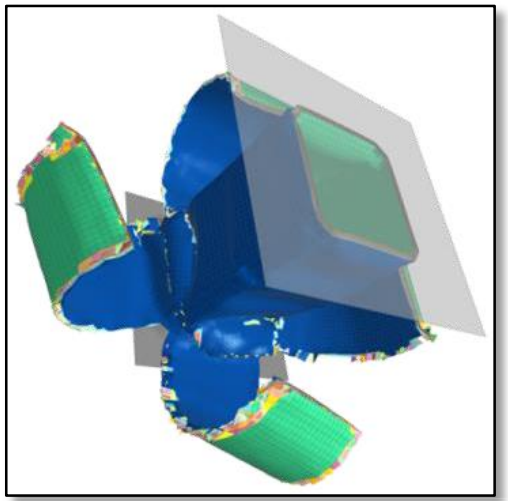
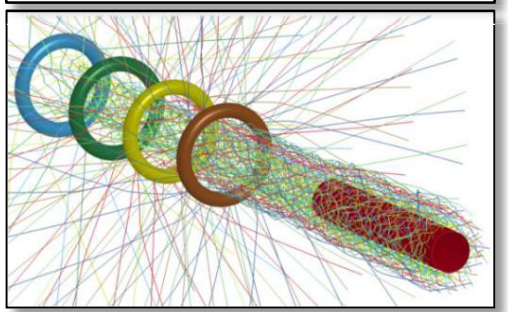
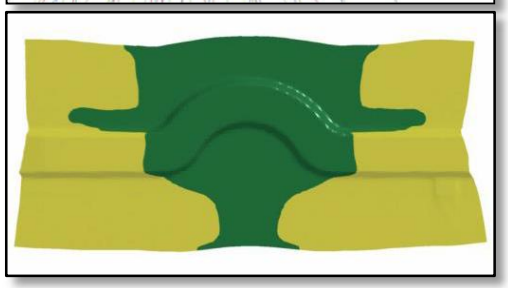






Aktuelle Entwicklungen bei der Simulation von FVK-Komponenten in der industriellen Anwendung mit LS-DYNA

S. Hartmann, C. Liebold, A. Haufe, T. Klöppel

DYNAmore GmbH, Stuttgart

4a Technologietag – Leichtbau und Composites

05. – 06. März 2015

DYNAmore GmbH – The Company

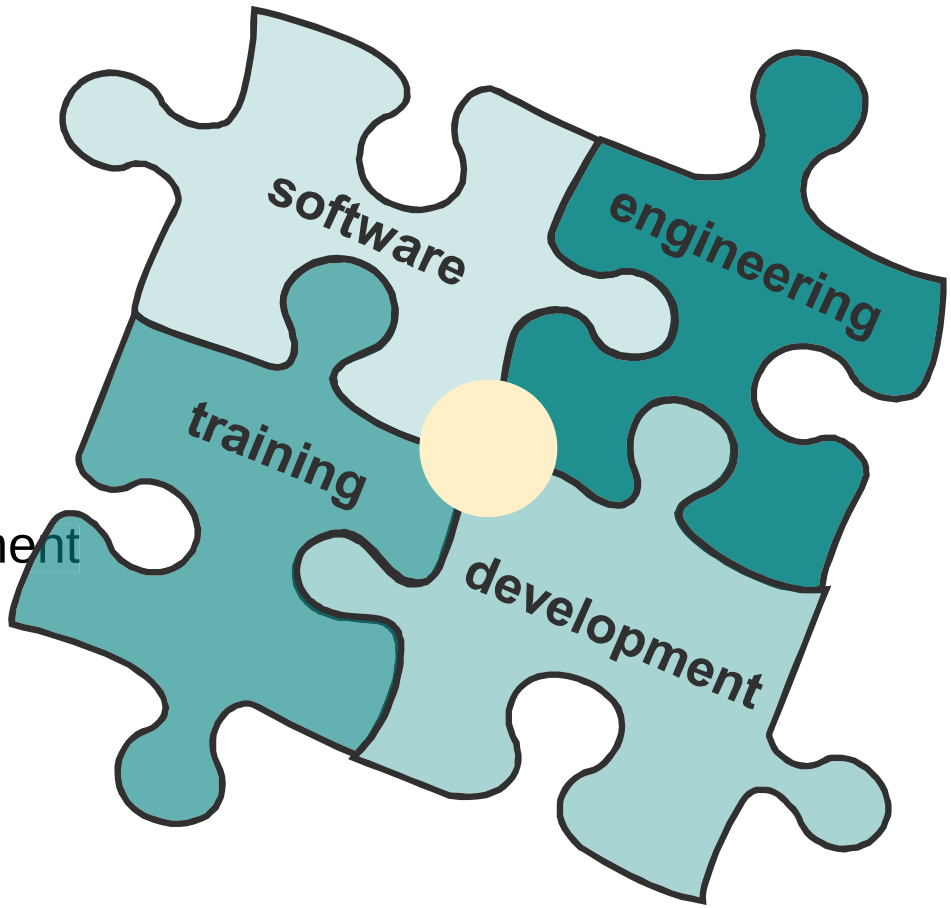
- Countries and Main Offices
  - Germany – headquarters in Stuttgart
  - Sweden – headquarters in Linköping
  - Switzerland – headquarters in Zurich
  - Italy – headquarters in Torino
- Further Offices
  - Ingolstadt
  - Dresden
  - Langlingen (Wolfsburg)
  - Berlin
  - Gothenburg
- On-site Offices
  - Sindelfingen & Untertürkheim (Daimler)
  - Weissach (Porsche)
  - Ingolstadt (Audi)
  - Gothenburg (Volvo)

DYNAmore – The People

- Who we are
  - In total 90 people
  - Civil and mechanical engineers, mathematicians, computer scientists,…
  - The employees are from 13 different countries
  - The fluctuation of employees is very low
  - The company is financially stable since its foundation

DYNAmore – The Services

- Software
  - European master distributor for LS-DYNA (w/o UK and France), plus TR
- Engineering
  - Benchmarking
  - Pilot projects
- Development
  - Software development
  - Material & dummy models
  - System & process integration
  - Customization & method development
- Training
  - Seminars & on-site coaching
  - Conferences
  - Support



LS-DYNA – The Applications

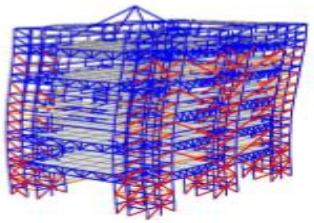
Automotive

Crash and Safety

NVH

Durability

Civil Engineering

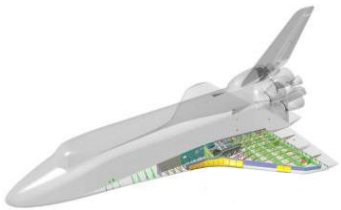


Concrete structures

Earthquake safety

Wind- & Waterpower

Aerospace

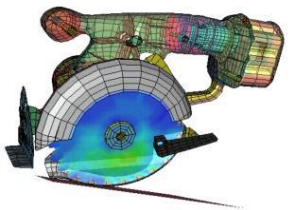


Bird strike

Containment

Crash

Electronics

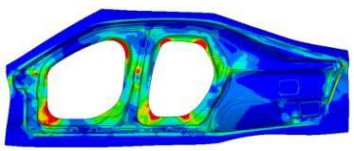


Drop analysis

Package analysis

Thermal

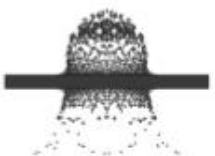
Manufacturing



Stamping

Forging

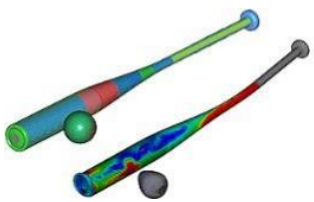
Defense



Detonations

Penetrations

Consumer Products

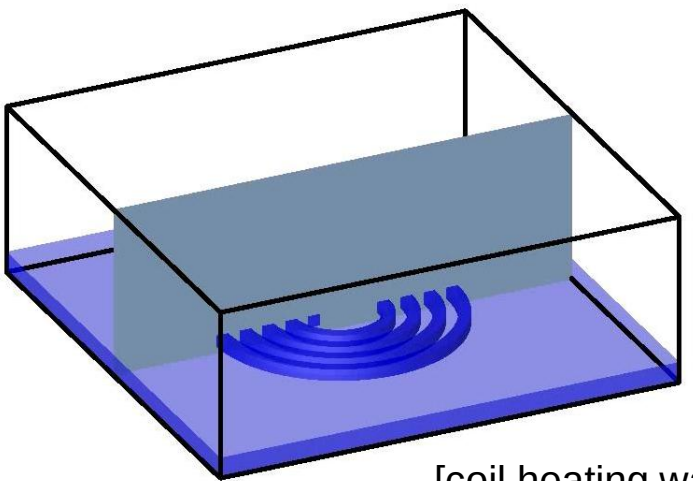


Biomechanics

LS-DYNA – The Multiphysics Solver

- Combine the capabilities
  - Explicit/ Implicit **structural** solver
  - **Thermal** solver & heat transfer
  - **Incompressible fluid** solver (ICFD)
  - **Compressible fluid** solver (CESE)
  - **Electromagnetics** solver (EM)
  - Frequency domain, acoustics, modal analysis
  - Finite elements, iso-geometric elements, ALE, EFG, SPH, DEM, CPM, …
  - User elements, materials, loads
- Into **one** scalable **code** for
  - highly **nonlinear transient** problems
  - **static** problems
- To enable the solution of
  - coupled **multi-physics** and
  - **multi-stage** problems
- On **massively parallel** systems

