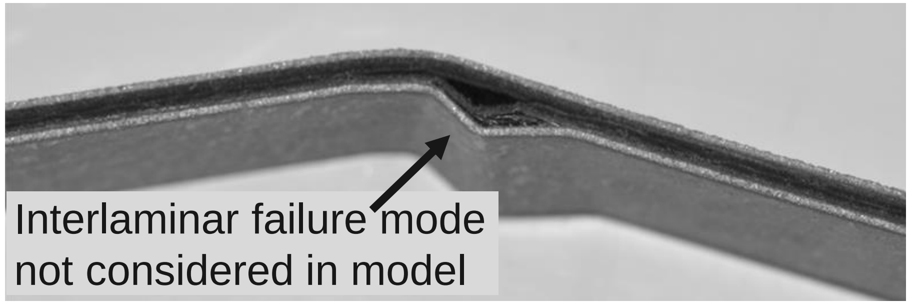
- St MHZ340 0.25 mm / CFRP 45 vol% 1.5 mm (total: 2.0 mm)
- CFRP (SCS) Young's Modulus: 90 GPa (0°), 10 GPa (90°)
  ➔ Influence of production on CFRP core

Pictures: J. Jaschinski (TU Dresden)

Calibration of FML on Specimen Level: Bending Tests

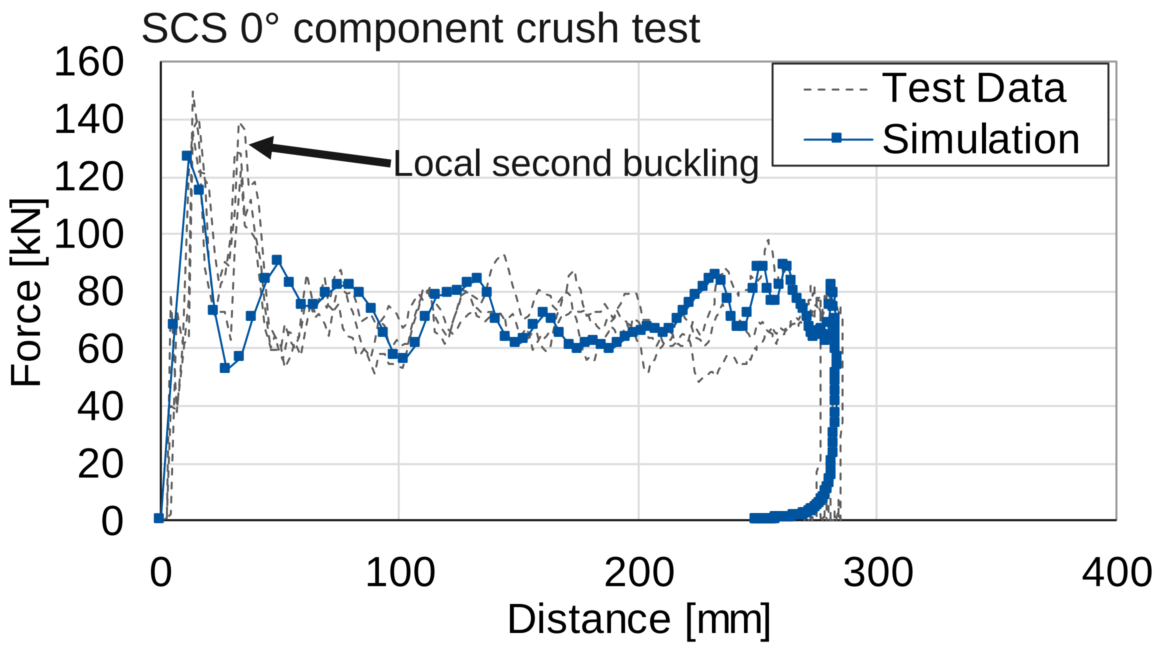




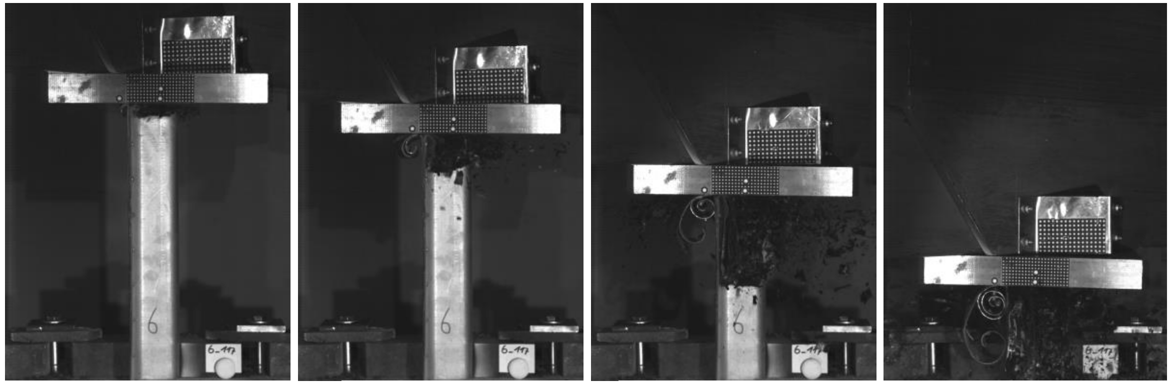


Pictures: J. Jaschinski (TU Dresden)

