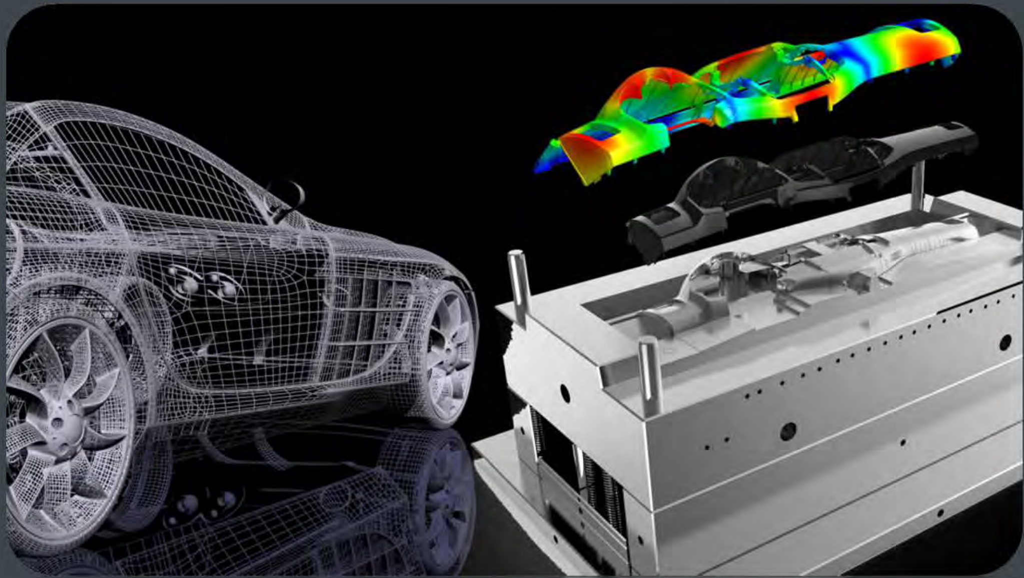

Influences of LS-DYNA-results by coupling with injection molding simulation

Tobias Schäfer

SimpaTec

SIMPATEC

Milestones

- Founded 2004 in Aachen
- Partner of Moldex3D
  - in Germany, Switzerland, Austria, BeNeLux, France, GB, Iran, Romania, Tunisia, Algeria, Marocco and Canada
- SimpaTec GmbH in Aachen, Offices in Reutlingen and Weimar
- SimpaTec SARL France, office in Guebwiller
- SimpaTec Asia, office in Bangkok, Thailand
- Since 2007 Reseller of Beaumont Technologies Inc.
- Since 2011 – Reseller of accuform, CZ
- Since 2017 SimpaTec GmbH Austria office in Linz
- Since 2017 Partnership with CT CoreTechnologie GmbH, Germany
- Since 2017 Partnership with MSC Software Corporation / e-Xstream engineering SA
- Planned in 2018 SimpaTec US, office in Greenville (SC)

Scope of work

- Service according to the requirements of the customer
  - Enginneering services (Injection moulding and FEM)
  - Professional partner for the plastic industry
  - Long time experience in simulation as well as in plastic processing
  - Product and process optimization
  - Costumer related training options (software and/or technology)
  - Support and consulting on site
  - RD (Software development)

- Commitment
  - Activities in public funded RD projects (e.g. lightweight)
  - Close relationship with universities
  - Seminars, conferences, workshops
  - Creation of networks

SIMPATEC

Software

Moldex3D – The software solution for the design and optimization of the plastic injection molding process

T-SIM – T-SIM simulates the complex manufacturing process of thermoforming.

B-SIM – B-SIM is a software package to simulate blow molding.

MeltFlipper® – Optimization of the component behavior using runner modification

3D Evolution – The software solution for fast, automatic data conversion and processing for CAD systems

Digimat – Multi-scale material modeling technology for plastic & composite materials and structures.

MSC Software – Simulating Reality, interbranch CAE Solutions

Outline

- Introduction
  - Overview of manufacturing processes
- Influences of manufacturing process
  - Short/long fibers
  - Fiber concentration and fiber length
  - Residual stresses
  - Weld lines
  - Fiber orientation tensor about thickness
- Challenges of coupling manufacturing data with FEA
  - Material modeling
  - Material models
  - Indicators
  - Reverse Engineering
  - Mapping of data
- Coupling of manufacturing processes, material modeling and structural analysis
- Conclusion: Case study

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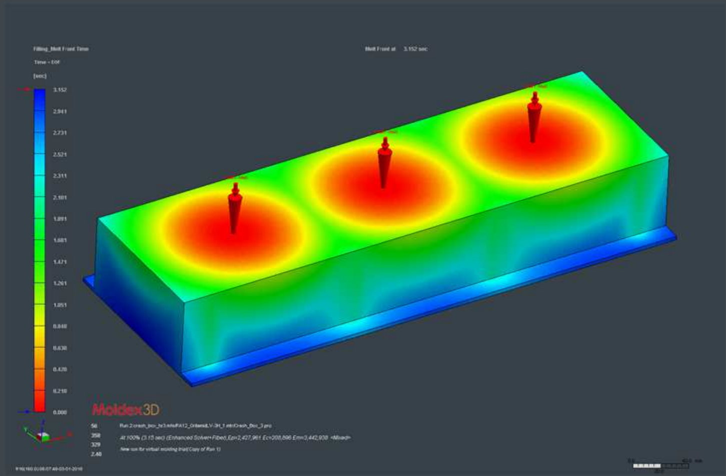
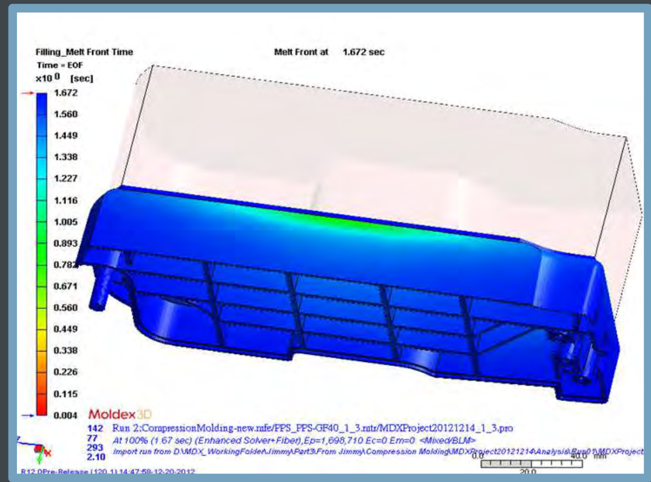
Overview of manufacturing processes

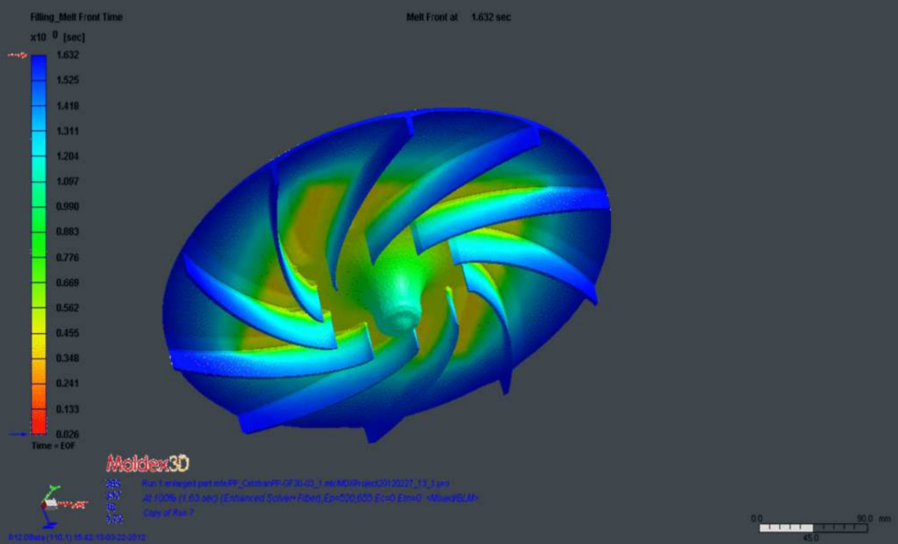
- Injection molding



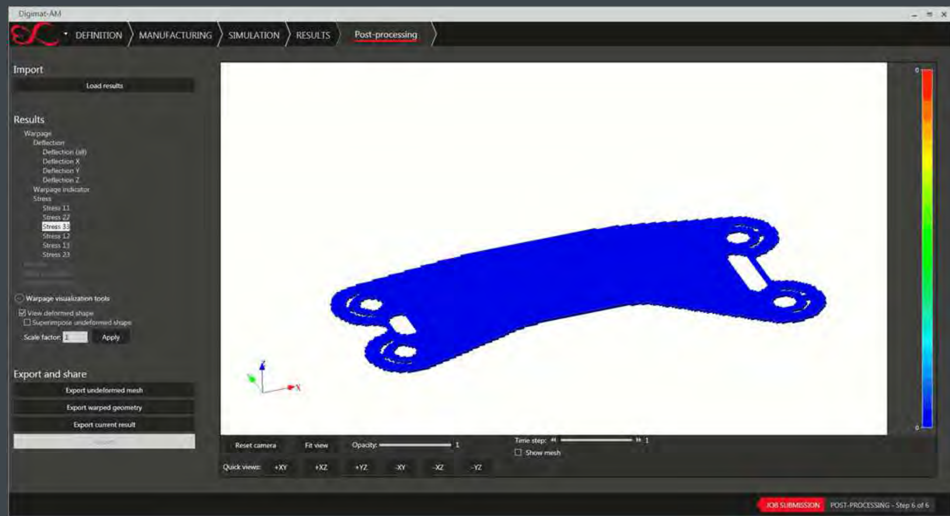
- Draping process



- Injection compression molding



- Additive manufacturing



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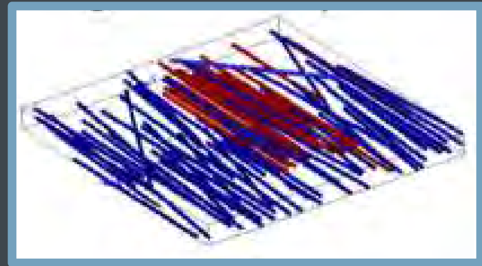
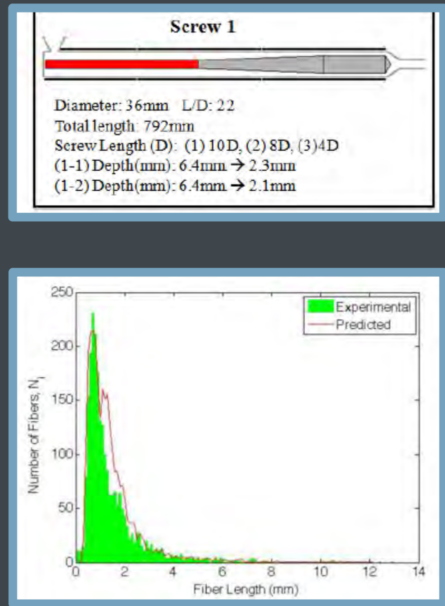
Influences of manufacturing process

- Short or long fiber reinforced plastics:
  - Carbon
  - Glass
  - Nature
- Fiber concentration / fiber breakage
- Residual stresses
- Fiber orientation tensor about thickness


Short fiber [1]


Long fiber [1]

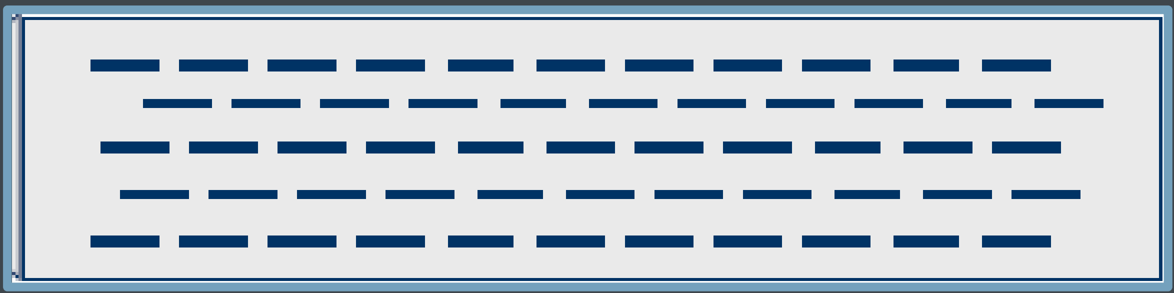

Fiber breakage [2]



Fiber breakage in screw [2]