Heart valve:
Courtesy of H. Mohammadi,
McGill University



[coil heating water]

Agenda

- Process simulation
  - Draping, Weaving and Braiding
  - Thermoplastic pre-pregs
  - Resin transfer molding (RTM)
  - Short/long fiber reinforced plastics
- Data Transfer - Mapping
  - Modeling aspects
  - Mapping examples
- Developments towards an increasing predictability for crushing simulations
- Conclusion and Outlook

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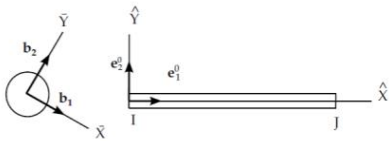
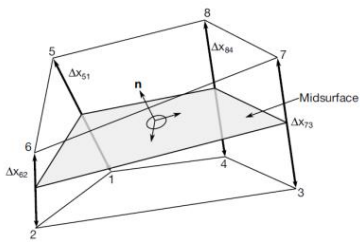
Braiding, weaving, draping

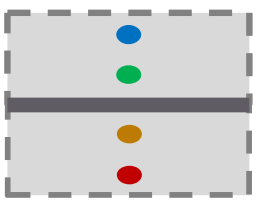
- Braiding simulation using *ELEMENT_BEAM_SOURCE for automatic element generation



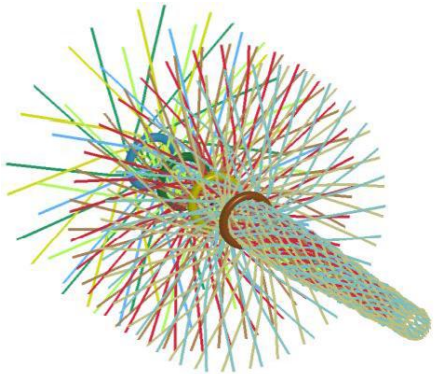
- Weaving simulation using shell- or even solid elements



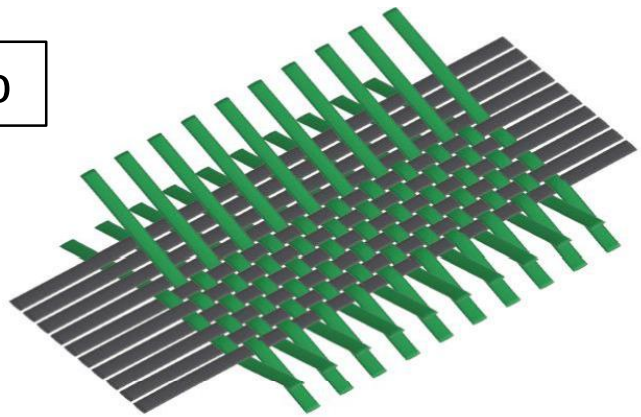
- Draping simulation using multi-layered (stacked) shell elements with different material orientations



micro



meso



macro

Thermoplastic pre-pregs – the process

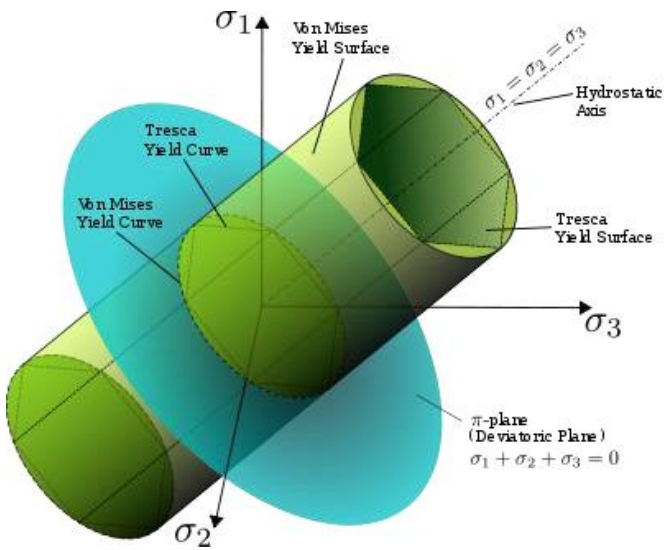
- Relatively short cycle times can be realized
- Process is reversible as no chemical curing occurs
- Properties of thermoplastic matrix material
  - At high temperature, molten material behaves like a viscous fluid
  - At low temperature, material can be described as an elasto-plastic solid
- Process overview

Thermoplastic pre-pregs – material model

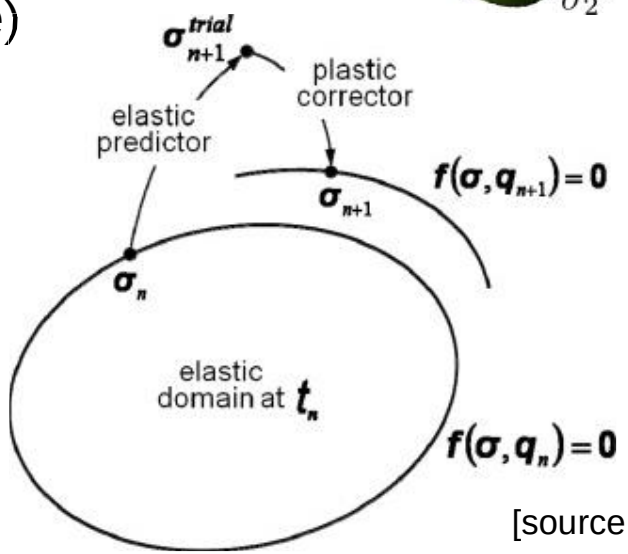
- Additive split for matrix and fiber contributions

- Matrix formulation
  - Elastic properties are defined with load curves w.r.t. to temperature (vs. strain-rate)
  - Von-Mises yield criterion is implemented
  - Yield stress is given by load tables w.r.t.
    - Temperature (vs. strain rate)
    - Equivalent plastic strain

  - Return-mapping algorithm



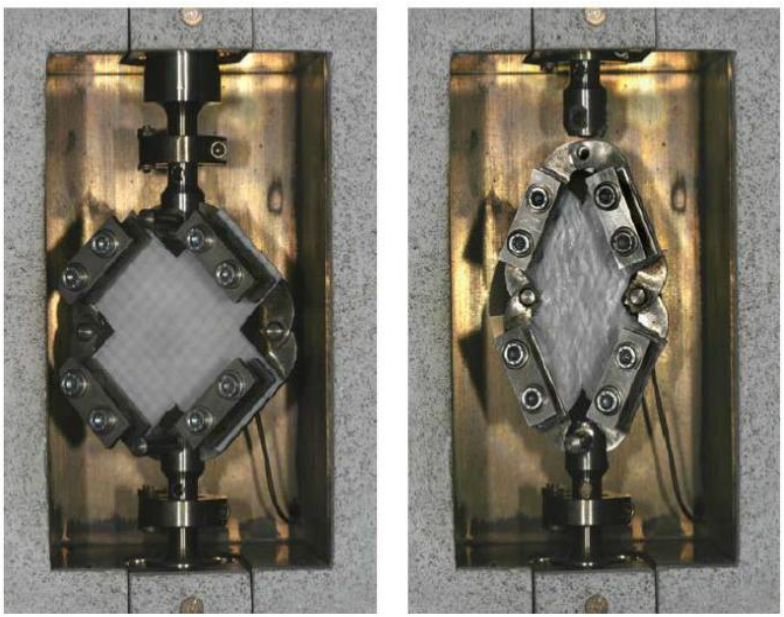
[source: www.wikipedia.de]

