A4 Technologietag, Kunststoffe auf dem Prüfstand – Testen und Simulieren

Multi-physics simulations with LS-DYNA

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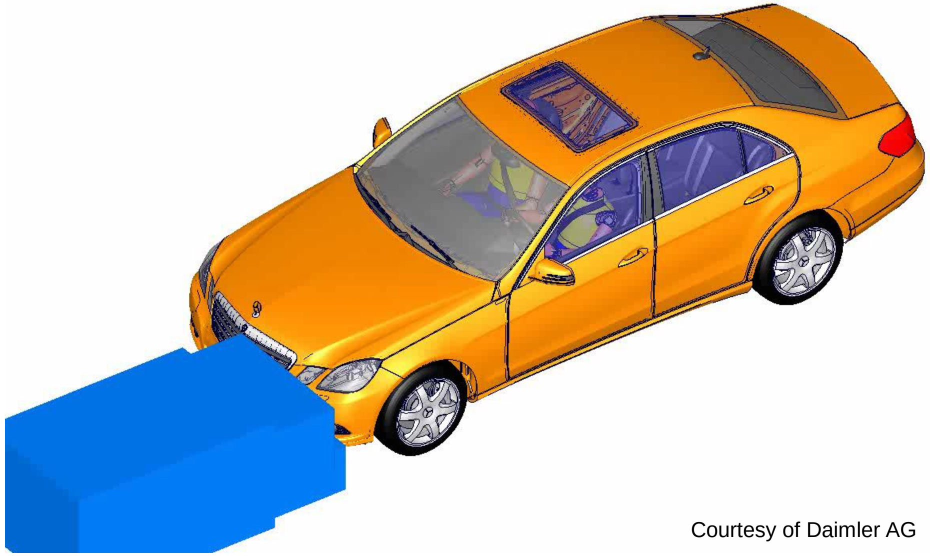
Outline

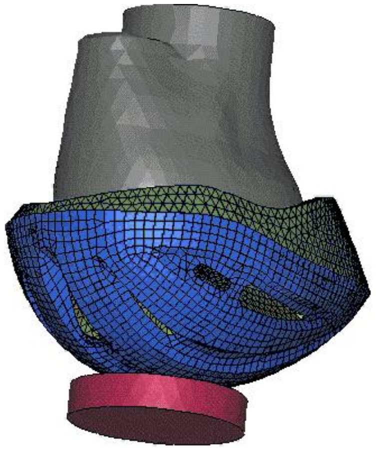
- Introduction
- Compression moulding of long-fibre reinforced plastic → sheet moulding compound (SMC)
- Additive manufacturing (AM)
- Summary

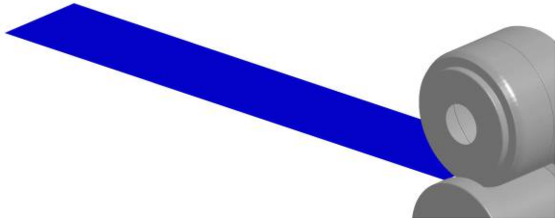
Introduction

- History of LS-DYNA and DYNAmore GmbH
  - 1976: John Hallquist develops DYNA3D at the Lawrence Livermore National Laboratories
  - 1987: John Hallquist founds LSTC in Livermore CA, DYNA3D becomes LS-DYNA3D
  - 1988: Prof. Schweizerhof + co-workers start with crash simulations in Germany
  - 2001: DYNAmore is established
  - 2011: DYNAmore acquires ERAB Nordic
  - 2011: DYNAmore assigned as Master distributor
  - 2011: DYNAmore SWISS established
  - 2013: DYNAmore Italia S.r.l. established
  - 2015: DYNAmore France established
  - 2017: DYNAmore Corp. established