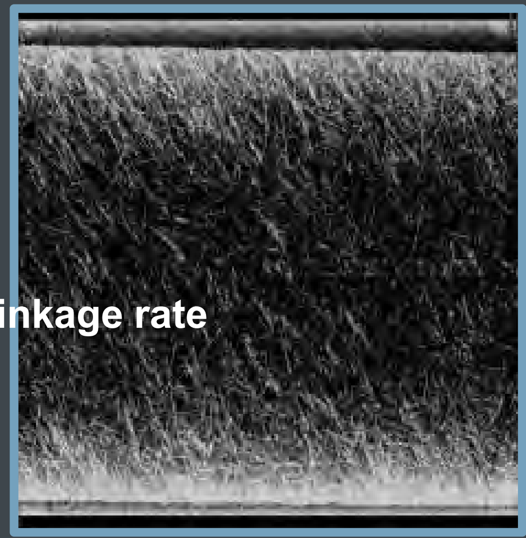
Influences of manufacturing process

- Short fiber
  - High orientation intensity



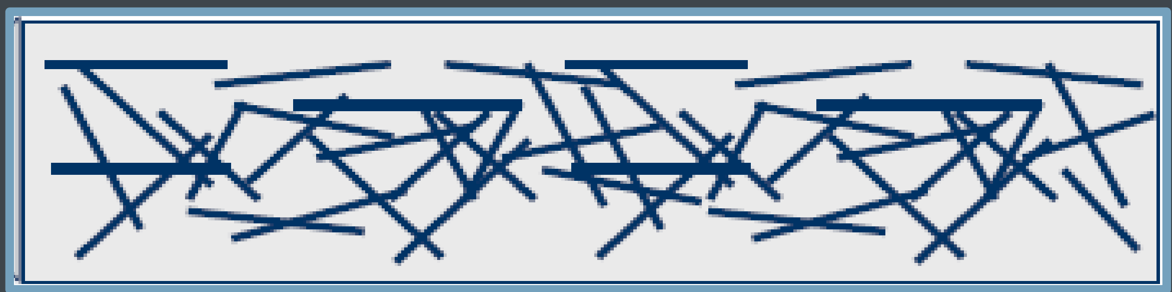
Orientation intensity SF [2]

High shrinkage rate



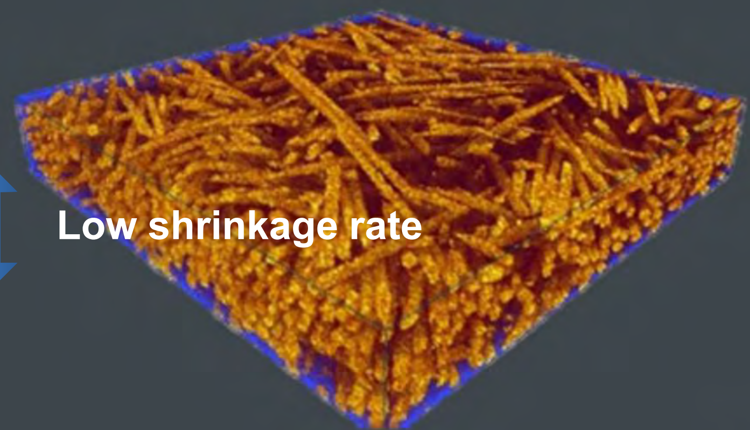
Fiber reinforced plastics [2]

- Long fiber
  - Low orientation intensity, low anisotropic



Orientation intensity LF [2]

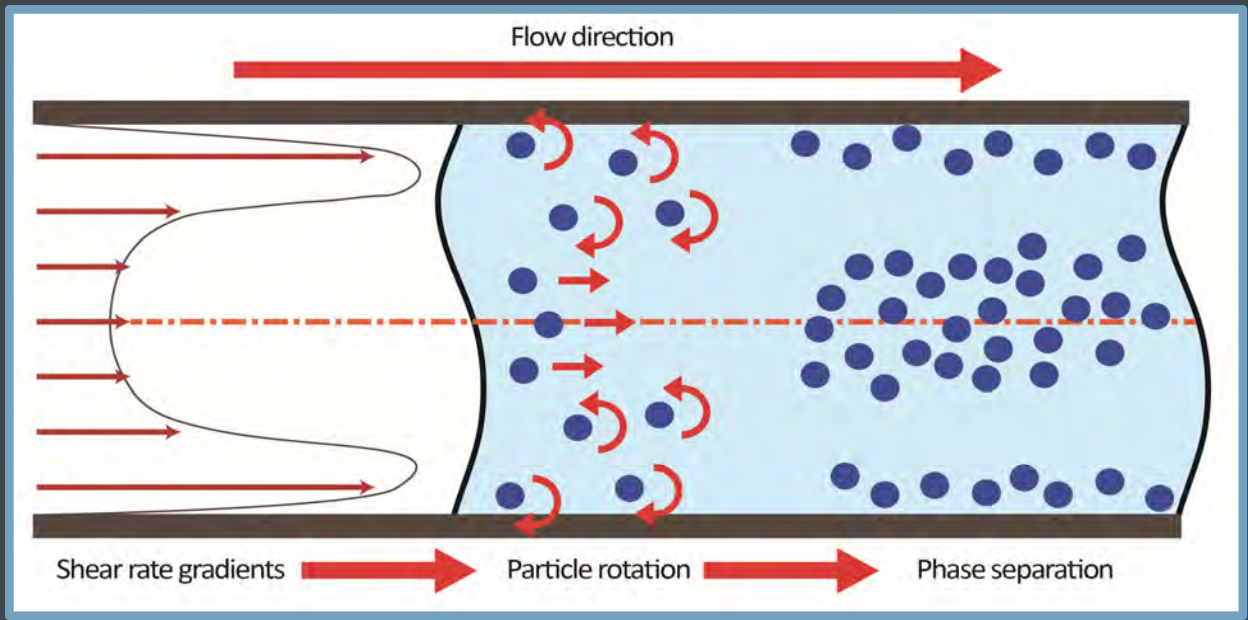
Low shrinkage rate



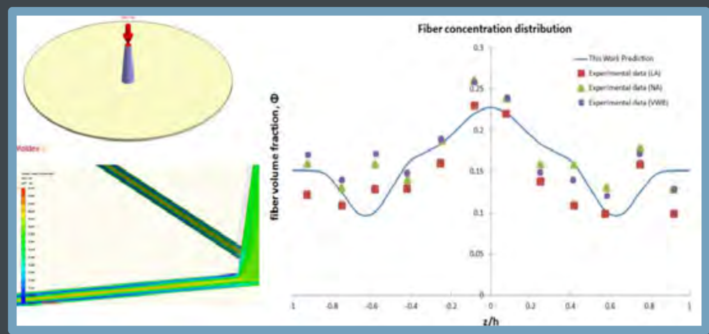
Microstructure of reinforced plastics [1]

Influences of manufacturing process

- Fiber concentration
  - Concentration corresponds to the fiber orientation and melt viscosity



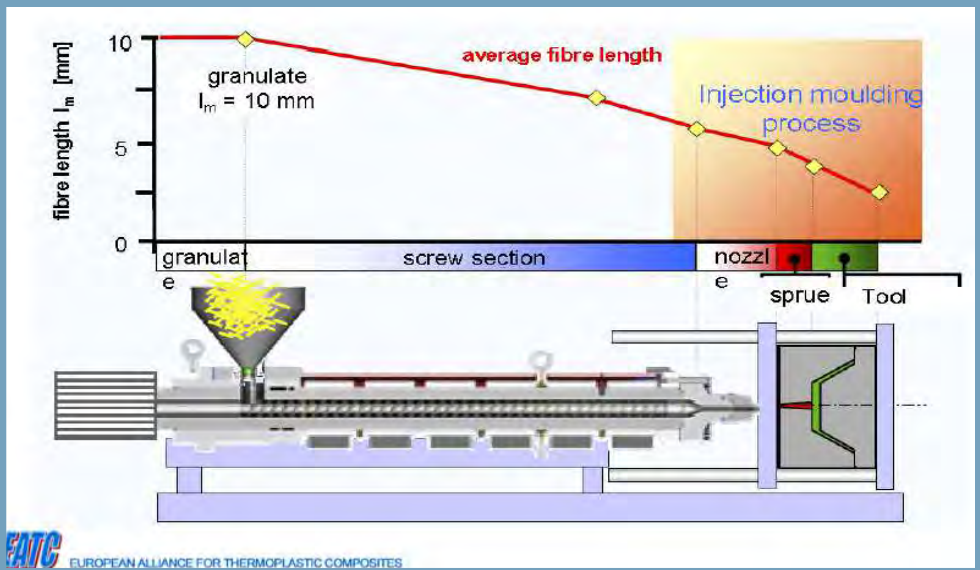
Fiber concentration [2]



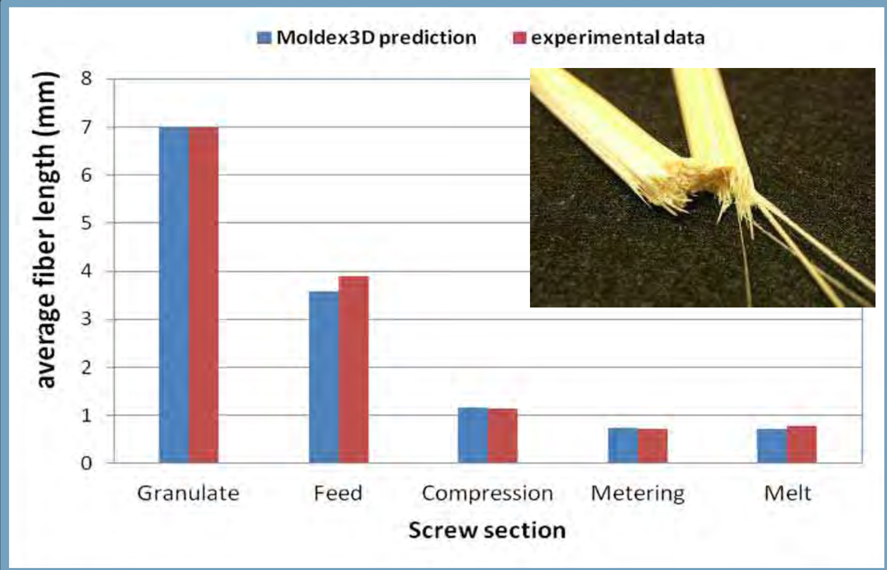
Fiber orientation tensor [2]

Influences of manufacturing process

- Fiber length – breakage prediction during screw-processing
  - The melt went through the screw melting and injecting process, high shear forces can easily snap the fibers
  - Apparent fiber length degradation, less than 1/5 the original length can be easily found in the finished part



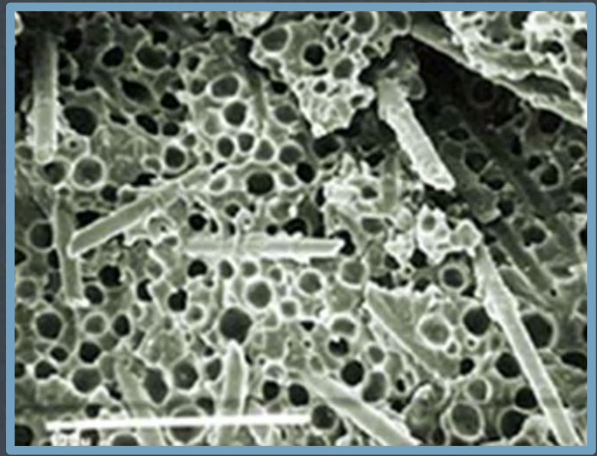
Fiber breakage in screw [2]



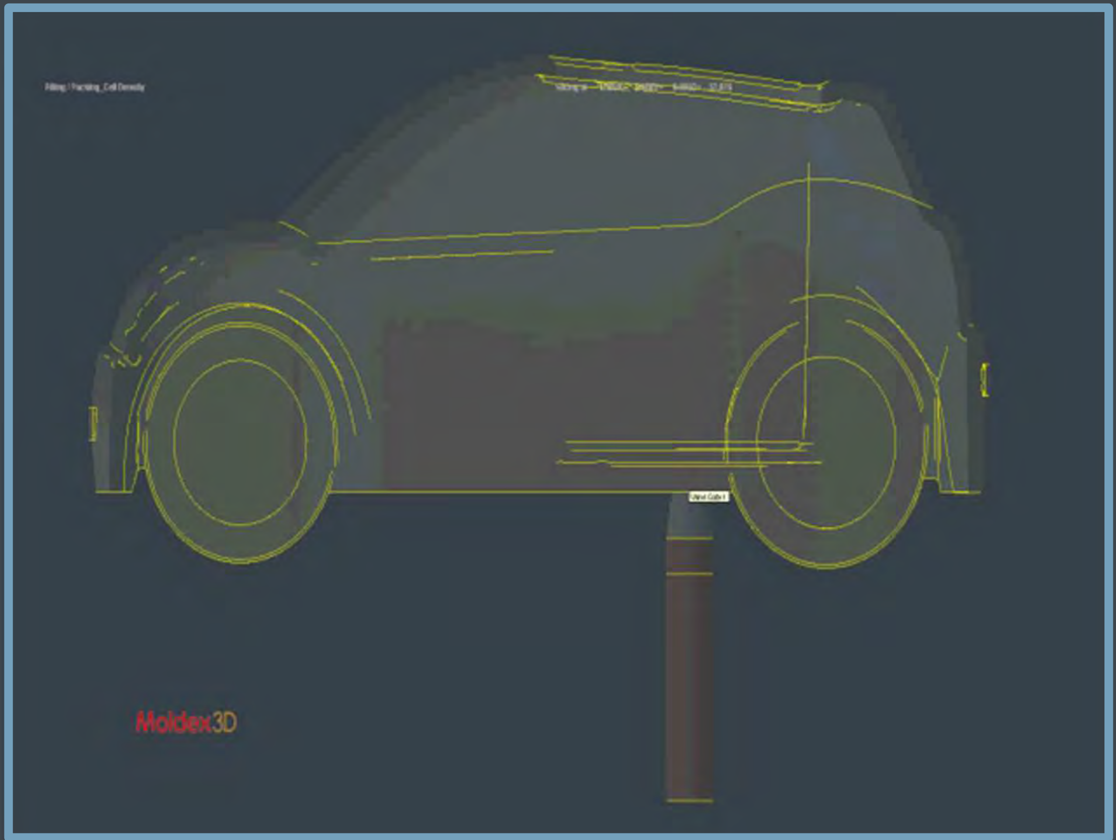
Average fiber length [2]

