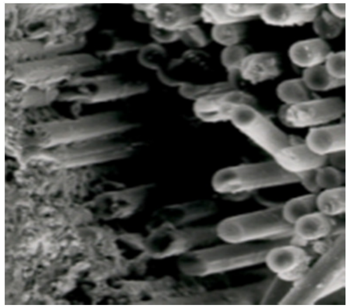
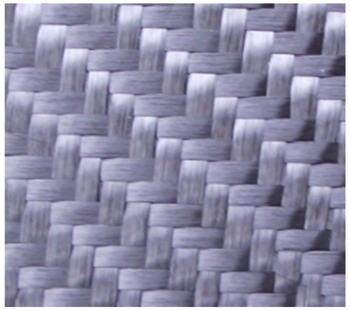




Simulation of the Manufacturing and Serviceability of Continuous Fiber-reinforced Plastics

Dr. Stefan Hartmann, Dr. André Haufe,
Dr. Thomas Klöppel, Christian Liebold

DYNAmore GmbH, Stuttgart

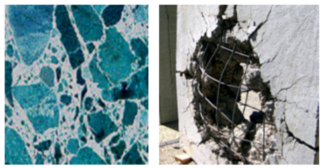
Webinar: Composite Analysis

02.04.2014

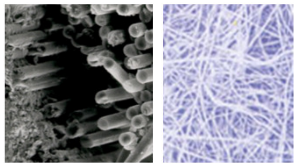
DYNA MORE

Composites

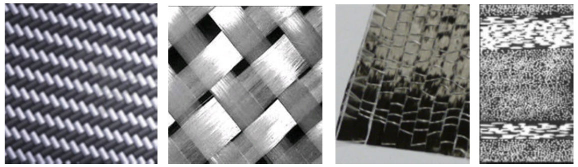
- A composite is a combination of two or more materials, differing in form or composition on a macroscale. The constituents do not dissolve or merge completely into one another, but can be physically identified and exhibit an interface.



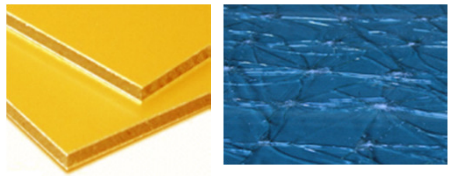
Concrete
(cement/stone/steel)



Short/long fiber reinforced polymers
(glass/PP)



Endless fiber reinforced polymers
(glass/carbon/PA/PP/EP)



Sandwich/Laminates
(alloy/polymer/..glass/PVB/…)

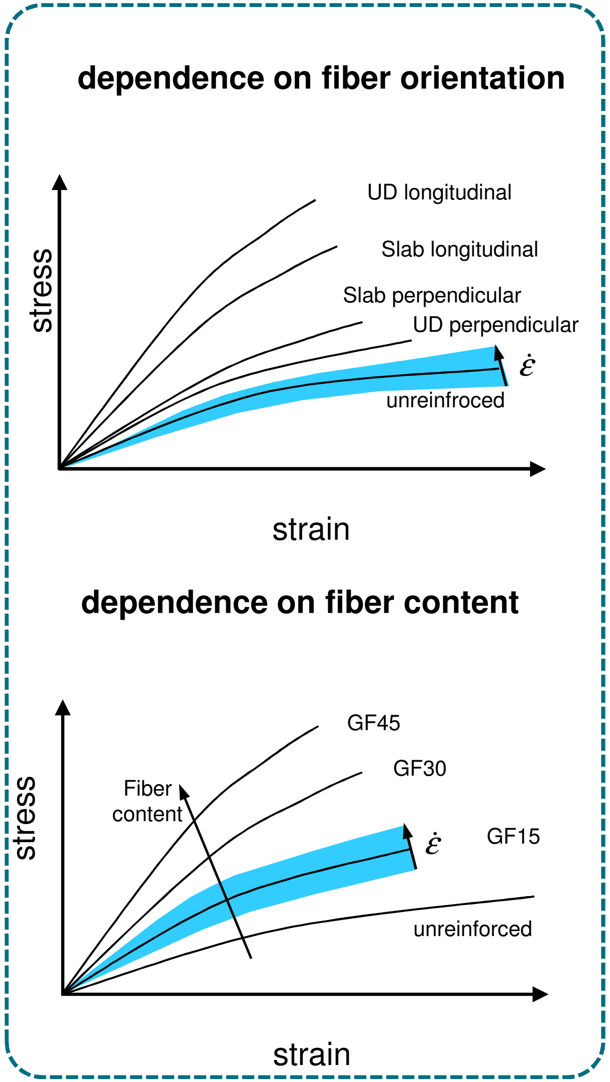
Chracteristic structure of fiber reinforced plastics

- Fiber **size** and **geometry** have significant influence on the part performance.

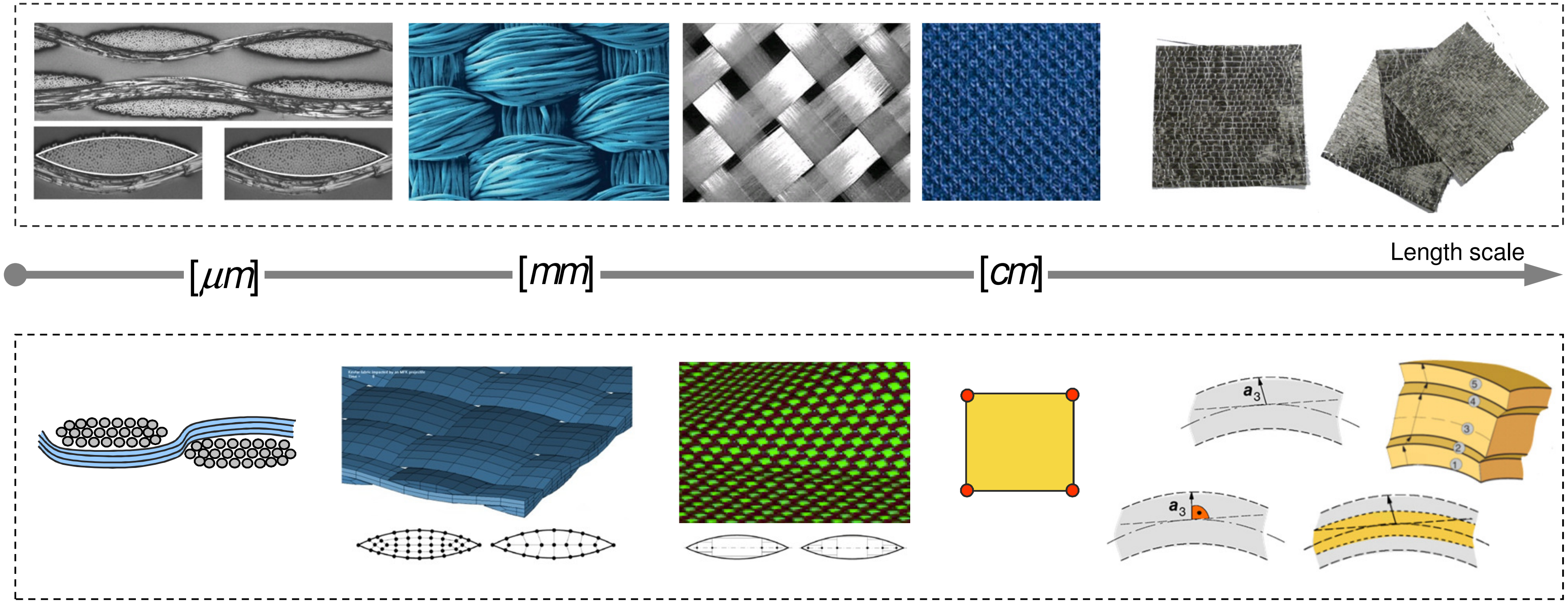
- Fibers show higher strength and stiffness than material in bulk form
  - Fewer internal defects
  - Aligned crystalline structure

- Strongly anisotropic tensile response
  - Typical stiffness ratio: 20:1 – 100:1
  - Fibers linear elastic, matrix non-linear

A thorough understanding of the manufacturing process is extremely important



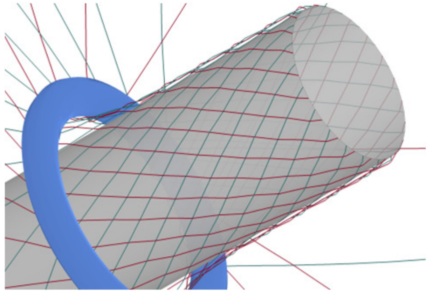
Length scale and modeling techniques



- The modeling strategy is to be defined based on
  - the length scale
  - the effects to be capturde by the simulation

Agenda

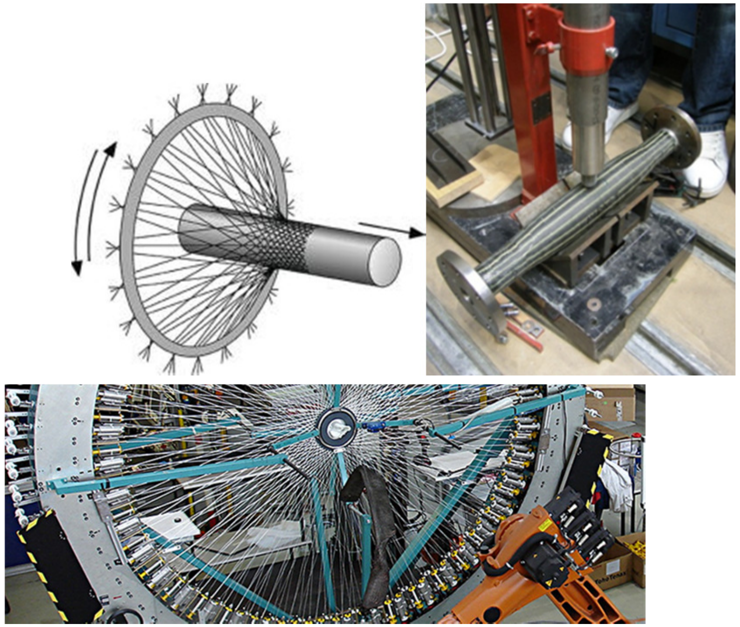
- Process simulation
  - Winding and Braiding
  - Draping
  - Thermoforming
- Crashworthiness analysis
  - Short and long fiber reinforced plastics
  - Continuous fiber reinforced plastics
- Mapping
- Summary



Producibility
Winding and Braiding

Winding and Braiding

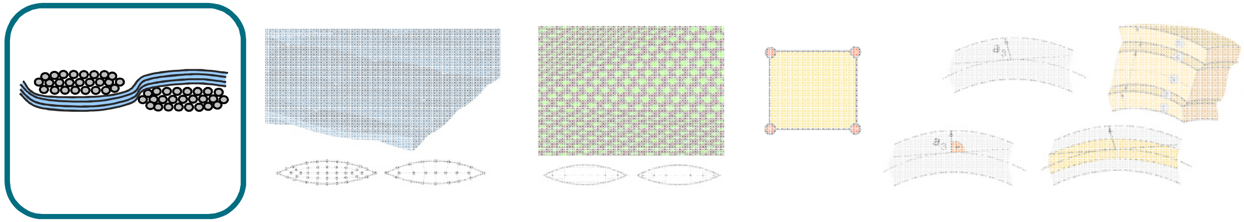
[ICD/ITKE, Uni Stuttgart]



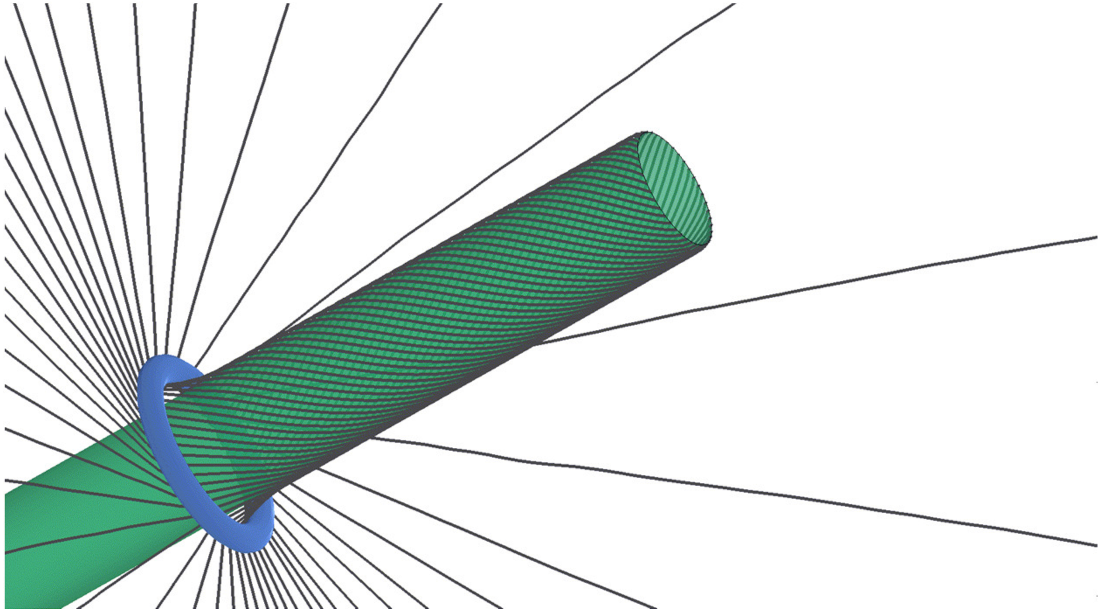
[IFB, Uni Stuttgart]

- Exact positioning and orientation of fibers for complex geometries
- Thorough planning of the manufacturing process is required

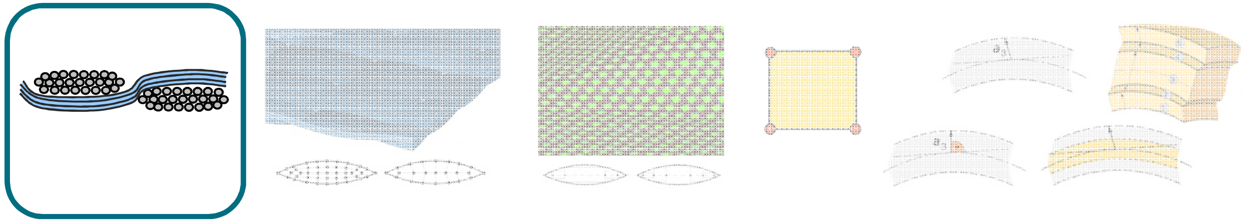
Winding and Braiding - Simulation

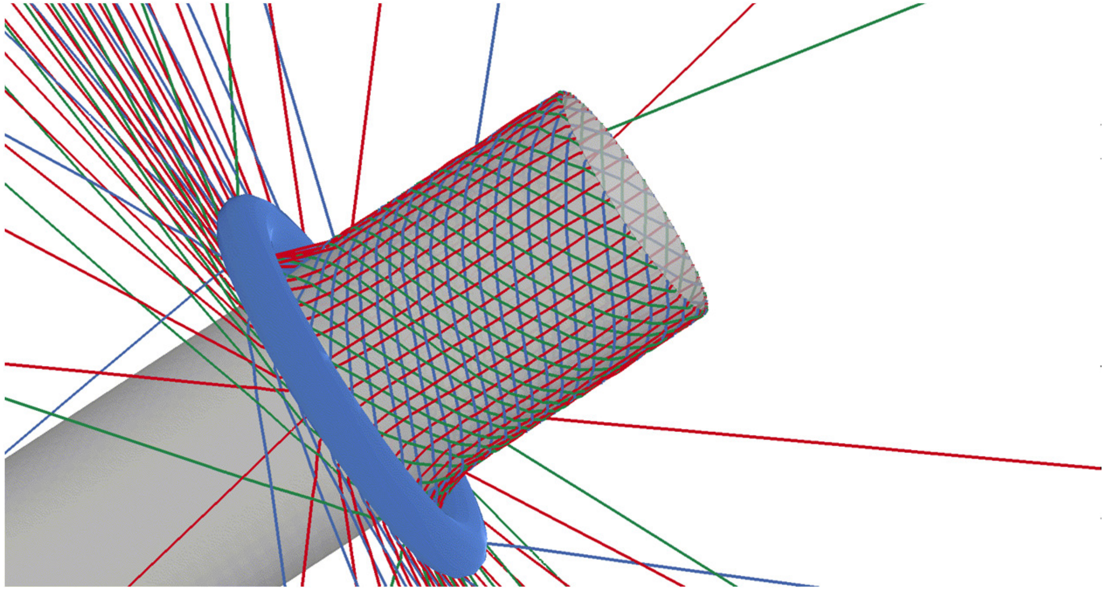


- 21 yarns
- 21543 beam elements
- 1 part
- Simple rotation of the fibers
- Braiding core is pushed through the braiding ring



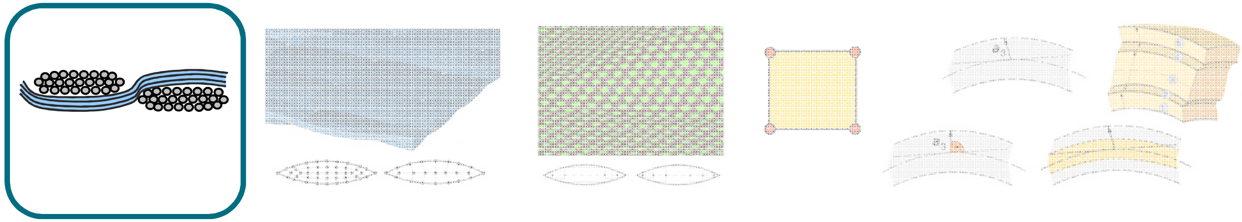
Winding and Braiding - Simulation



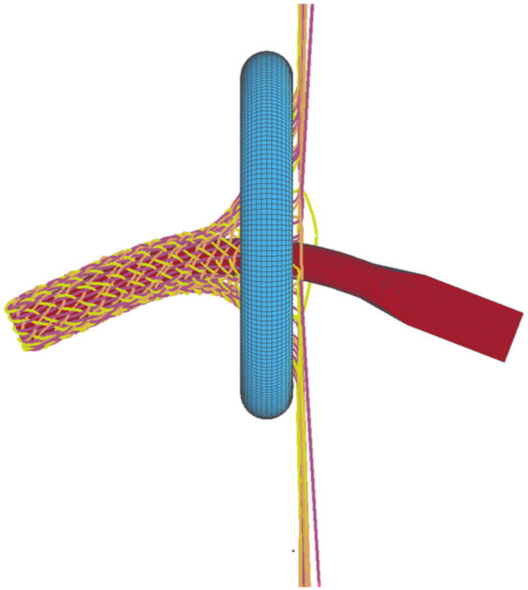


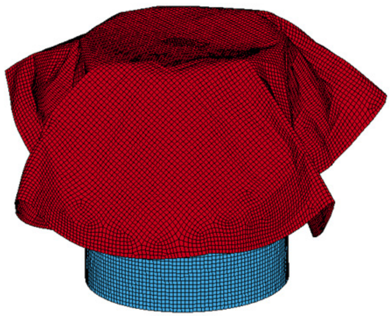
- 84 yarns
- 174348 beam elements
- 3 parts
- Half the elements used as UD – reinforcement
- Fibers are rotated and then moved to create the braiding-pattern
- Braiding core is pushed through the braiding ring

Winding and Braiding - Simulation



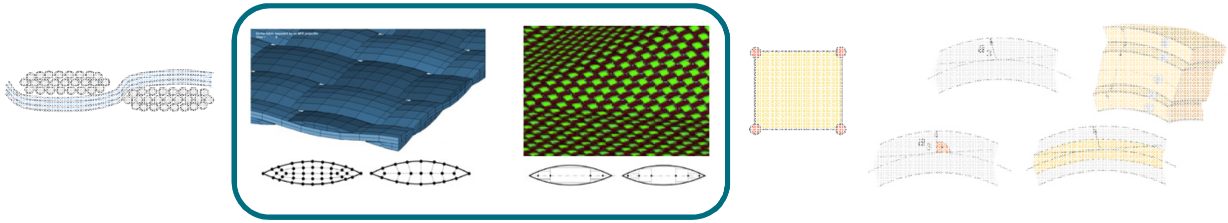
- 48 yarns
- 25236 beam elements
- 48 discrete elements
- 6 parts
- Fibers are rotated and then moved to create the braiding-pattern
- Braiding core is pushed through the braiding ring