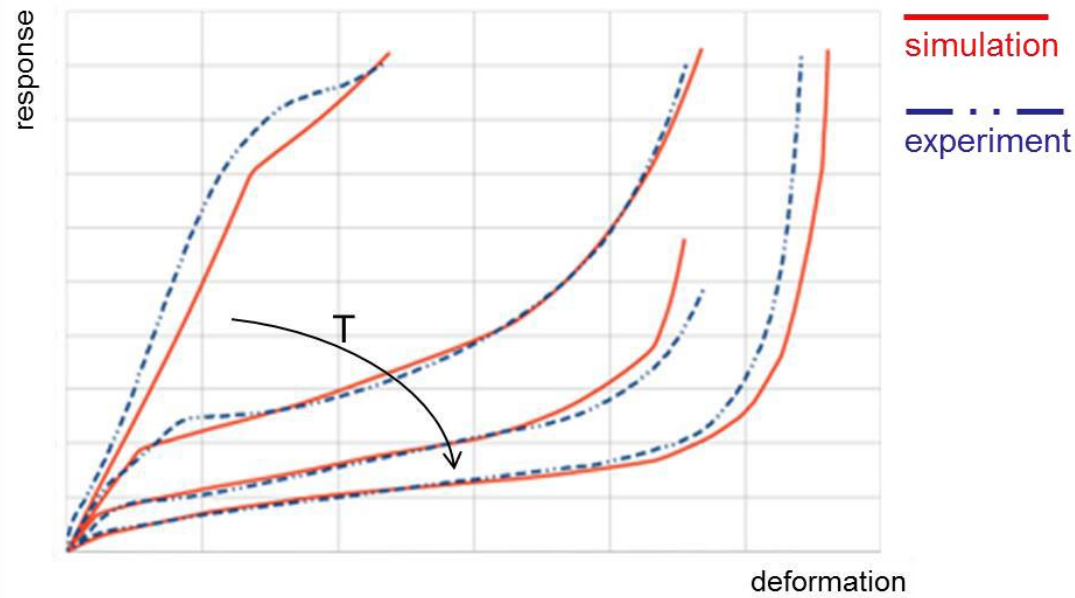


[source: Neto et al, 2008]

Thermoplastic pre-pregs – material model validation

- Picture frame test is simulated for different temperatures
- Simulation results show good agreement with experimental data
  - Realistic non-linear shear behavior of fabric (highest temperature)
  - Effect of matrix curing with decreasing temperature is well captured



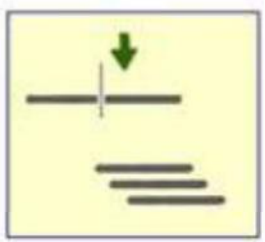


Resin transfer moulding (RTM) – the process

- In general, thermosets (e.g. epoxy) have superior mechanical properties as compared to thermoplastics

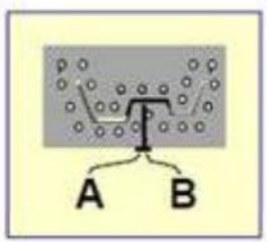
- All manufacturing processes involve a chemical curing of a liquid resin
  - Curing is induced by high temperatures and chemical additives
  - Chemical reactions of curing are nonreversible

- Process overview

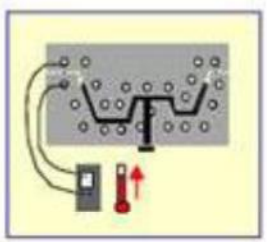


preparation of textile

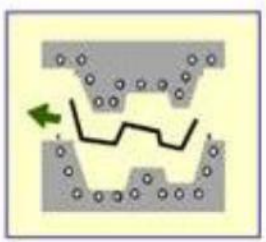
draping



infiltration



curing

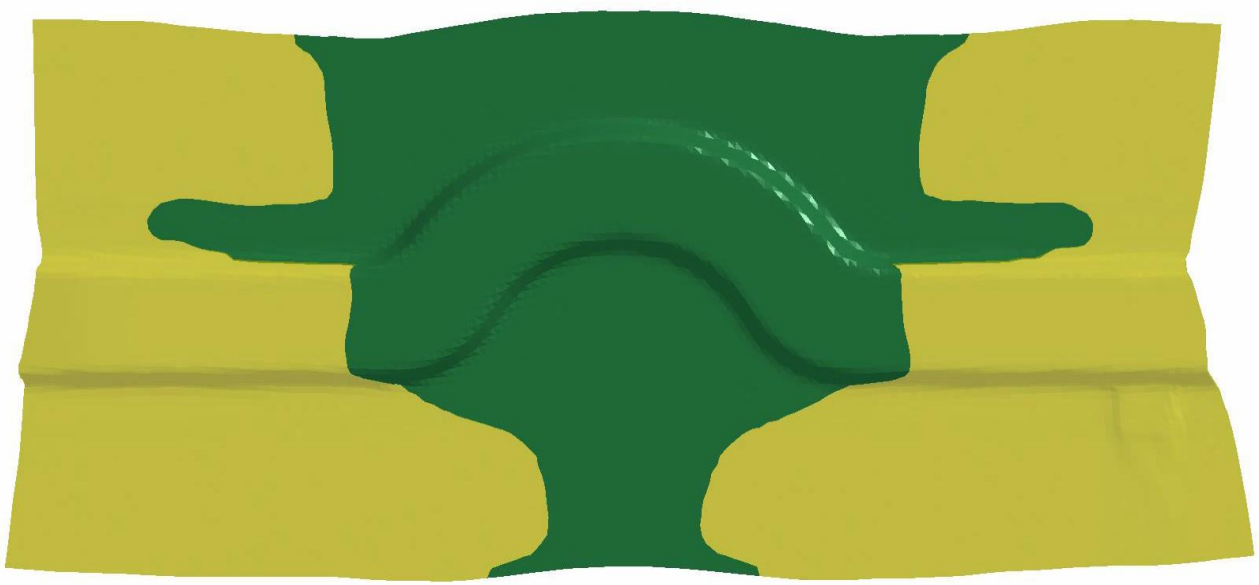


final part

[source: Benteler-SGL]

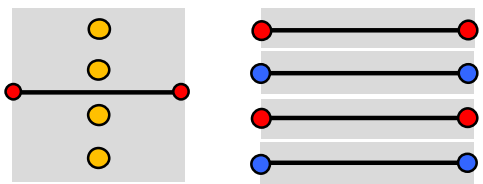
Resin transfer moulding (RTM) – LS-DYNA modeling

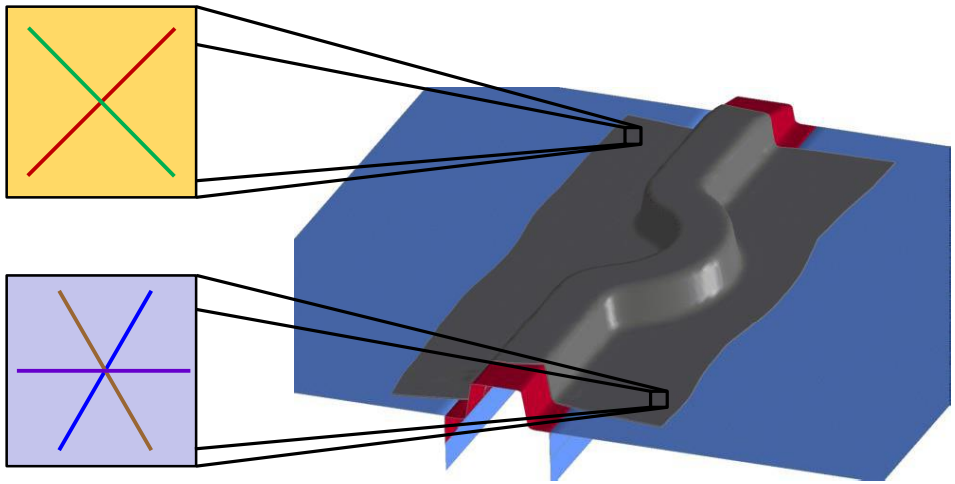
- Preliminary simulation with isotropic porosity
- Mesh obtained from draping simulation
- Flow induced by pressure inlet
- One injection point for resin is considered (blue)



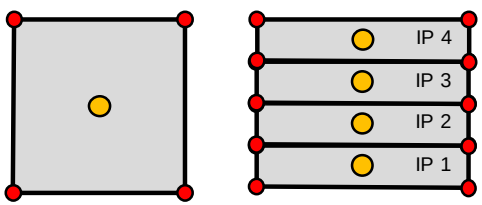
Resin transfer moulding (RTM) – LS-DYNA modeling

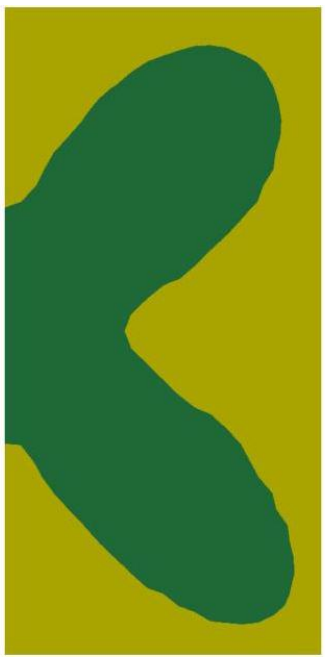
- Draping simulations are usually performed using (stacked) shell elements.