Influences of manufacturing process

- Porosity of foams
  - Cell density
  - Cell concentration



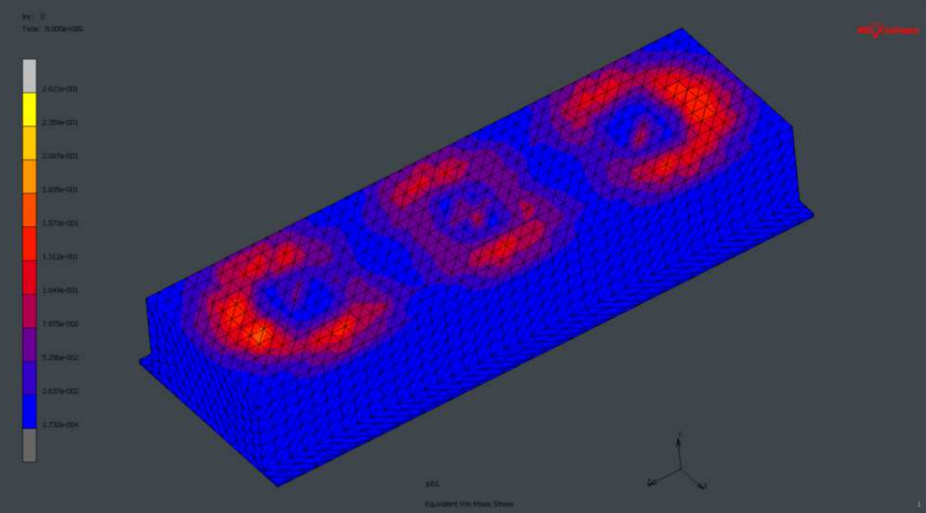
Porosity and fiber Source: [5]



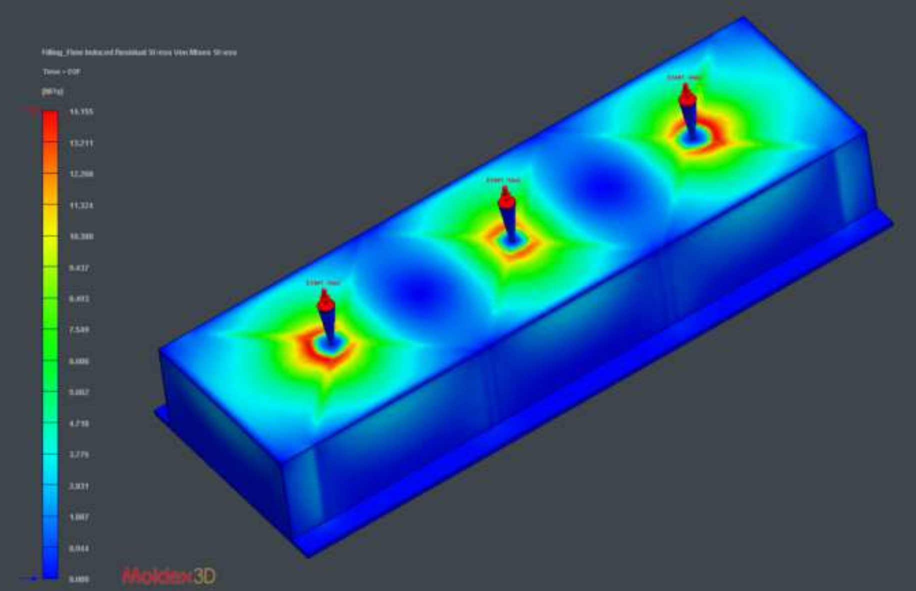
Cell density

Influences of manufacturing process

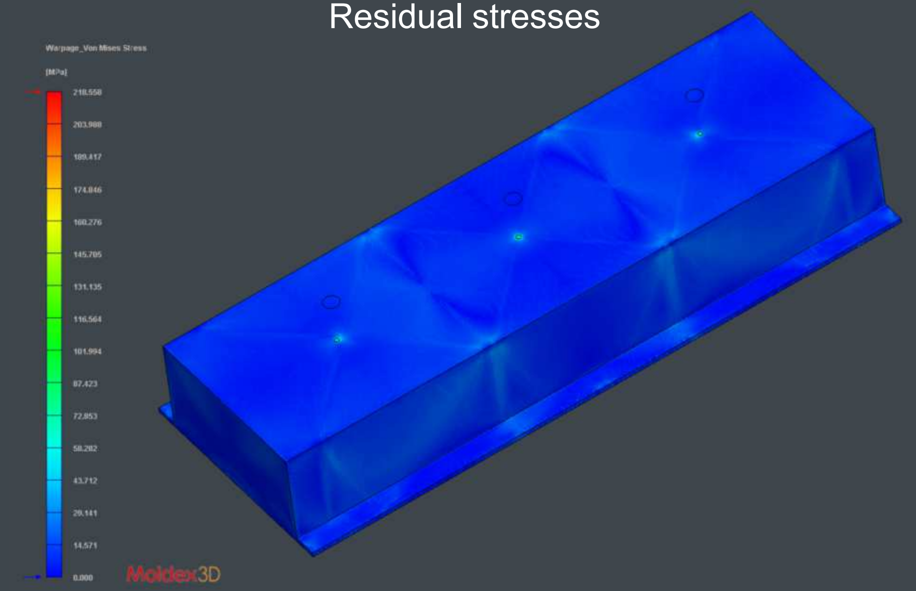
- Residual stresses
- Flow induced residual stress
- Thermal induced residual stress



Residual stresses



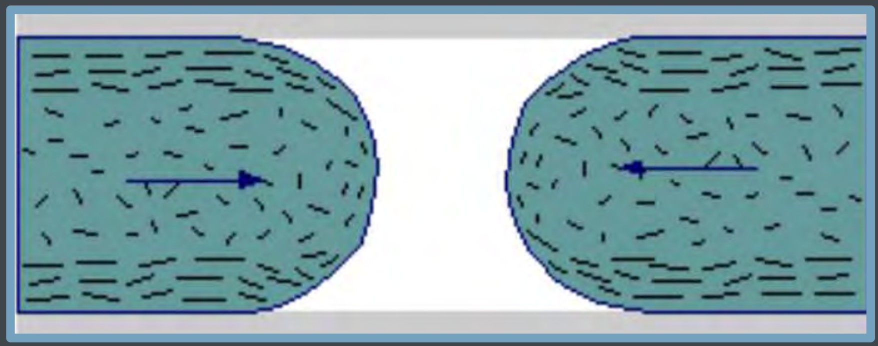
Flow induced residual stress



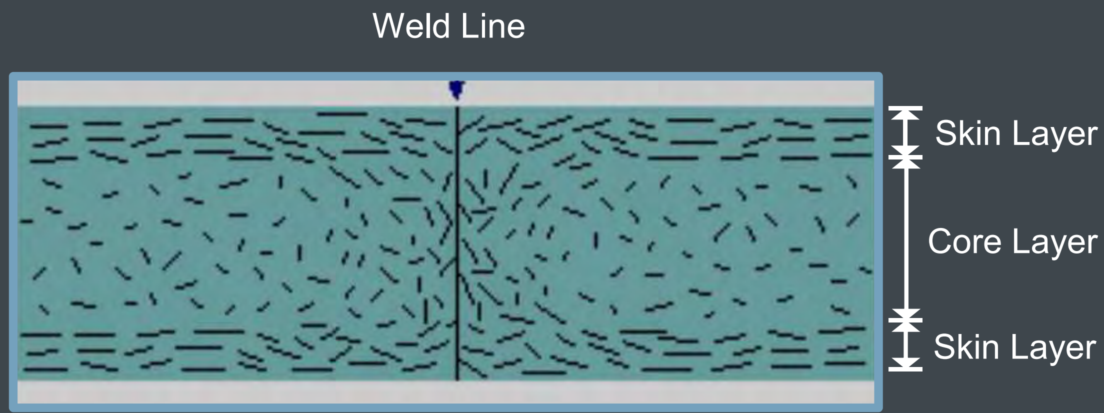
Thermal induced residual stress

Influences of manufacturing process

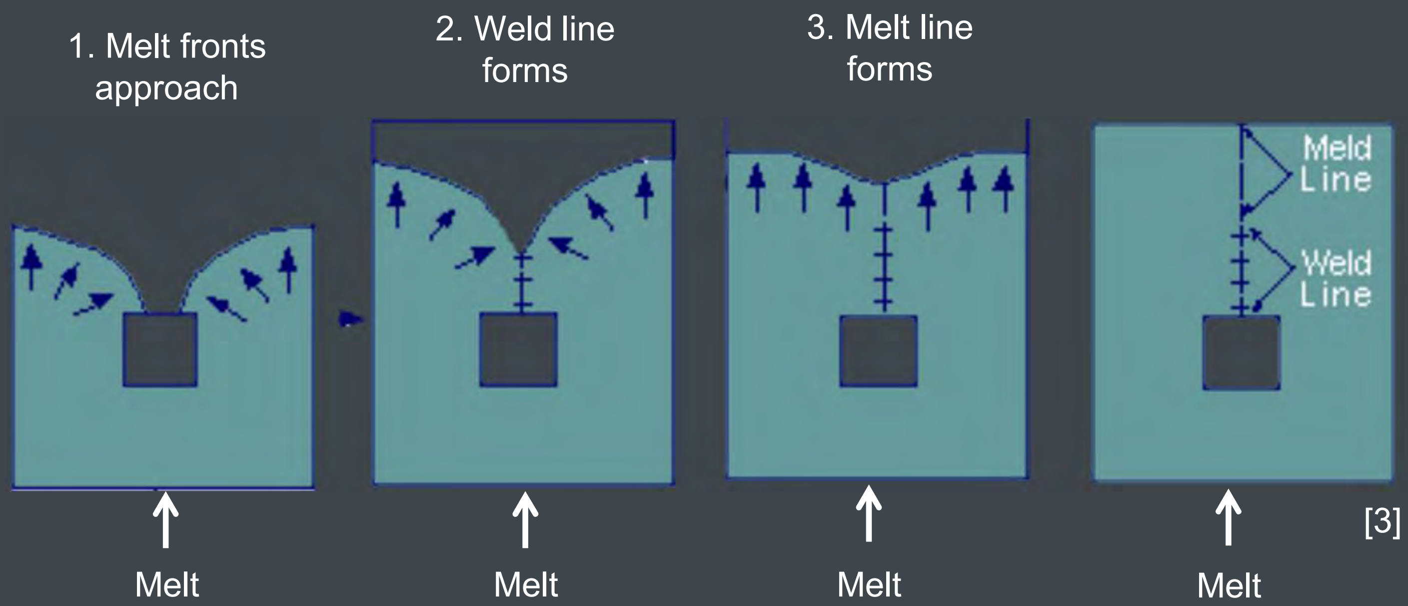
- Weld lines



Fiber reinforced material; melt fronts approach [3]

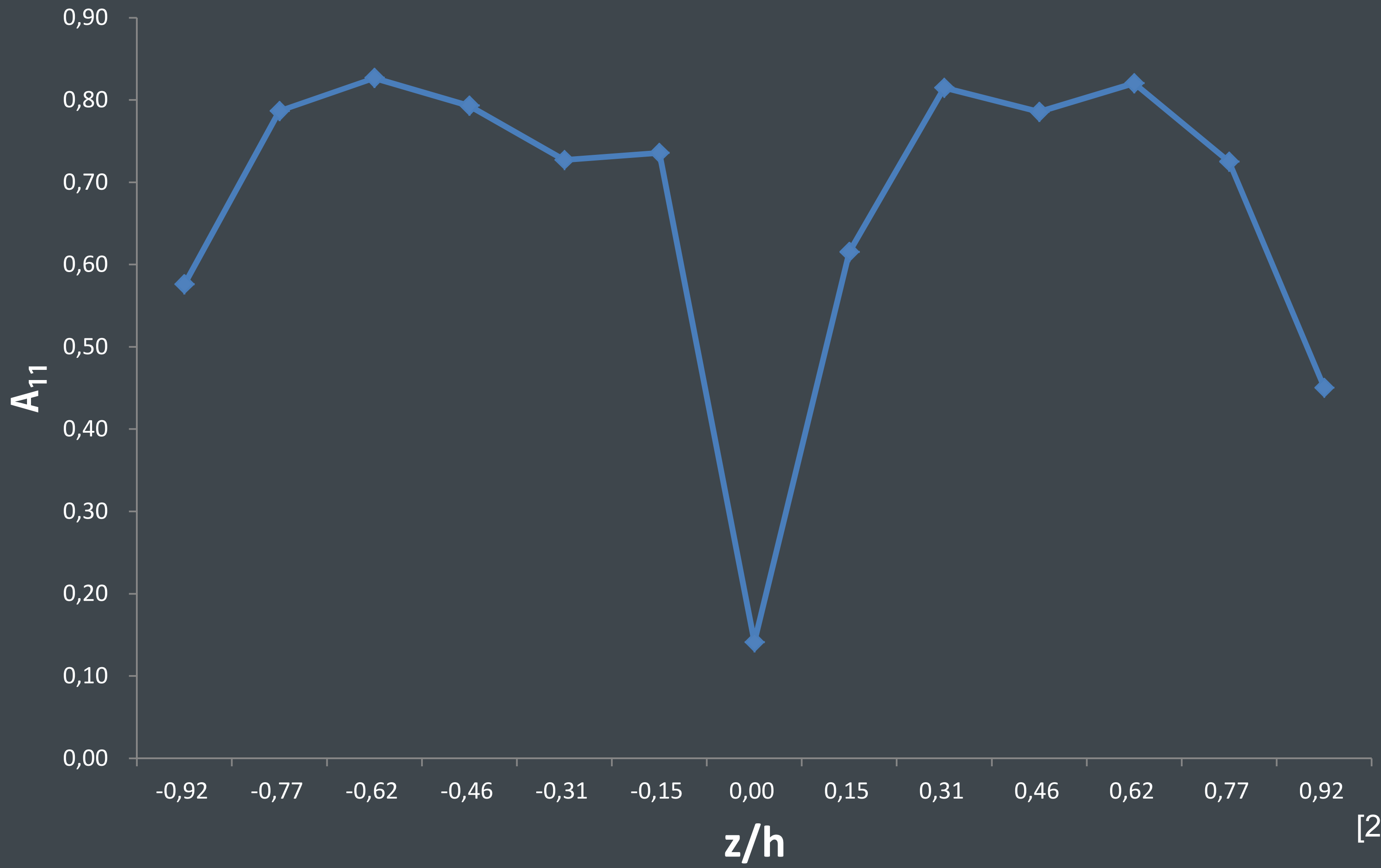


Weld line formation in fiber-reinforced material [3]