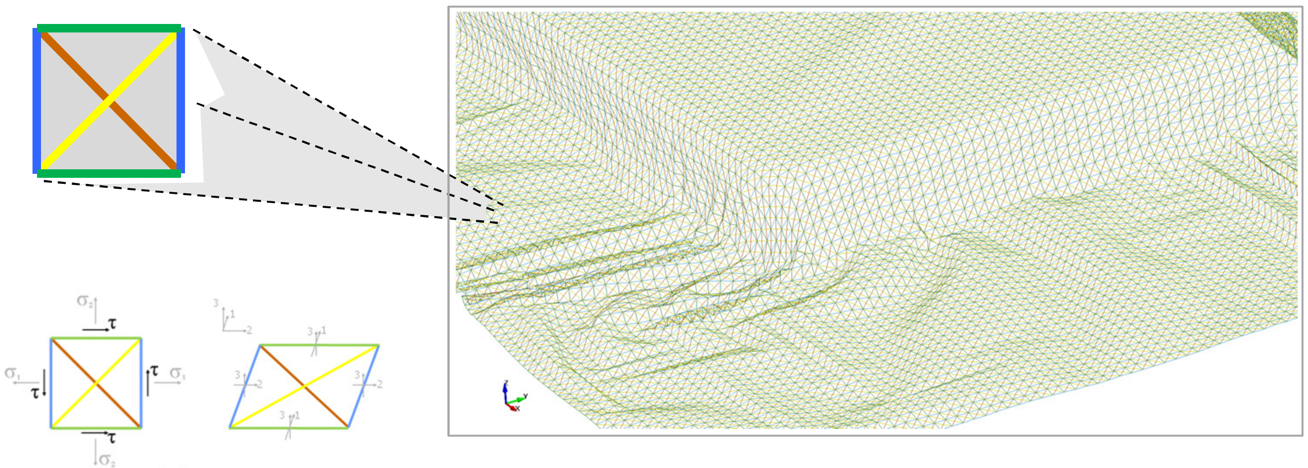


Producibility
Draping

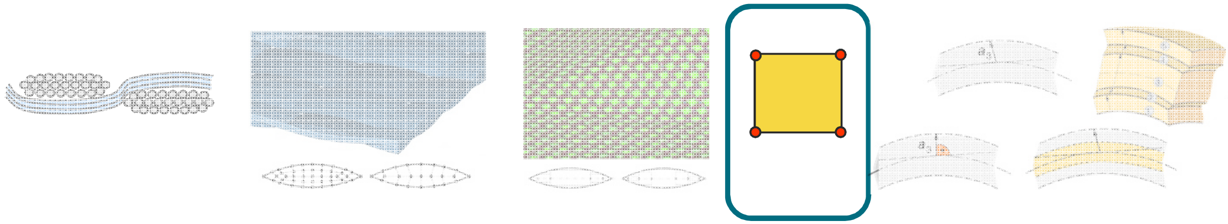
Draping – Simulation with discrete elements



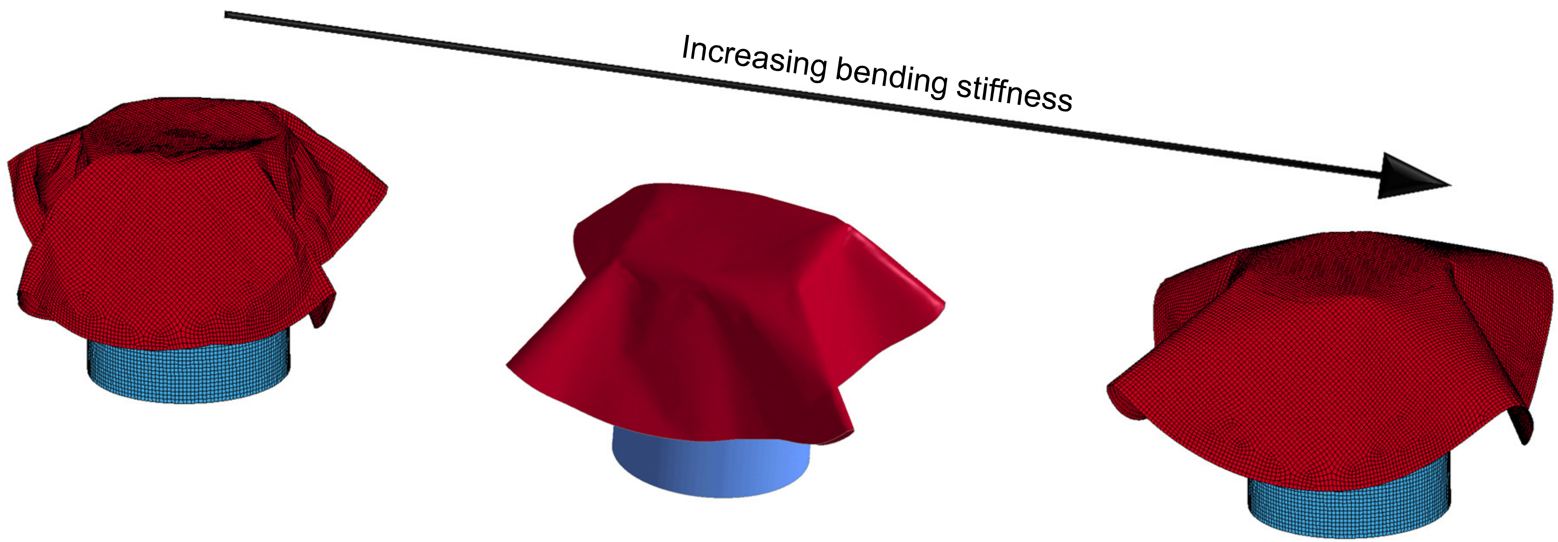
- Warp and weft direction *MAT_LINEAR_ELASTIC_DISCRETE_BEAM
- Diagonal behavior modeled with *MAT_CABLE_DISCRETE_BEAM
- This approach allows to model positive and negative shear loading



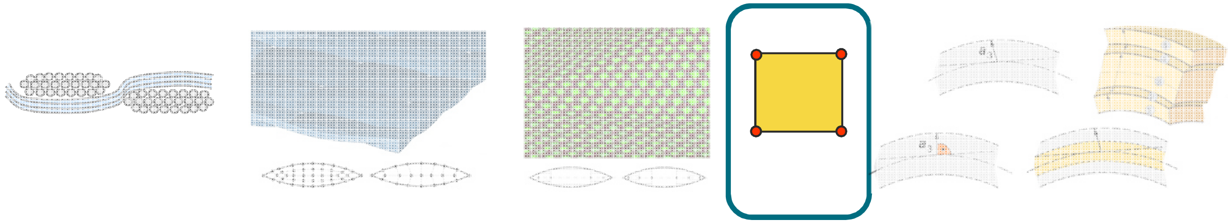
Draping – *MAT_034 (*MAT_FABRIC)



- Material describes an orthotropic material behavior
- Requires discretization with membrane elements
- Allows to add a bending resistance by defining an additional elastic



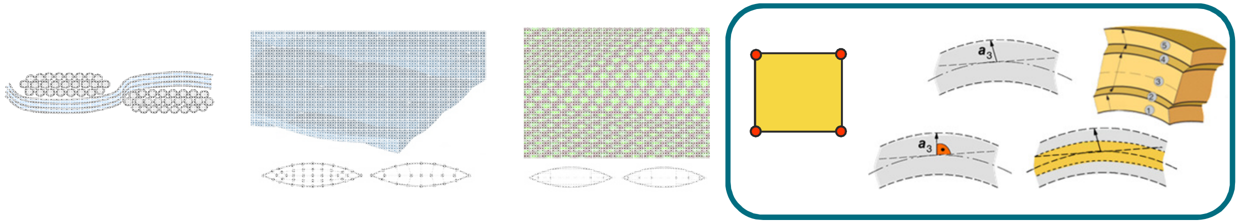
Draping – *MAT_234 / *MAT_235



- *MAT_234 (*MAT_VISCOELASTIC_LOOSE FABRIC)
  - Micromechanical approach
  - Mathematical description for geometry and kinematic of symmetrical woven fabric
  - Looking angle is taken into account
  - Viscoelastic enhancement for higher shear strain
- *MAT_235 (*MAT_MICROMECHANICS_DRY_FABRIC)
  - Micromechanical approach with homogenization strategy (RVE)
  - Mathematical description of symmetrical woven fabric
  - Looking angle is taken into account

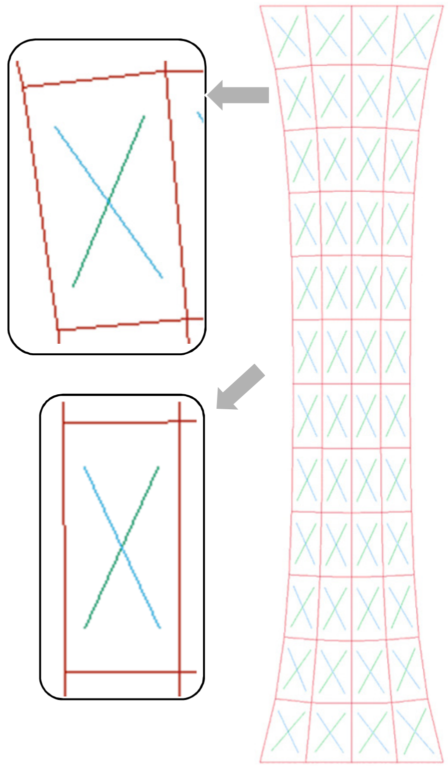
Draping – *MAT_249

New!

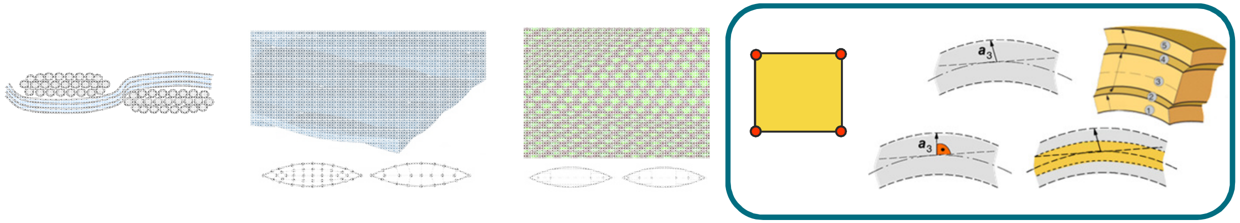


- *MAT_249
  - Macroscopic, hyperelastic and anisotropic material formulation
  - Up to three different fiber families can be defined in any integration point
  - Stress-strain response for tension and compression given as load curve
  - Non-linear elasto-plastic shear behavior also defined be load curve input

  - Contains thermo-elasto-plastic material for thermoplastic matrix

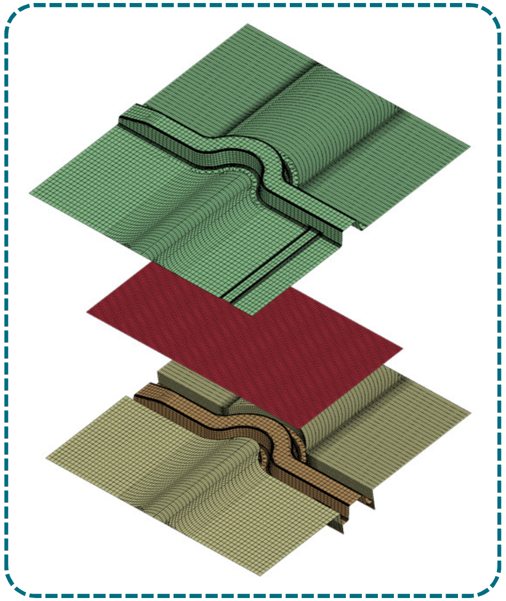


Draping – *MAT_249

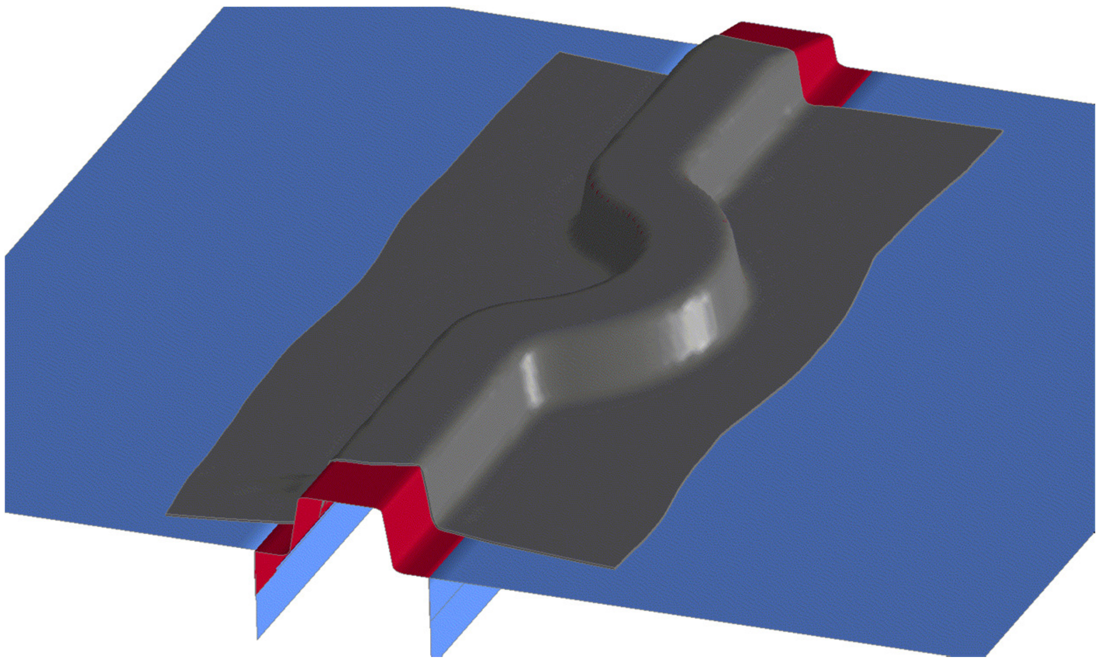


New!

- S-Rail Example

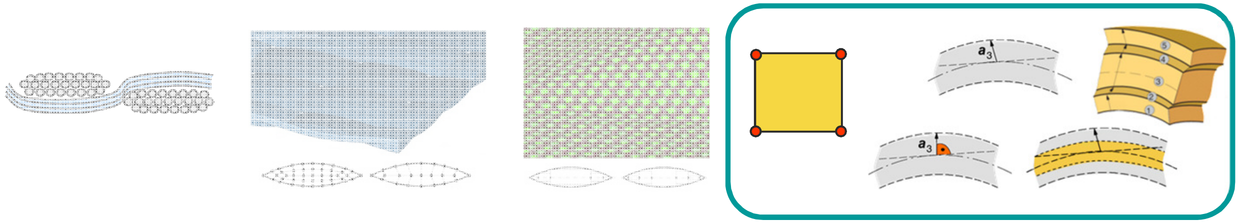


geometry:
Benteler-SGL

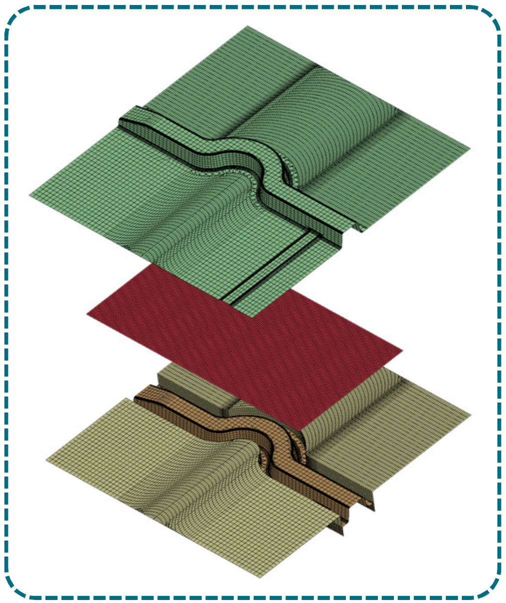


Draping – *MAT_249

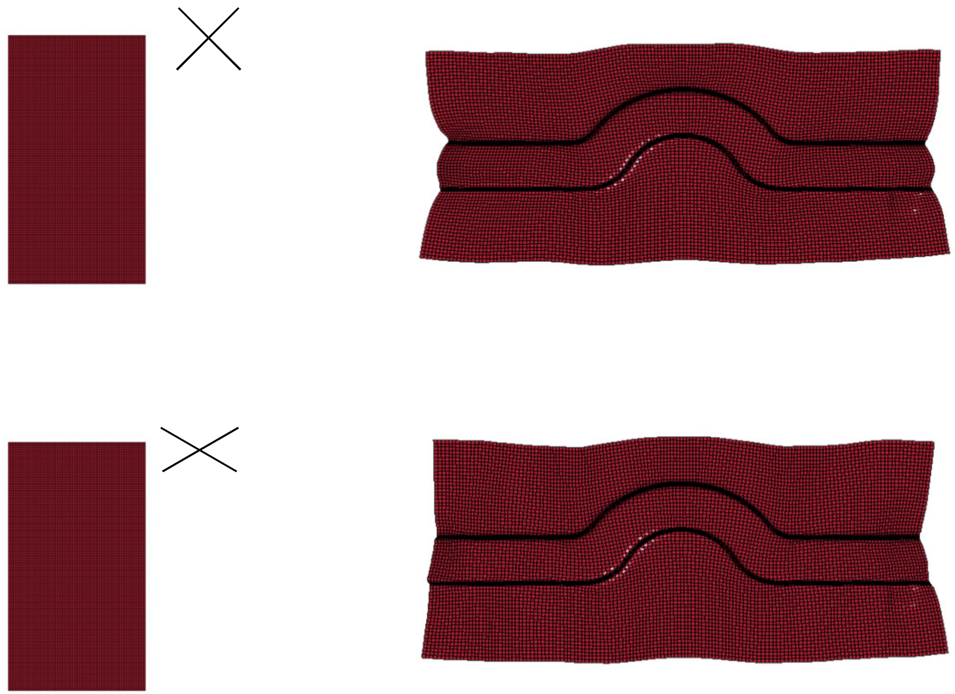
New!



- S-Rail Example



geometry:
Benteler-SGL

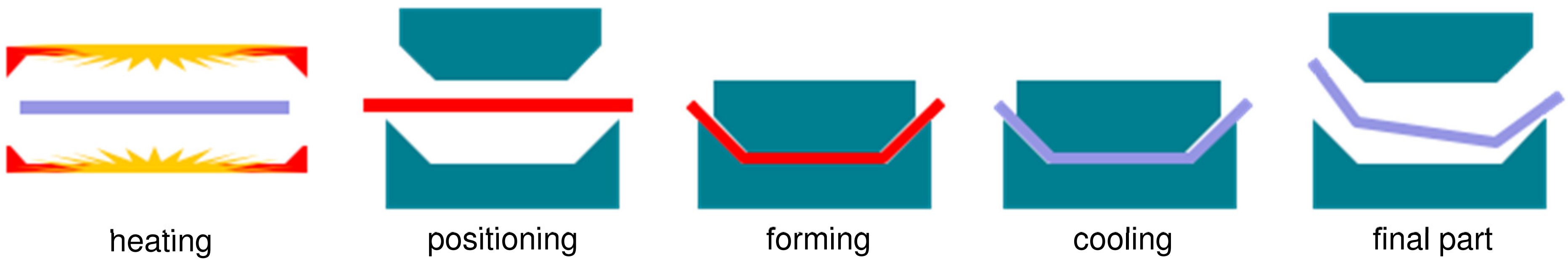


Producibility
Organo sheet

Thermoplastic pre-pregs – process overview

- 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

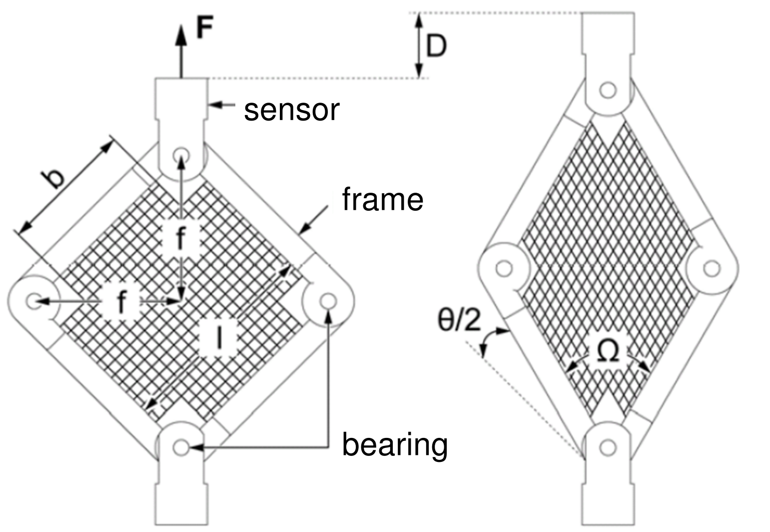


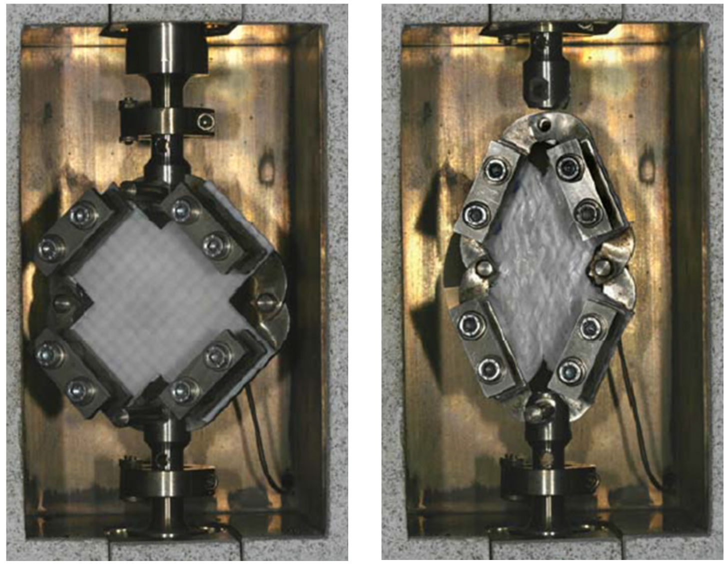
- Process is reversible as no chemical curing occurs