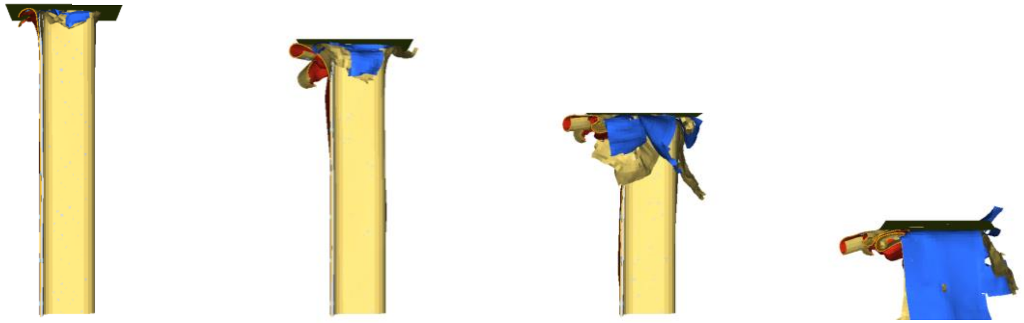
Calibration of FML on Component Level: Crush Tests



- Hat profile SCS with 1.5 mm CFRP core layer
- Impact: 300 kg falling mass with v_0=11.5 m/s
- Initial force of 130 kN followed by an energy absorbing phase at ~70-80 kN
- Good correlation between simulation and test data/video
- Delamination between CFRP and steel covered