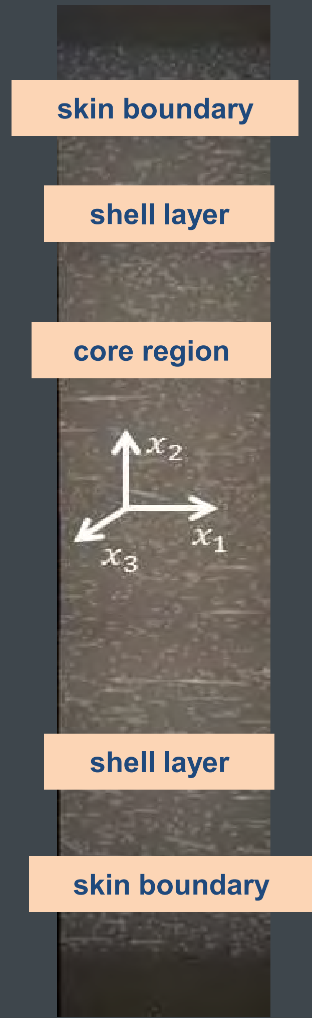


Influences of manufacturing process

- Fiber orientation tensor through thickness



[2]

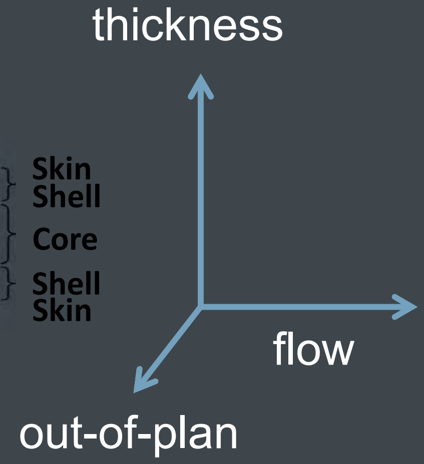


[2]

Influences of manufacturing process

- Fiber orientation through thickness
  - Flow directional orientation, a11
  - Cross-flow directional orientation, a22
  - Out-of-plan directional orientation, a33

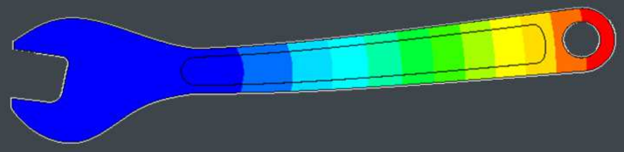
[2]



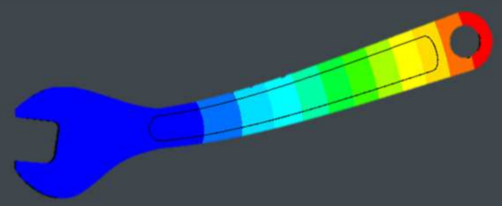
$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

a11+a22+a33 = 1

- Structure analysis: Deformation
  - Orientation determines the fiber induces anisotropic mechanical properties



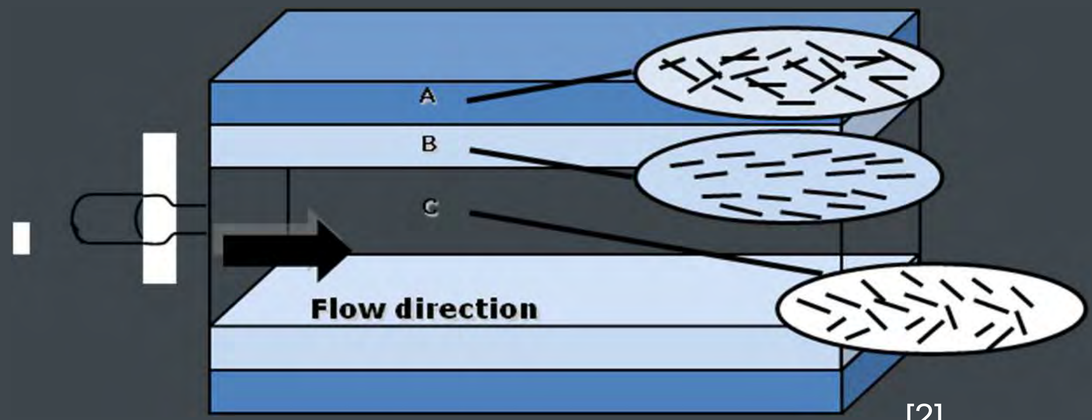
Anisotropic (With Fiber Orientation) [2]



Isotropic (Without Fiber Orientation) [2]

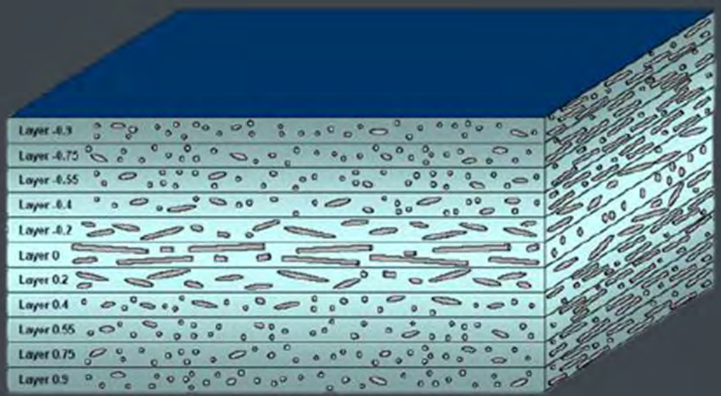
Influences of manufacturing process

- Structure of thickness
  - Consist different layer
    - Skin
    - Core



[2]

- Core / skin effect depends on shear rates, temperatures, flow behavior



Different Layers through thickness [1]

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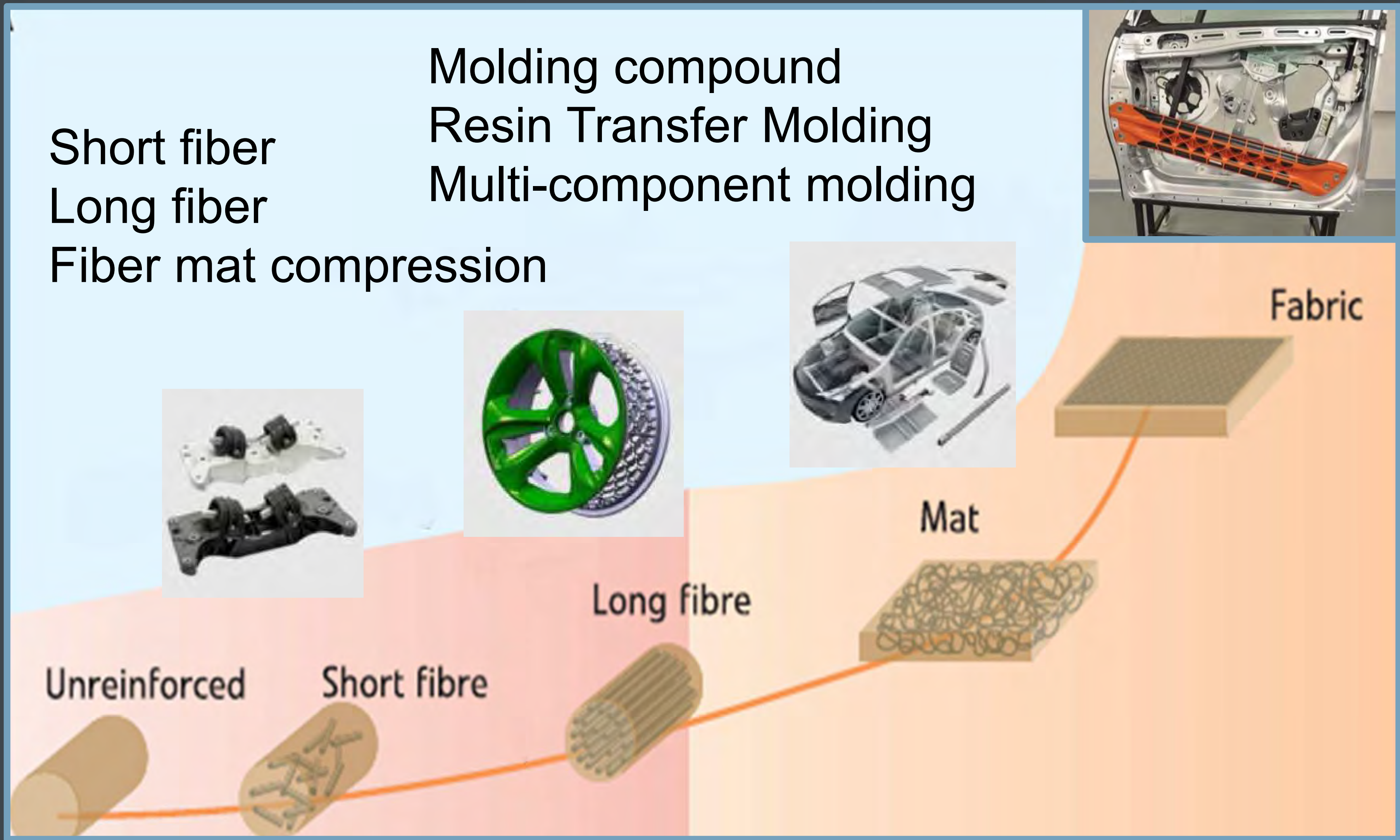
Challenge of coupling manufacturing data with FEA

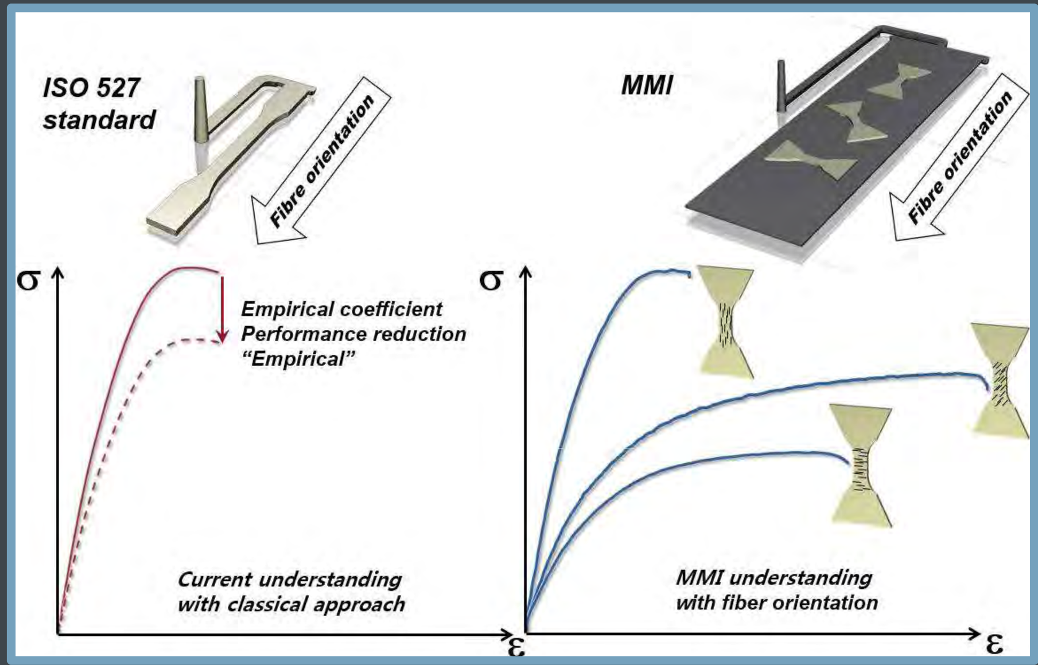
Hybrid

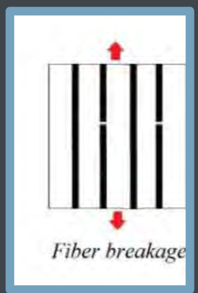


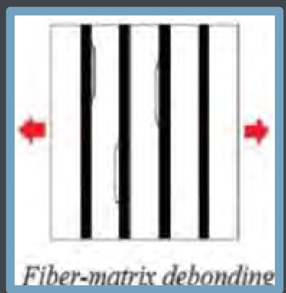
Challenges of materials [2]

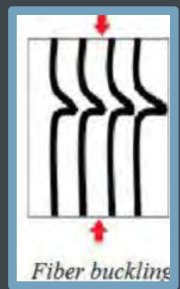
Challenge of coupling manufacturing data with FEA