- Relatively short cycle times can be realized

Thermoplastic pre-pregs – picture frame test

- Standard experimental set-up to characterize shear behavior
- Results show significant temperature dependence
  - At low temperature, matrix material dominates
  - At high temperature, behavior similar as for dry fabric material

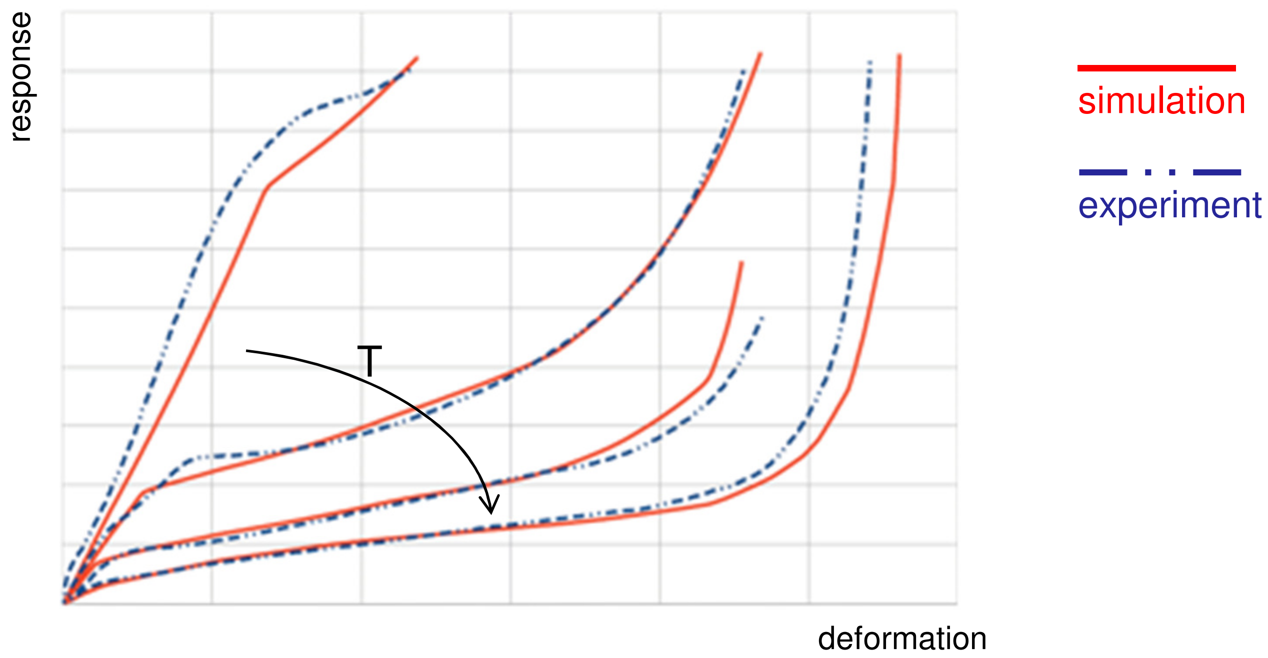




Thermoplastic pre-pregs – Validation

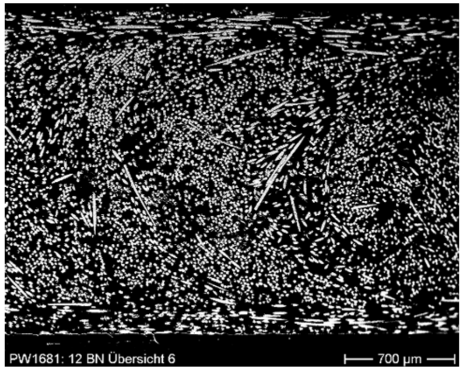
New!

- Picture frame test is simulated for different temperatures
- Simulation result 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



Agenda

- Process simulation
  - Winding and Braiding
  - Draping
  - Thermoforming
- Crashworthiness analysis
  - Short and long fiber reinforced plastics
  - Continuous fiber reinforced plastics
- Mapping
- Summary



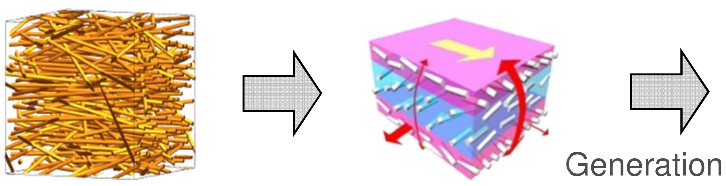
Serviceability
Short and long fibers

Anisotropic elastic solution with MAT_002_ANIS

- Hyperelastic (total) formulation using Green-Lagrange strain $\mathbf{E}$

$$\boldsymbol{\sigma} = J^{-1}\mathbf{F}\cdot\mathbf{S}\cdot\mathbf{F}^T = J^{-1}\mathbf{F}\cdot\mathbf{C}\cdot\mathbf{E}\cdot\mathbf{F}^T$$

- Elastic-anisotropic behavior, stiffness matrix with 21 independent coefficients:



Generation of constitutive data

$$\mathbf{C} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\ & & C_{33} & C_{34} & C_{35} & C_{36} \\ & & & C_{44} & C_{45} & C_{46} \\ & sym. & & & C_{55} & C_{56} \\ & & & & & C_{66} \end{bmatrix}$$

- Several possibilities to define material directions, e.g. AOPT, ELEMENT_SOLID_ORTHO, …
- No plasticity, no damage, no failure (but: brittle failure possible via *MAT_ADD_EROSION)

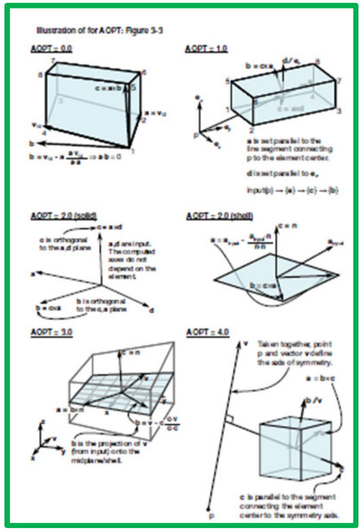
*MAT_(ANISO)TROPIC_ELASTIC

New!

CARD #1	mid	ro	c11	c12	c22	c13	c23	c33
CARD #2	c14	c24	c34	c44	c15	c25	c35	c45
CARD #3	c55	c16	c26	c36	c46	c56	c66	aopt
CARD #4	xp	yp	zp	a1	a2	a3	macf	ihis
CARD #5	v1	v2	v3	d1	d2	d3	beta	ref

$$\sigma_{ij} = C_{ijkl}\varepsilon_{kl}$$

- C_{ij}: constants in the 6x6 anisotropic constitutive matrix
- AOPT: usual options to define the material's coordinate system
- ihis: flag for element-wise definition of the stiffness tensor with *INITIAL_STRESS_SOLID



*INITIAL_STRESS_SOLID

New!

CARD #1	eid	nint	nhisv	large	iveflg	ialegp	nthint	nthhsv

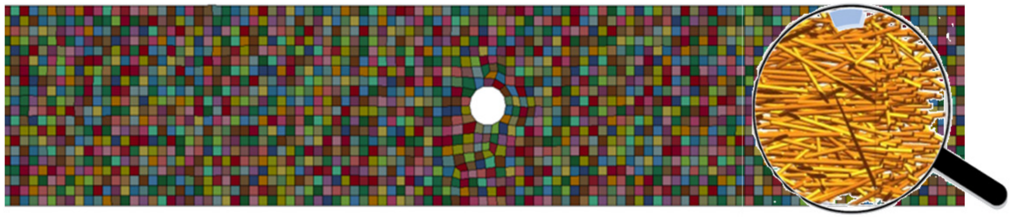
CARD #2	sigxx	sigyy	sigzz	sigxy	sigyz
CARD #3	sigzx	eps	hisv1	hisv2	hisv3
CARD #4	hisv4	hisv5	hisv6	hisv7	hisv8
CARD #5	hisv9	hisv10	hisv11	hisv12	hisv13
CARD #6	hisv14	hisv15	hisv16	hisv17	hisv18
CARD #7	hisv19	hisv20	hisv21		

- The matrix entries C_{ij} are written onto the history variables per integration point.

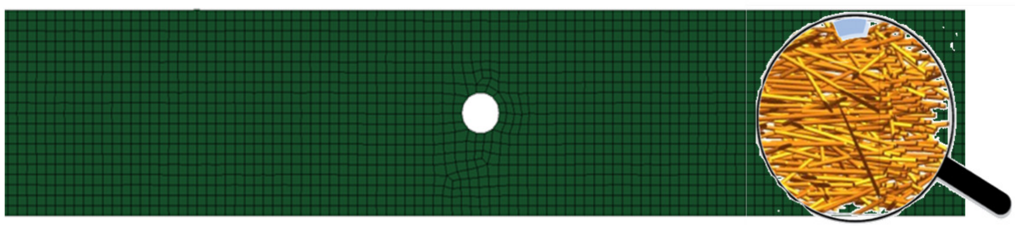
- Setting `ihisv=21` in MAT_002 will take into account the fully anistropic stiffness tensor
  (e.g. hisv#1 – hisv#21 have to be defined in DYNAIN for instance)

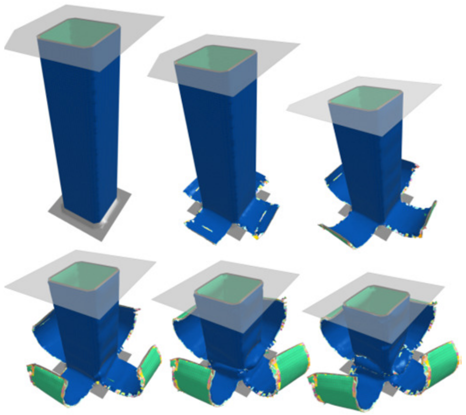
Anisotropic elastic solution with MAT_002_ANIS

- Direct input in material card
  - Drawback: inhomogeneous distribution (e.g. from previous short fiber filling simulation) in component needs individual part definition for every element



- Initialization with *INITIAL_STRESS_SOLID (new option in next Release R7.1)
  - Only one part definition for whole component. Anisotropic coefficients are part of material's history field and can therefore be initialized for each integration point individually.

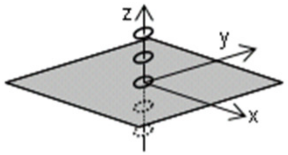




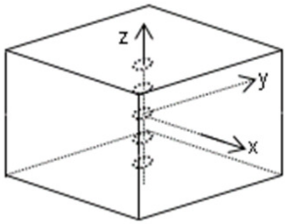
Serviceability
Continuous fiber reinforced plastics

Domposite damage – modeling aspects

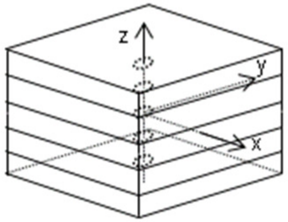
intralaminar



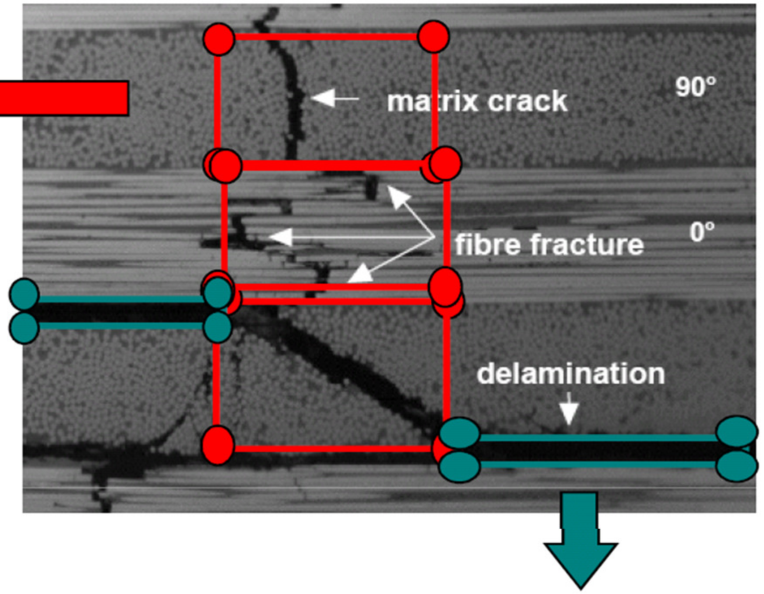
layered thin shell elements
+ numerical „cheap“ (thickness has no influence on critical time step size)
+ combination of single layers to sublaminates
- no stresses in thickness dir.



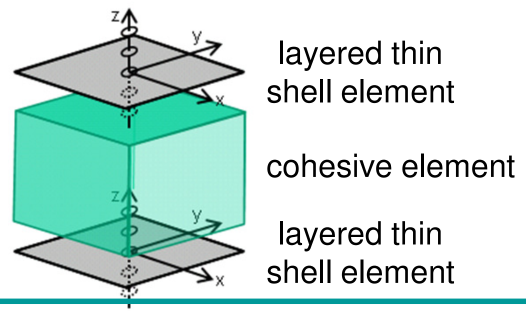
layered thick shell elements
+ 3D stress state
+ combination of single layers to sub-laminates
- thickness influences the critical time step size



solid elements
+ 3D stress state
- one element for every single layer
→ numerical „expensive“

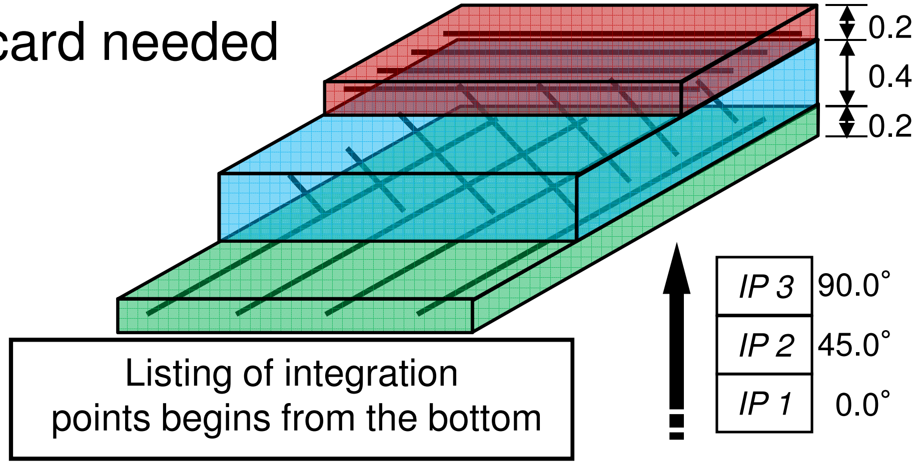


interlaminar
- cohesive elements
- tiebreak contacts



Ply definition with *PART_COMPOSITE(_TSHELL)

- Part-wise definition of lay-ups
- No *SECTION_SHELL-keyword card needed
- Material models, thicknesses and angles are defined for each layer
- Add as many cards as necessary

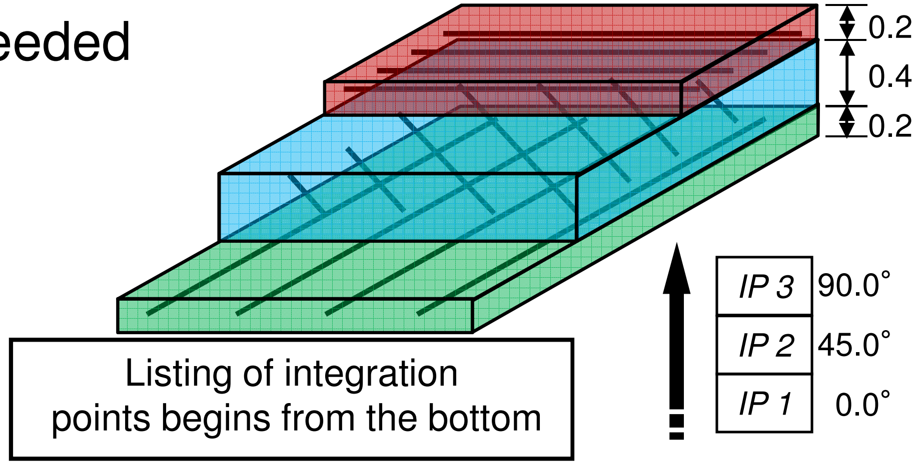


***PART_COMPOSITE(_TSHELL)**

	1	2	3	4	5	6	7	8
Card 1	PID	ELFORM	SHRF	NLOC	MAREA	HGID	ADOPT	
	28	2	0.0	0.0				
Card 2	MID1	THICK1	BETA1		MID2	THICK2	BETA2	
	1	0.2	0.0		2	0.4	45.0	
Card 3	MID3	THICK3	BETA3		MID4	THICK4	BETA4	
	3	0.2	90.0					
...								

Ply definition with *ELEMENT_(T)SHELL_COMPOSITE

- Element-Wise definition of lay-ups
- *SECTION_SHELL-keyword is needed
- Material models, thicknesses and angles are defined for each layer
- Add as many cards as necessary
- Allows the definition of different lay-ups within one part

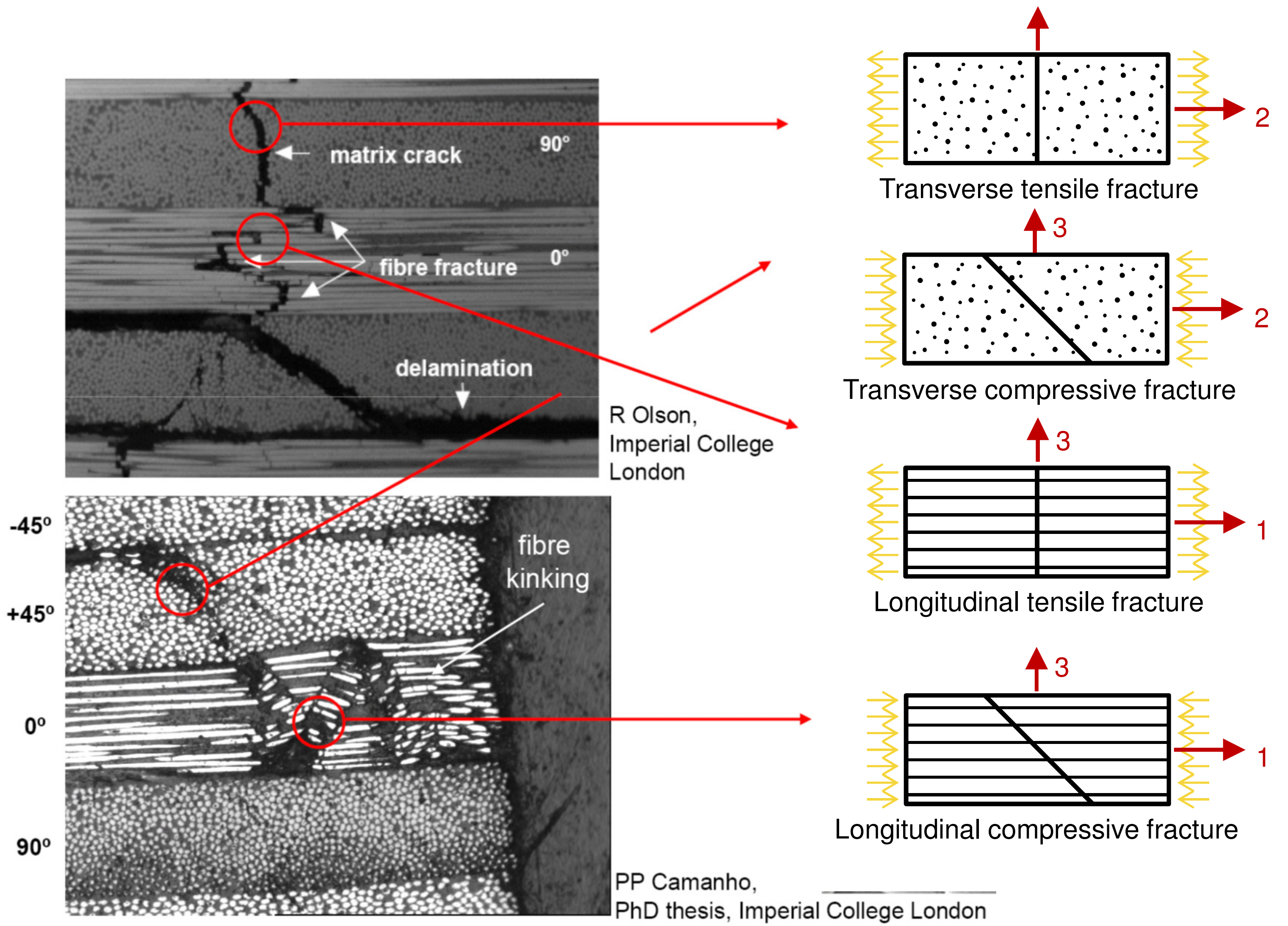


***ELEMENT_(T)SHELL_COMPOSITE**

	1	2	3	4	5	6	7	8	9	10
Card 1	EID	PID	N1	N2	N3	N4	N5	N6	N7	N8

	1	2	3	4	5	6	7	8
Card 2	MID1	THICK1	BETA1		MID2	THICK2	BETA2	
	1	0.2	0.0		2	0.4	45.0	
Card 3	MID3	THICK3	BETA3		MID4	THICK4	BETA4	
	3	0.2	90.0					
...								