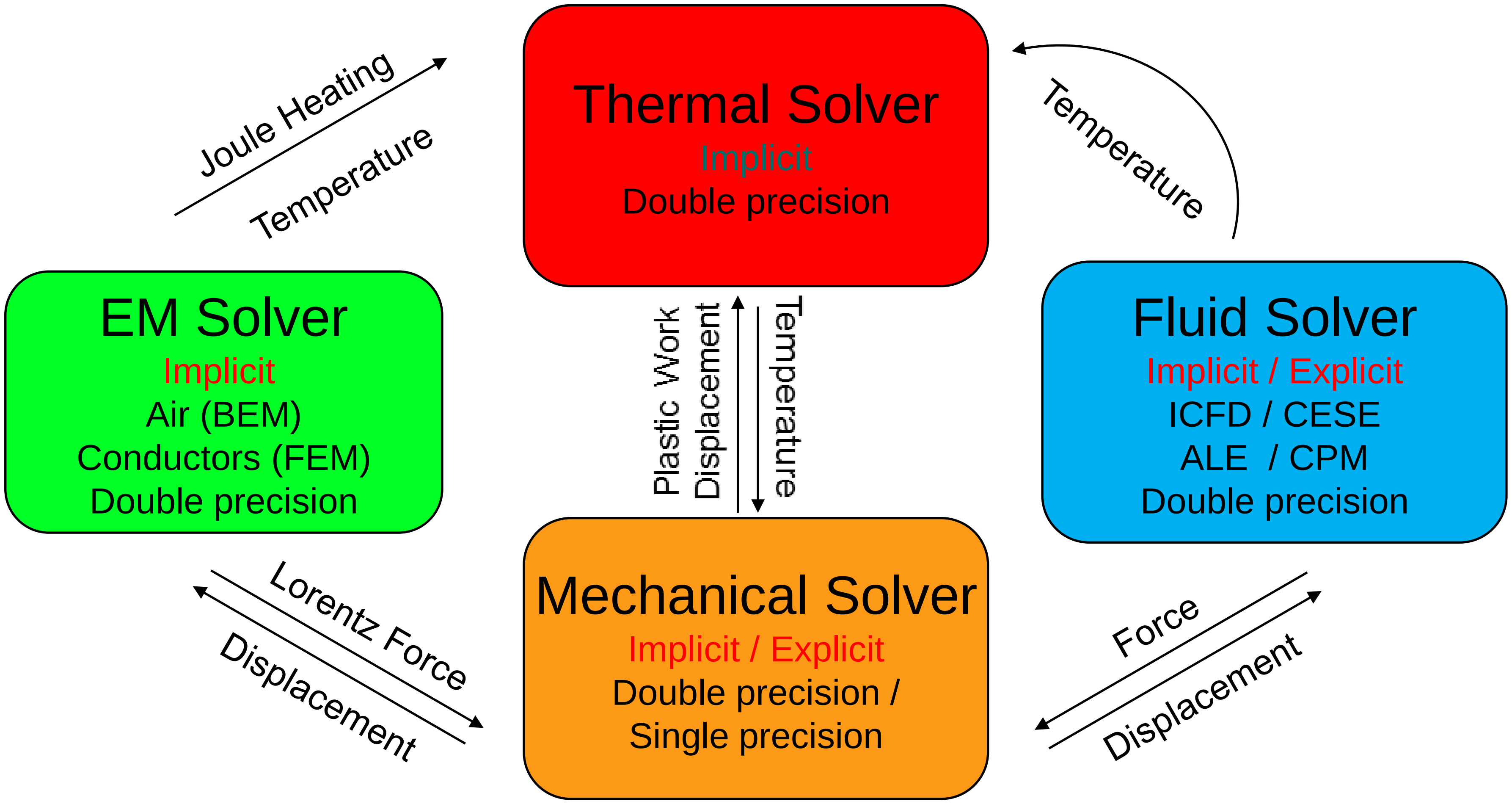
Courtesy of Daimler AG





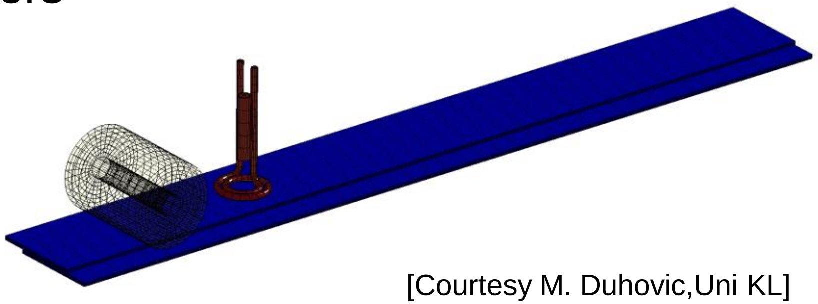
Introduction

- Multi-physics coupling in LS-DYNA

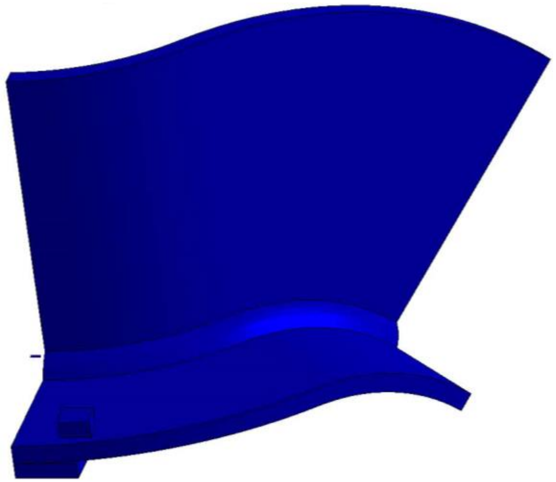


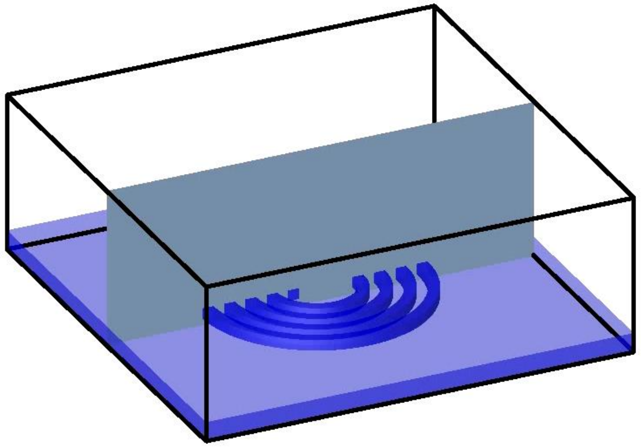
Introduction

- Combining the capabilities of different solvers
  - Explicit/implicit structural solver
  - Thermal solver and heat transfer
  - Incompressible fluid solver (ICFD)
  - Compressible fluid solver (CESE)
  - Electromagnetics solver (EM)
  - Frequency domain solver (NVH)
  - FEM, ALE, EFG, SPH, DEM, …
  - User-defined subroutines (elements, materials)
- One-code strategy
  - Static and nonlinear transient problems
  - Efficient solution of coupled multi-physics problems
  - Massively parallel solution strategy



[Courtesy M. Duhovic,Uni KL]





Compression moulding of long-fibre-reinforced plastics

Compression moulding of long-fibre-reinforced plastics

- Fibre-reinforced plastics
  - Compound of a fibre network and a supporting matrix
  - Engineered material
    - enhanced stiffness/strength-to-weight ratio, design of weak spots
    - material and structure are built together (manufacturing process influences product quality)

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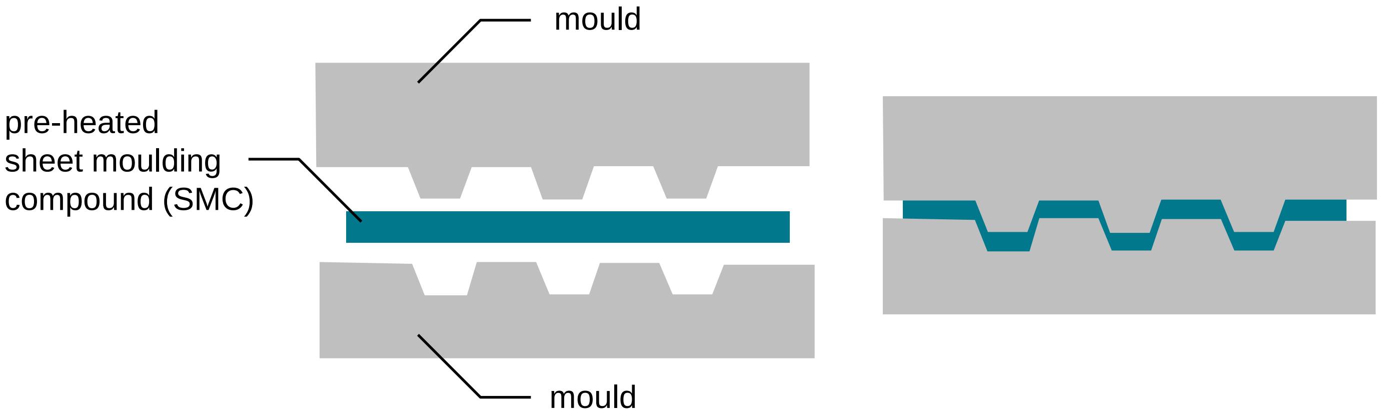
- Compression moulding
  - Production of complex-shaped structures
  - High-volume compression method
  - Advanced composite thermoplastics, e. g.
    - Unidirectional tapes
    - Woven fabrics
    - Randomly-oriented fibre mats

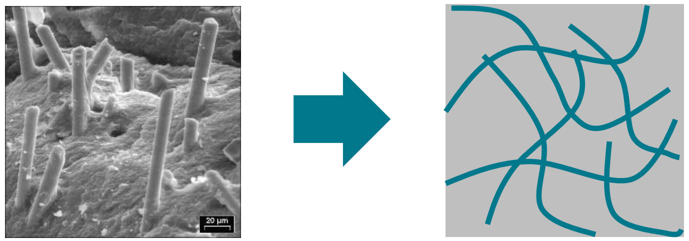


Compression moulding of long-fibre-reinforced plastics

- Why to simulate the manufacturing process?
  - Moulding forces
  - Temperature distribution
  - Spatial distribution of fibre density and fibre directions
  - Contour accuracy

MICROSCOPIC MODELLING

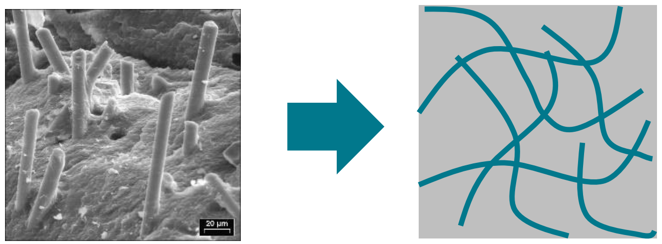
- Description of the microstructure as it is
  - Direct description of fibre-fibre interactions
  - Direct description of fibre-matrix interaction

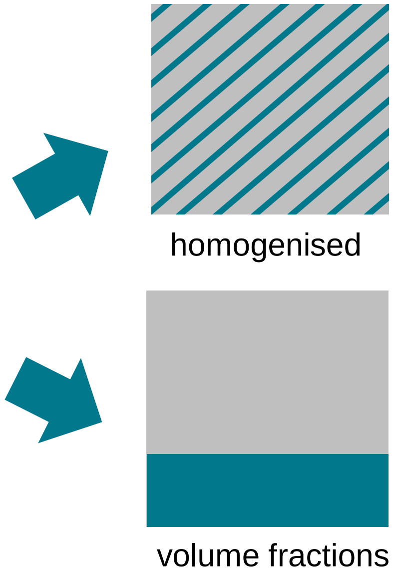


- Knowledge of microstructure needed
- Usually computational expensive

MACROSCOPIC MODELLING

- Homogenised description of microstructure
  - Indirect interactions via homogenised material model