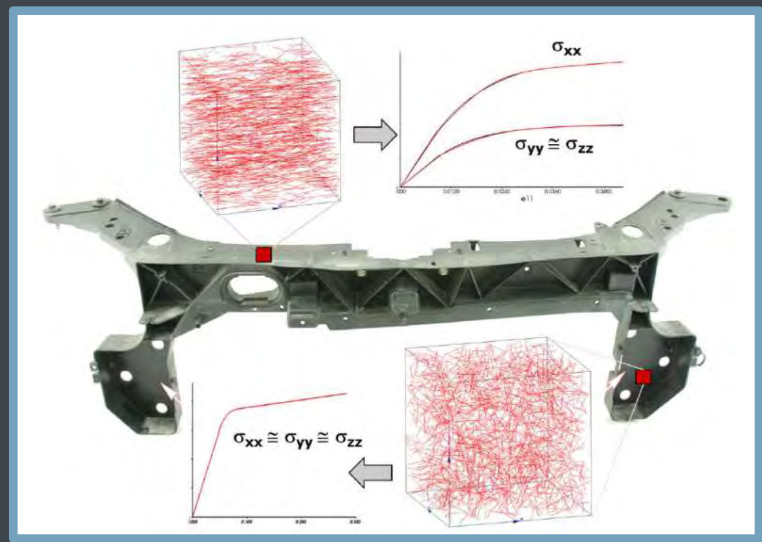
- Anisotropy / Orthotropy
- Non-linearity
- Rate dependency
- Temperature dependency
- Complex failure mechanismus
  - Fiber breakage
  - Fiber-matrix debonding
  - Fiber-buckling







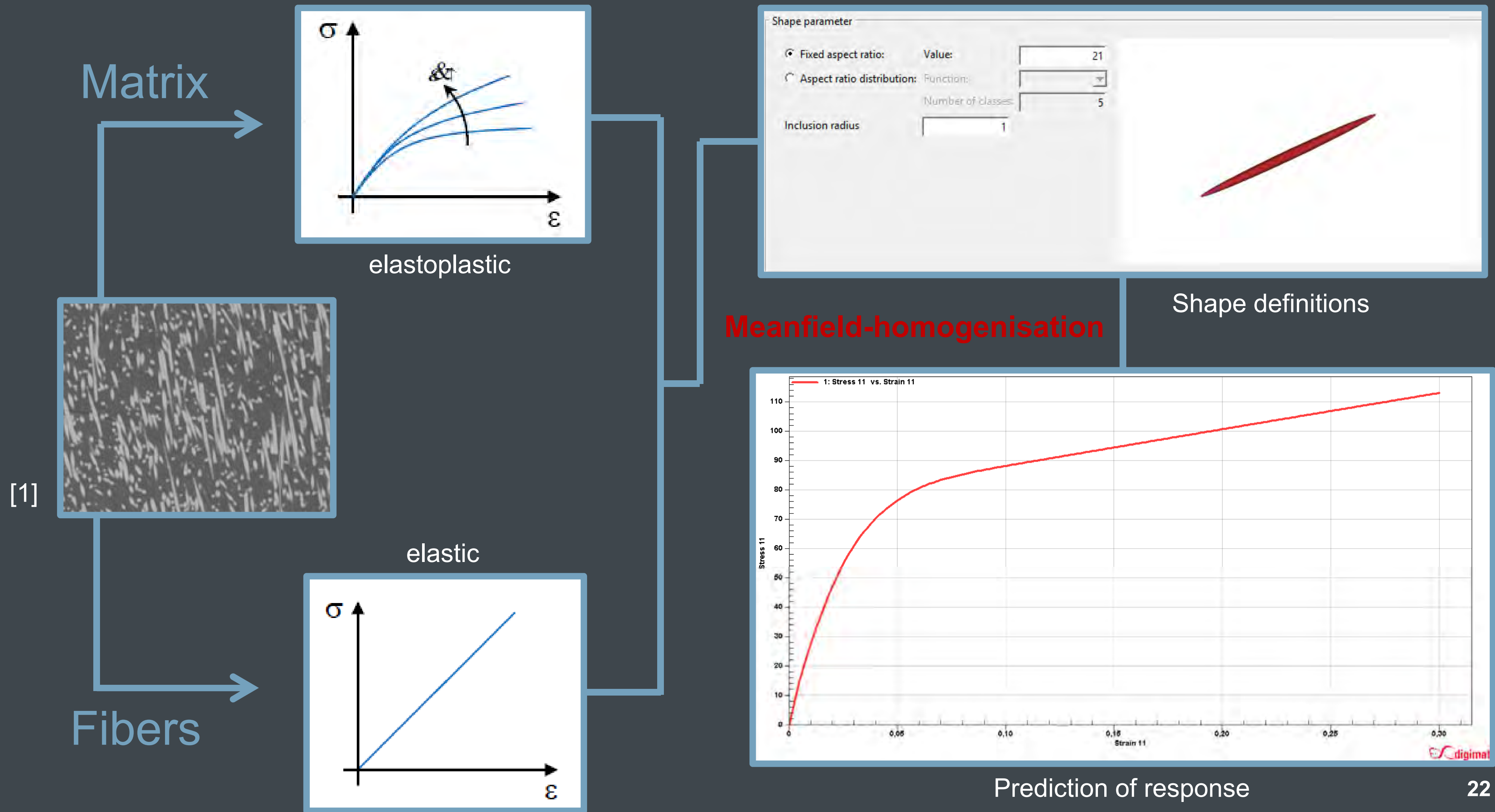




[1]

Materialmodelling

- Prediction of material behavior with mean-field homogenisation

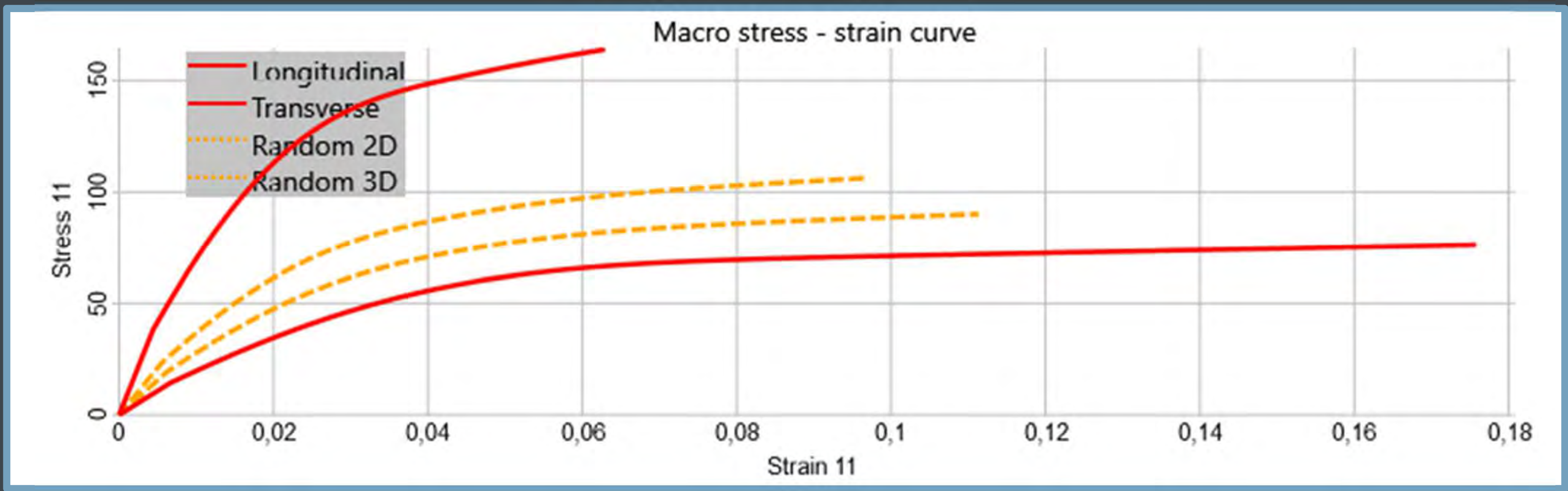


Material modeling

- Available material models in Digimat

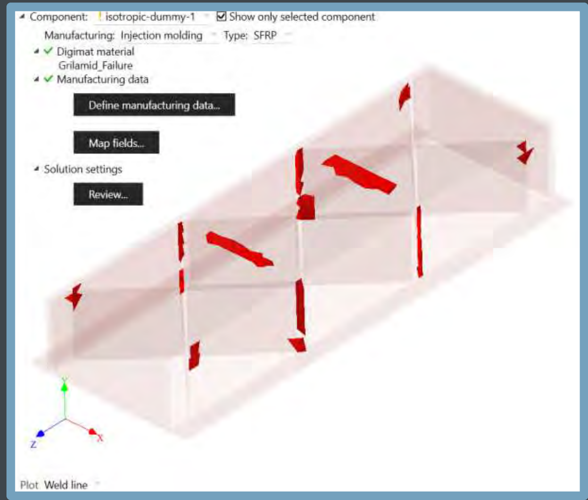
- Strain-rate independent:
  - (Thermo-) elastic
  - (Thermo-) elastoplatic
  - (Thermo-) elastoplastic with damage

- Strain-rate dependent
  - (Thermo-) viscoplastic
  - (Thermo-) elastoviscoplastic
  - Viscoelastic-viscoplastic

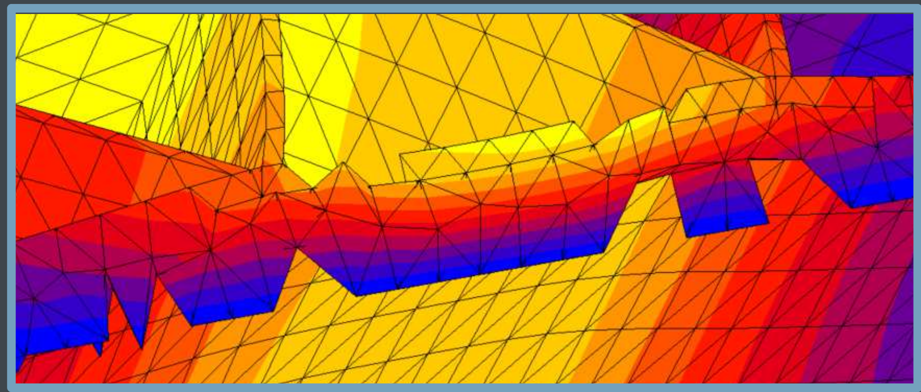


Material modeling

- Define criteria for indicators
- Weld line indicator
  - Knockdown-factor
  - Criteria for each phase of microstructure
- Stiffness reduction
  - With damage
  - With deleting elements
- Failure indicator