Failure mechanisms in fiber reinforced composites



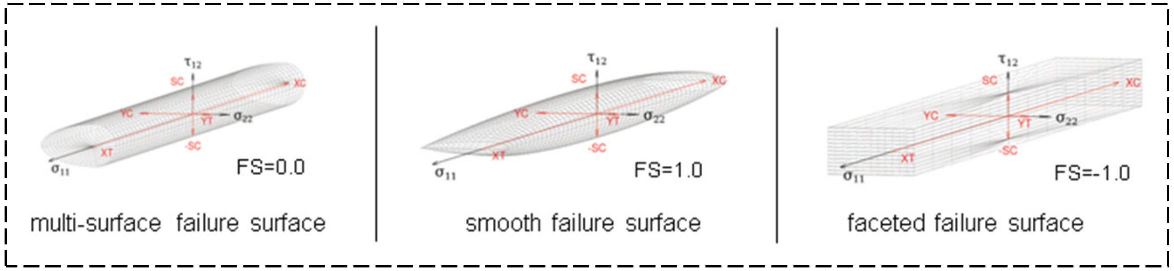
LS-DYNA: Available models for composite structures

- *MAT_022: (*MAT_COMPOSITE_DAMAGE)
  - plane stress
  - Chang-Chang failure criteria: fiber tension, matrix tension/compression
  - fiber compression is missing
  - "sudden" failure: E1,E2,nu12,G12 = 0.0

- *MAT_054/055: (*MAT_ENHANCED_COMPOSITE_DAMAGE)
  - plane stress
  - failure criteria (54: Chang-Chang – 55: Tsai-Wu):
    fiber tension/compression, matrix tension/compression
  - failure: stresses kept constant till failure strain reached,
    then: E1,E2,nu12,G12 = 0.0

LS-DYNA: Available models for composite structures

- *MAT_058: (*MAT_LAMINATED_COMPOSITE_FABRIC)
  - plane stress
  - Hashin failure criteria: fiber tension/compression, matrix tension/compression
  - exponential damage model

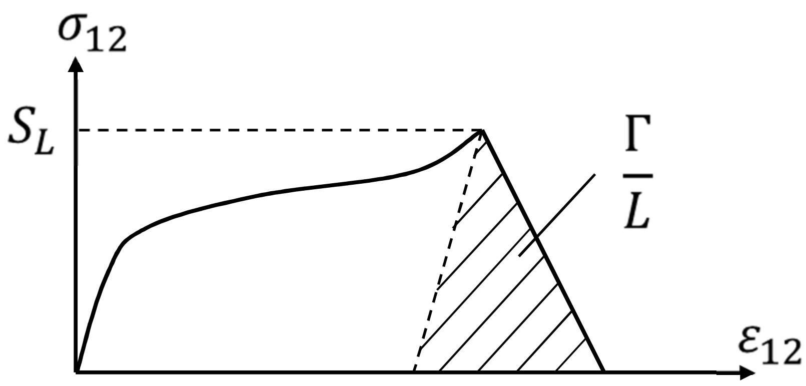


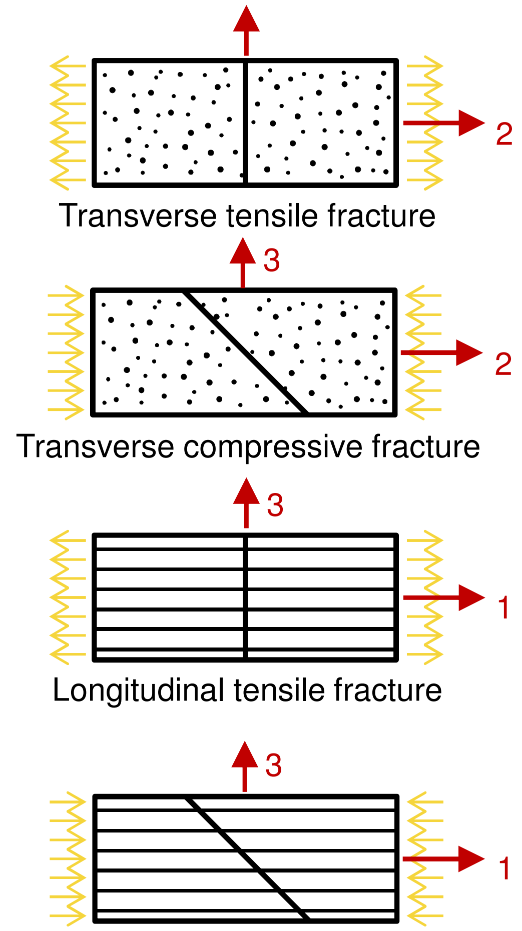
- *MAT_059: (*MAT_COMPOSITE_FAILURE_Option_MODEL)
  - Option: SHELL/SOLID

LS-DYNA: New models for composite structures

New!

- *MAT_261: (*MAT_LAMINATED_FRACTURE_DAIMLER_PINHO)
  - Coupled failure criterion based on 3D-stress state
  - complex 3D-fibre kinking model
  - Matrix failure invokes search for controlling fracture plane
  - linear softening law based on fracture toughness
  - 1D-plasticity-model (mixed hardening) for in-plane shear behavior defined by load curve

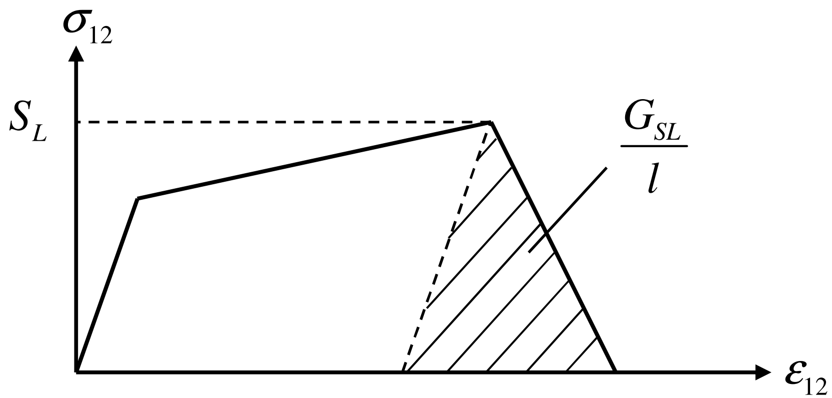


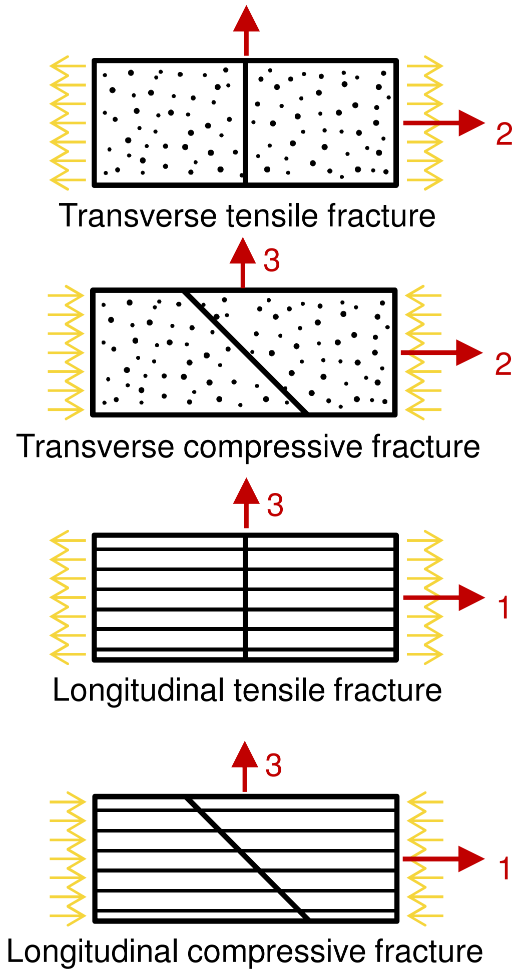


LS-DYNA: New models for composite structures

New!

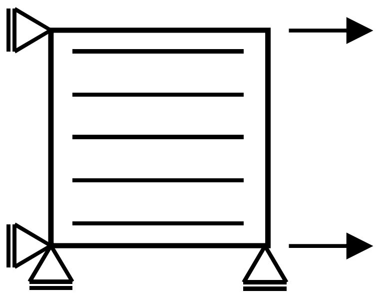
- *MAT_262: (*MAT_LAMINATED_FRACTURE_DAIMLER_CAMANHO)
  - Coupled failure criterion based on 2D-stress state
  - Constant fiber misalignment angle based on shear and longitudinal compressive strength
  - Matrix failure with fixed planes
  - (Bi-)linear softening law based on fracture toughness
  - 1D-plasticity-model (linear mixed hardening) for in-plane shear behavior





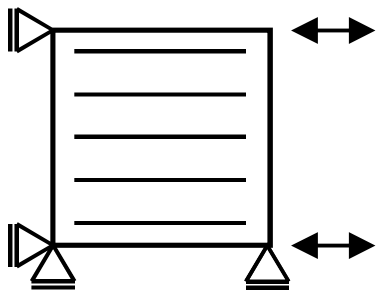
Comparison of different material models

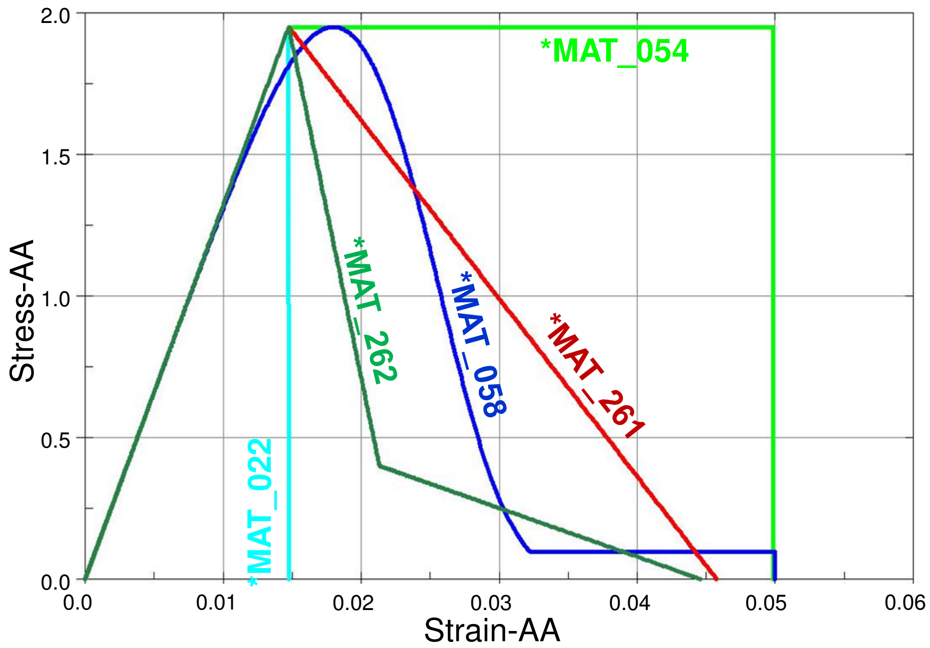
fiber tensile load (A-E)

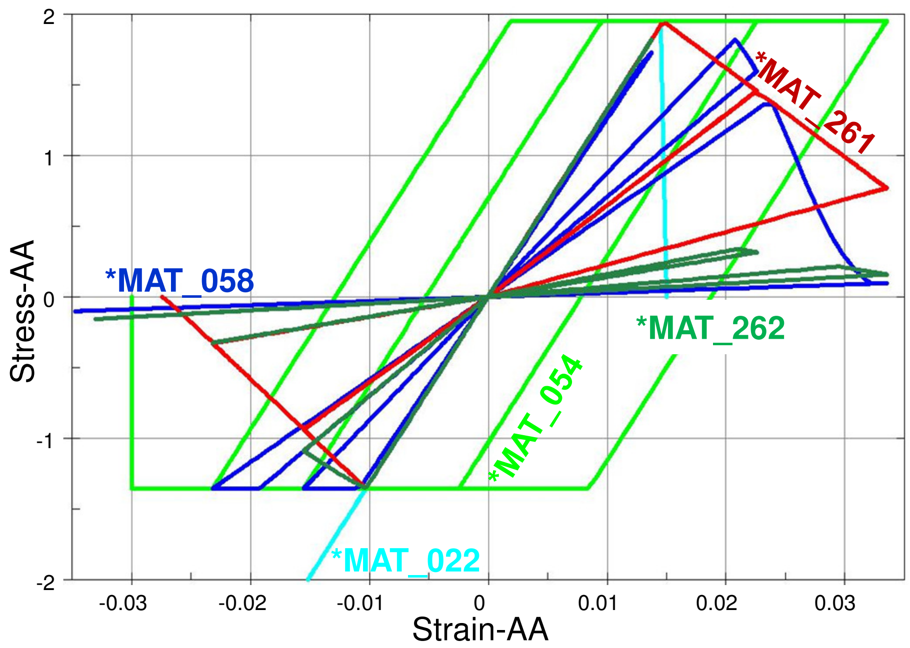


Material Parameter:
EA= 132.0 [kN/mm²]
XT= 1.95 [kN/mm²]
XC= 1.35 [kN/mm²]
… (model dependent)

fiber fiber cyclic load (A-K)

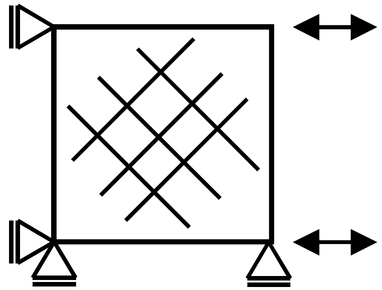




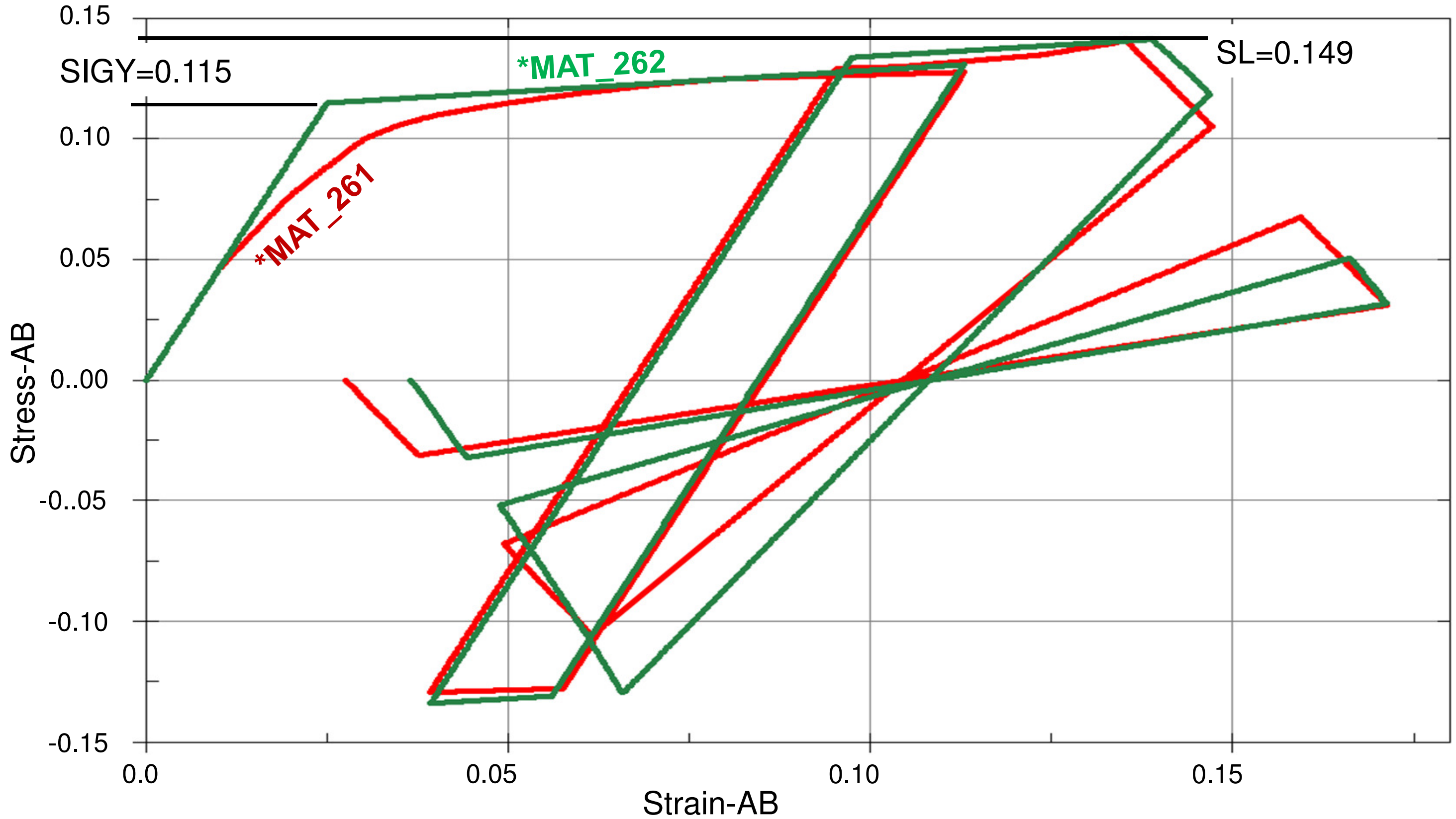


DYNA MORE

Comparison of different material models



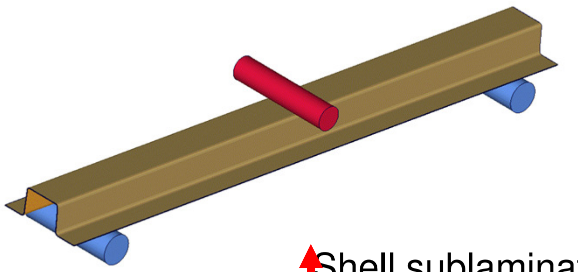
- 1-Element-Test, Single-Layer (‚SHELL‘, ELFORM=2)
- Cyclic test with a +/-45° layup (A-M)