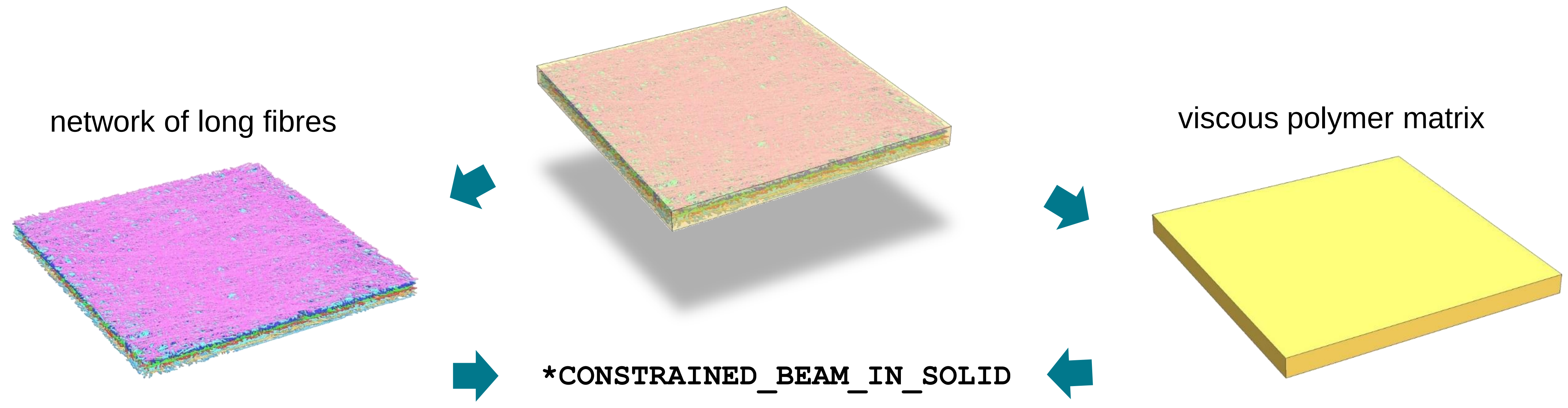




- Computational less expensive
- Homogenised material models

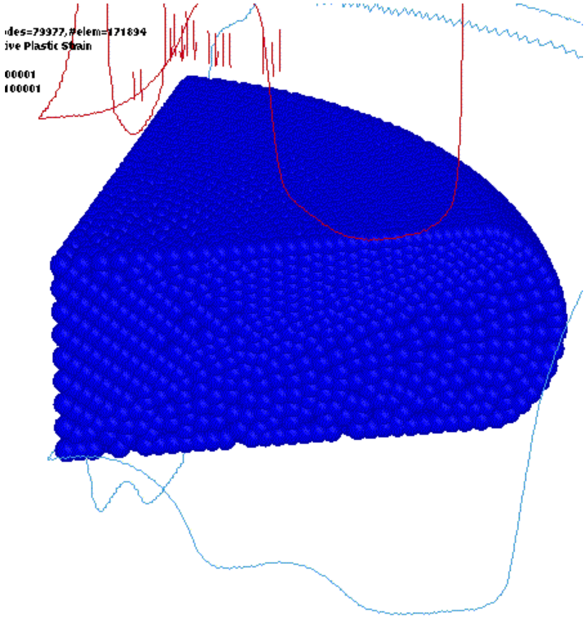
Compression moulding of long-fibre-reinforced plastics

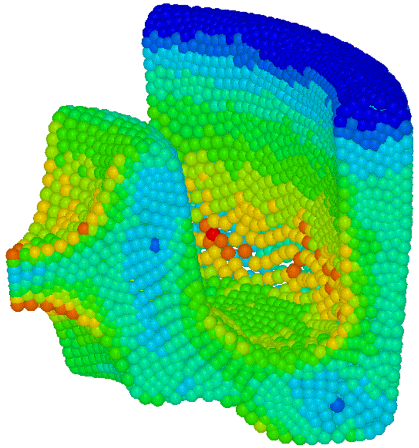
- Microscopic modelling approach in LS-DYNA [*Hayashi, Chen & Hu* 2017] (JSOL & LSTC)
  - Fibre-matrix interaction via **`*CONSTRAINED_BEAM_IN_SOLID`** (CBIS)
  - Fibre-fibre interaction (fibre network) through **`*CONTACT_AUTOMATIC_GENERAL`**
  - Large deformations of the fibre-matrix compound via Element-free Galerkin (EFG)



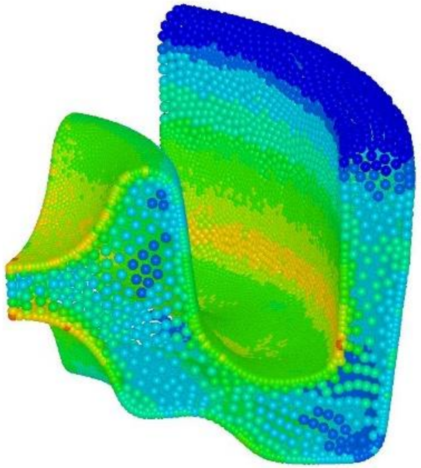
Compression moulding of long-fibre-reinforced plastics

- Microscopic modelling approach in LS-DYNA [*Hayashi, Chen & Hu* 2017]
  - Viscous polymer matrix through viscoelastic material (**`*MAT_ELASTIC_WITH_VISCOSITY)`** and EFG method
    - EFG allows for large deformations including mesh-refinement (global and local)
    - Coupled thermal-structural simulation possible, e. g. heat-triggered curing
    - Macroscopic viscosity (composed of matrix viscocity and fibre sliding within matrix)