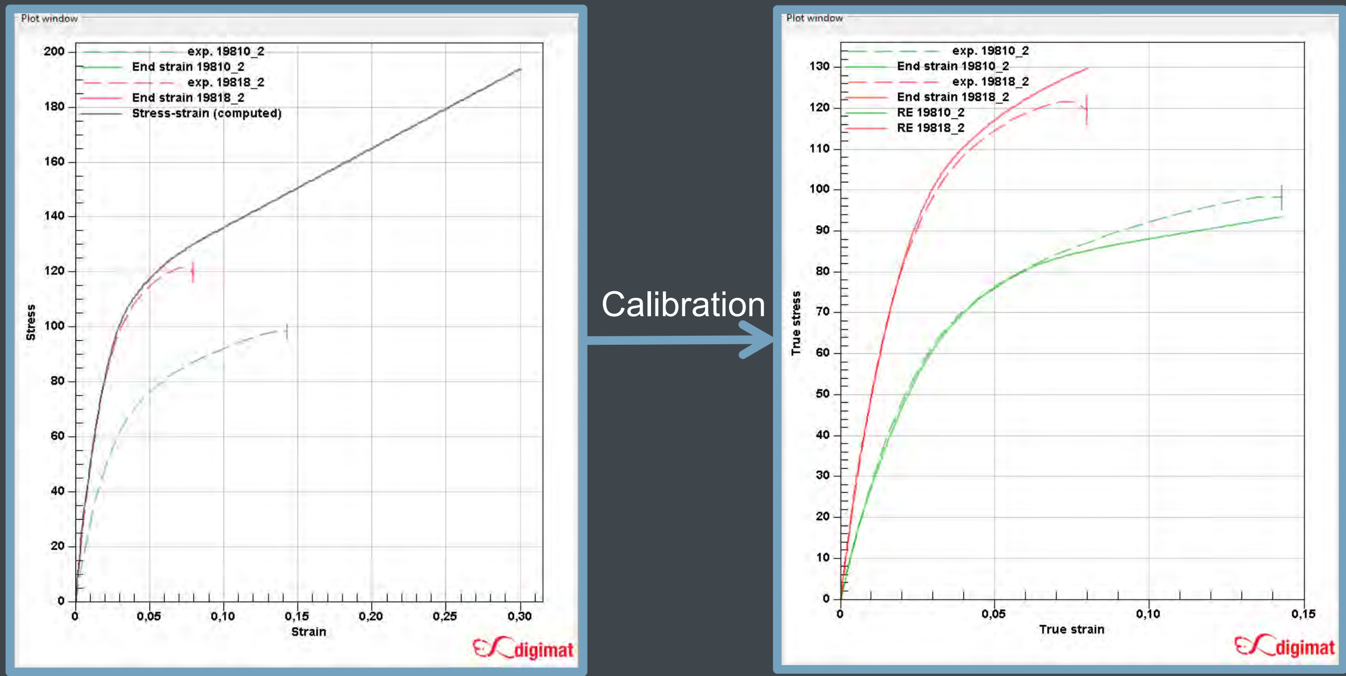
Weld line elements



Element deletion

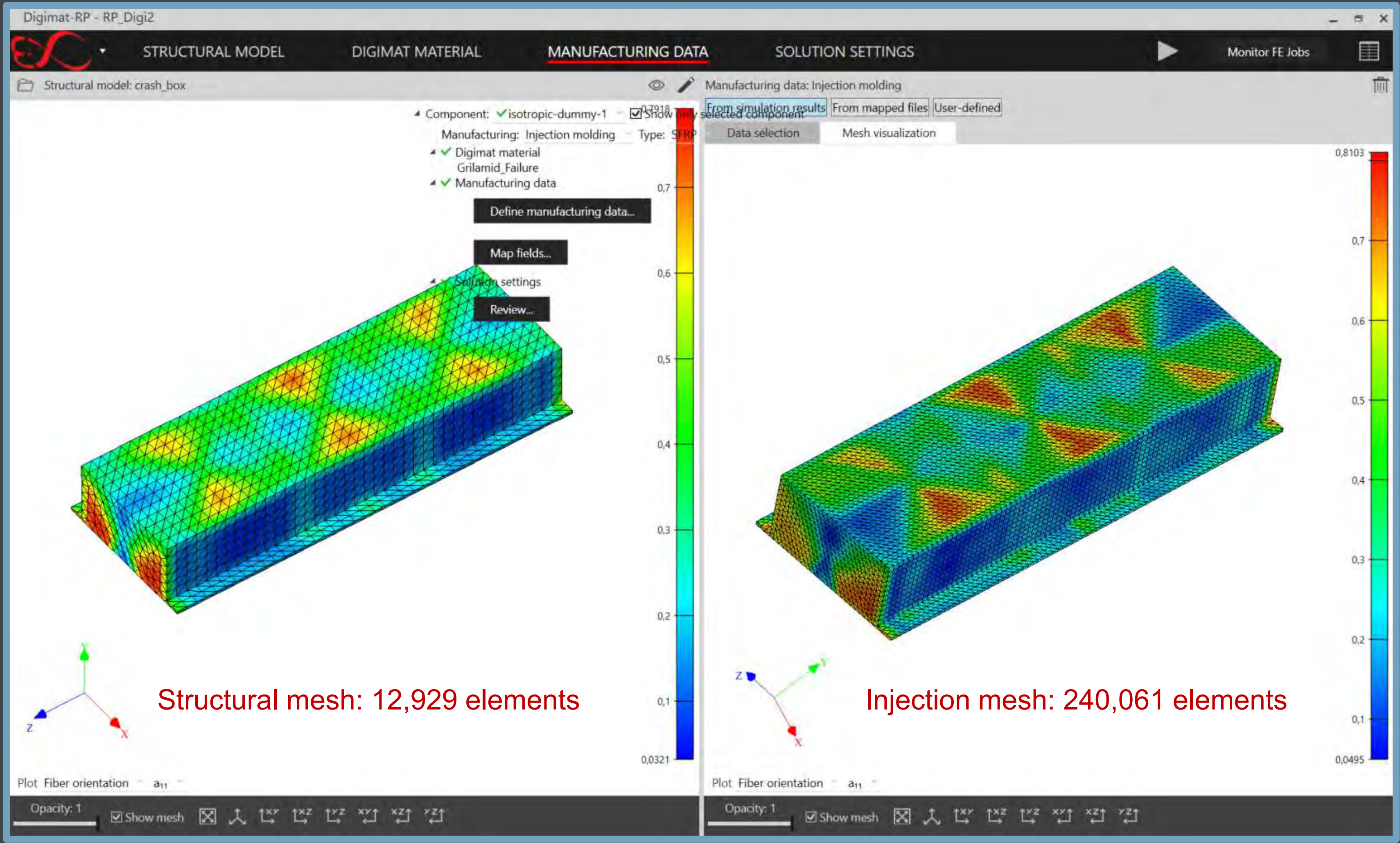
Material modeling: Reverse Engineering

- Calibrate the Digimat material with experimental curves
  - Automatic
  - Interactiv
- Calibrate three curves in 0°/45°/90° of fiber orientation:
  - Trend of curves
  - Anisotrope properties of the microstructure
  - Failure



Material modeling

- Mapping of different data (Prediction / CT-Scan)



Material modeling: CT Scan

- μ -CT

Measurements

σ/ε curves

Material Model

Anisotropic (non) linear

Mapping

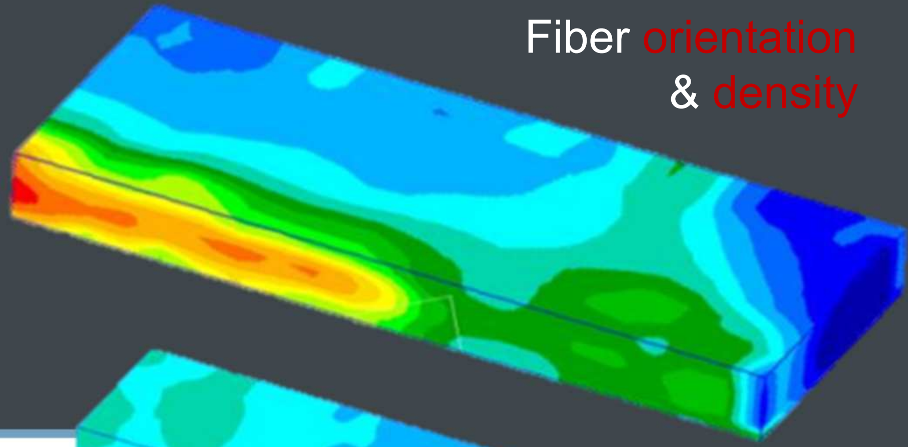
Structural mesh

FEA

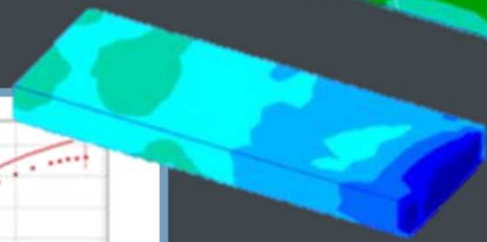
Structural analysis

Measurements

→ μ -CT

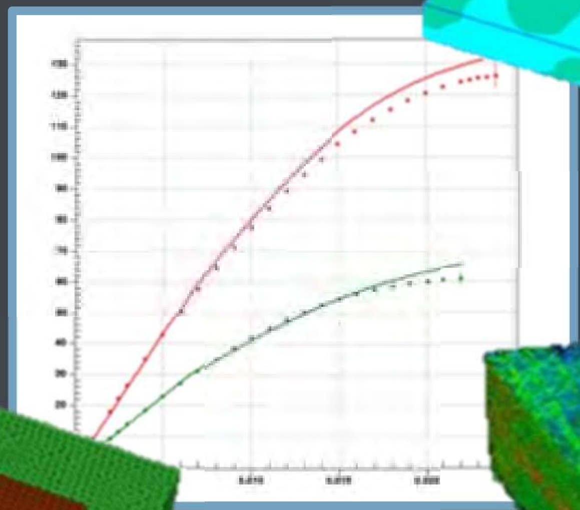


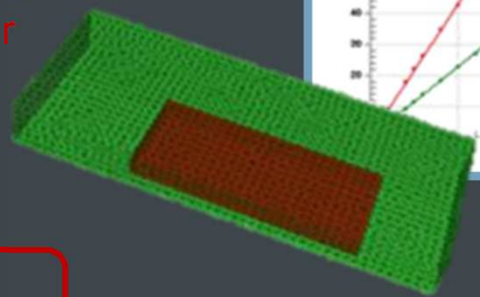
Fiber orientation & density

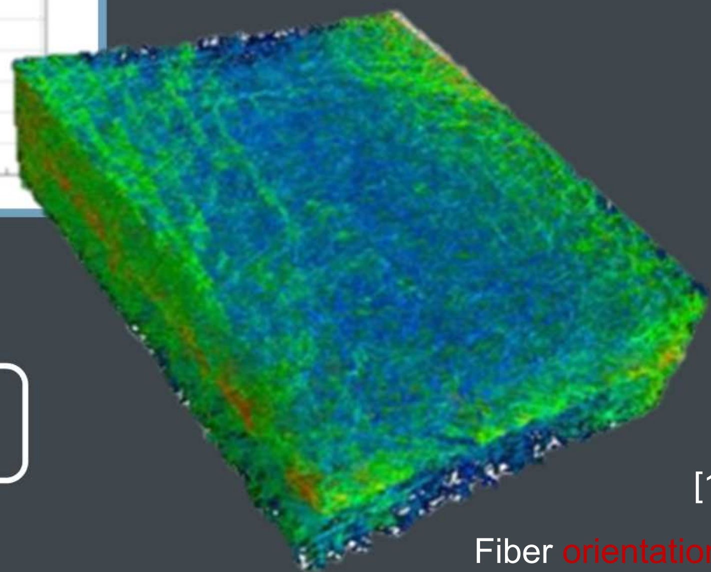


Stress contribution

Fiber orientation







[1]

Fiber orientation & density

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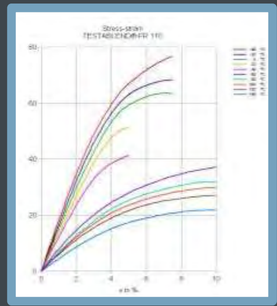
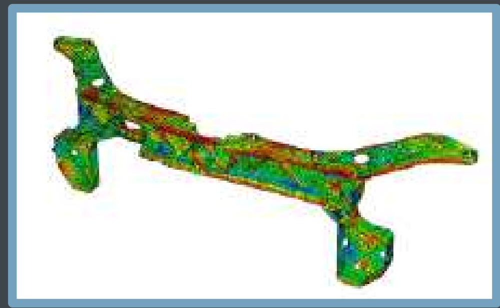
Digimat: From manufacturing process to performance

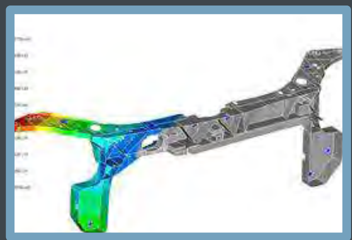
- Standard approach: Manufacturing process and FEA uncoupled

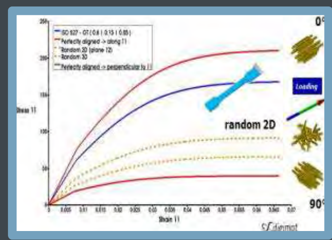


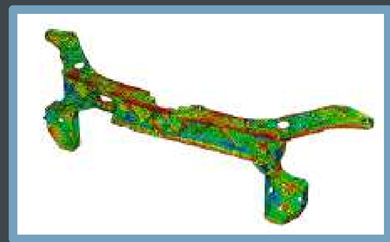


Geometry → Homogeneous Material Law → FEA Analysis

- Digimat approach: Manufacturing process and FEA coupled







[1]

Geometry → Manufacturing Process → Fiber Orientation → Anisotropic Material Law → Fully coupled FEA Analysis

Coupling of manufacturing data, material modeling and structural analysis

SIMPATEC

Manufacturing Process → Material Modeling → Structural Analysis

- Injection molding
- Injection compression molding
- Foam injection molding
- …

Digimat

- Fiber orientation
- Fiber shape
- Fiber weight
- Fiber length
- Porosity
- Orientation of toolpath
- …

- Static
- Crash
- Fatique
- Noise Vibration Harshness (NVH)
- …

[1]

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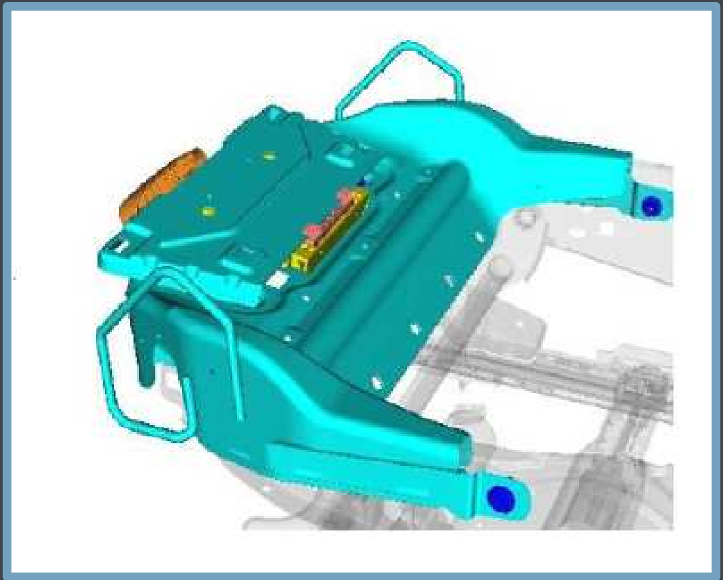
Faurecia Seat – Design of SFRP