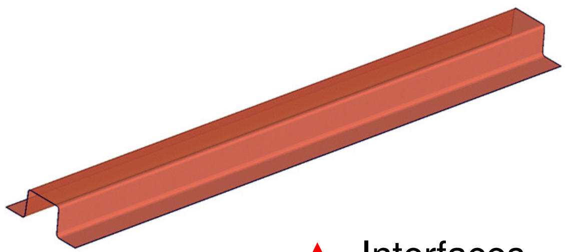
Preliminary results

three point bending of a hat profile

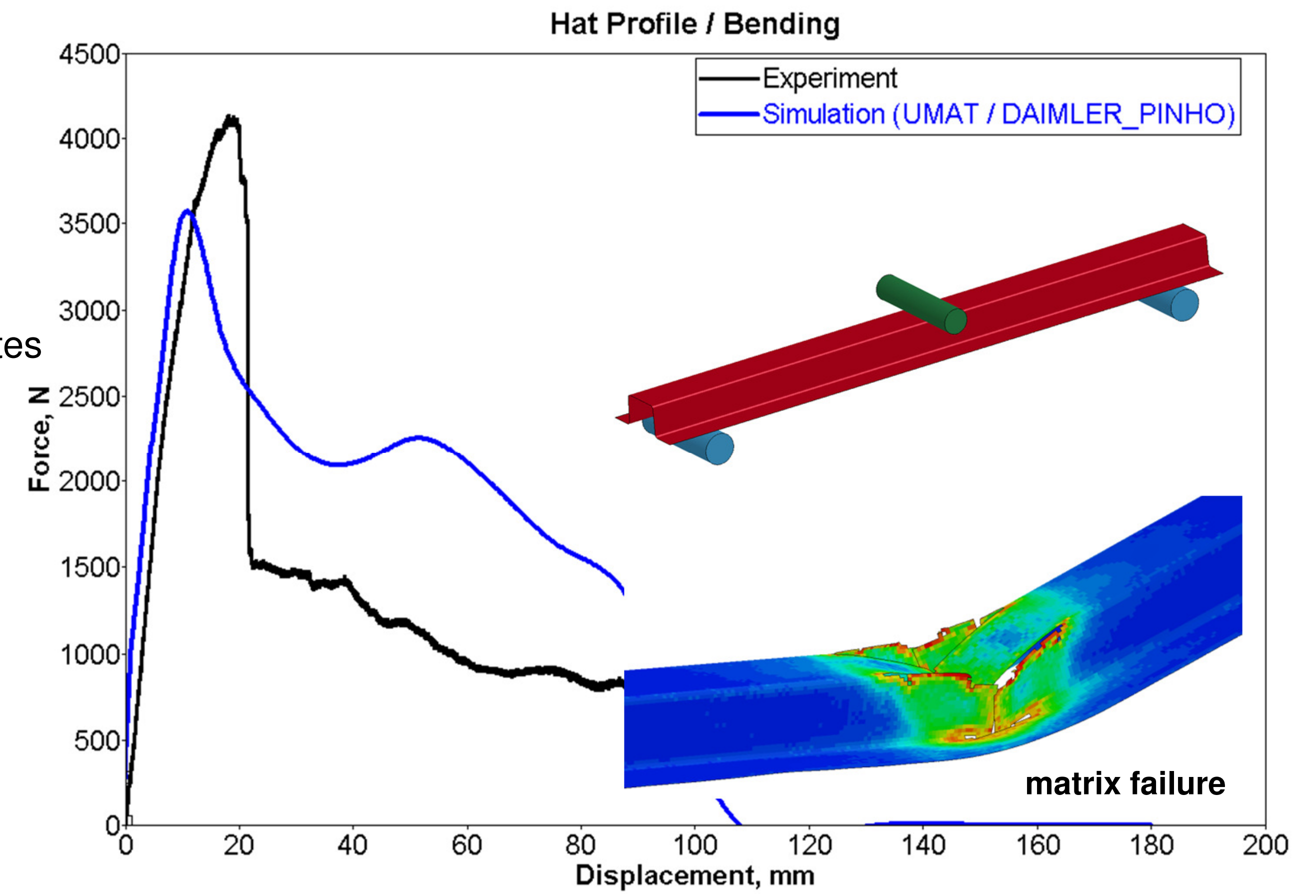
- single shell with a thickness of 2mm / carbon fibers in epoxy resin
  - [90°/0°/45°/-45°/0°/90°/-45°/45°/0°/90°]



Shell sublaminates
Local failure



Interfaces
Local failure



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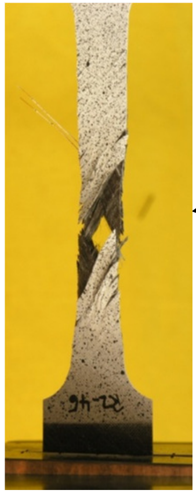
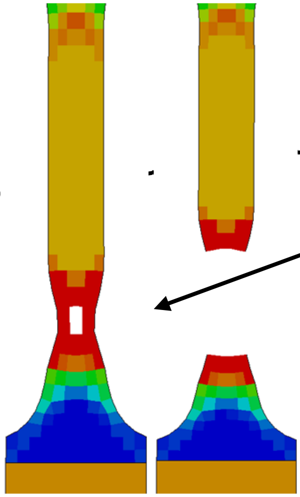
DYNA MORE

shear specimen

- single shell with a thickness of 2mm / carbon fibers in epoxy resin - [45°/-45°]$_{3S}$

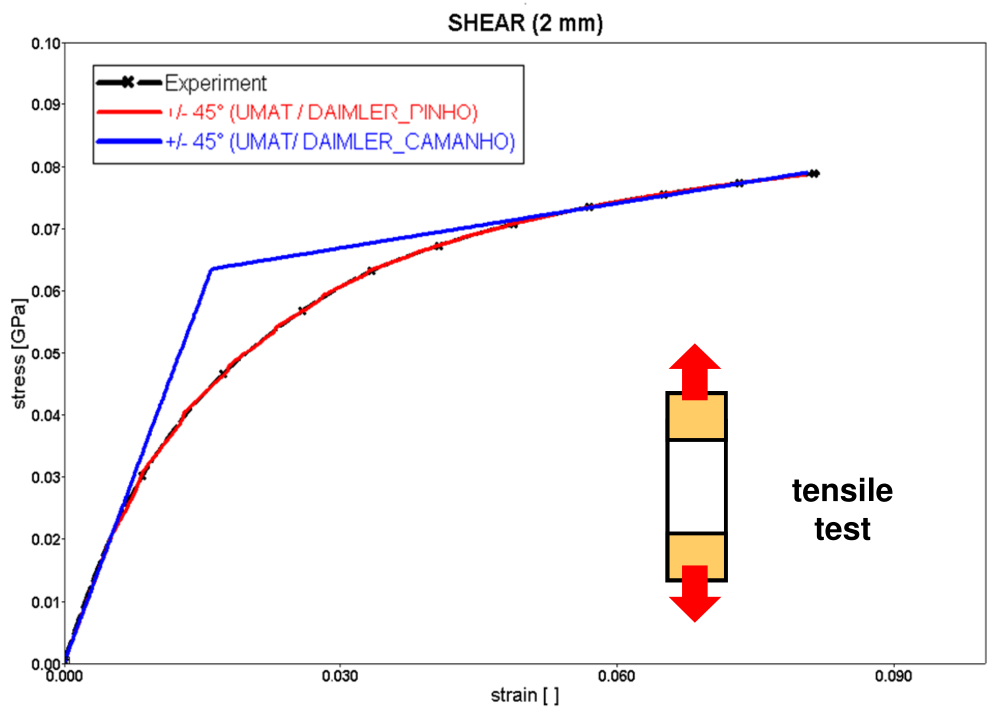


Experiment



Simulation

Shear plasticity



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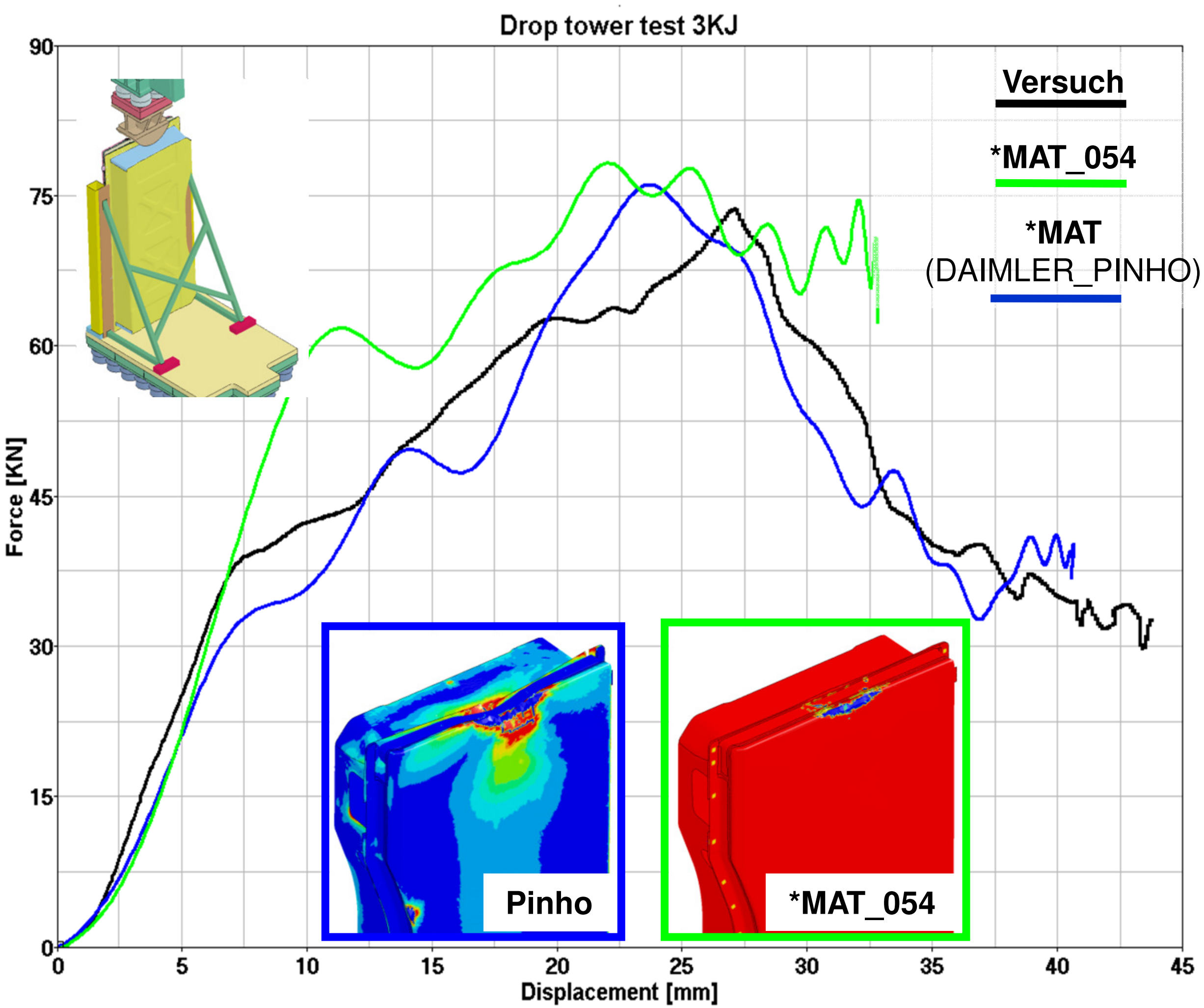
FEUP Faculdade de Engenharia

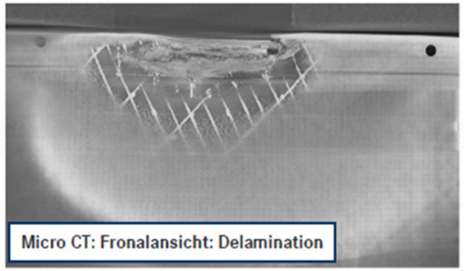
DYNA MORE

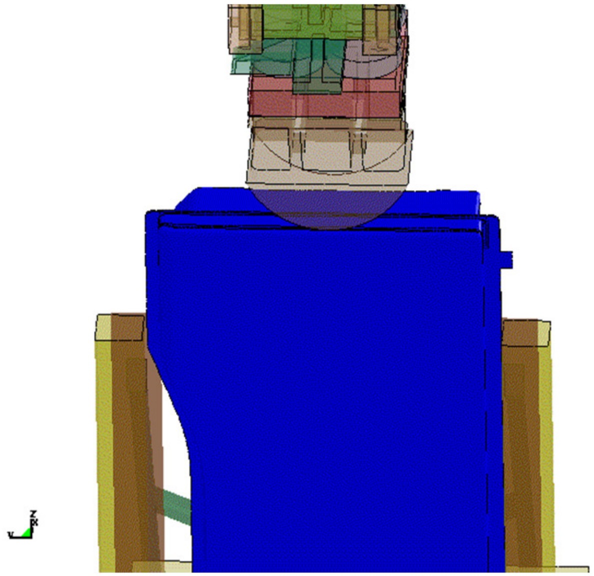
Preliminary results

CFRP Box, Carbon-Epoxy



CT: Evaluation of damage





DAIMLER

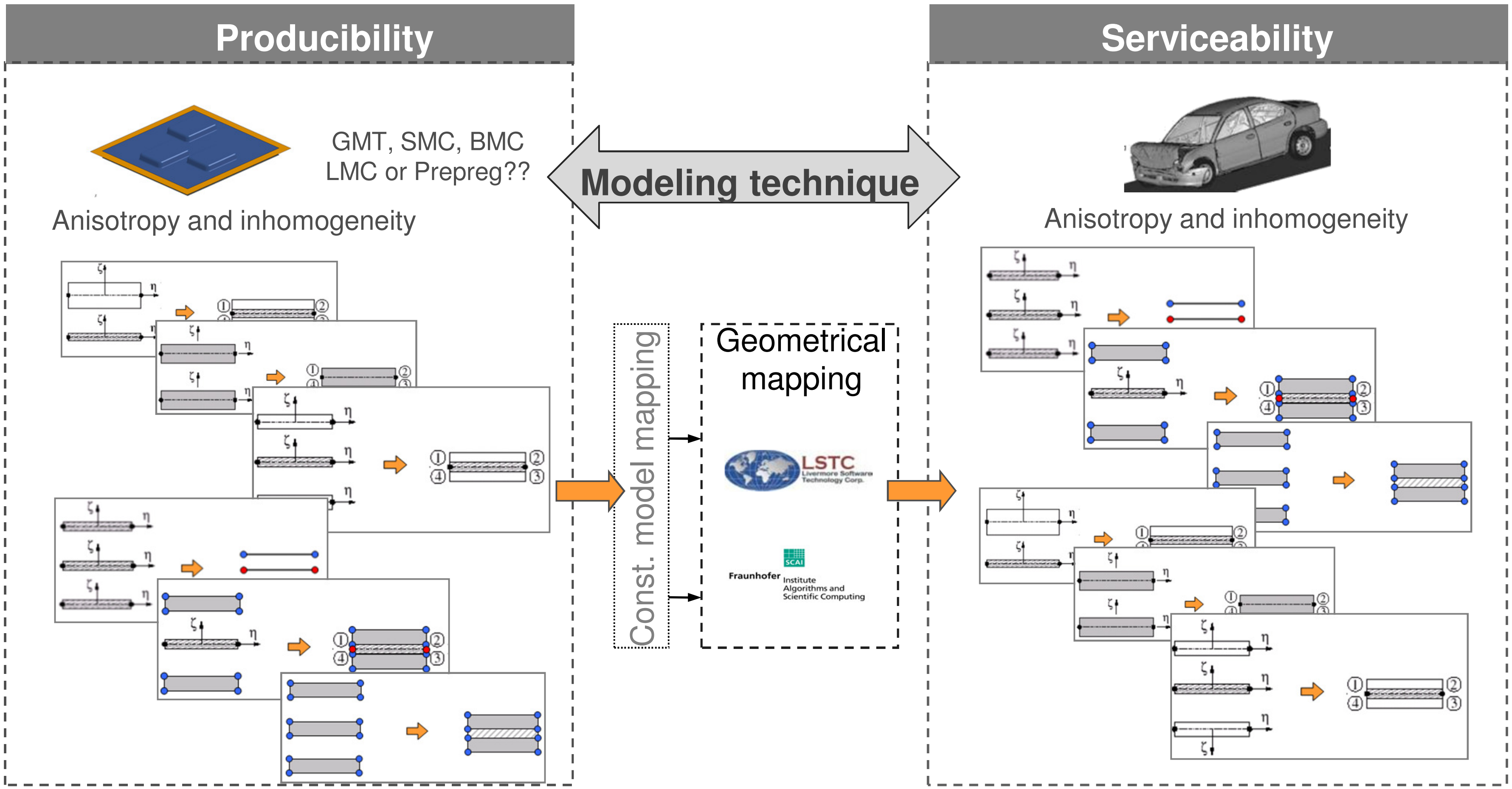
DYNA MORE

Agenda

- Process simulation
  - Winding and Braiding
  - Draping
  - Thermoforming
- Crashworthiness analysis
  - Short and long fiber reinforced plastics
  - Continuous fiber reinforced plastics
- Mapping
- Summary

Mapping between producibility and serviceability

- Different applications use different modeling techniques, constitutive models, standards and validation procedures.

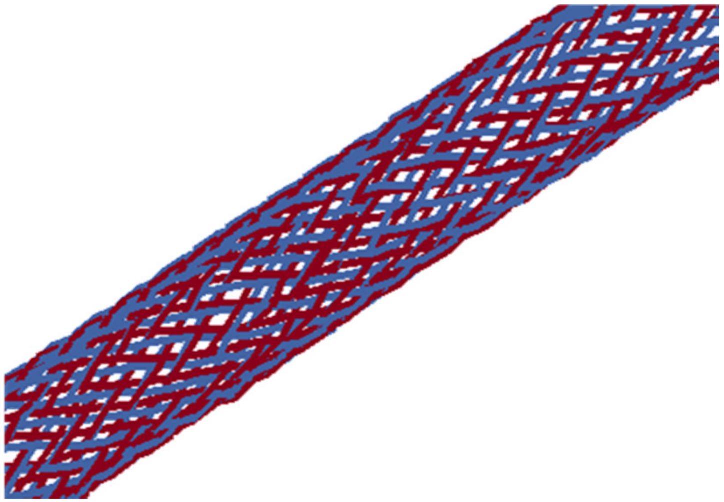


Mapping between producibility and serviceability

- Source: Braiding Simulation
- Target: Crash structure discretized with shell elements

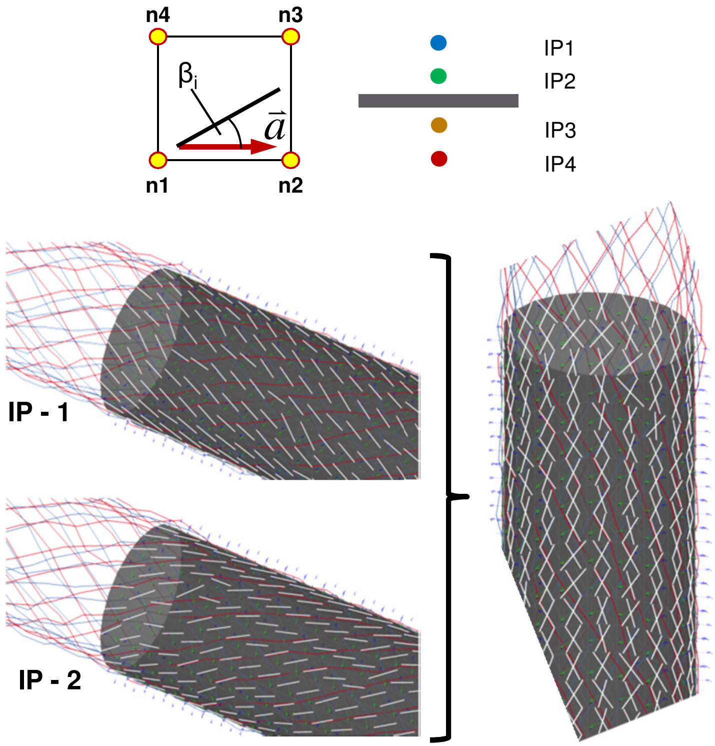
Producibility

- Fiber orientation defined by beam elements
- Structure organized in different parts



Serviceability

AOPT = 0

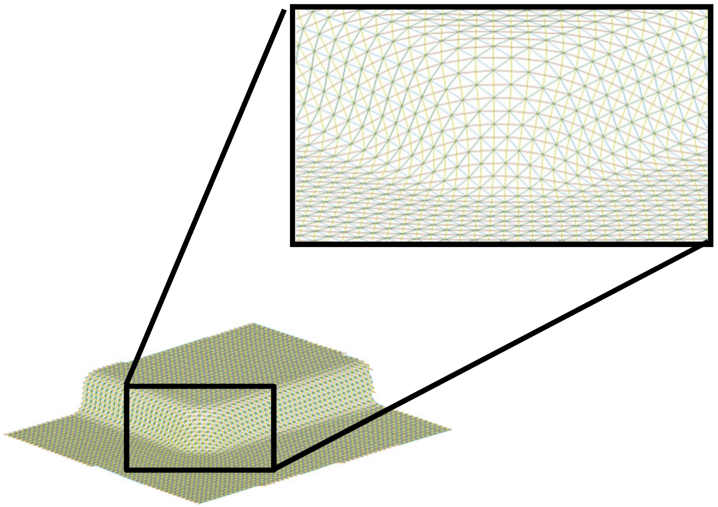


Mapping between producibility and serviceability

- Source: Draping Simulation with beam elements
- Target: Crash structure discretized with shell elements

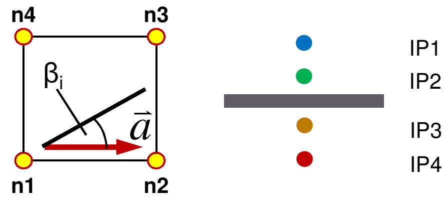
Producibility

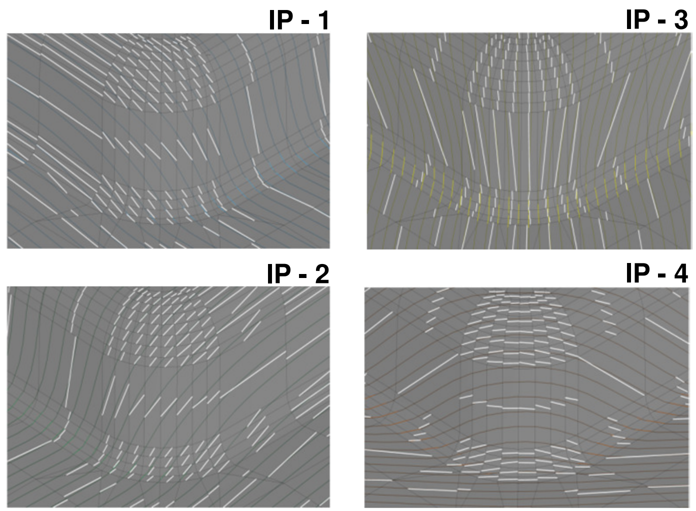
- Fiber orientation defined by beam elements
- Each part defines a different fiber family