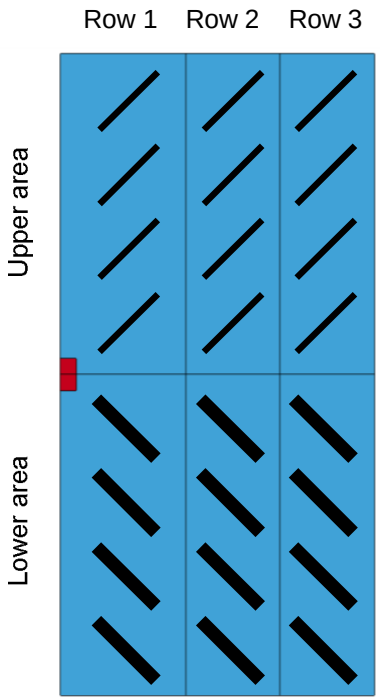




- For further infiltration with ALE, results have to be mapped on (stacked) solild elements using a porosity tensor.

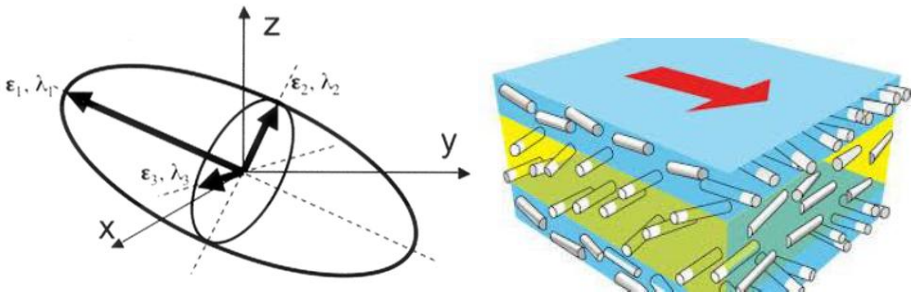




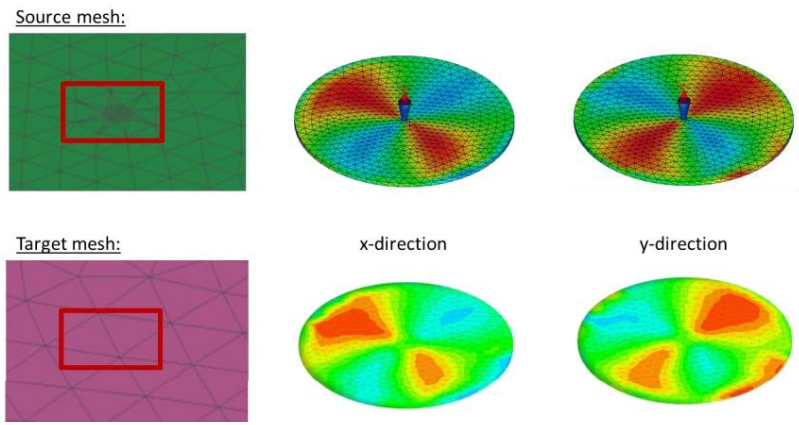


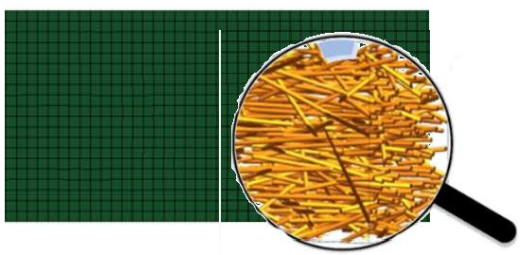
Short/long fiber reinforced plastics

- Simulations usually performed with special infiltration software tools
- Output is usually a fiber orientation tensor
- Different meshes for infiltration and ongoing simulations
- Anisotropy should be considered within further simulations
- Map information onto appropriate material model in LS-DYNA (i.e.: anisotropic, elasto-plastic)



[source: Fraunhofer - EMI]





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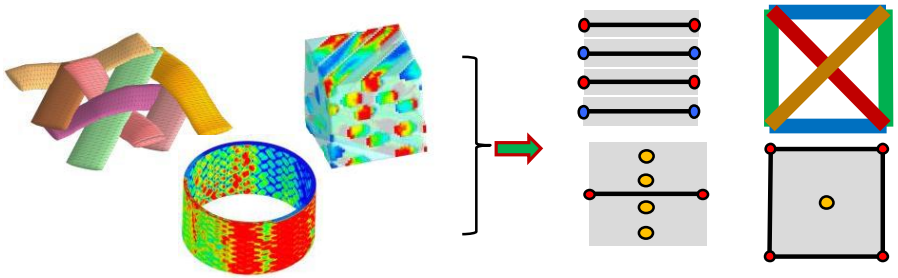
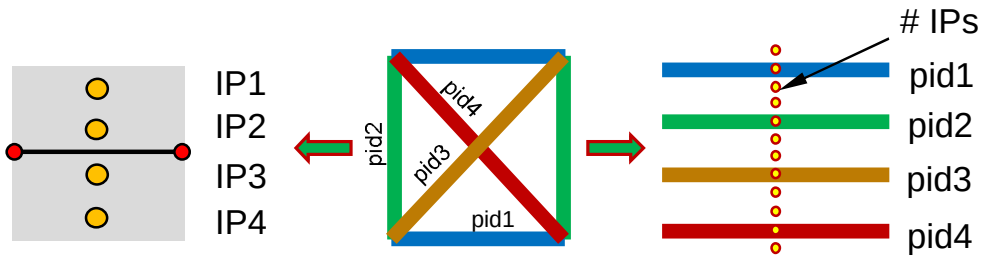
Modeling aspects - discretization

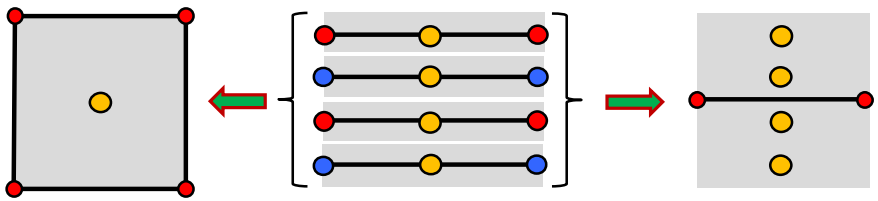
- RVE, experimental Data ➡ Shell, Stacked-Shell, Beam, Solid, Stacked-Solid…