- Challenge:
  - Metal Replacement by TECHNYL®

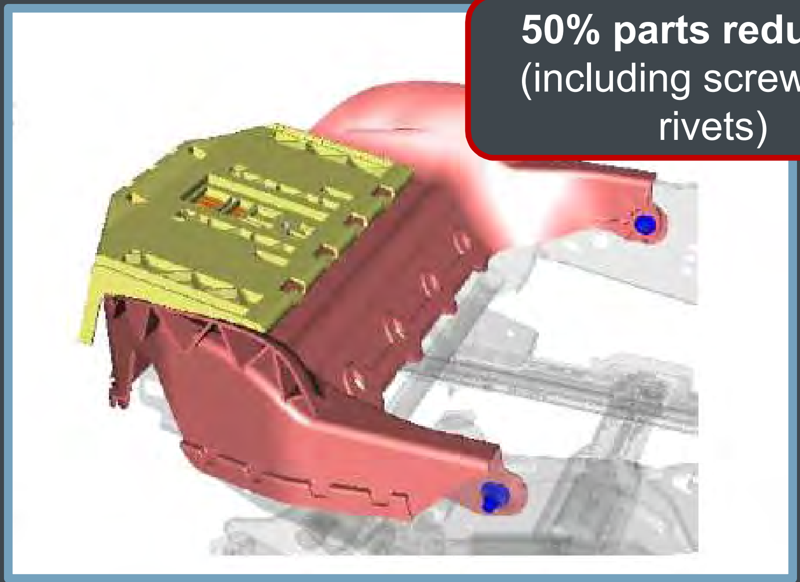
Reference Seat
- All steel



- Cushion length adjustment and powered tilt function
  - 2,750 g

Multifunctional Seat Pan
- Injected PA6/GF30

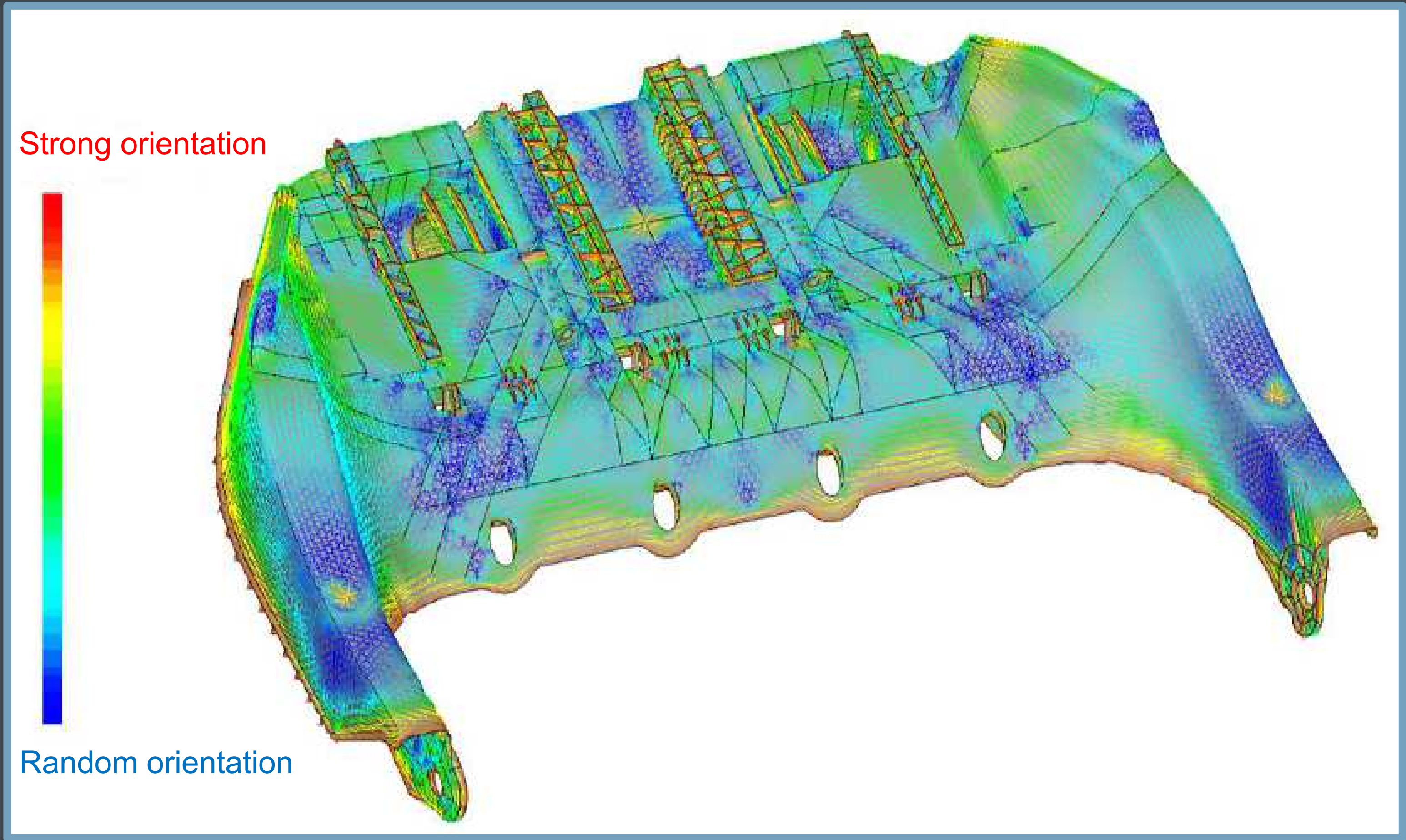
50% parts reduction (including screws and rivets)



- Same functionality
  - 1,665 g

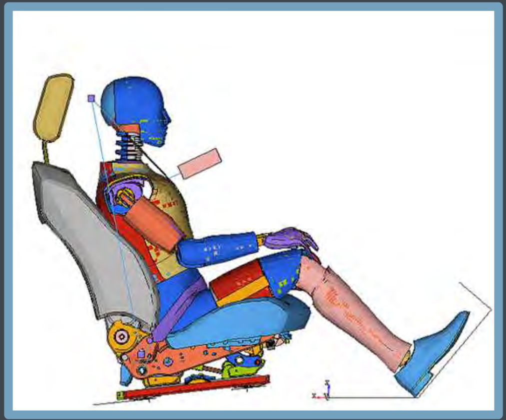
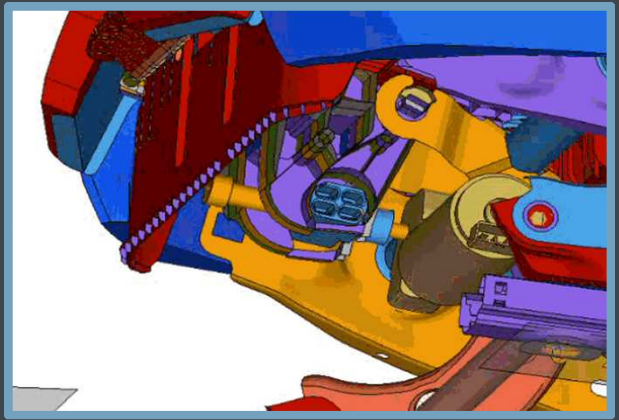
Faurecia Seat – Design of SFRP

- Injection Molded Part
  - Fiber orientation from injection molding process

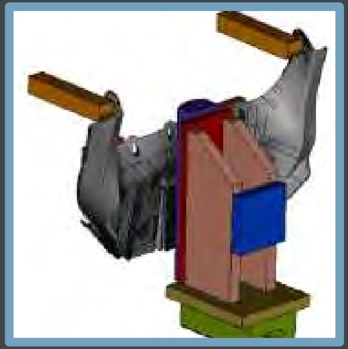


Faurecia Seat – Design of SFRP

- **Simulation Strategy**
  - Complete front crash test and simulation (65 km/h)
    - Tests performed at Faurecia facilities
    - **LS-Dyna explicit analyses at Solvay**

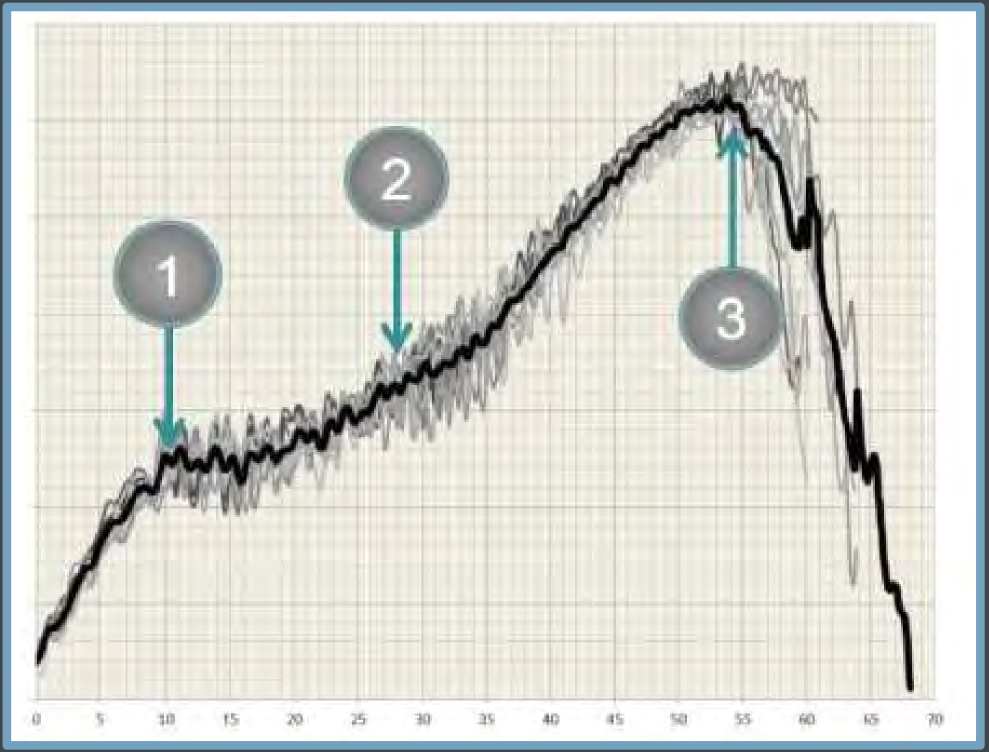



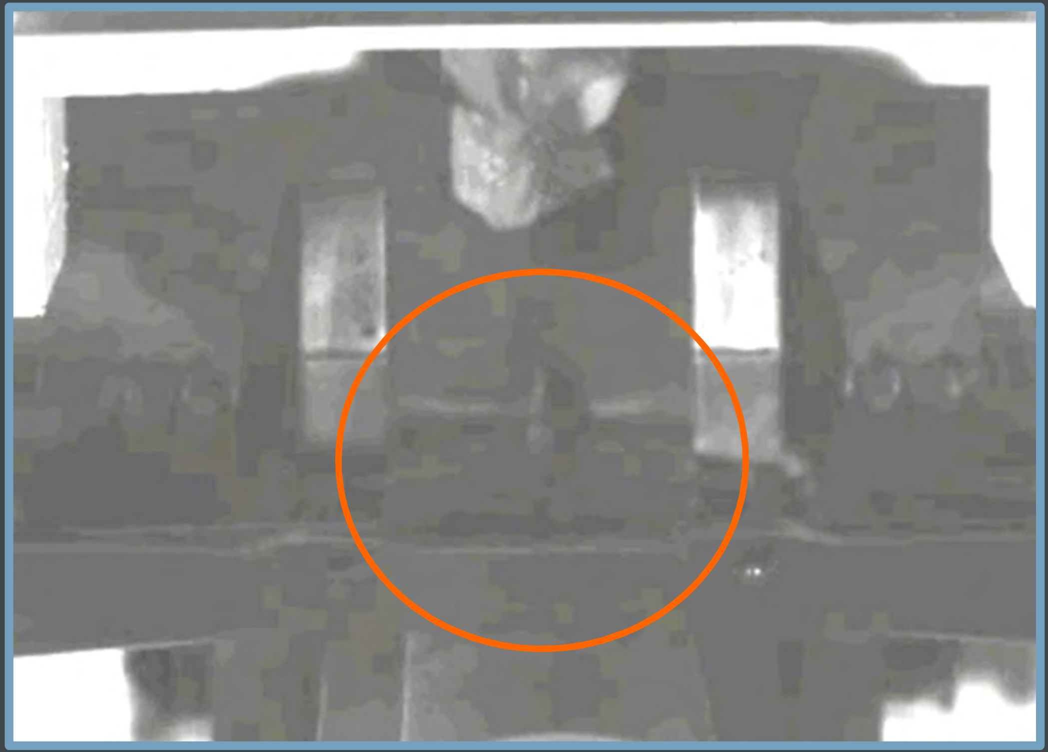
  - Investigation of a simple sub-system
    - Tests and simulation performed at Solvay application development laboratory

Faurecia Seat – Design of SFRP

- **Failure Correlation**
  - Focus on 3 significant events
    - Rib buckling
    - Rib failure
    - Failure evolution