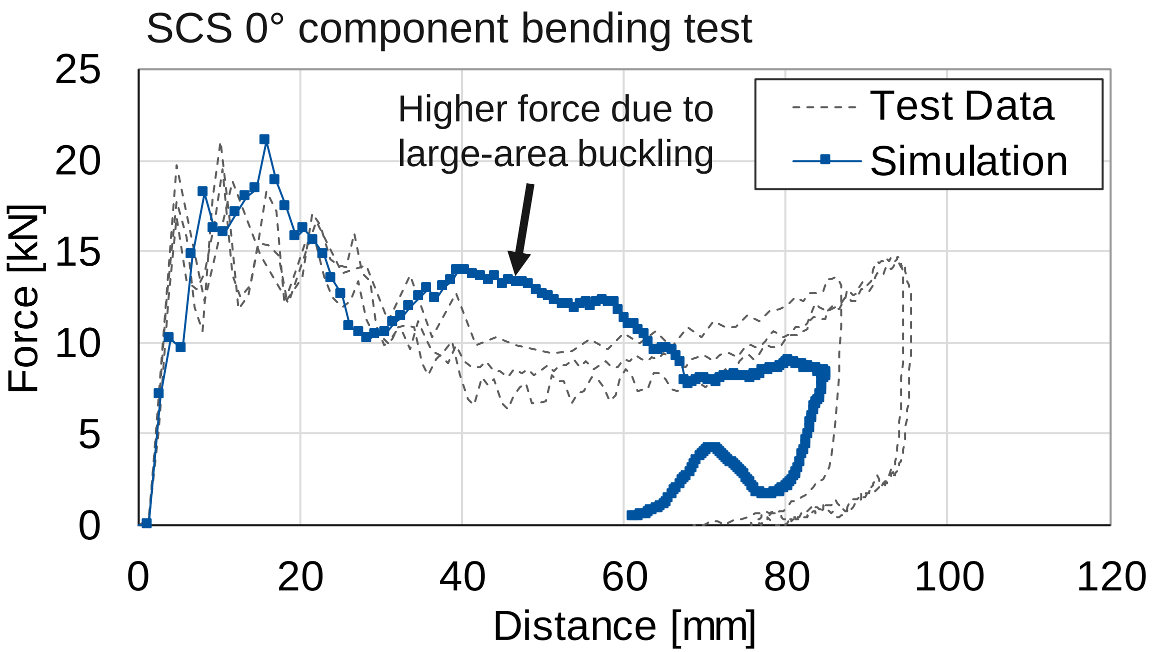


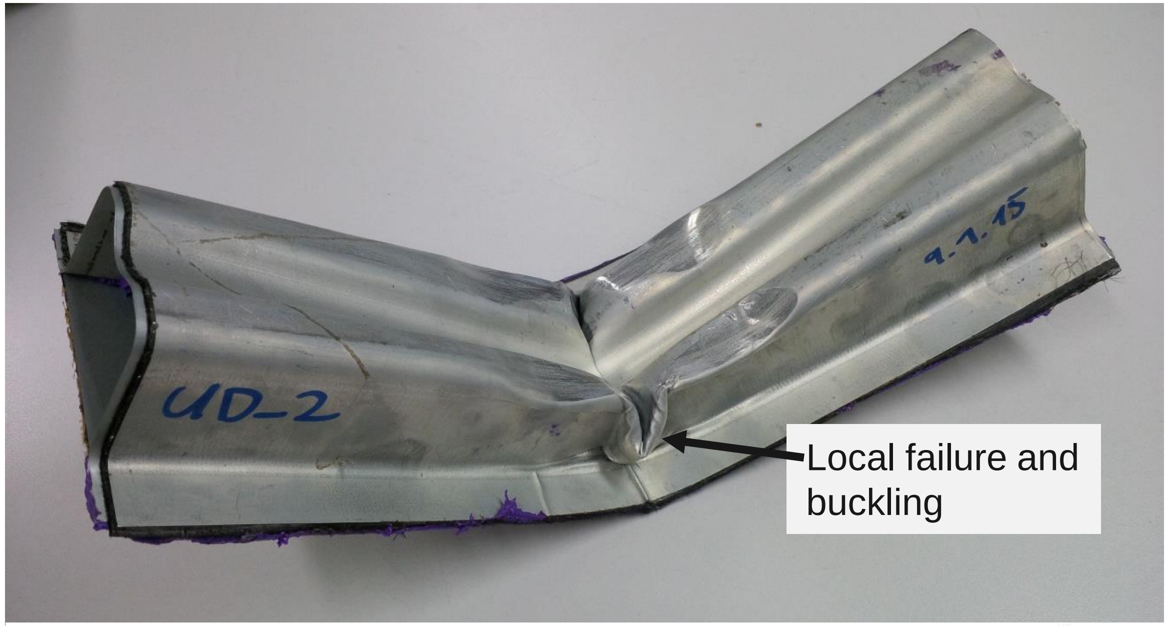
t = 4 ms t = 8 ms t = 19 ms t = 55 ms

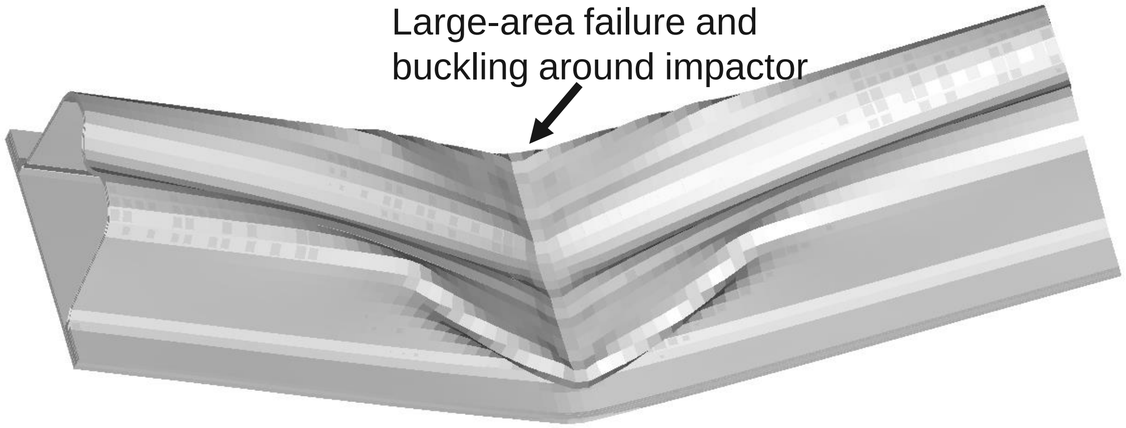


Yellow: St MHZ340 outer layer
Red/Blue: CFRP core layer