Serviceability

AOPT = 0



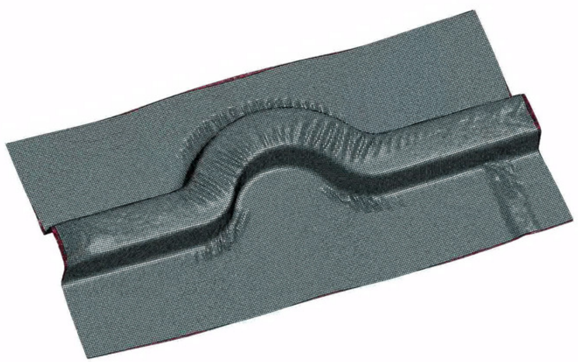


Mapping between producibility and serviceability

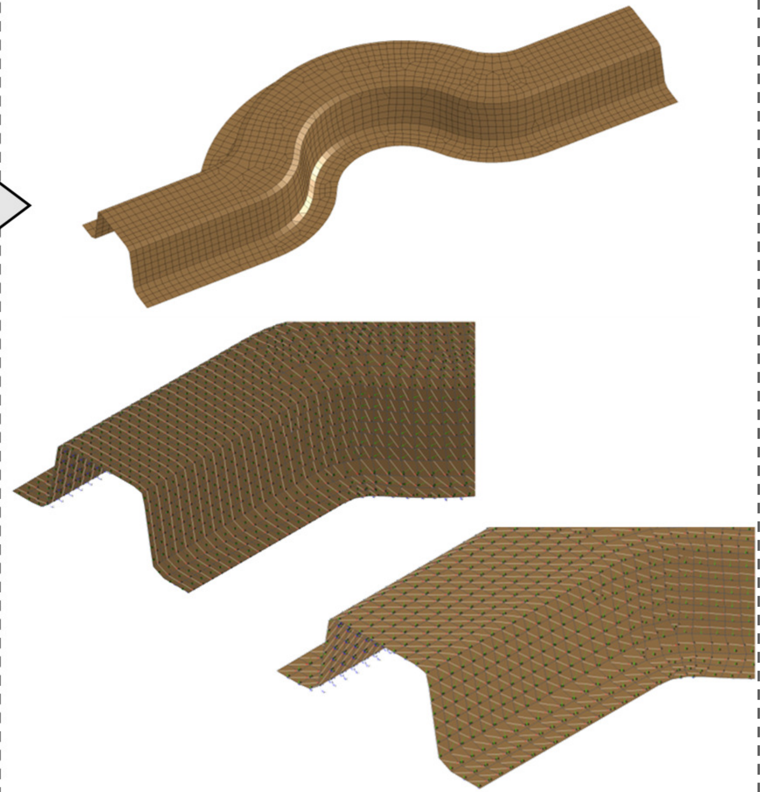
- Source: Draping Simulation with beam elements
- Target: Crash structure discretized with shell elements

Producibility

- Draping with *MAT_249
- Fiber directions are internal variables of the material formulation



Serviceability



Agenda

- Process simulation
  - Winding and Braiding
  - Draping
  - Thermoforming

- Crashworthiness analysis
  - Short and long fiber reinforced plastics
  - Continuous fiber reinforced plastics

- Mapping

- Summary

Summary

- Process simulation with LS-DYNA
  - Tailored modeling techniques for different length scales
  - Examples for winding, braiding and draping processes
  - New thermo-mechanical material model for thermoplastic prepregs

- Serviceability
  - New features for short and long fiber reinforced plastics (work in progress)
  - A variety of different material models for simulation of continuous fiber reinforced plastics

- Mapping
  - Between different length scales
  - Between different modeling approaches

Thank you very much for your attention!

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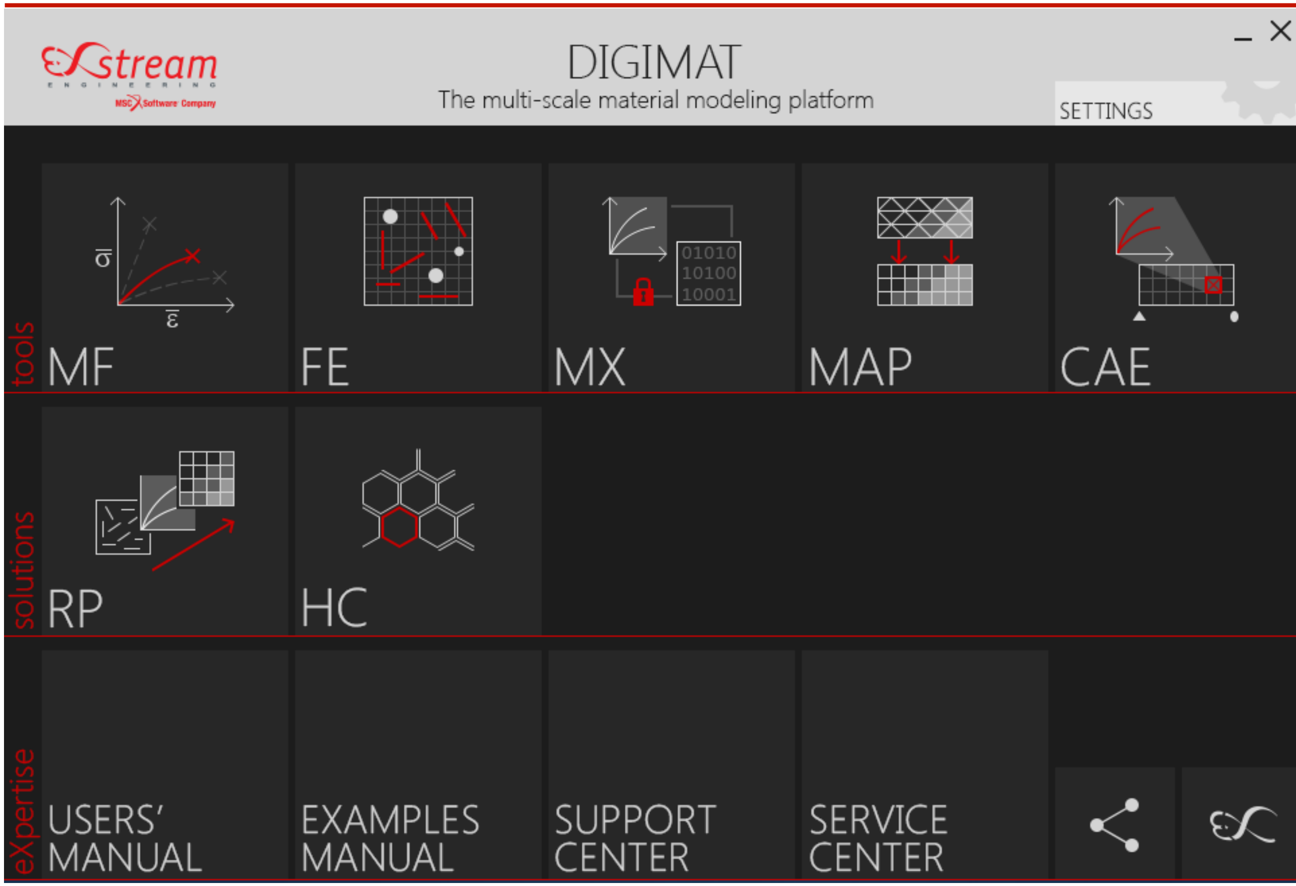
Acknowledgement

The research leading to these results has received funding from the Federal Ministry of Education and Research in the project “T-Pult” and from the Federal Ministry for Economic Affairs and Energy (Central Innovation Program SME) in the project “Swim-RTM”.

Process Chain Modeling

Composite Materials

April 2014



Dr. Jan Seyfarth

Product Manager Digimat

Email: Jan.Seyfarth@e-Xstream.com

Mobile: +49 (0)176 / 70 55 47 59

e-Xstream engineering

Company

- **Who are we…? A MSC Software Company!**

✓ **Team of 30+ persons**

- PhDs (65%)
- MS & BS Engineering (25%)
- Marketing, Finance & Admin (10%)

✓ **Material experts**

- Micromechanics

Amsterdam, October 2012

✓ **It's all about…**

COMPOSITES

- **Worldwide Partner Network**

✓ **Material Experts**

- Material Suppliers

✓ **Service Providers**

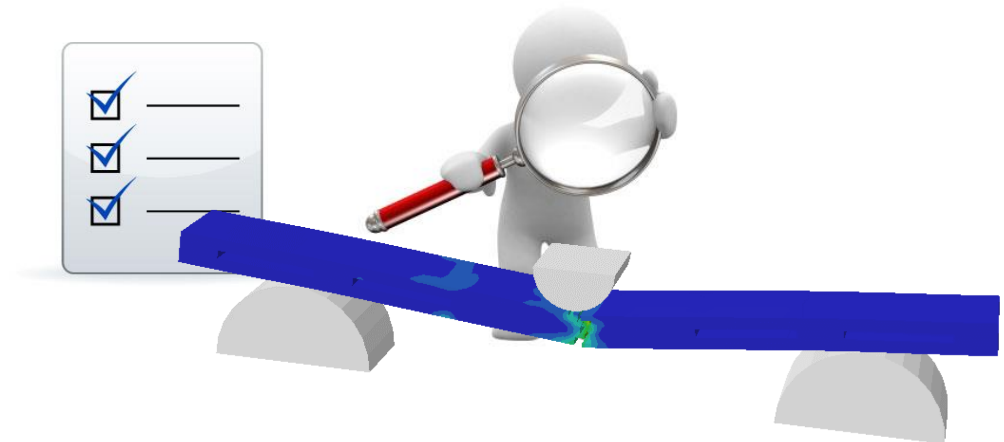
- Industrial
- R&D

– **Software**

- **Providers**
- **Resellers**

Process Chain Modeling

Composite Materials

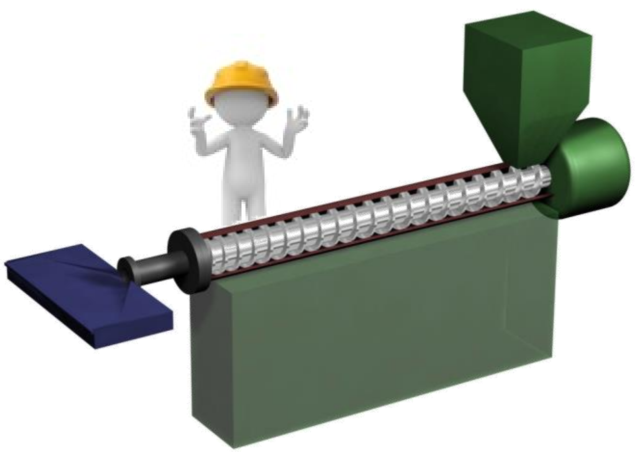


DESIGN

Final performance

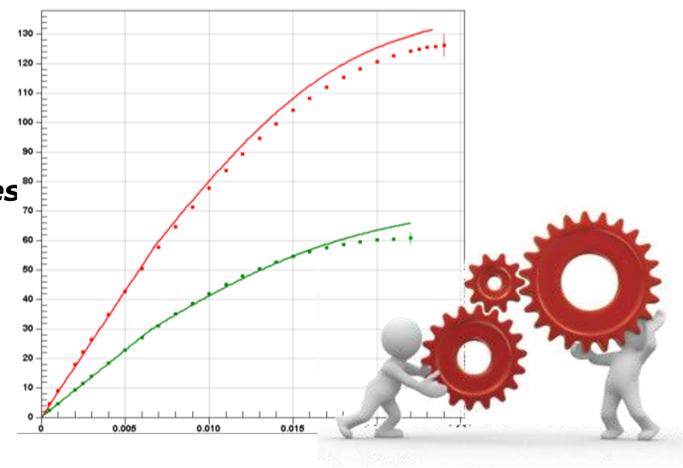
MANUFACTURING

Local microstructure



MATERIAL

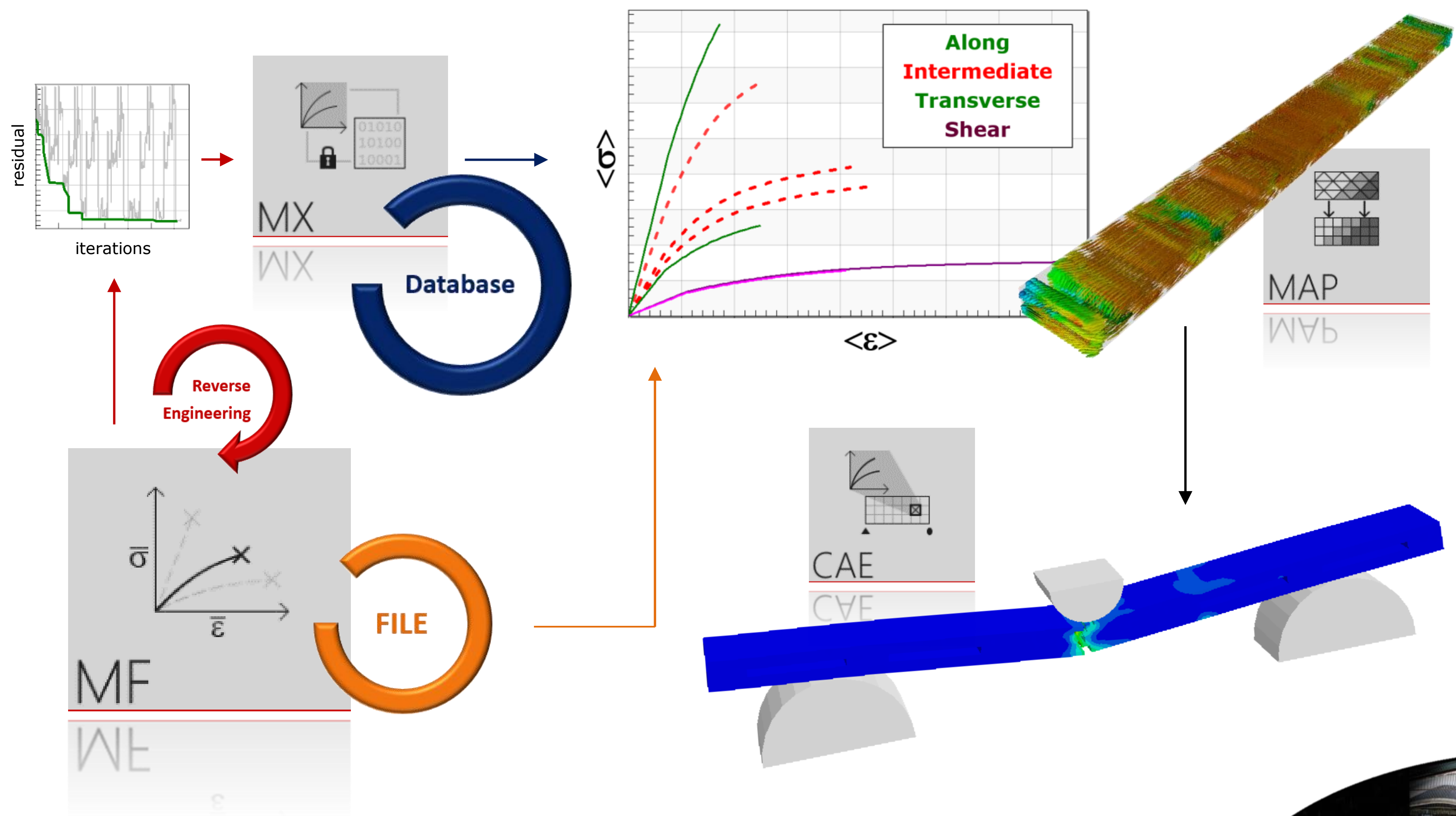
Distributed properties



Process Chain Modeling

Composite Materials

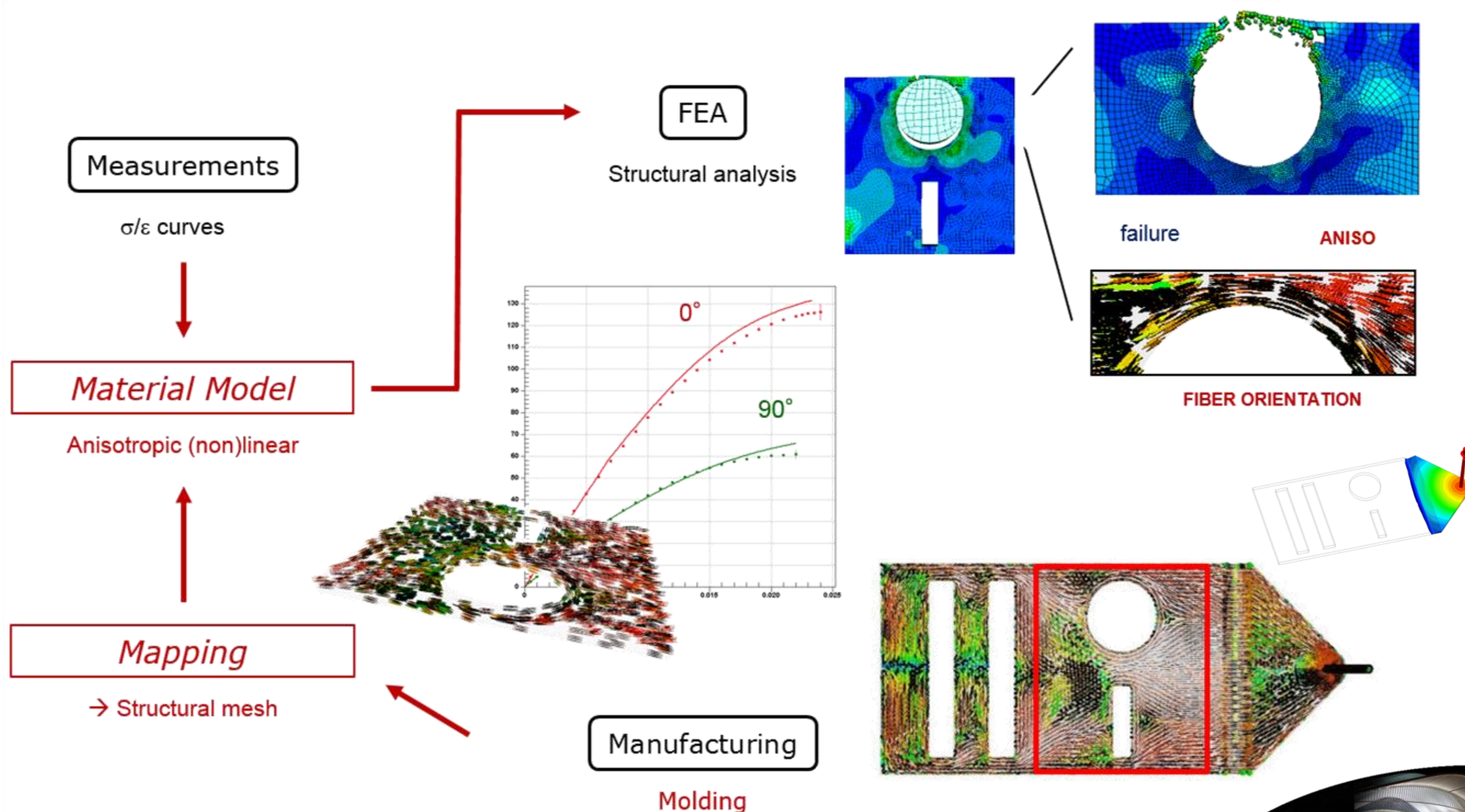
- Workflow – From Material to Structural Engineering