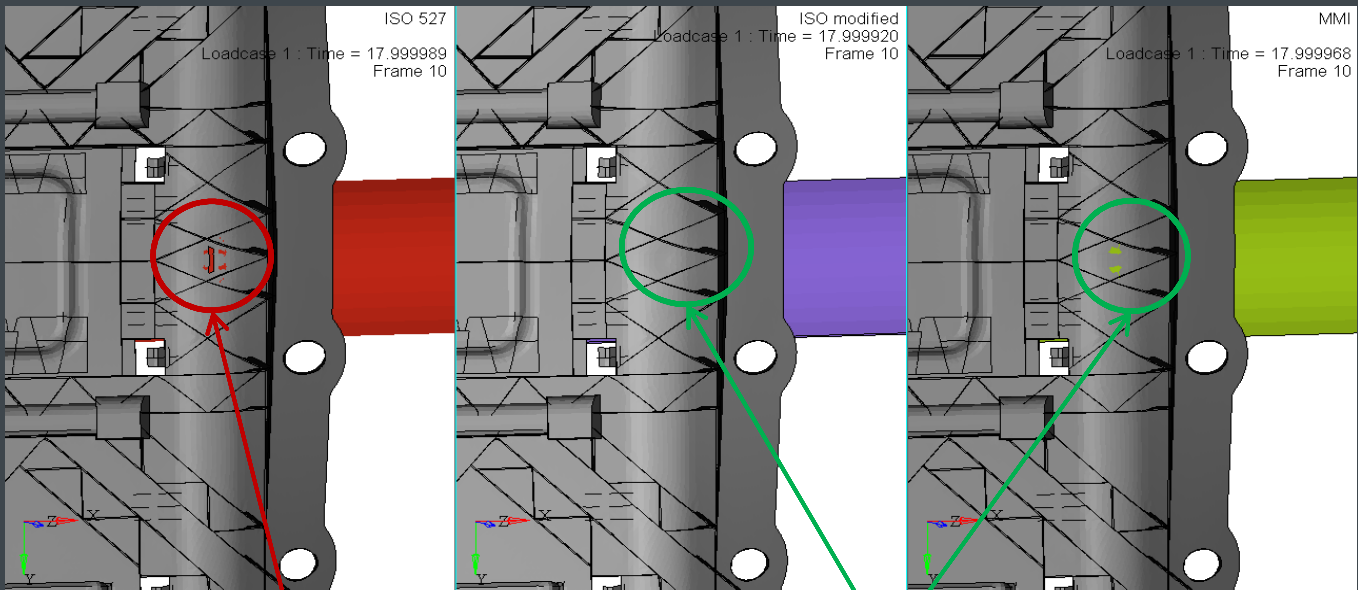


Faurecia Seat - Design of SFRP

Failure Correlation

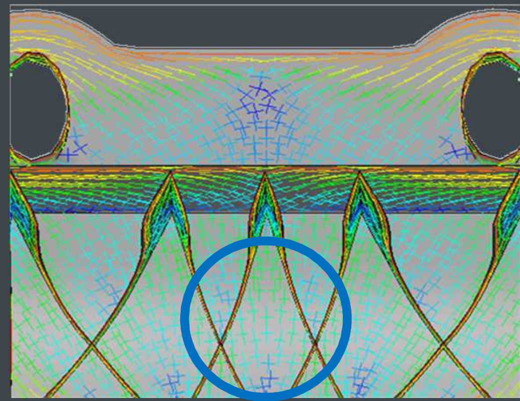
- After 10 ms: rib buckling

Standard | Empirical | MMI



First failure,
Wrong prediction,
The part do not fail yet.

No failure as in experiment,
Good prediction.



In ISO 527 sample, stress and fibre direction are aligned. Material is seen as having a brittle behaviour.

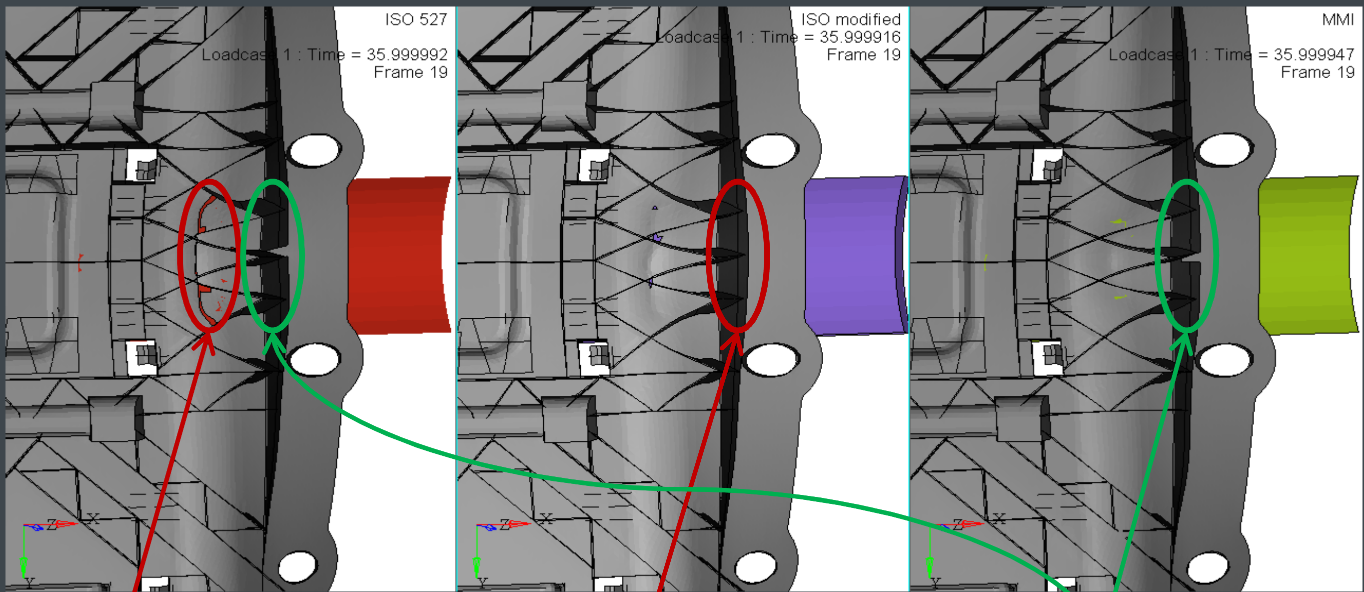
In the part, fiber and stress are not aligned. Thus, the material is more ductile than expected with a standard ISO 527 based material model.

No failure occurs yet.

Faurecia Seat - Design of SFRP

- **Failure Correlation**
  - After 28 ms: rib failure

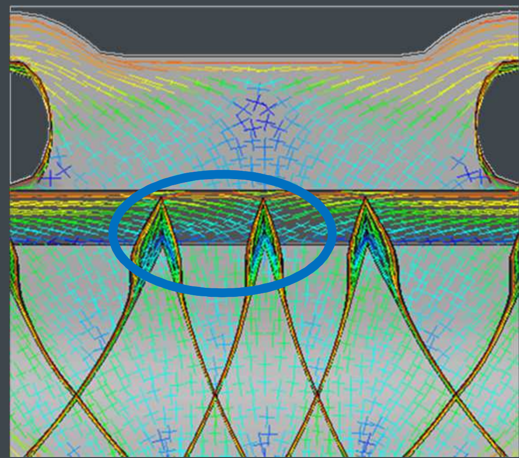
Standard | Empirical | MMI



Transverse failure,
Wrong prediction.

Rib should fail,
Wrong prediction.

Rib fails as experiment,
Good prediction.

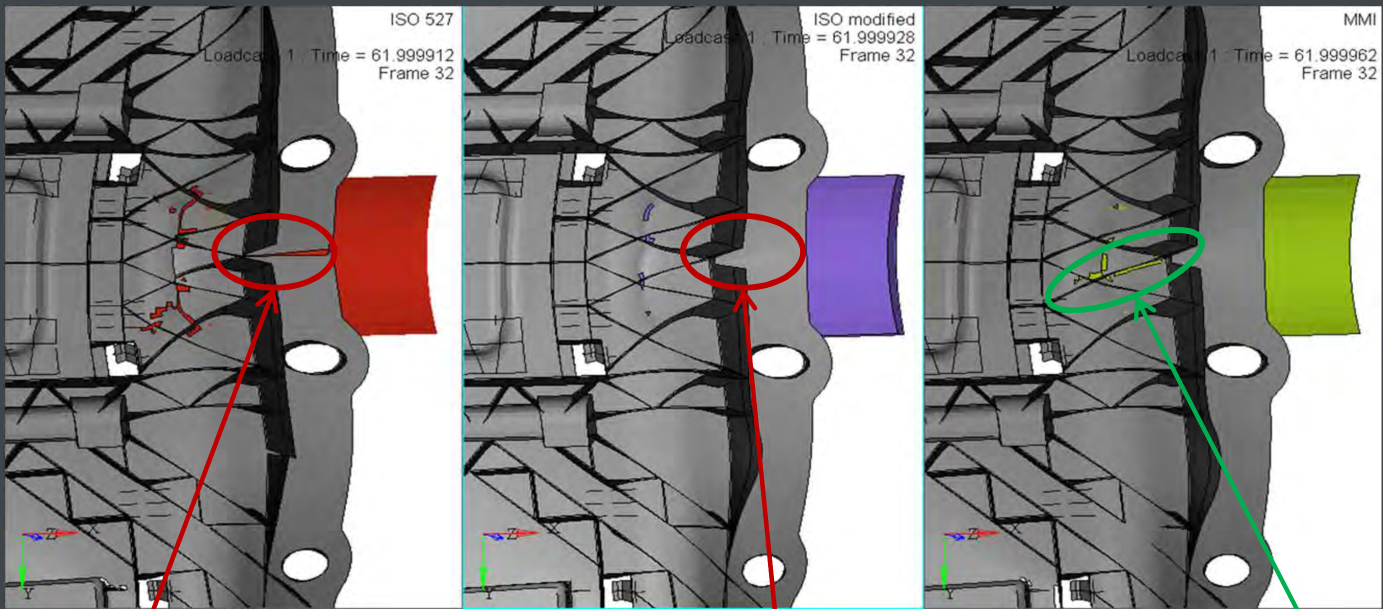


In top of rib, fibre orientation and stress direction are aligned as in an ISO 527 sample, this is why failure occurs at same time in standard and MMI.

Faurecia Seat - Design of SFRP

- **Failure Correlation**
  - After 54 ms: first failure evolution

Standard | Empirical | MMI | Experiment



Failure goes in wrong direction.

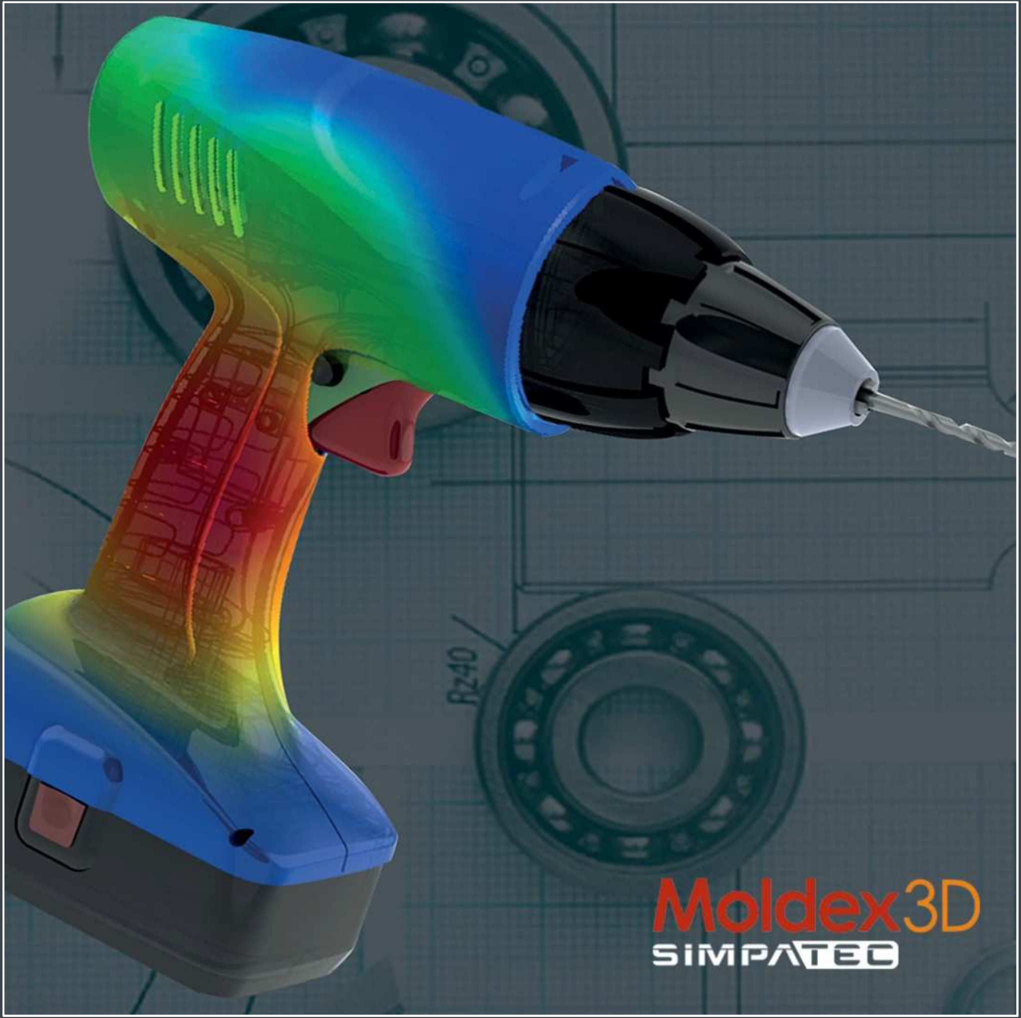
Failure stops.
Wrong prediction.

Failure continues following rib base,
Good prediction.

Sources:

- [1] e-Xstream; Digimat Training documents 2018.0;
- [2] CoreTech System Co.,Ltd; Moldex3D: Fiber R16
- [3] Weld line: http://www.dc.engr.scu.edu/cmdoc/dg_doc/develop/trouble/weldmeld/f6000001.htm
- [4] e-Xstream; Case study: Faurecia seat (Faurecia/Solvay)
- [5] http://www.genesisllc.com/gpe/images/mucell_glass.gif

Questions?
Don’t hesitate to contact us:



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