Calibration of FML on Component Level: Bending Tests

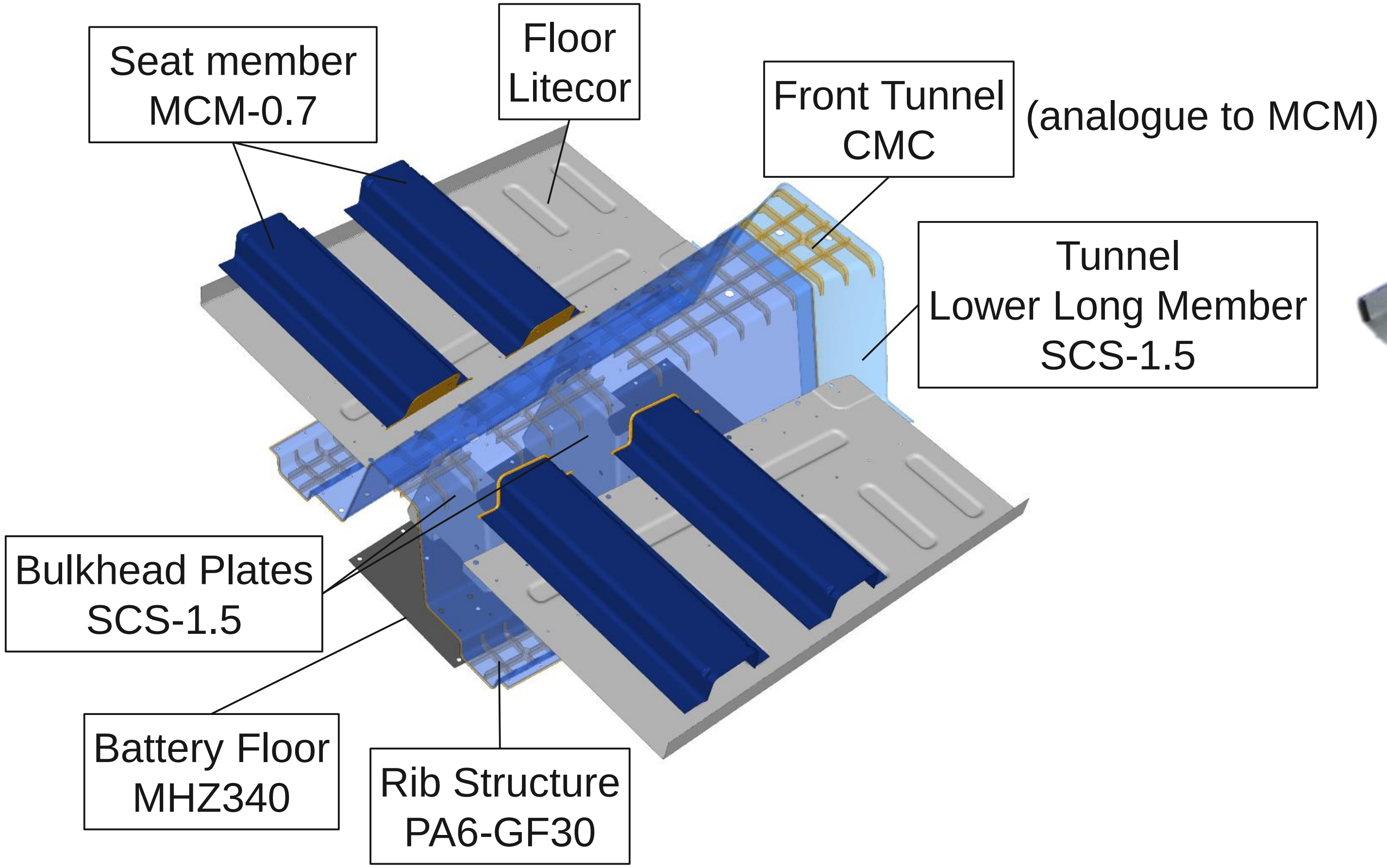




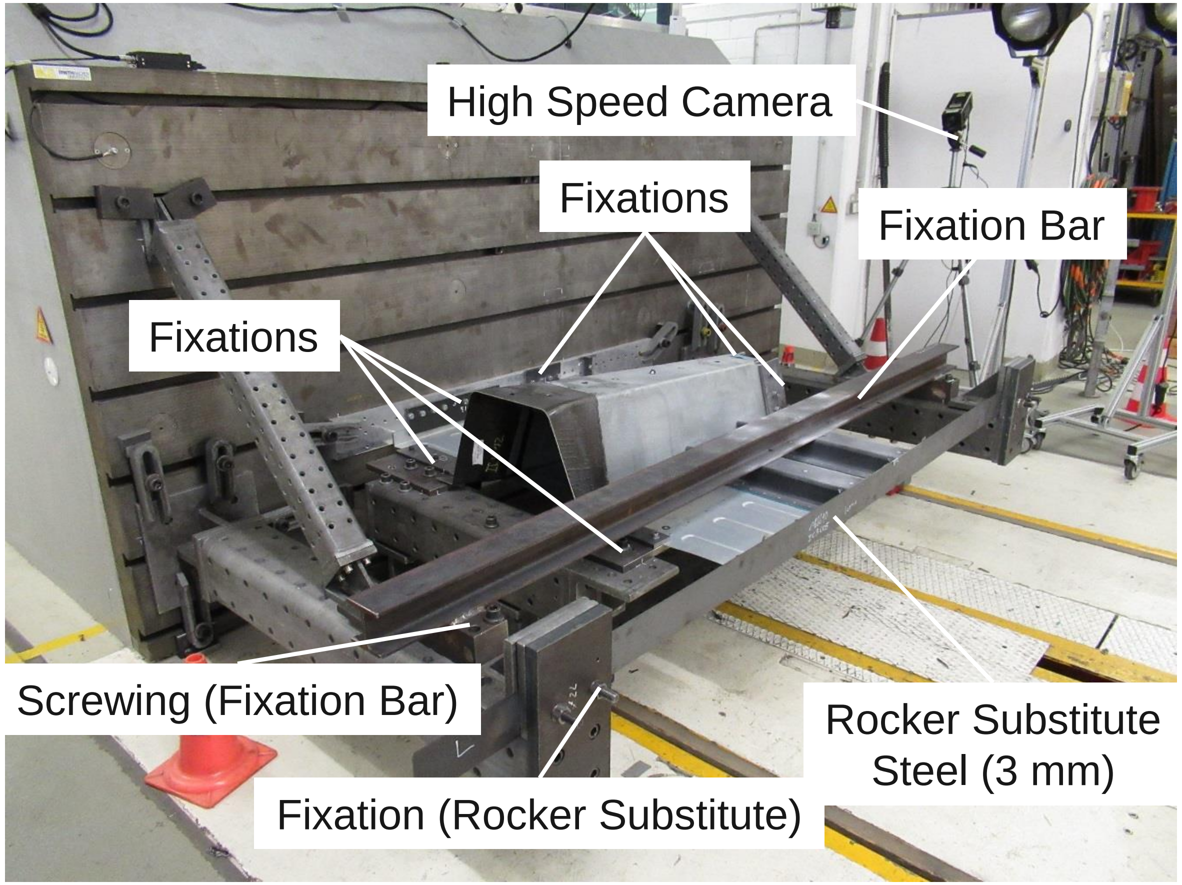


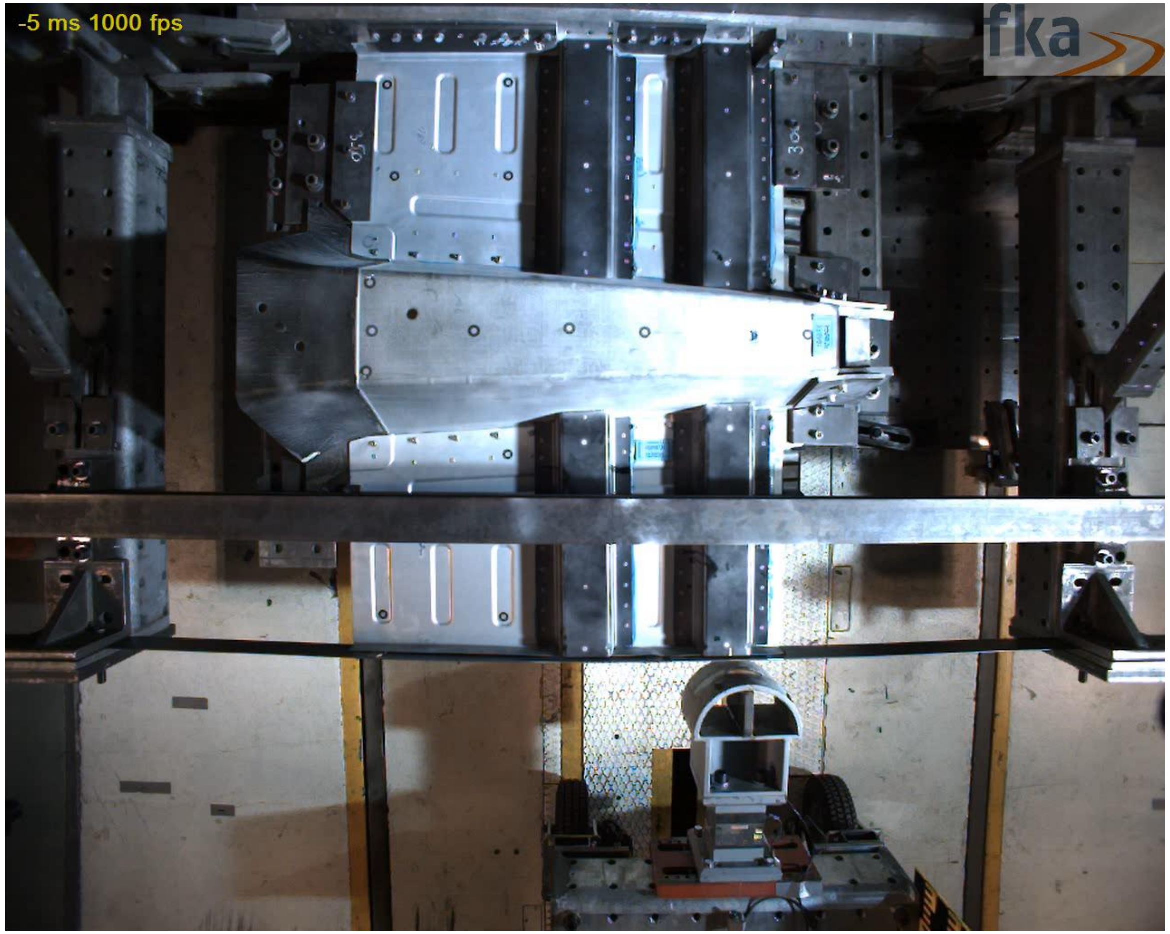
- Hat profile SCS with 1.5 mm CFRP core layer
- Impact: 51 kg falling mass with v_0=6.15 m/s
- Initial force of 21 kN (good correlation) followed by an energy absorbing phase at ~10-15 kN (deviant behaviour)
- Explanation/current status: Mesh of 5 mm element size cannot cover the initial local effect → large-area failure