Process Chain Modeling

Composite Materials

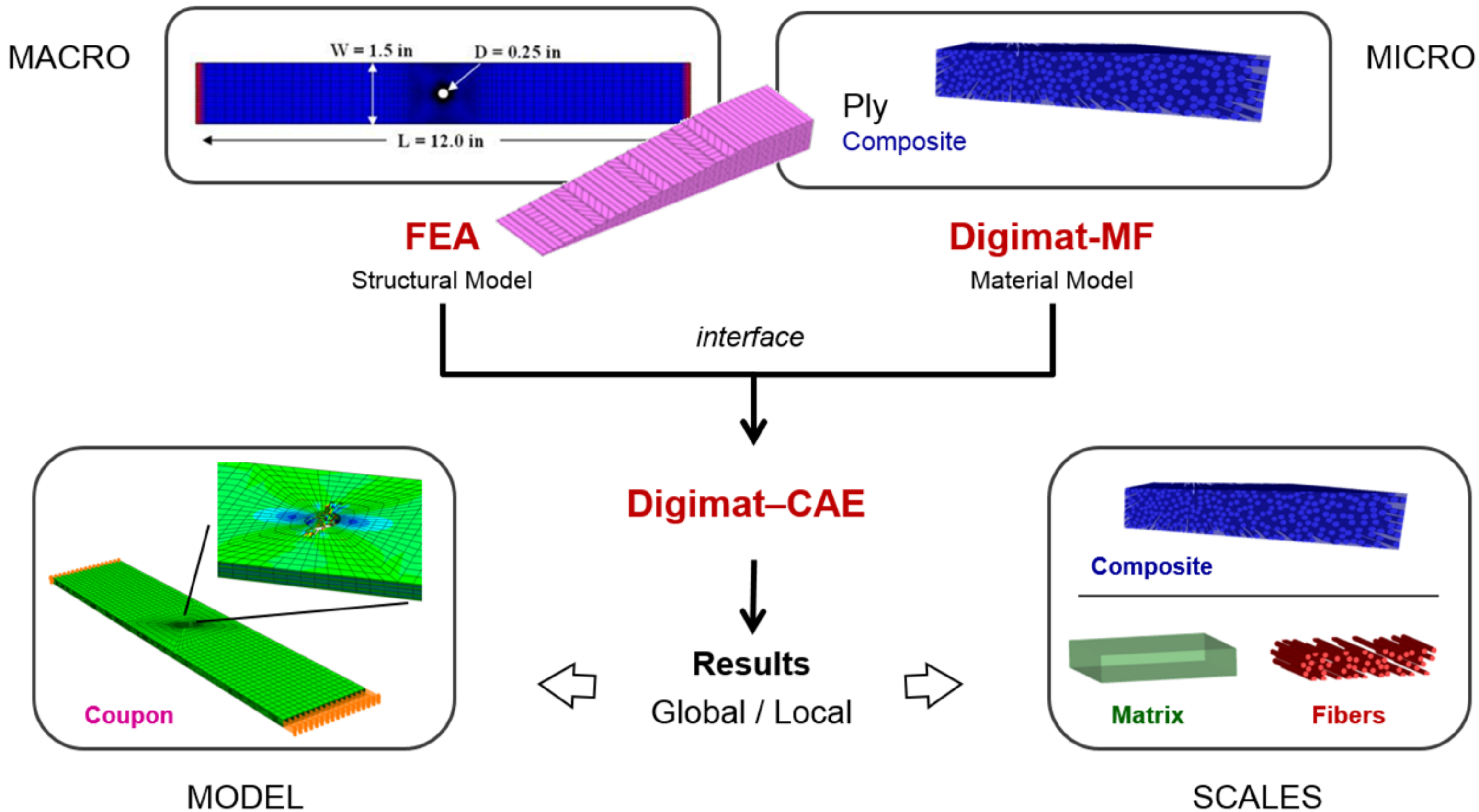
- Short Fiber Reinforced Plastics → Molding Impact on Stiffness & Failure



Process Chain Modeling

Composite Materials

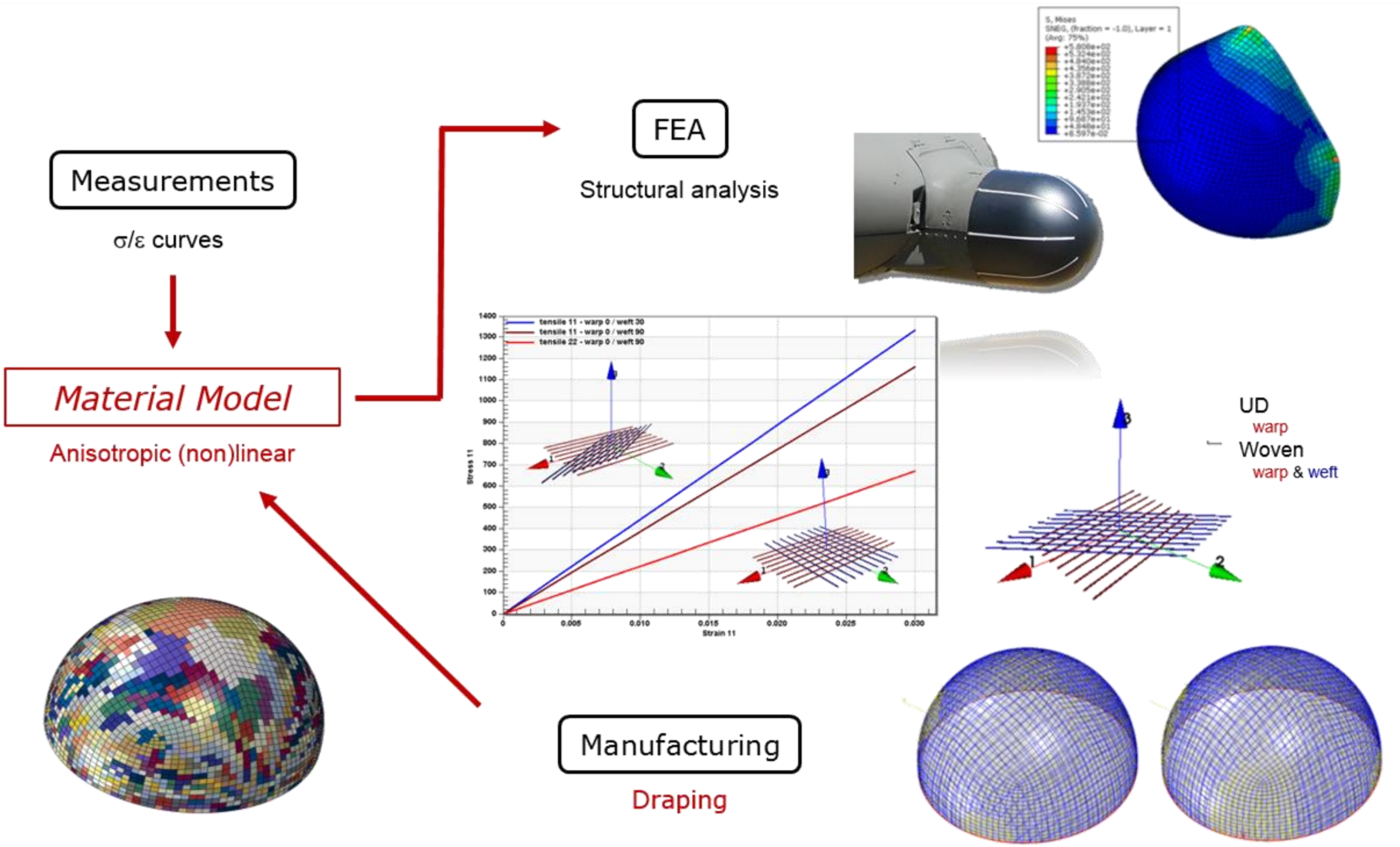
- UD Composites → Micro / Macro Bridging the Scales



Process Chain Modeling

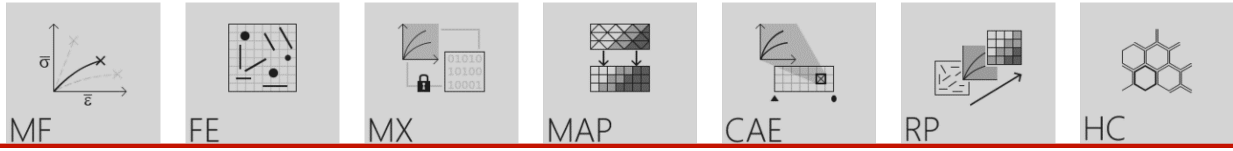
Composite Materials

- Woven Composites → Draping Impact on Stiffness & Failure

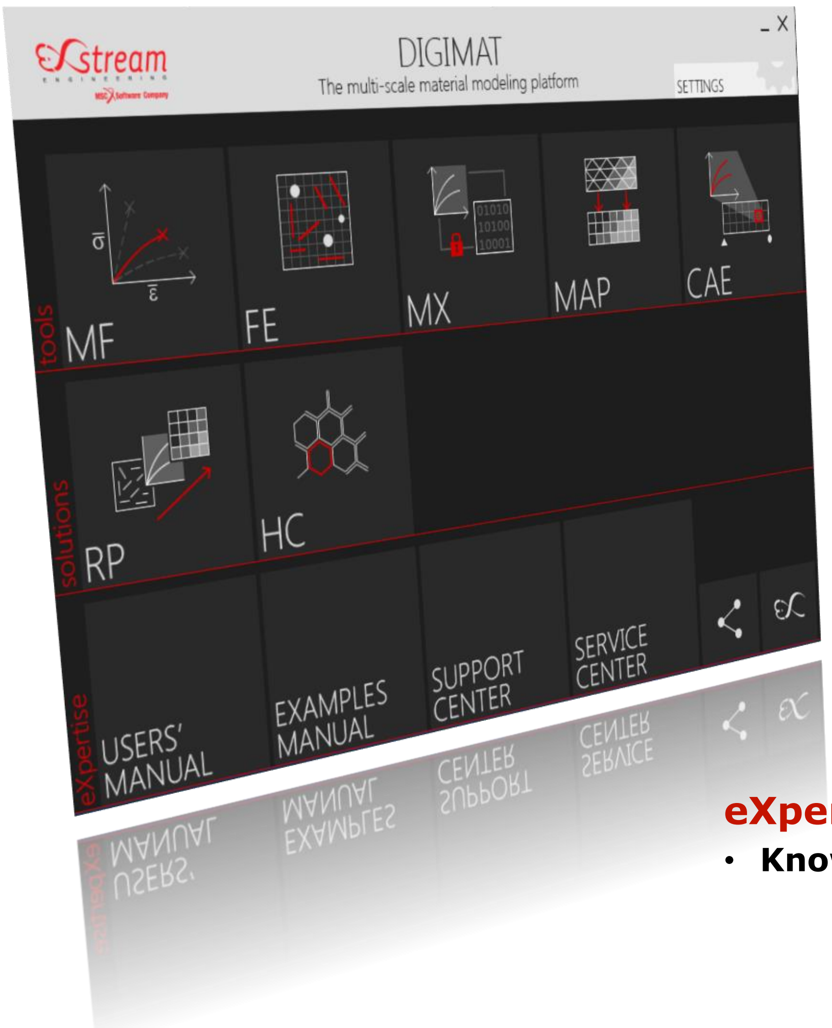


Digimat

Software



Nonlinear Multi-Scale Modeling Platform



Tools

- **For experts**
- **Modular environment**

Solutions

- **For designers**
- **Integrated environments**
- **Workflow oriented**

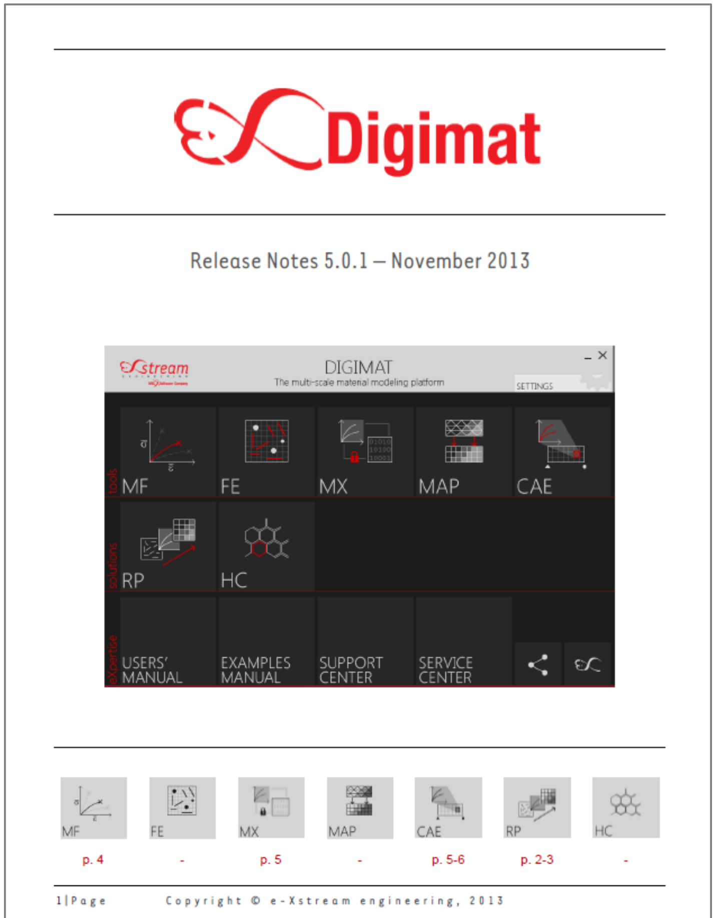
eXpertise

- **Knowledge transfer**

Digimat
Software

April 2014

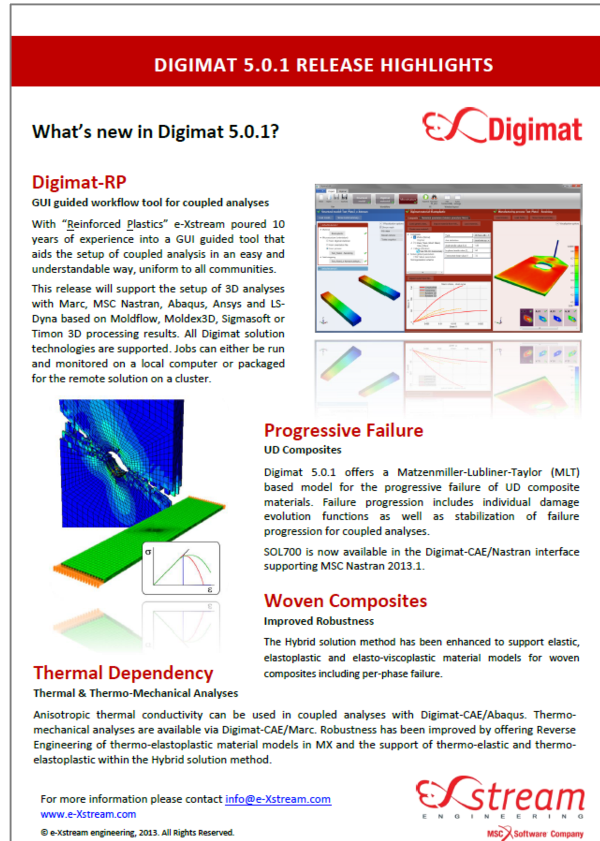
Release Notes & Highlights


Digimat

Release Notes 5.0.1 – November 2013

MF	FE	MX	MAP	CAE	RP	HC
p. 4	-	p. 5	-	p. 5-6	p. 2-3	-

1|Page   Copyright © e-Xstream engineering, 2013


DIGIMAT 5.0.1 RELEASE HIGHLIGHTS

What's new in Digimat 5.0.1?

Digimat

Digimat-RP

GUI guided workflow tool for coupled analyses

With "Reinforced Plastics" e-Xstream poured 10 years of experience into a GUI guided tool that aids the setup of coupled analysis in an easy and understandable way, uniform to all communities.

This release will support the setup of 3D analyses with Marc, MSC Nastran, Abaqus, Ansys and LS-Dyna based on Moldflow, Moldex3D, Sigmasoft or Timon 3D processing results. All Digimat solution technologies are supported. Jobs can either be run and monitored on a local computer or packaged for the remote solution on a cluster.

Progressive Failure

UD Composites

Digimat 5.0.1 offers a Matzenmiller-Lubliner-Taylor (MLT) based model for the progressive failure of UD composite materials. Failure progression includes individual damage evolution functions as well as stabilization of failure progression for coupled analyses.

SOL700 is now available in the Digimat-CAE/Nastran interface supporting MSC Nastran 2013.1.

Woven Composites

Improved Robustness

The Hybrid solution method has been enhanced to support elastic, elastoplastic and elasto-viscoplastic material models for woven composites including per-phase failure.

Thermal Dependency

Thermal & Thermo-Mechanical Analyses

Anisotropic thermal conductivity can be used in coupled analyses with Digimat-CAE/Abaqus. Thermo-mechanical analyses are available via Digimat-CAE/Marc. Robustness has been improved by offering Reverse Engineering of thermo-elastoplastic material models in MX and the support of thermo-elastic and thermo-elastoplastic within the Hybrid solution method.

For more information please contact info@e-Xstream.com
www.e-Xstream.com

e-Xstream engineering
MSC Software Company

Digimat

Software

CAE

5.0.1

- **MSC Nastran SOL400**
  - ✓ 2013.1
- **MSC Nastran SOL700**
  - ✓ 2013.1
- **Marc**
  - ✓ 2012 → Thermo-mechanical

MSC Software

- Abaqus
  - ✓ 6.12
- Ansys
  - ✓ 14.5 → Initial stresses…
- LS-Dyna
  - ✓ 6.1
- Radioss
  - ✓ v11

SIMULIA

ANSYS

LSTC Livermore Software Technology Corp.

Altair

HIGHLIGHTS 5.0.1

Progressive Failure
Hybrid for Woven

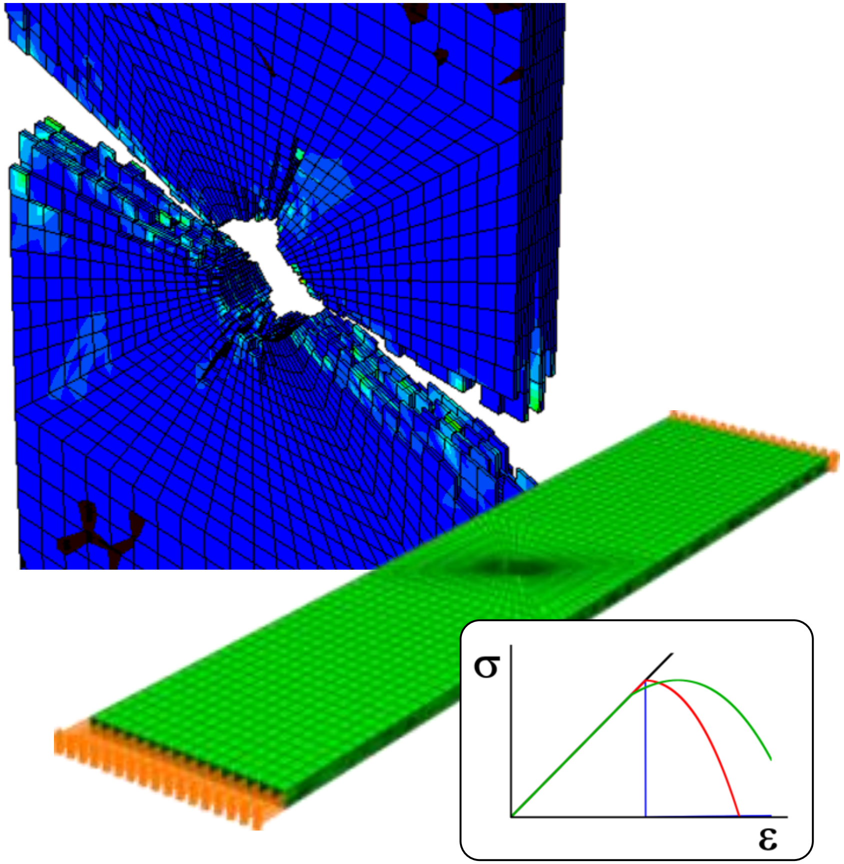
Progressive Failure

Highlights 5.0.1

UD Composites

✓ Macroscopic model

- **Stiffness**
  - Linear elasticity
- **Failure**
  - Hashin 2D
  - Hashin 3D
  - Hashin-Rotem 2D
- **Damage**
  - Matzenmiller / Lubliner / Taylor
  - Individual damage control functions
  - Stabilization of failure progression