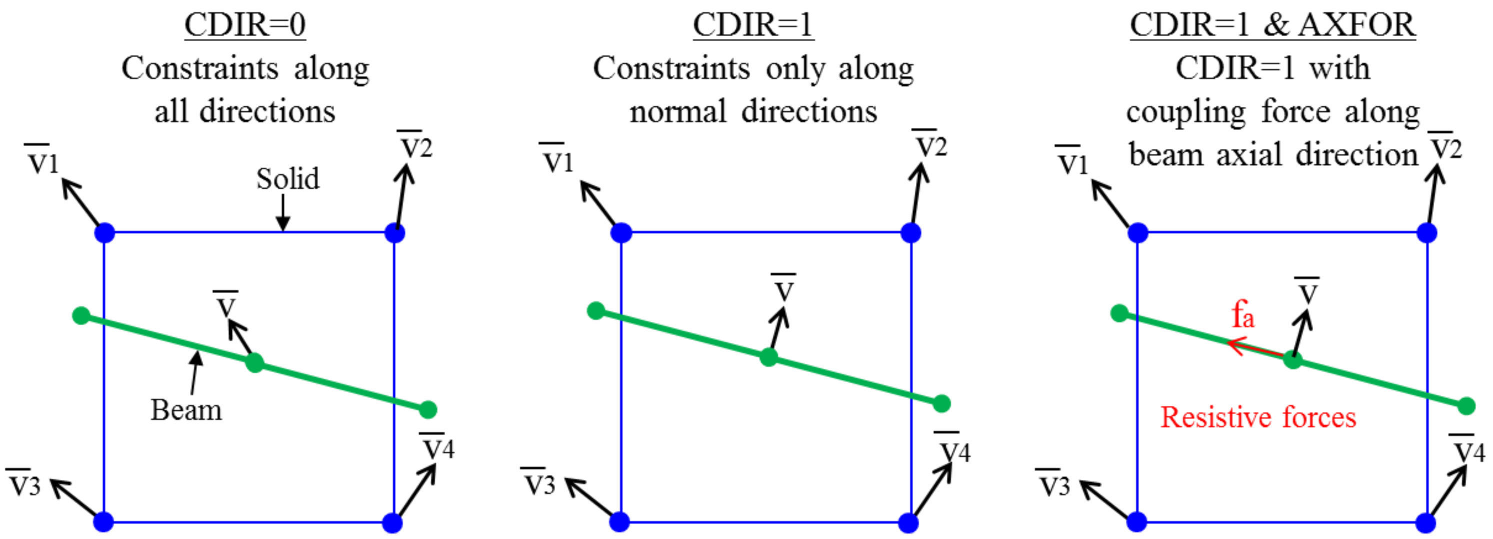
global refinement



local refinement

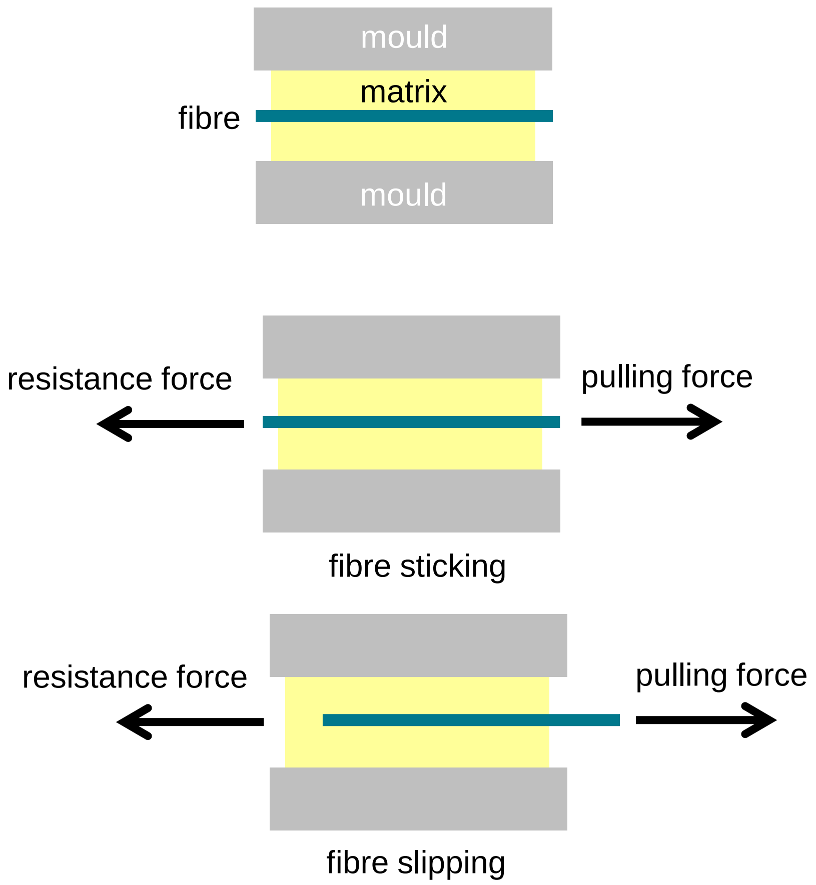
Compression moulding of long-fibre-reinforced plastics

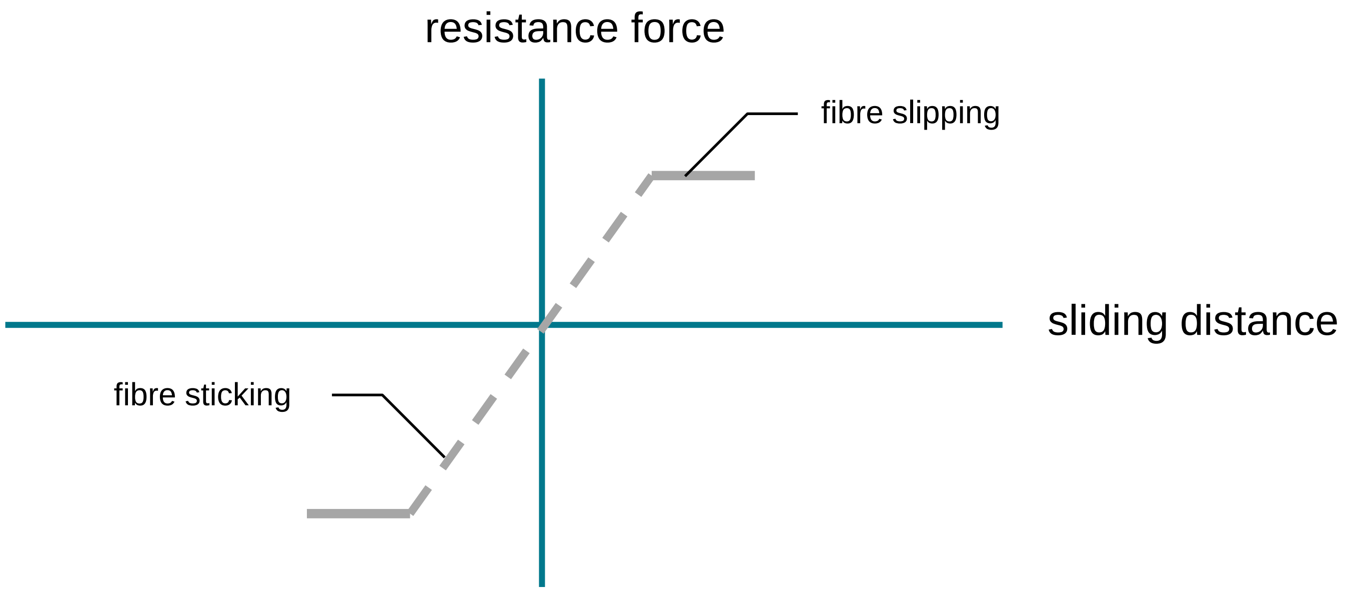
- Microscopic modelling approach in LS-DYNA [*Hayashi, Chen & Hu* 2017]
  - **`*CONSTRAINED_BEAM_IN_SOLID`** (CBIS)
    - Regular beams embedded into solid structure
    - Constraint acceleration and velocity, like **`CTYPE=2`** in **`*CONSTRAINED_LAGRANGE_IN_SOLID`**
    - Several fibre-matrix interaction are possible, e. g. via user-defined function



Compression moulding of long-fibre-reinforced plastics

- Microscopic modelling approach in LS-DYNA [*Hayashi, Chen & Hu* 2017]
  - Fibre-matrix interaction