Development and Manufacturing of a Prototype

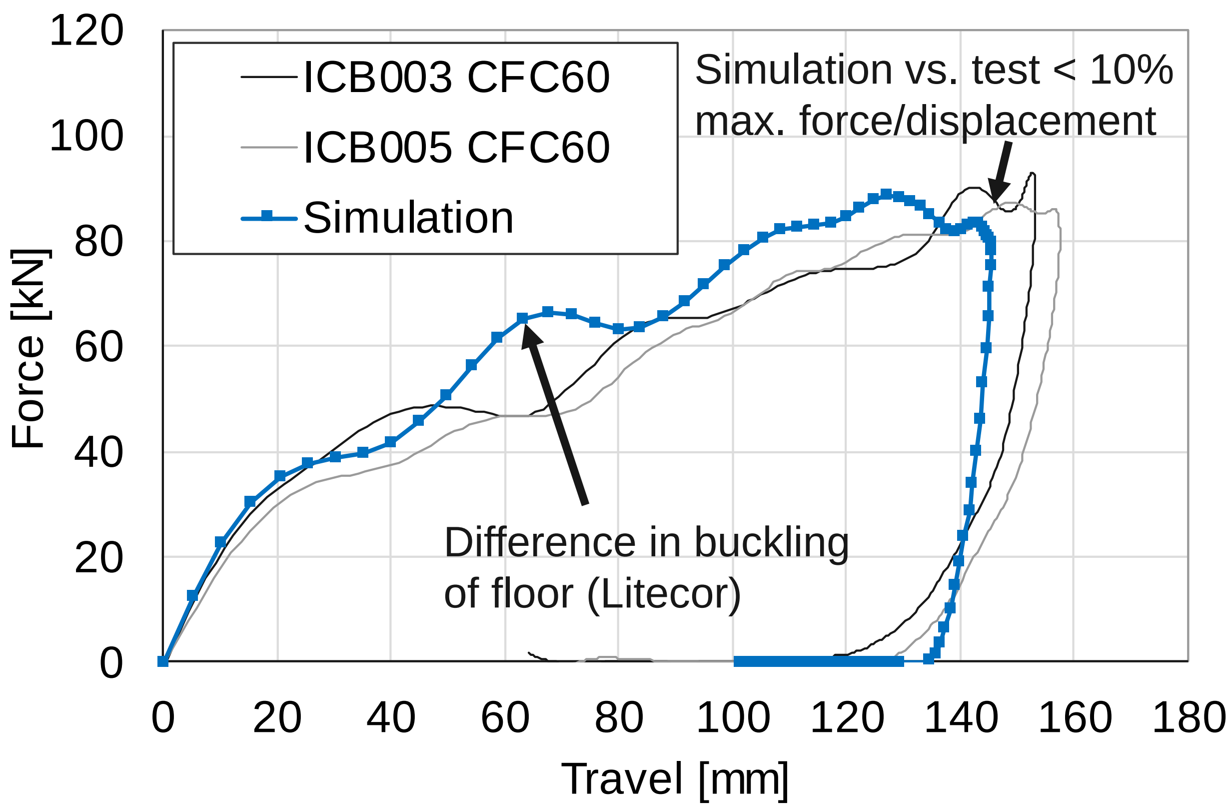


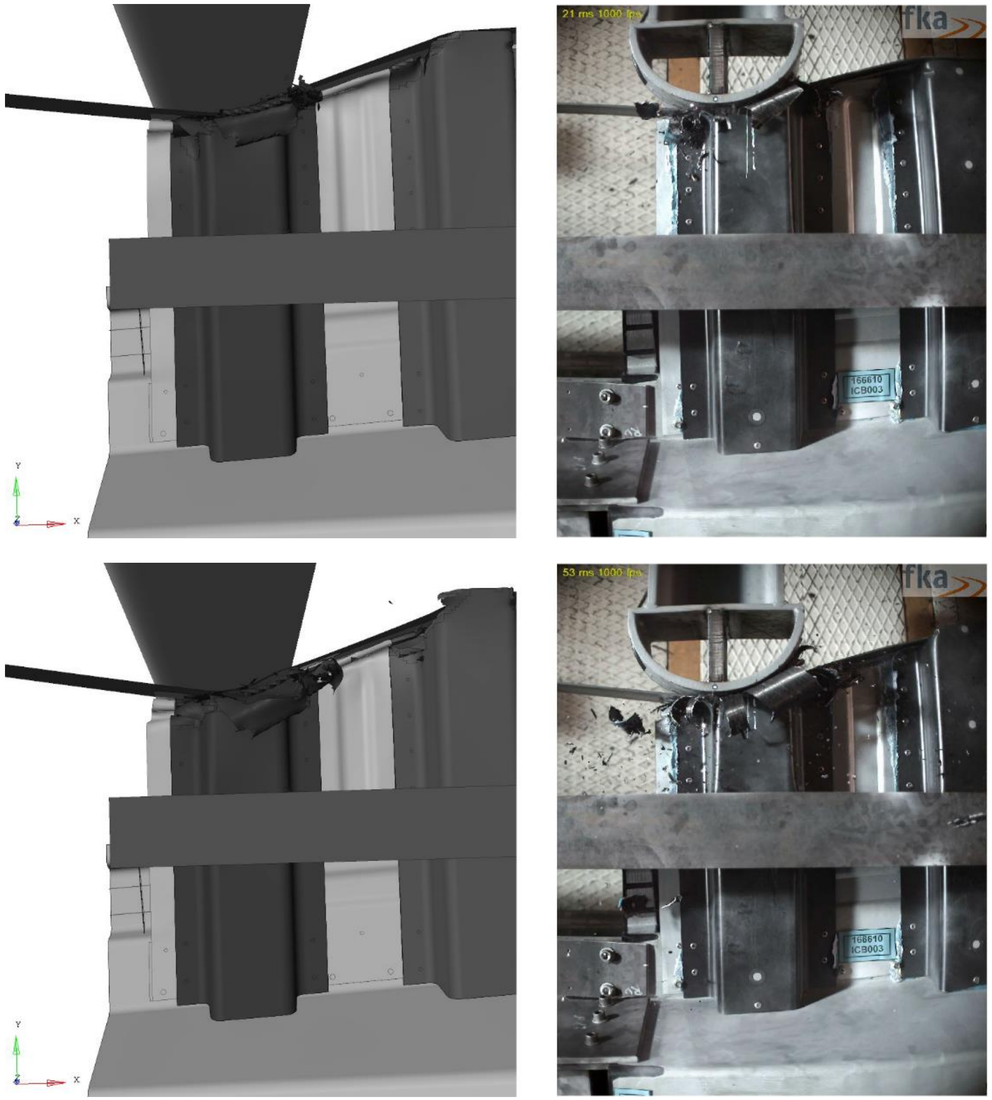
Testing of the FML Floor Structure under Crash Load