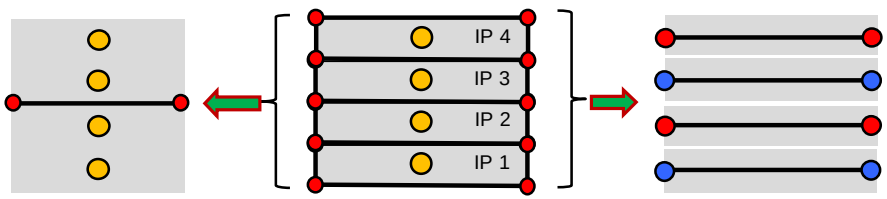
- Beam ➡ Shell, Stacked-Shell



- Stacked-Shell ➡ Solid, Shell



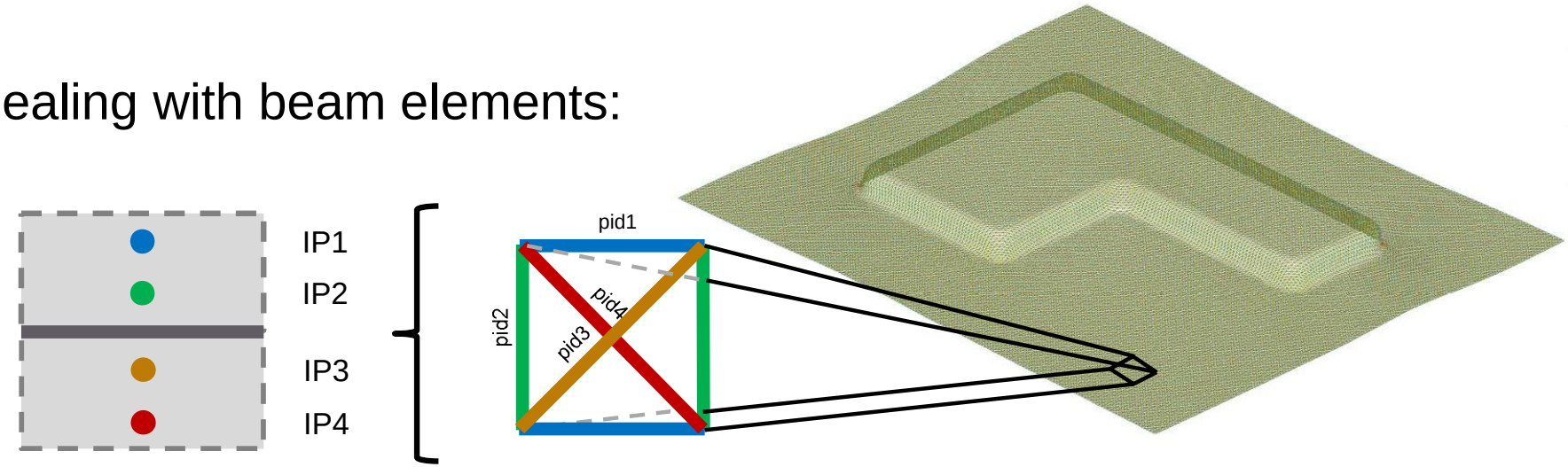
- Stacked-Solid ➡ Shell, Stacked-Shell



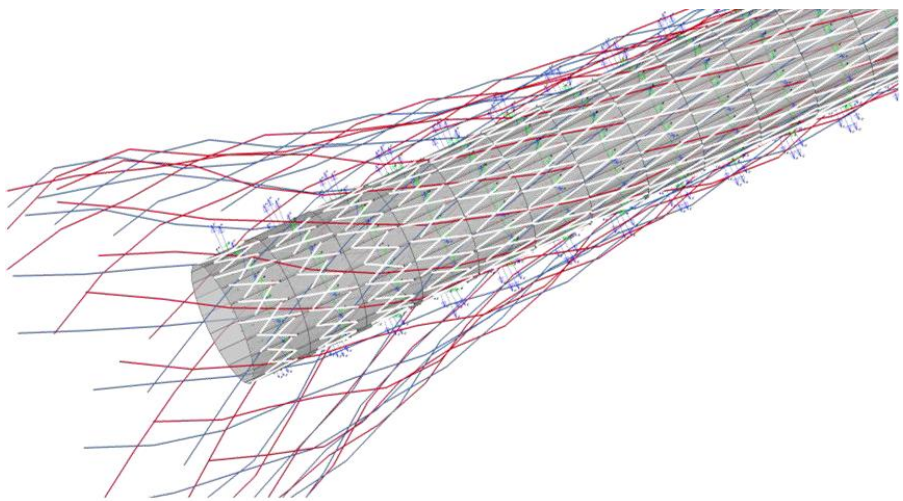
- and many more…

Mapping example

- Dealing with beam elements:

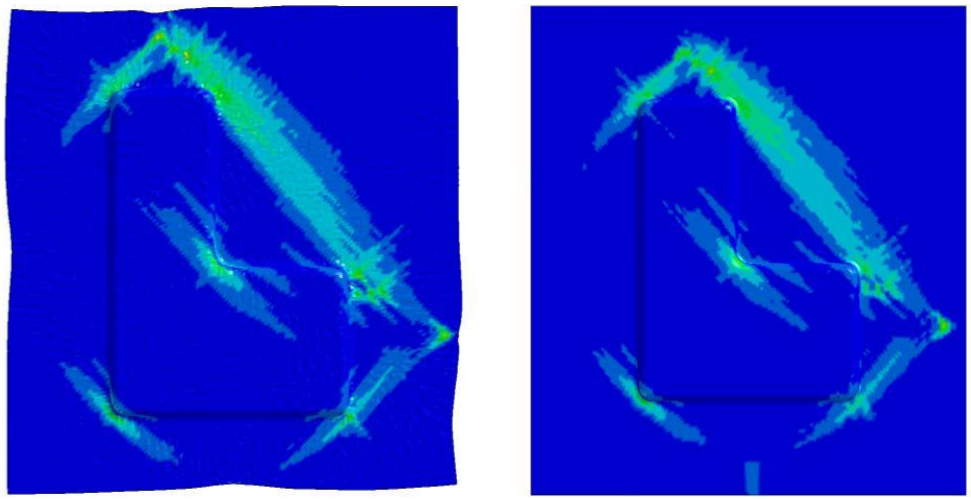


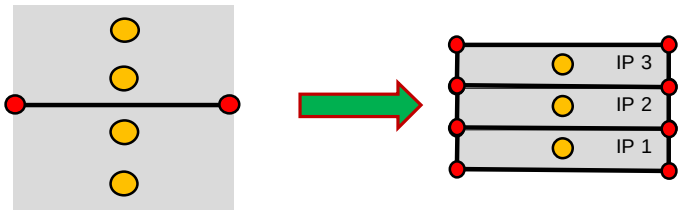
- Mapping can be performed in different ways
  - One direction for each integration point
  - Usage of a multi-directional material



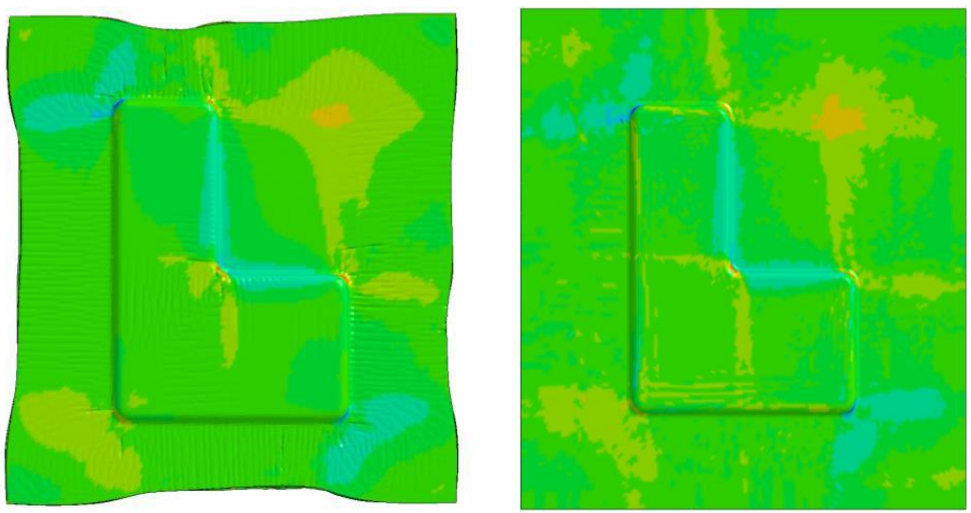
Mapping example

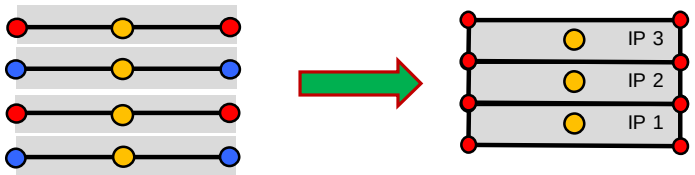
v. Mises Stress:





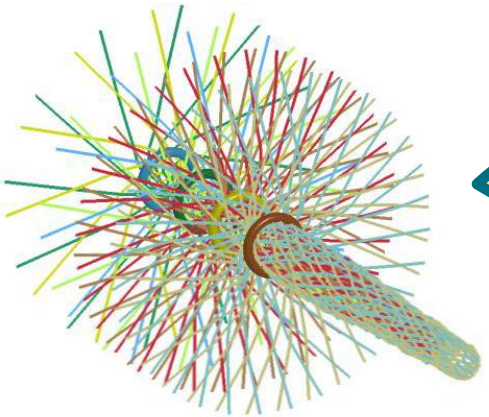
HISV #1:



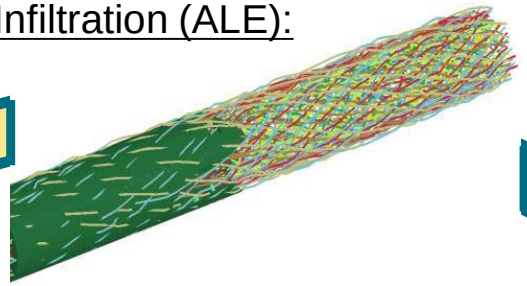


Process chain

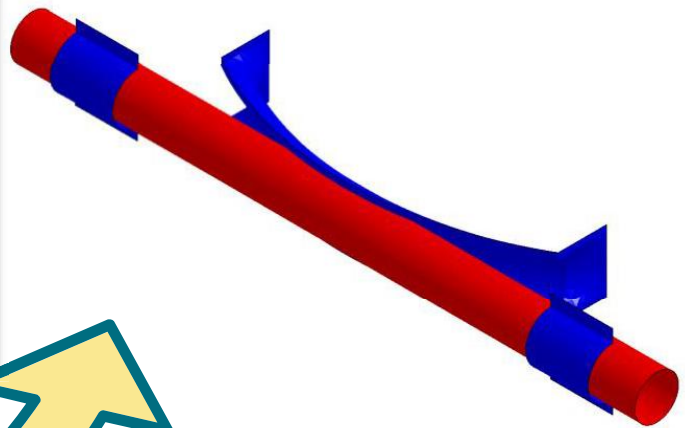
Braiding:



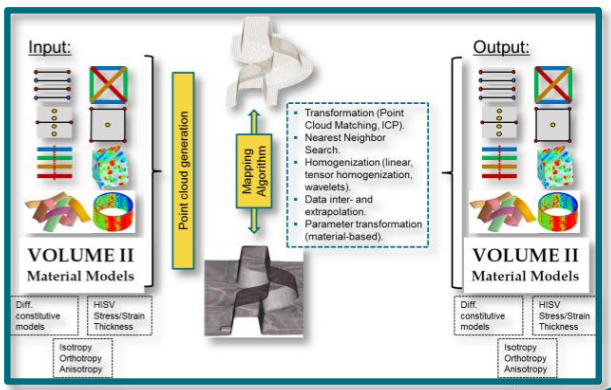
Infiltration (ALE):