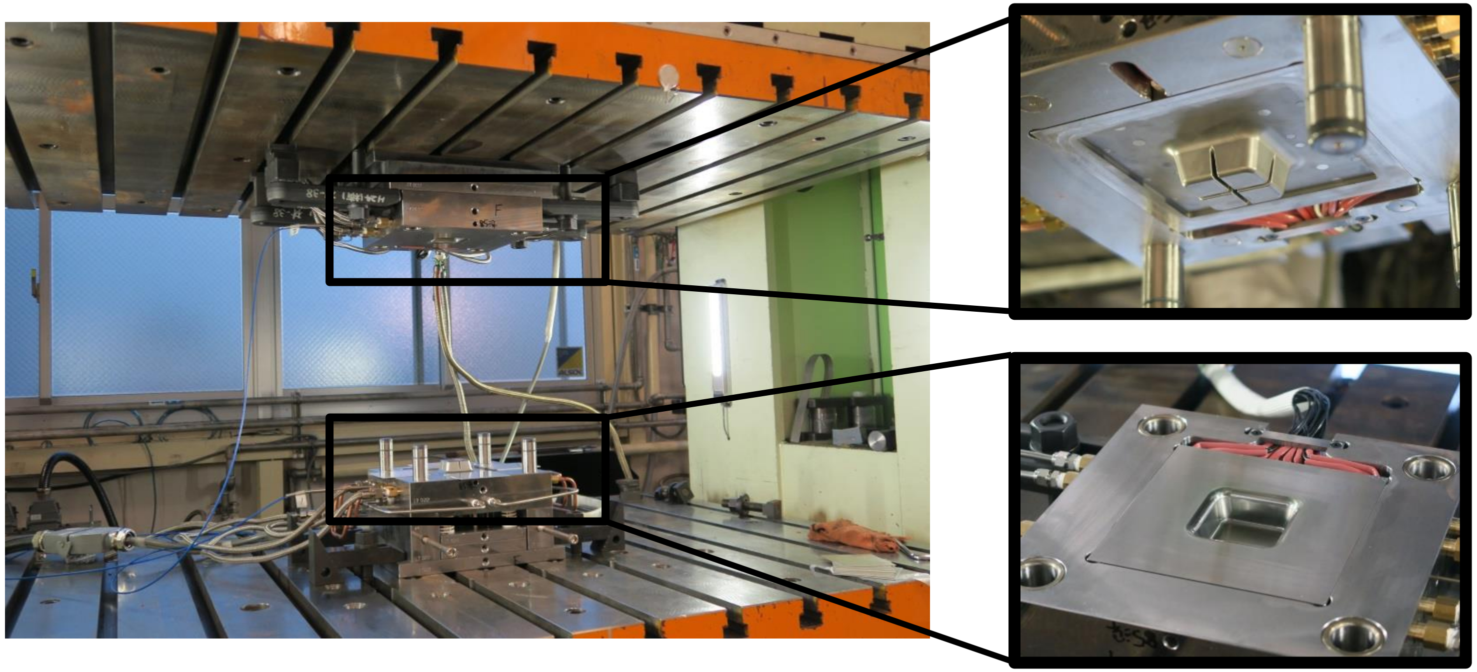


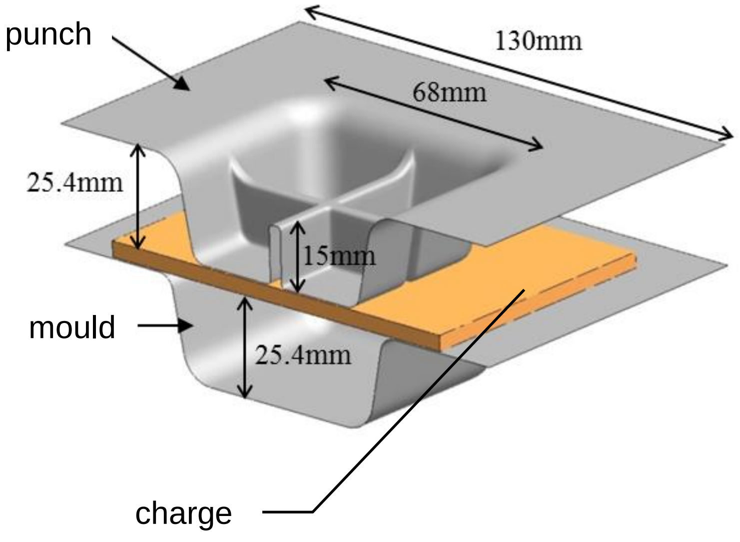


→ elasto-plastic sliding interaction via a user-defined subroutine

Compression moulding of long-fibre-reinforced plastics

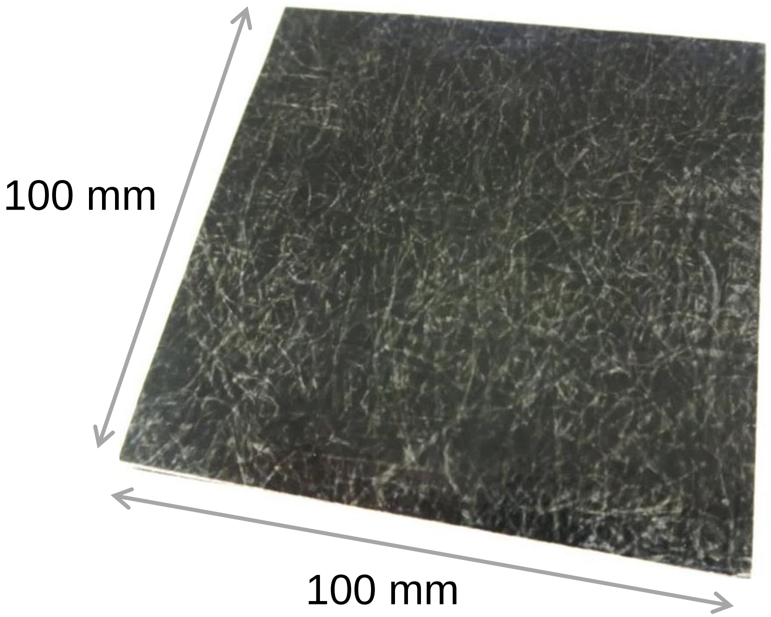
- Example problem (cross-ribbed component)



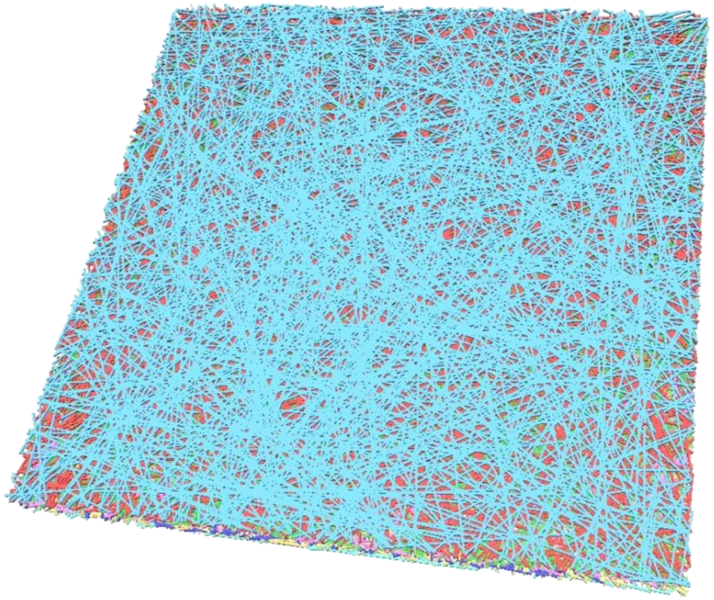


Compression moulding of long-fibre-reinforced plastics

- Example problem (cross-ribbed component)
  - Tepex® flowcore (Bond-Laminates GmbH)
    - Glass fiber length: 30-50mm
    - Fiber orientation: 2D random
    - Volume fraction: 47%
    - Matrix: Polyamide Nylon6 (PA6)



LS-DYNA model



Compression moulding of long-fibre-reinforced plastics

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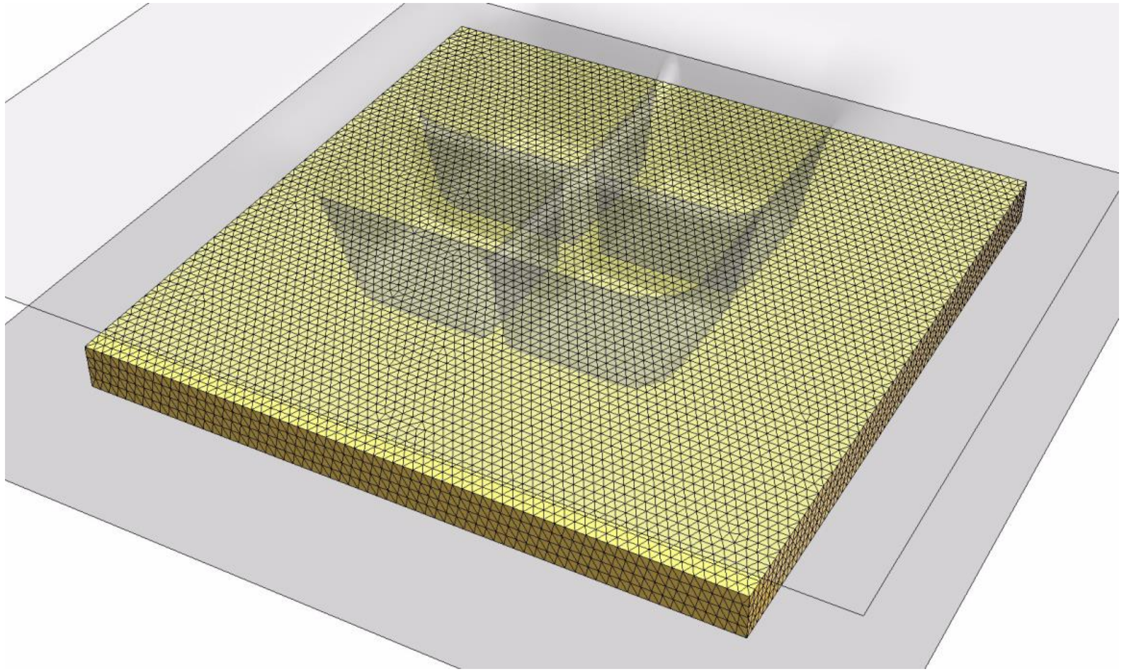