Test Evaluation and Comparison with Simulation

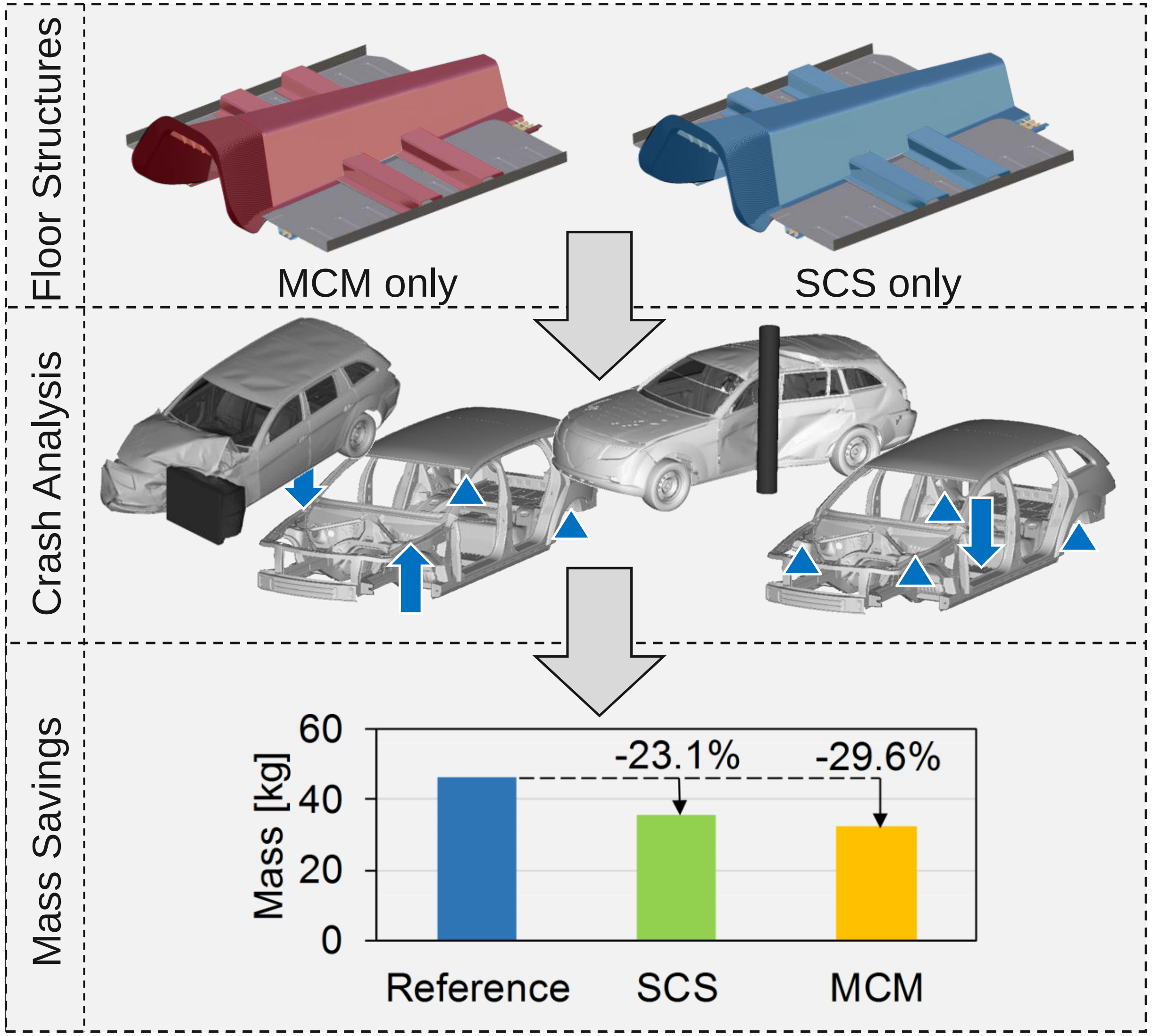




- Good overall correlation of simulation and test in structural behaviour, maximum force and maximum impactor travel
- Rupture of seat member (MCM) is covered in simulation
- Stability of tunnel structure (SCS) is predicted

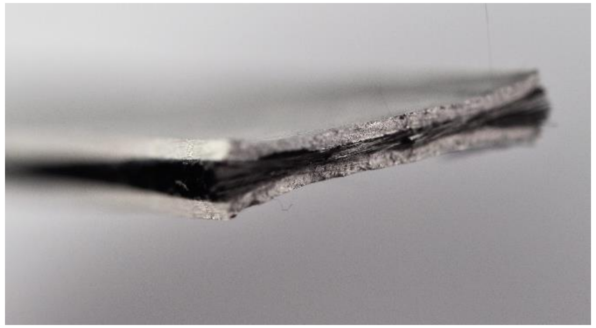
Application on Full Vehicle Level – Lightweight Design Study

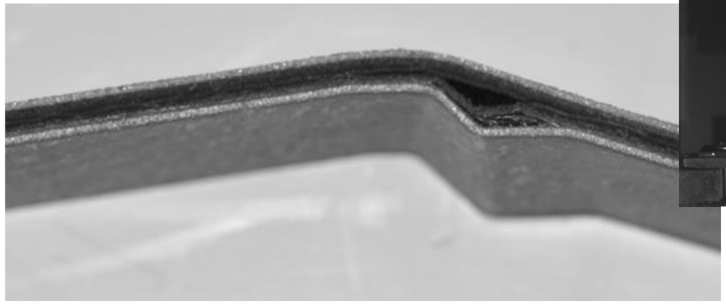
- Reference vehicle: High strength steel state-of-the-art
- Construction of two floor structures: MCM only, SCS only (non-crash structures in AZ31b / Steel-Thermoplastic)
- Geometry of FML floor structure considers manufacturing and joining constraints (bending, rivets, adhesives)
- Crash analysis targets: same structural key parameters
  - Intrusion passenger compartment / battery comp.
  - Accelerations
  - Survival space
- Lightweight benefit of SCS floor structure: 23.1%
  - energy absorption via buckling and bending
- Lightweight benefit of MCM floor structure: 29.6%
  - failure mainly due to rupture and crushing
- If the mass comparison only considers SCS/MCM parts: Lightweight benefit with SCS/MCM roughly the same: 28% overall weight saving, seat members >40%

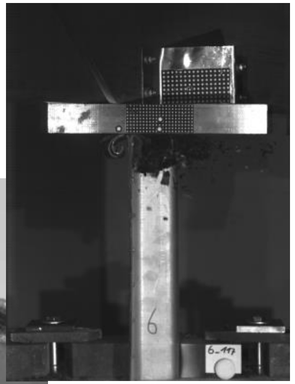