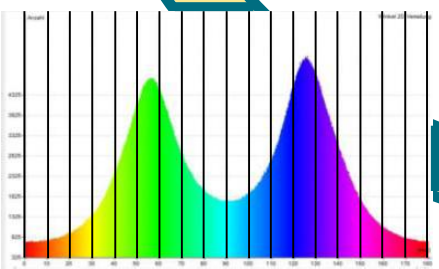
Forming (MAT_249):



Mapping:



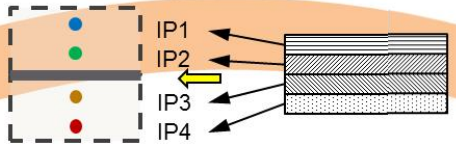
Experimental validation:



The digital prototype (ARENA 2036)

Bundesministerium
für Bildung
und Forschung

Material modeling & mapping

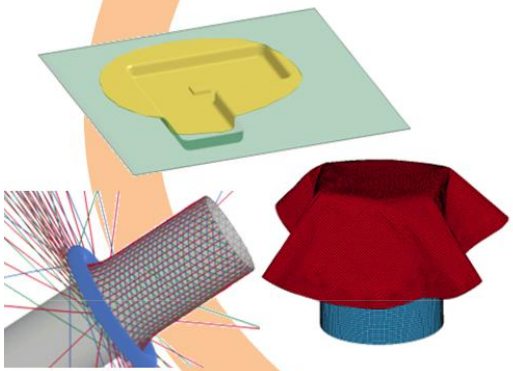


ARENA 2036

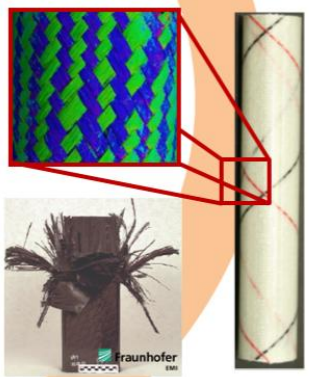
Digital Prototype

- Software development
- Interface programming
- Modeling techniques
- Homogenization
- Material modeling

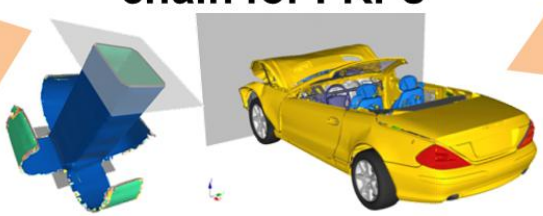
Processing



Experimental Verification



Closing the process chain for FRPs



DLR DYNA MORE IFB DAIMLER IFB Institut für Flugzeugbau

Agenda

- Process simulation
  - Draping, Weaving and Braiding
  - Thermoplastic pre-pregs
  - Resin transfer molding (RTM)
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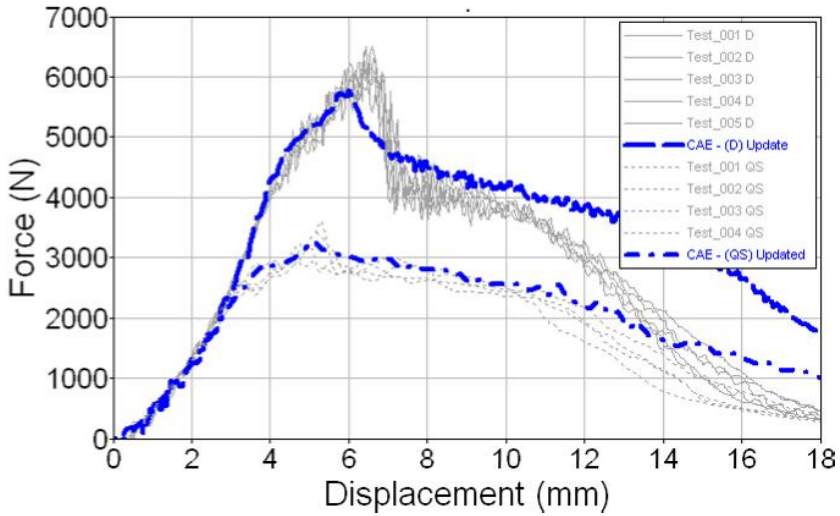
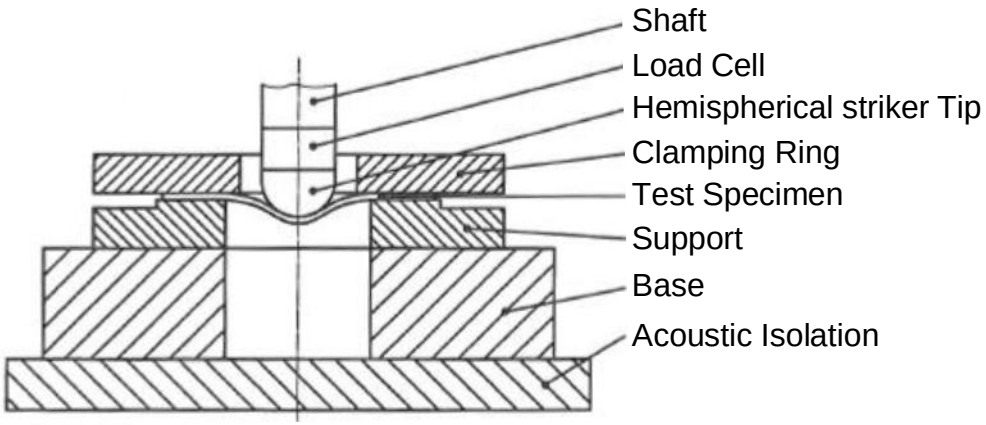
Available material models in LS-DYNA

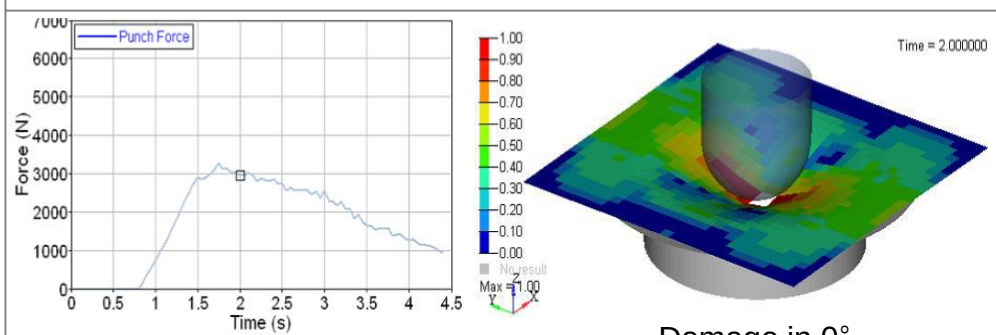
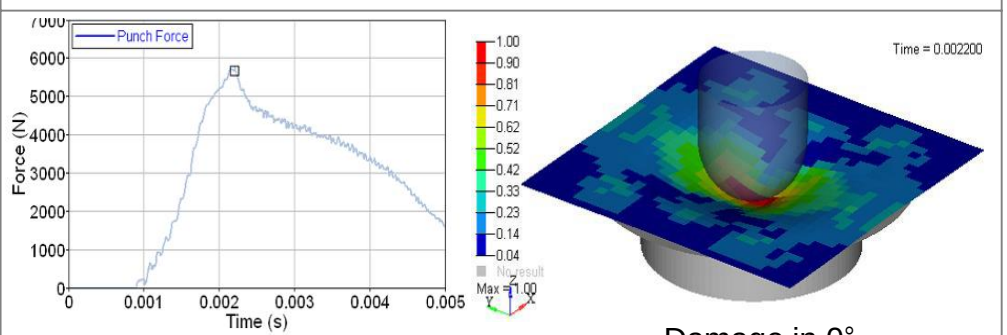
	Element	Failure criteria	Rate dependency	Remarks
***MAT_022:** COMPOSITE_DAMAGE	Shell, Tshell, Solid	Chang-Chang	-	ALPH doesn't affect stress vs. strain relationship. (same for 054/055)
***MAT_054/055:** ENHANCED_COMPOSITE_DAMAGE	Shell, Tshell, Solid	54: Chang 55: fiber: Chang matrix: Tsai-Wu	rate dependent strength via *DEFINE_CURVE	Fiber tensile and compressive strengths can be reduced after matrix failure. Minimum stress limit factor. Crash front algorithm.
***MAT_058:** LAMINATED_COMPOSITE_FABRIC	Shell, Tshell (1,2)	Modified Hashin	rate dependent Strengths and strains via *DEFINE_CURVE	Smooth increase of damage. Special control of shear behavior of fabric. Minimum stress limit factor. Crash front algorithm.
***MAT_059:** COMPOSITE_FAILURE_MODEL	Shell, Tshell, Solid, SPH		-	Similar to 054. Crash front algorithm. Minimum stress limit factor.
***MAT_158:** RATE_SENSITIVE_COMPOSITE_FABRIC	Shell, Tshell	Modified Hashin	Viscosity based on isotropic viscoelasticity	Same as 058.
***MAT_261:** LAMINATED_FRACTURE_DAIMLER _PINHO	Shell, Tshell, Solid	Pinho	-	Considers the state-of-the-art Puck's criterion for inter-fiber failure
***MAT_262:** LAMINATED_FRACTURE_DAIMLER _CAMANHO	Shell, Tshell, Solid	Camanho	-	Considers the state-of-the-art Puck's criterion for inter-fiber failure