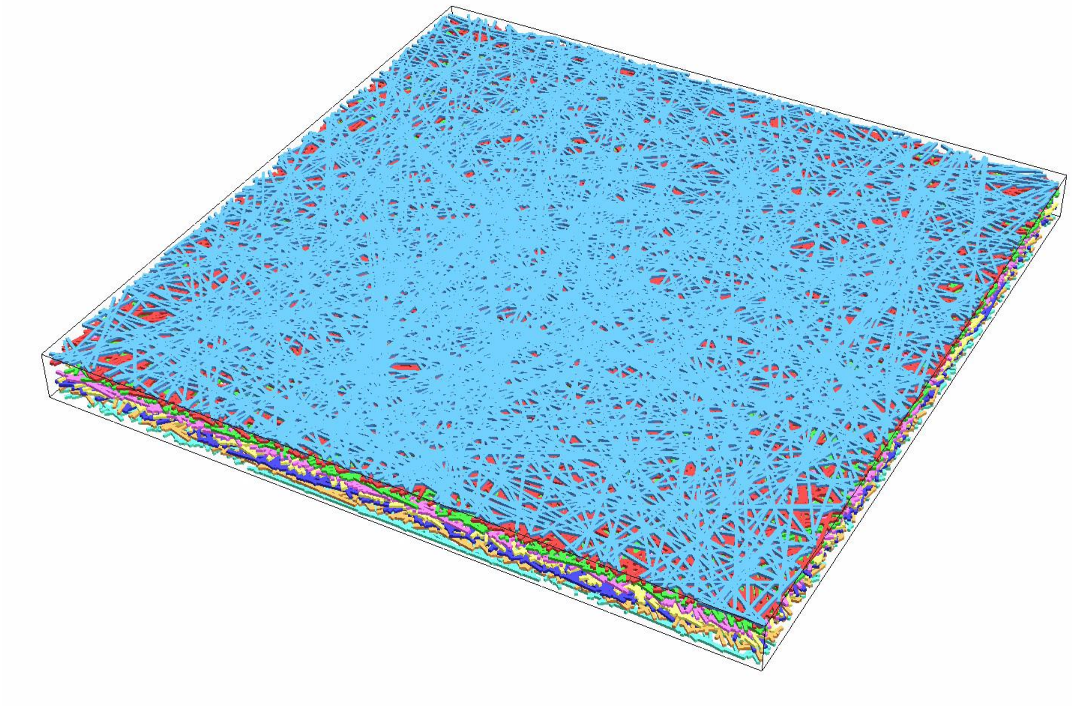

Compression moulding of long-fibre-reinforced plastics

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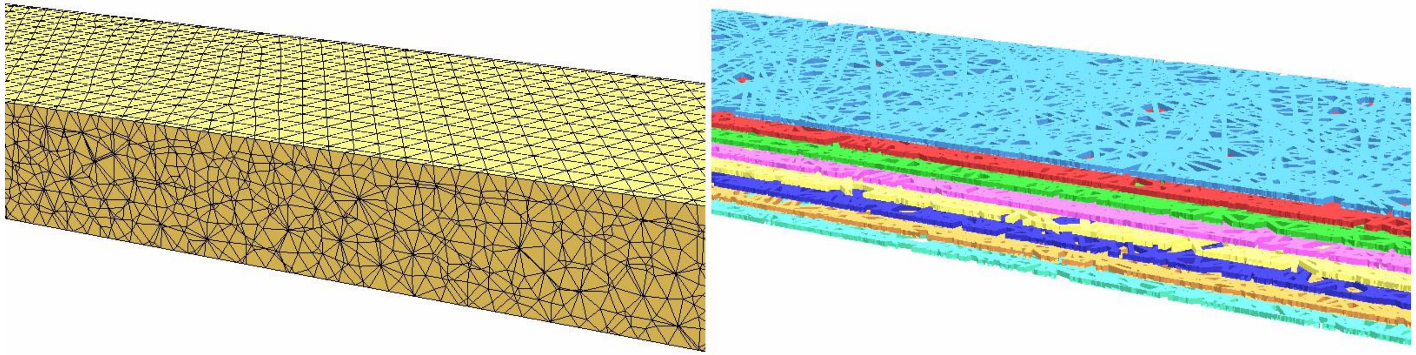

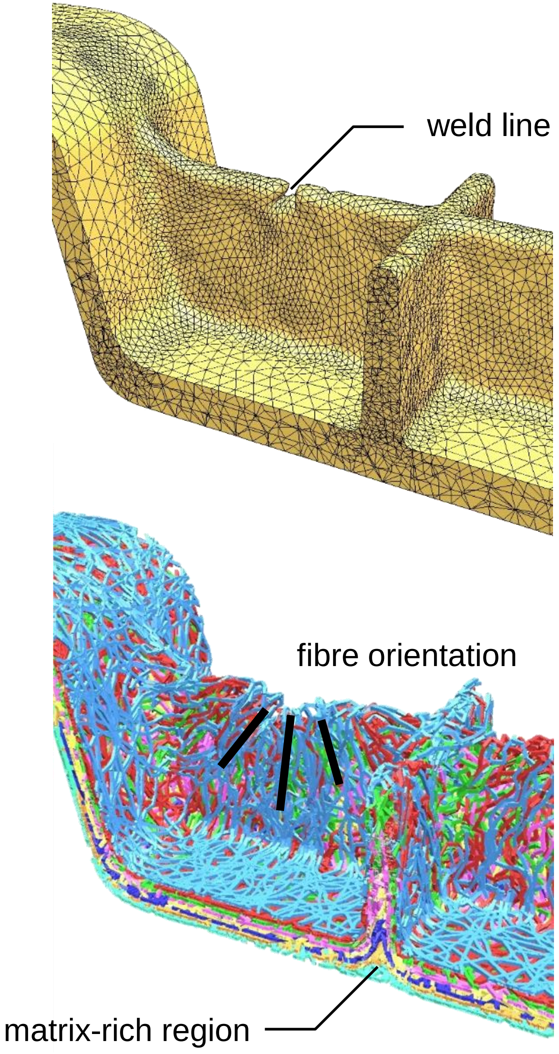

Compression moulding of long-fibre-reinforced plastics

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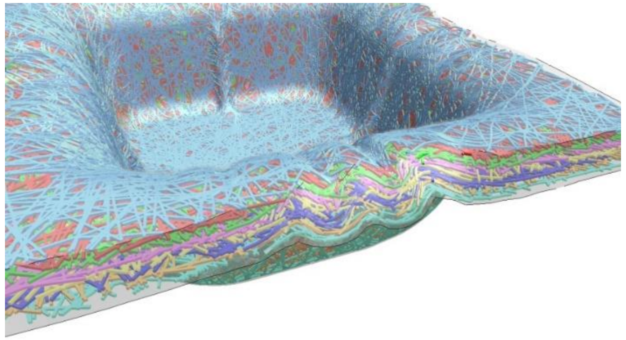