Conclusion

- Motivation of FMLs in body applications by “tailored” properties
  Ductility (metal) + spec. energy absorption (CFRP) + stiffness (sandwich)
- Steel-CFRP and Magnesium-CFRP were chosen as representatives
- Modelling in simulation using stacked shell-approach
  - metal and CFRP as shell, cohesive zones as interface
- Production process has high impact on material properties
  - new calibration method needed, only metal is calibrated as monolithic material, CFRP has to be calibrated via FML tests
- Tensile, bending, hat profile tests for calibration, validation via prototype floor structure in pole crash → Validation success
  - interlaminar failure observed in specimen bending (not considered)
  - bending of hat profile shows deviant deformation behaviour
- Model was applied on a full vehicle crash model with FML-floor structure (SCS and MCM), lightweight study shows 28% possible weight saving
- Components under axial load (unidirectional core) up to 40% savings in mass compared to high strength steel reference







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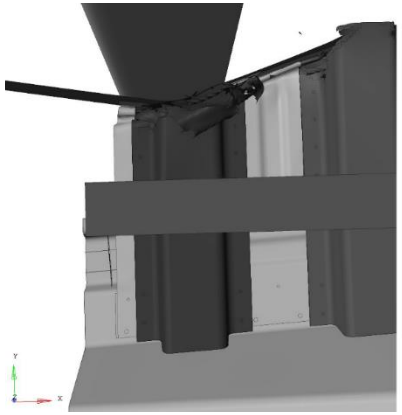

Contact

Thank you for your attention! Questions?

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