- *MAT_LAMINATED_COMPOSITE_FABRIC (*MAT_058)
  - Example: Punch Test (DIN EN ISO 6603-2)
    - PA6 GF46 Organo-sheet
    - Loading speed:
      a) Quasi-static: $\dot{\varepsilon} \sim 0.001\ [1/s]$
      b) Dynamic: $\dot{\varepsilon} \sim 200\ [1/s]$





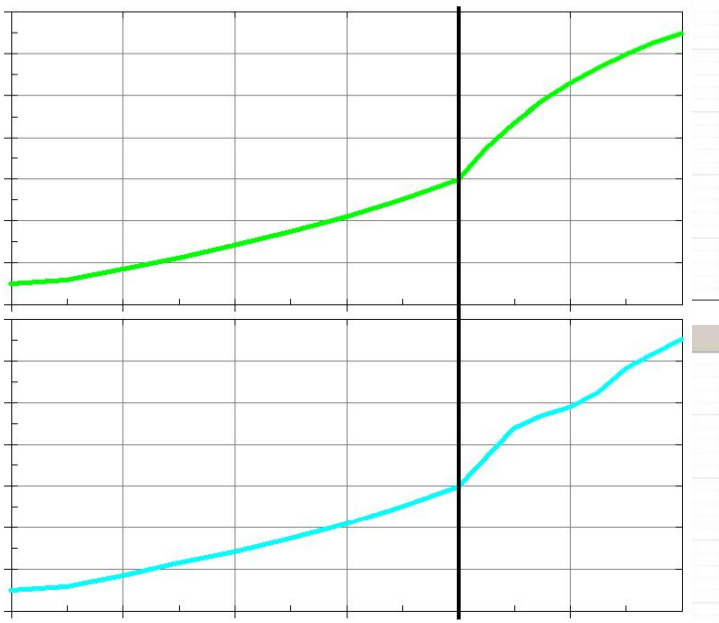
Disc Punch Test Configuration

Quasi-Static Response	Dynamic Response
	
Damage in 0°	Damage in 0°

from: Jerome Coulton (HYUNDAI Motor Group), *Improvements to material 58*, LS-DYNA Forum, 2013

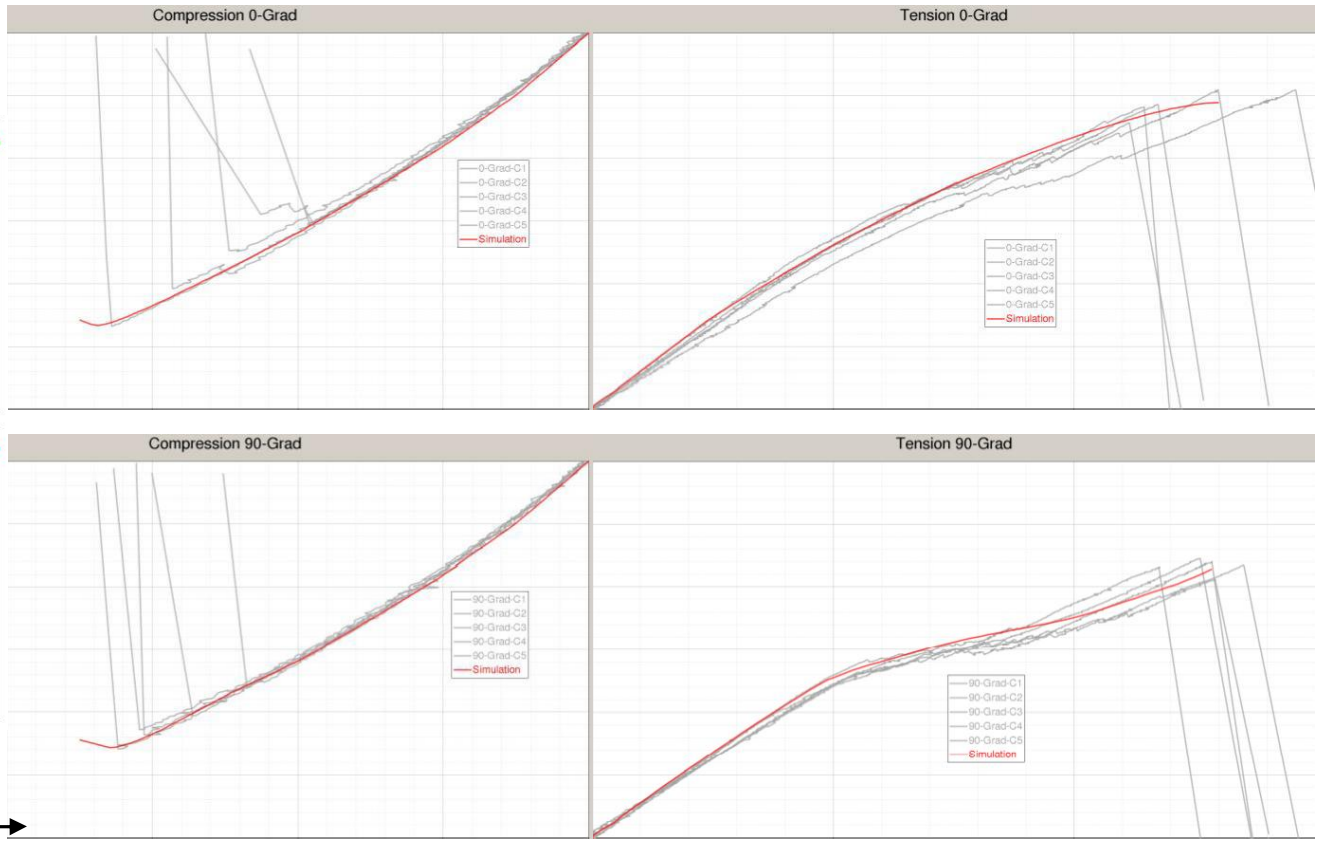
- *MAT_LAMINATED_COMPOSITE_FABRIC (*MAT_058)
  - Example: Adjusting non-linear material properties for woven composite