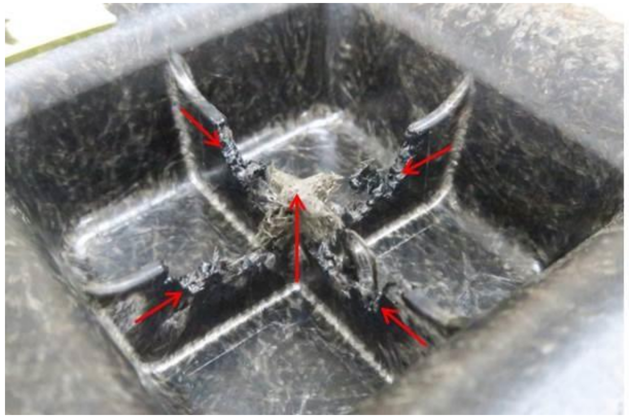

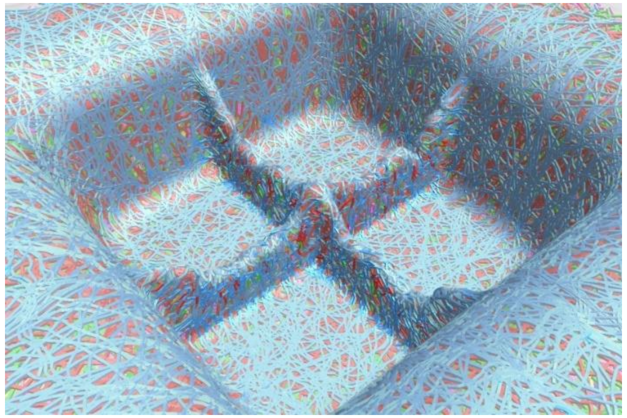

Compression moulding of long-fibre-reinforced plastics

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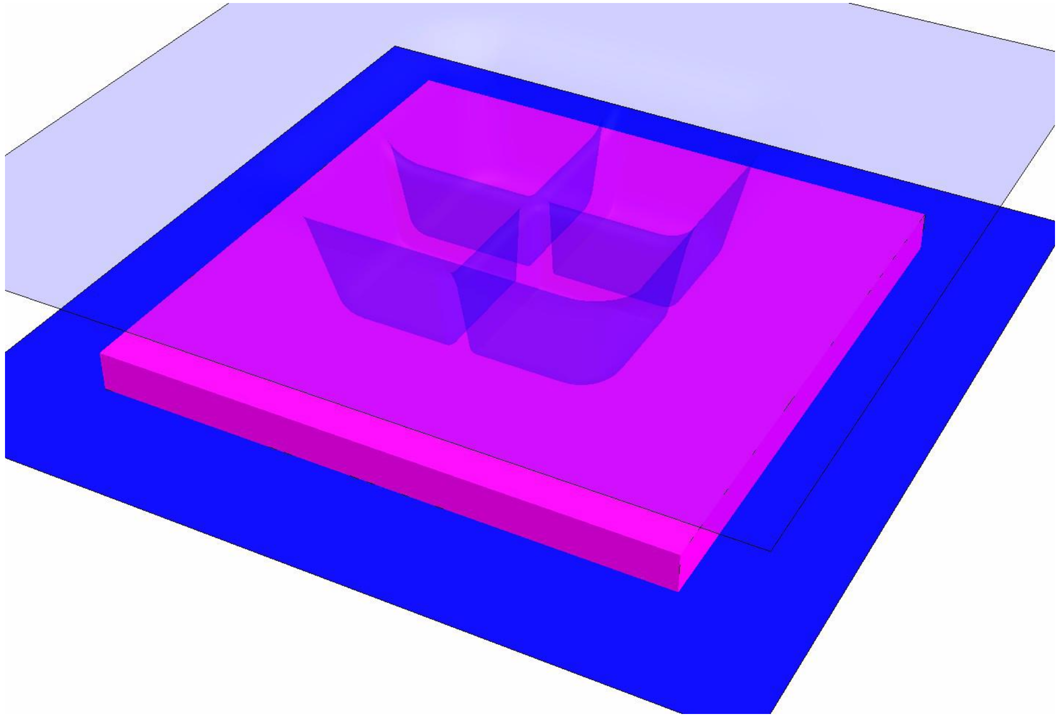
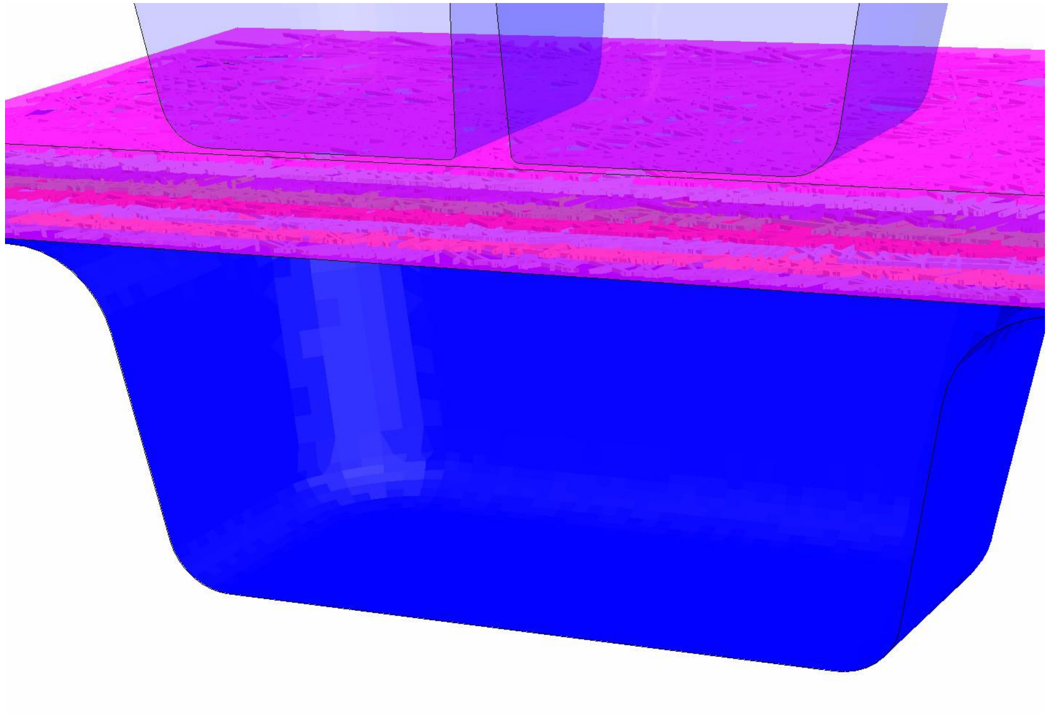
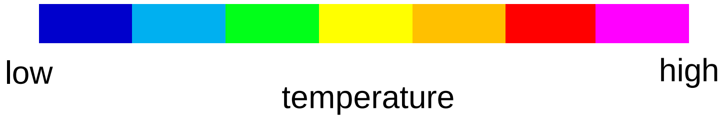






Compression moulding of long-fibre-reinforced plastics

- Simultions to predict
  - Punch reaction force
  - Heat transfer and temperature distribution
  - Filling behaviour and timing
  - Distribution of fiber volume fraction
  - Fiber orientation and deformation
  - Axial force of fibers
  - Stress occurring in matrix
  - Identification of weld line locations and matrix rich region

Additive manufacturing

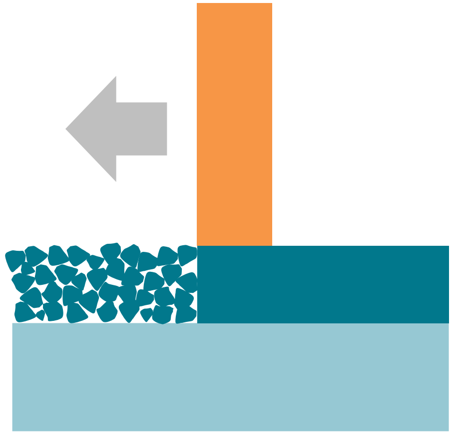
Additive manufacturing (AM)

- Material is added to build structures
  - Manufacturing of complex shapes
  - Rapid prototyping (reduced lead time and costs)
- Different strategies, e. g.
  - Fused-deposition modelling (FDM)
    - Extrusion of small beads or streams of material (filament)
    - Thermoplastic or metal filament is heated within nozzle head
    - Layer-wise build of structure
  - Selective laser sintering (SLS)/Selective laser melting (SLM)
    - Melting of powder granules using high-energy laser
    - Layer-wise build of structure
- Why to simulate?
  - Contour accuracy and mechanical properties of the final work piece
  - Initial stress/strain distribution before mechanical analysis of structure
  - Optimisation of production cycle





FDM

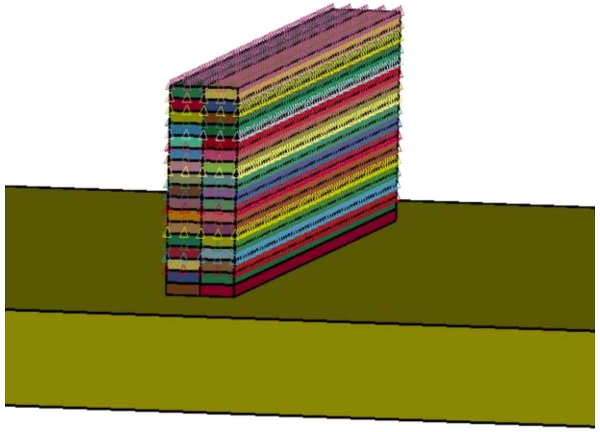

SLS/SLM

Additive manufacturing (AM)

- Modelling approaches in LS-DYNA
  - Simulation needs to account for thermal problem (heat transfer) and material adding
  - Approaches by DYNAmore Nordic AB to tackle material adding and heat transfer problem

FULL MODELL

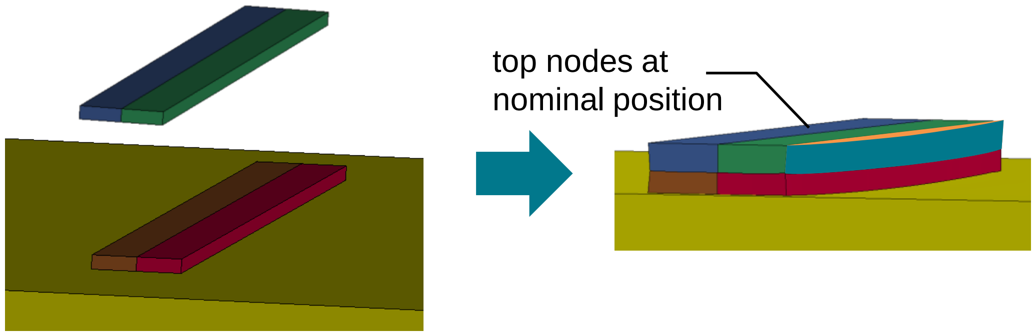
- Whole model available but inactive (ghost model)
- Layers are gradually activated



- Layers follow vertical deformation of active material
- However, high simulation costs due to ghost model

SINGLE LAYER

- Structure is build layer-wise by gradually importing the layers



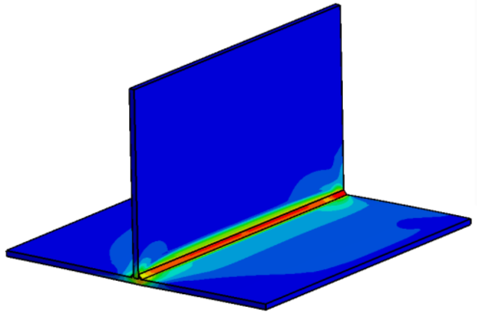
- Only active layers are simulated → numerical efficient
- But, amount of added material is incorrect as only bottom nodes follow deformation → volume consistent approach, which requires pre-processing stage before layer placement