Curve-definition for EA



Curve-definition for EA

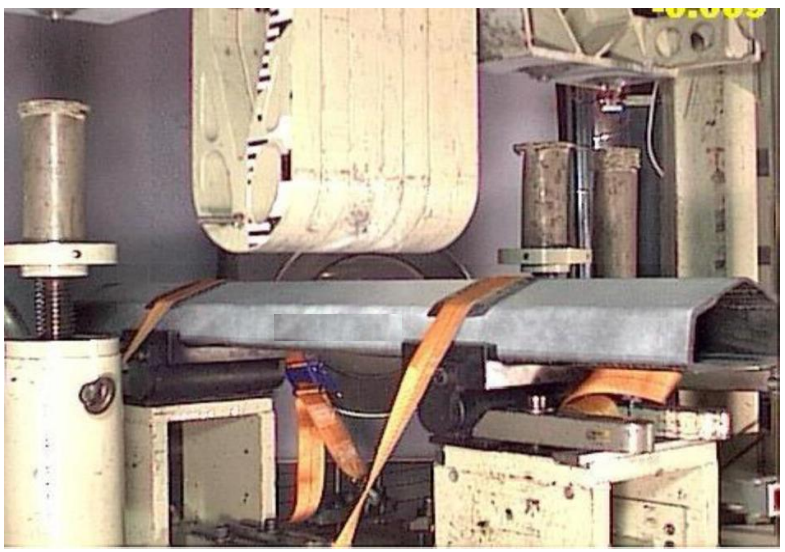
compression tension

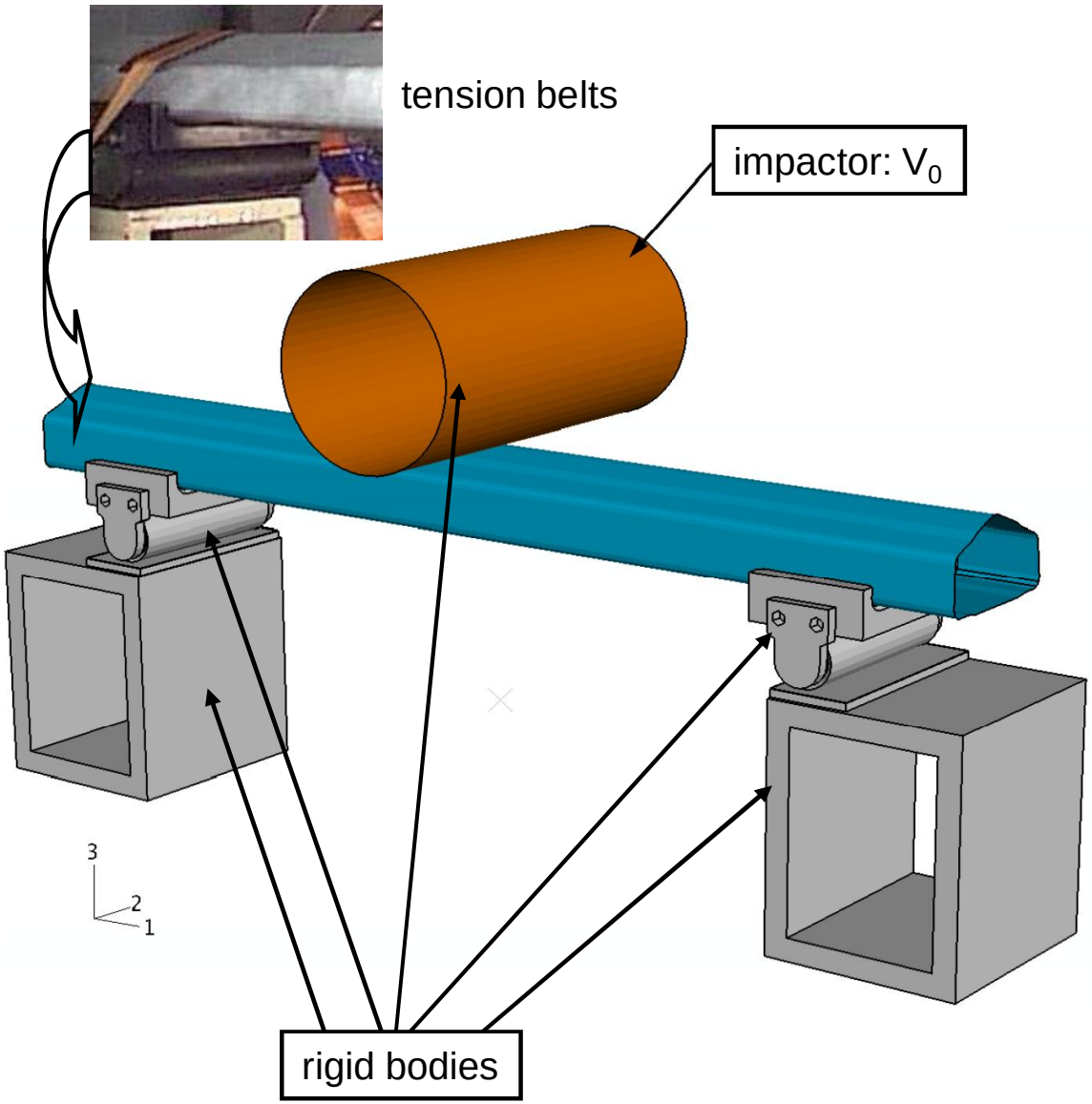


- Non-linear elastic, orthotropic material properties for EA, EB via *DEFINE_CURVE

3-point-bending

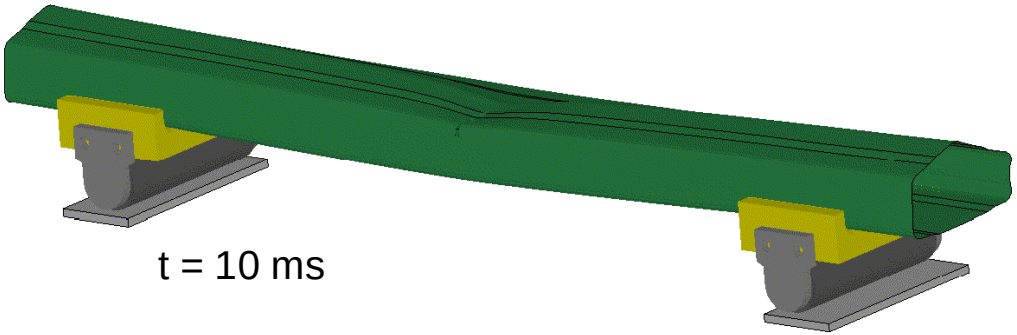
- support and impactor as rigid bodies
- tension belts with pre-stressed beams
- girder with layered shell elements (12 layers, *ELFORM=2*) and material model from P. Camanho

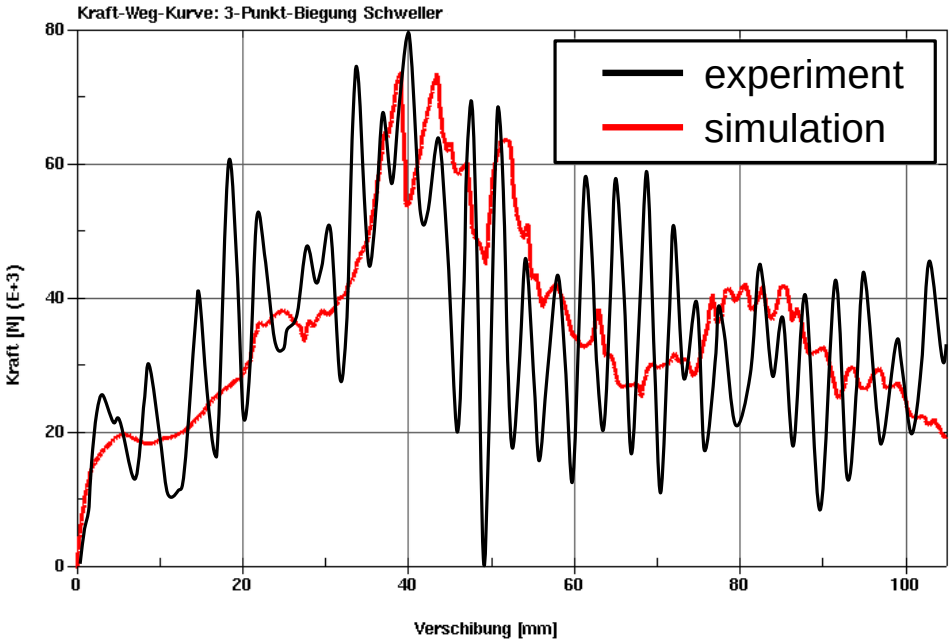


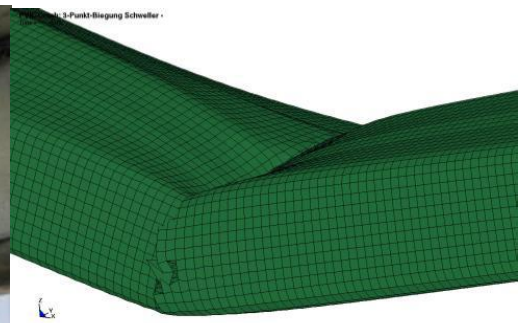


3-point-bending

LS-DYNA with material model
from P. Camanho (UserMat now MAT_262)







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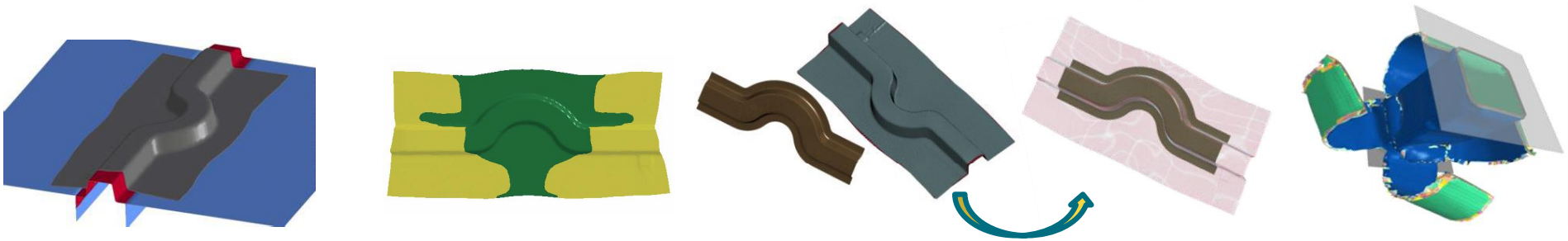
Conclusion and Outlook

- Various methods for process simulations as well as state of the art material- and failure models are available in LS-DYNA in order to fully simulate all the steps along the process chain for fiber reinforced plastics.

- Nevertheless, further enhancements are to be made towards a closed process chain by means of a proper data transfer and homogenization schemes for different mesh sizes, modeling techniques and data transformation between different coordinate systems but also for different solver solutions.



LS-DYNA – Learn More

- 10th European LS-DYNA Conference 15 – 17 June 2015, Würzburg, Germany
- Congress Centrum Würzburg
- Call for Papers: ~~13 February 2015~~
  extended to: **6 March 2015**
- Topics:
  - Composites
  - Crash
  - Multiphysics
  - Recent developements
  - Optimization
  - Joining techniques
  - Particle methods
  - …

Thank you for your attention!