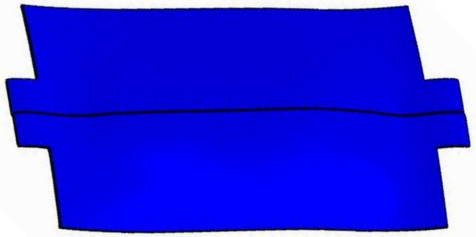
Additive manufacturing (AM)

- Modelling approaches in LS-DYNA
  - Simulation needs to account for thermal problem (heat transfer) and material adding
  - Approaches by DYNAmore Nordic AB to tackle material adding and heat transfer problem

INCREMENTAL HEAT SOURCE

- Inherit from welding simualtion
  → heat source follows a predefined path followed up by a cooling simulation

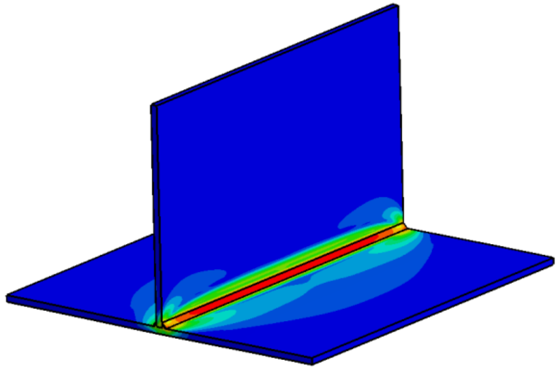




- Time consuming as path can be long

HEAT DUMPING

- Commonly used in welding simulations
- Whole weld is heated up through volumetric heat source followd up by a cooling simulation



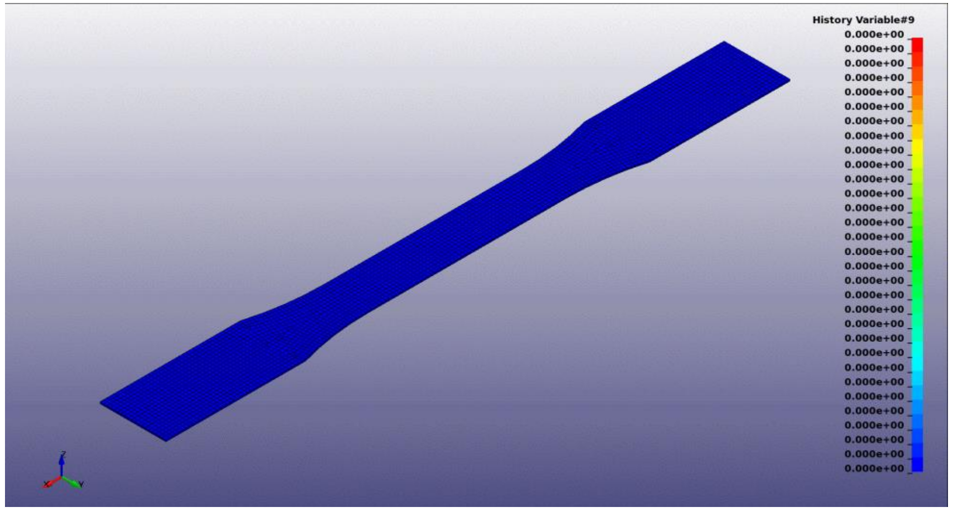
- Thermal loading depends on the volume, speed and length of the weld and a temperature rise time

Additive manufacturing (AM)

- Modelling in LS-DYNA
  - Approach by DYNAmore (C. Liebold & T, Klöppel)

GHOST ELEMENTS

- Elements of strucuture exists from the beginning, but are inactive → ghost elements
- Elements are gradually activated by distant heat source once heat threshold (melting temperature) is exceeded
- Material properties of ghost elements
  - Should have a negletible influence on simulation
  - But provide mesh movement at weld seam



- Welding path controlled by G-Code format

```
G21 ;metric values
G90 ;absolute positioning
M82 ;set extruder to absolute mode
M107 ;start with the fan off
G28 X0 Y0 ;move X/Y to min endstops
G28 Z0 ;move Z to min endstops
G1 Z15.0 F9000 ;move the platform down 15mm
G92 E0 ;zero the extruded length
```

Summary

- Applications in LS-DYNA
  - Compression moulding of fibre-reinforced plastics
  - Additive manufacturing
    - FEM-based layer-wise approach by DYNAmore Nordic AB
    - FEM-based ghost-element approach by DYNAmore → consideration of DEM approach

More Information on the LSTC Product Suite

- **Livermore Software Technology Corp. (LSTC)**
  www.lstc.com
- **LS-DYNA**
  - Support / Tutorials / Examples / FAQ
    www.dynasupport.com
  - More Examples
    www.dynaexamples.com
  - Conference Papers
    www.dynalook.com
  - European Master Distributor
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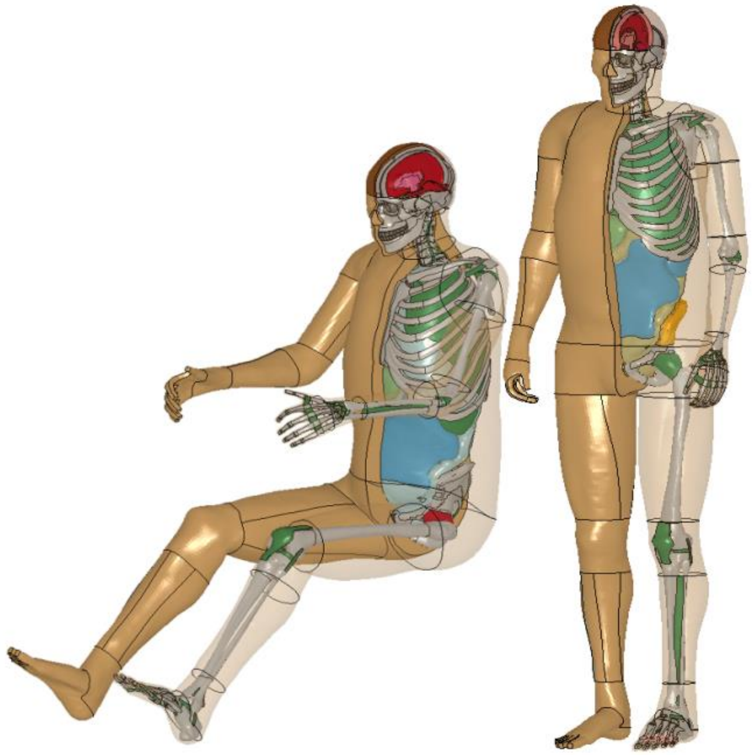

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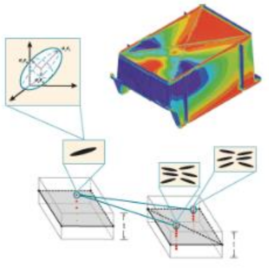
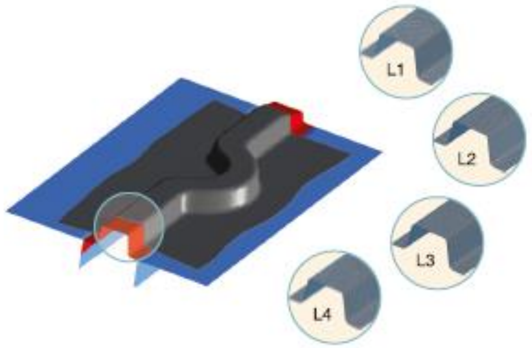
Meet DYNAmore

- ENVYO and Composite Analysis:
  12 March 2018, Stuttgart
  - Presentations from BMW, DLR, EDAG, JSOL,
    Opel Automobile,
    Politecnico di Torino and DYNAmore.
  - Agenda and Registration:
    www.dynamore.de/info-envyo





- 15th International LS-DYNA Users Conference 2018:
  10-12 June Dearborn, Michigan
  - http://www.ls-dynaconferences.com
    - 600 attendees expected
- 15. Deutsches LS-DYNA Forum
  15-17 October 2018, Bamberg
  - www.dynamore.de/forum201
    - 350 attendees expected
    - Workshops on specific topics

Your questions, please!