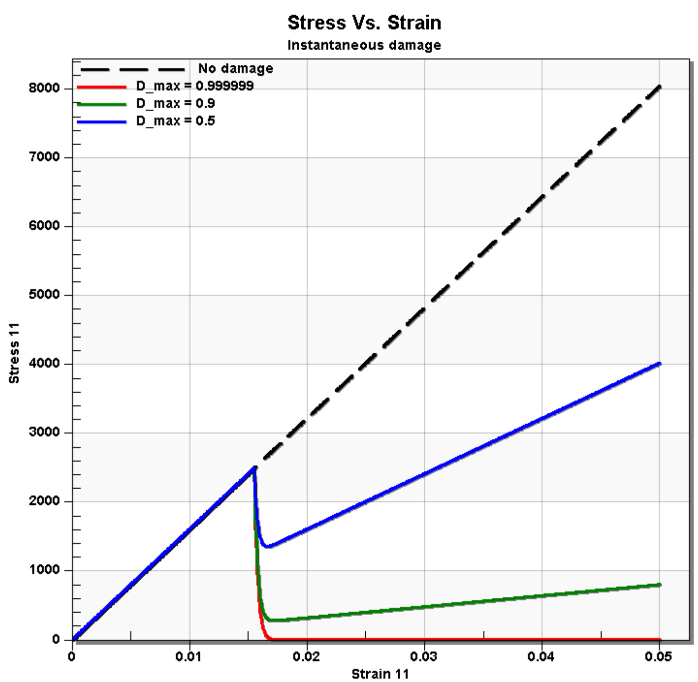


Progressive Failure

Highlights 5.0.1

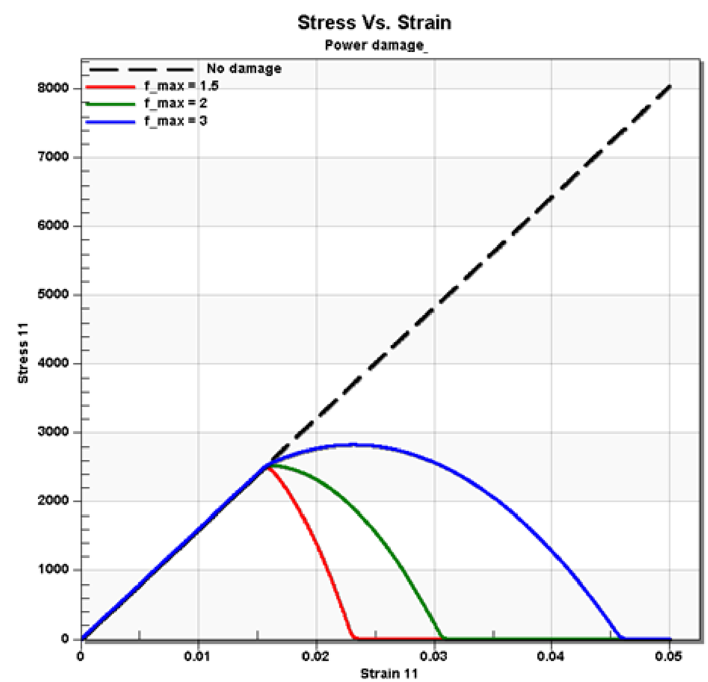
UD Composites

- ✓ Stiffness / Damage / Failure



Instantaneous failure

Remaining stiffness



Damage

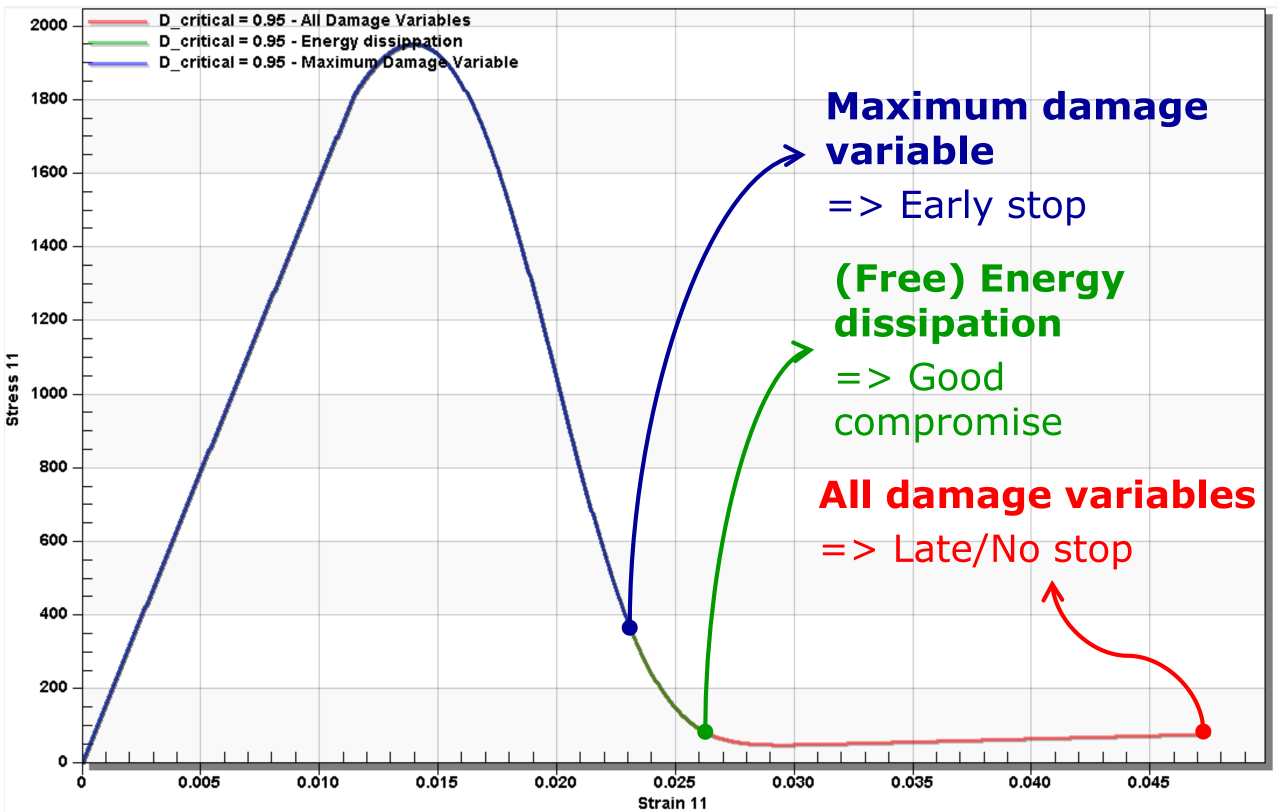
Complete failure

Progressive Failure

Highlights 5.0.1

UD Composites

- ✓ Analysis control by damage evaluation

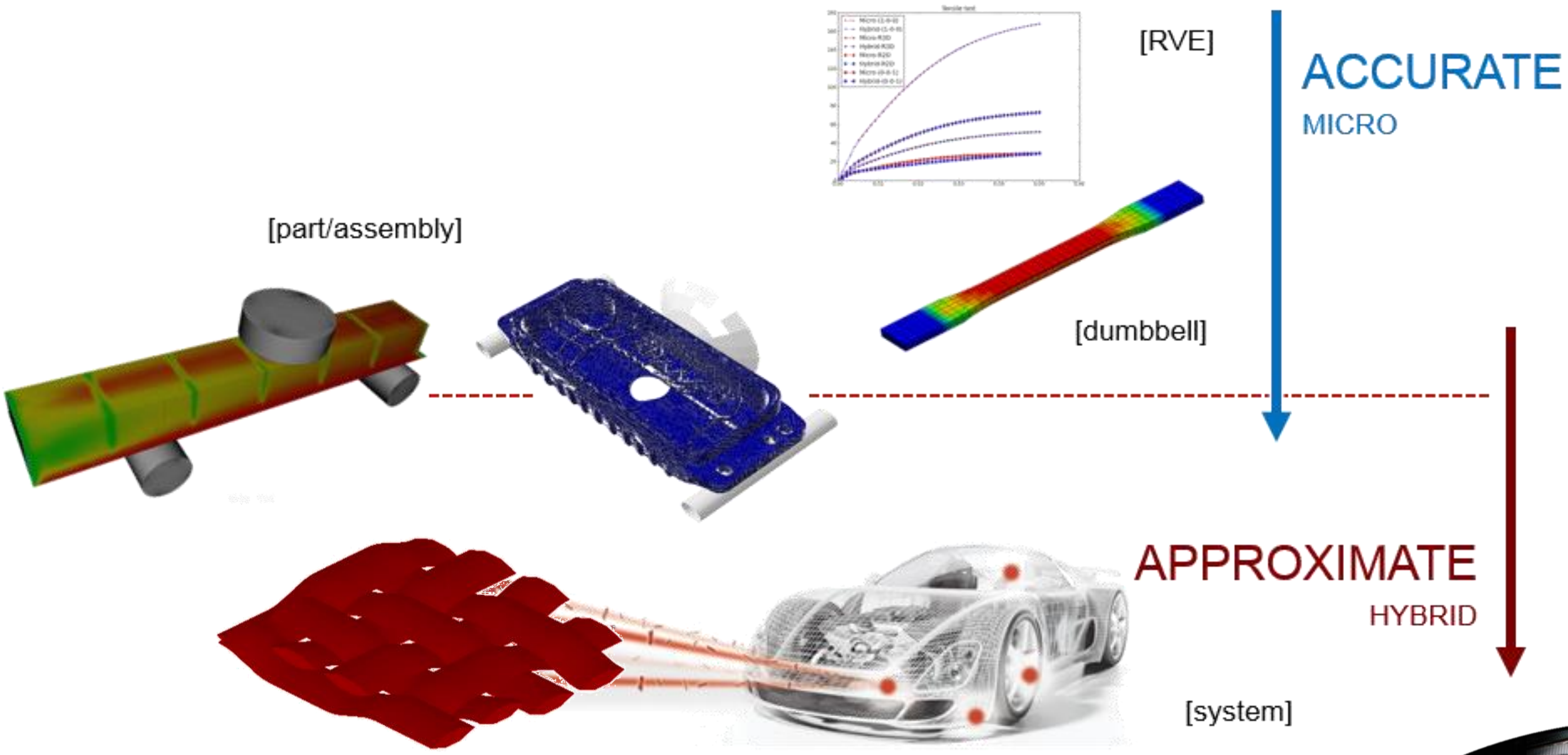


Hybrid for Woven

Highlights 5.0.1

Hybrid solution

✓ Towards system level…

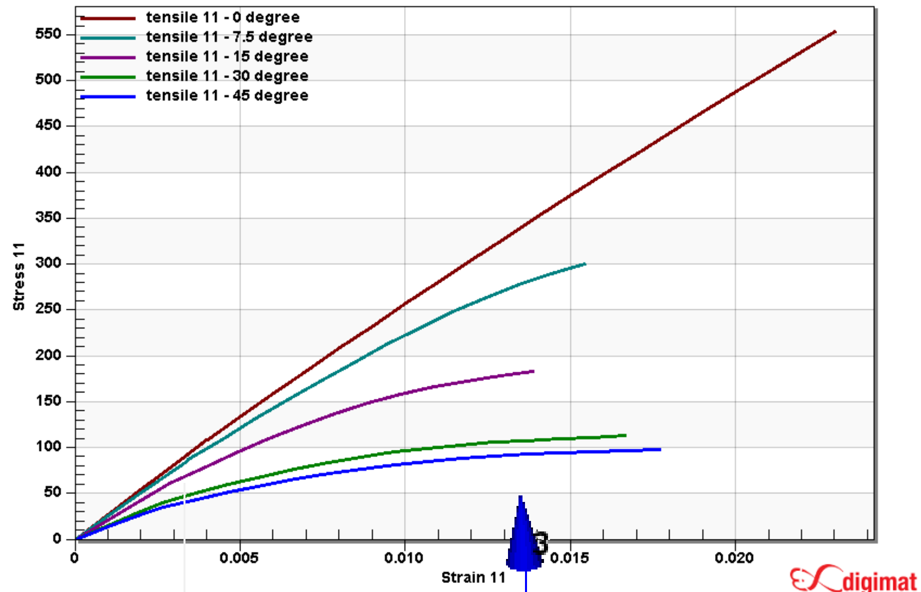


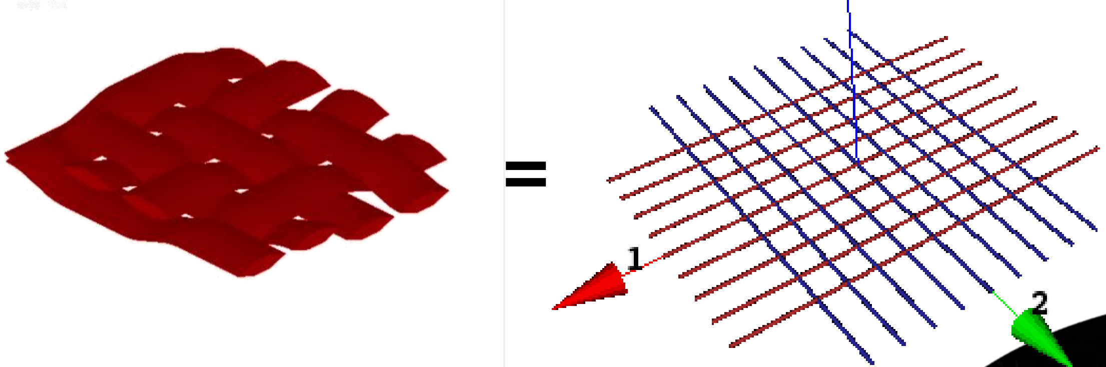
Hybrid for Woven

Highlights 5.0.1

Woven Composites

- ✓ Material model
  - Basic & homogeneous yarns
  - Stiffness
    - Elastic
    - Elastoplastic
    - Elasto-Viscoplastic
  - Failure
    - Per-phase



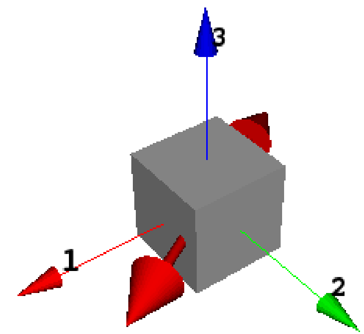


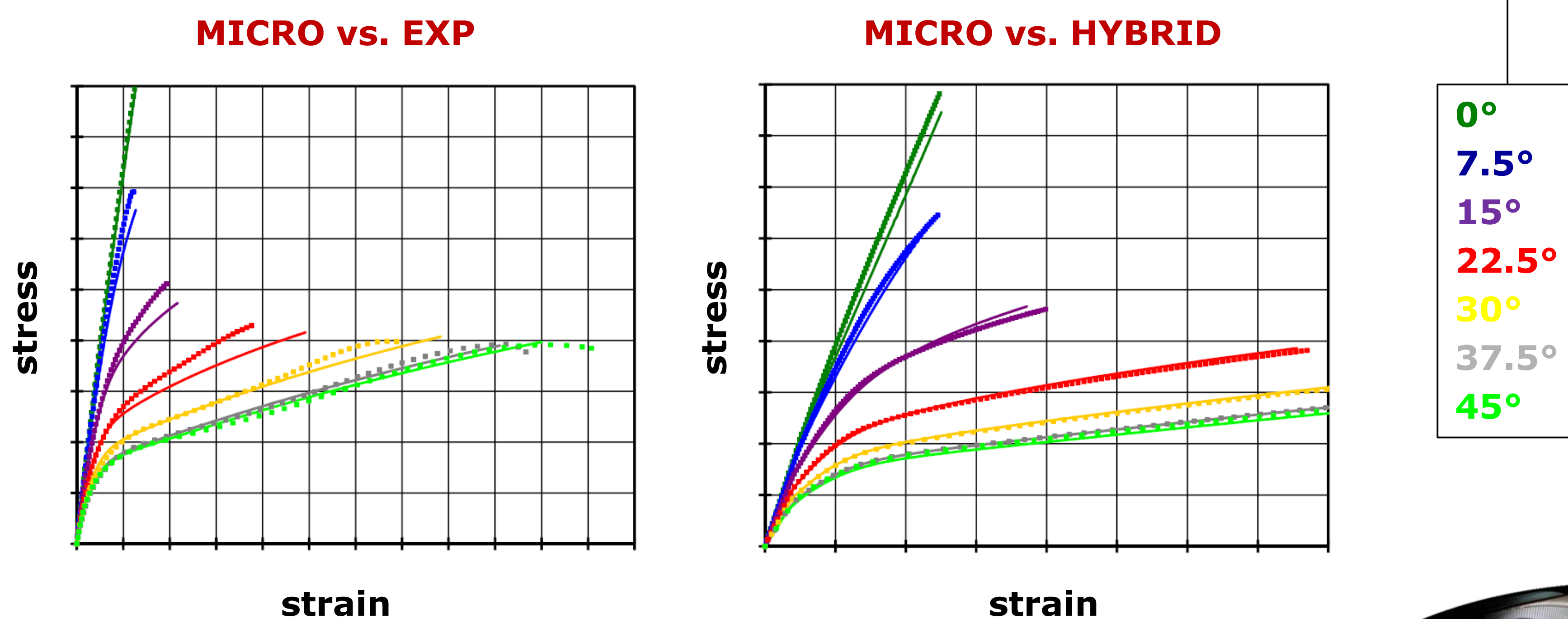
Hybrid for Woven

Highlights 5.0.1

Woven Composites

- ✓ Elastoplastic / failure
  - Excellent correlation with experiments





DIGIMAT CLASSICS

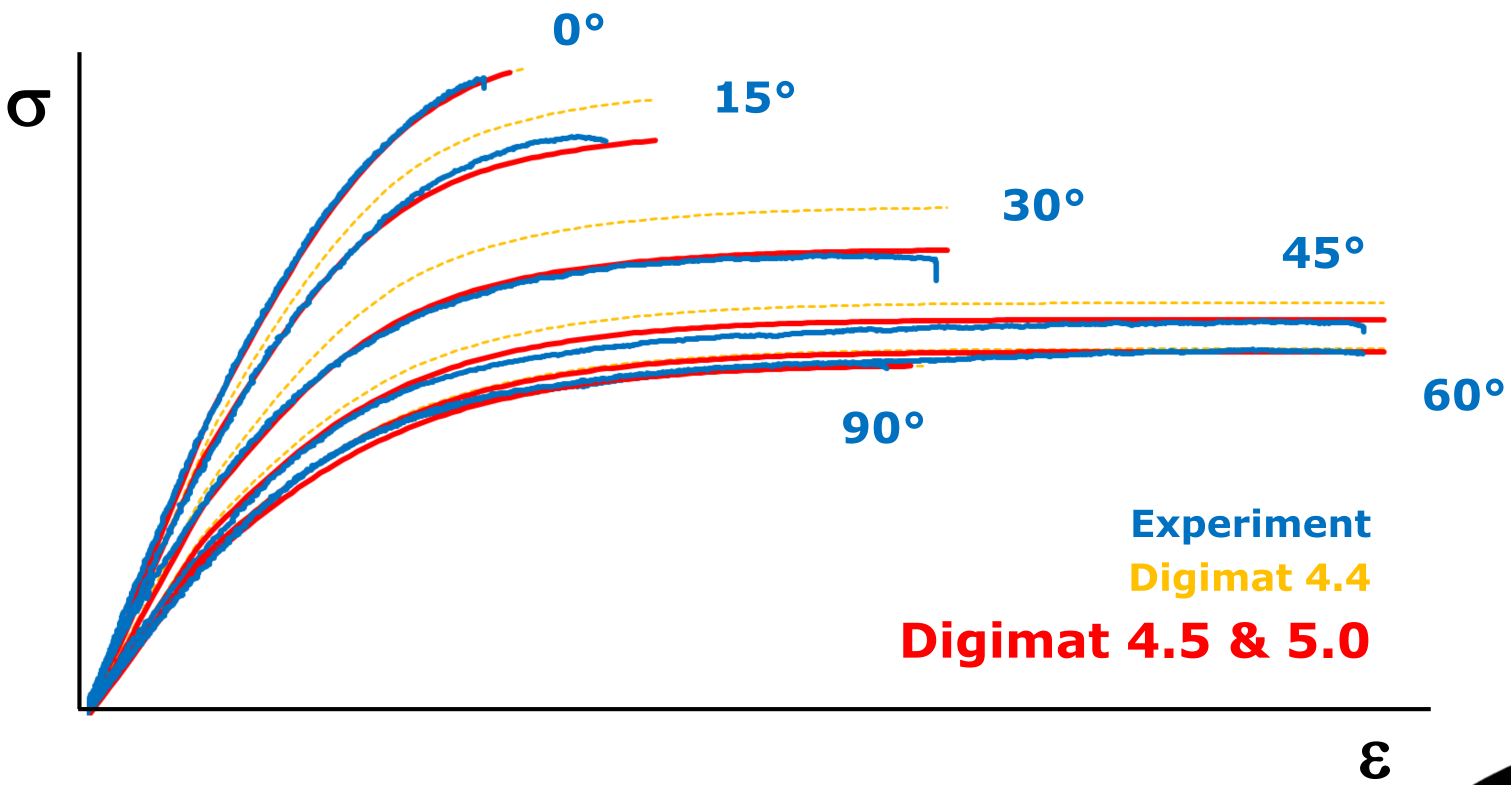
Short Fiber Reinforced Plastics
in Digimat 5.1

Stiffness

Robust/Fast/Easy

Hybrid solution

✓ Improved accuracy



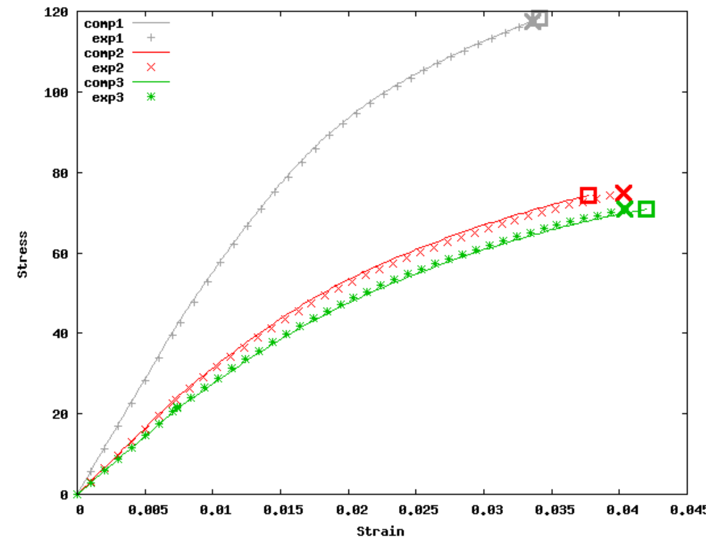
Failure

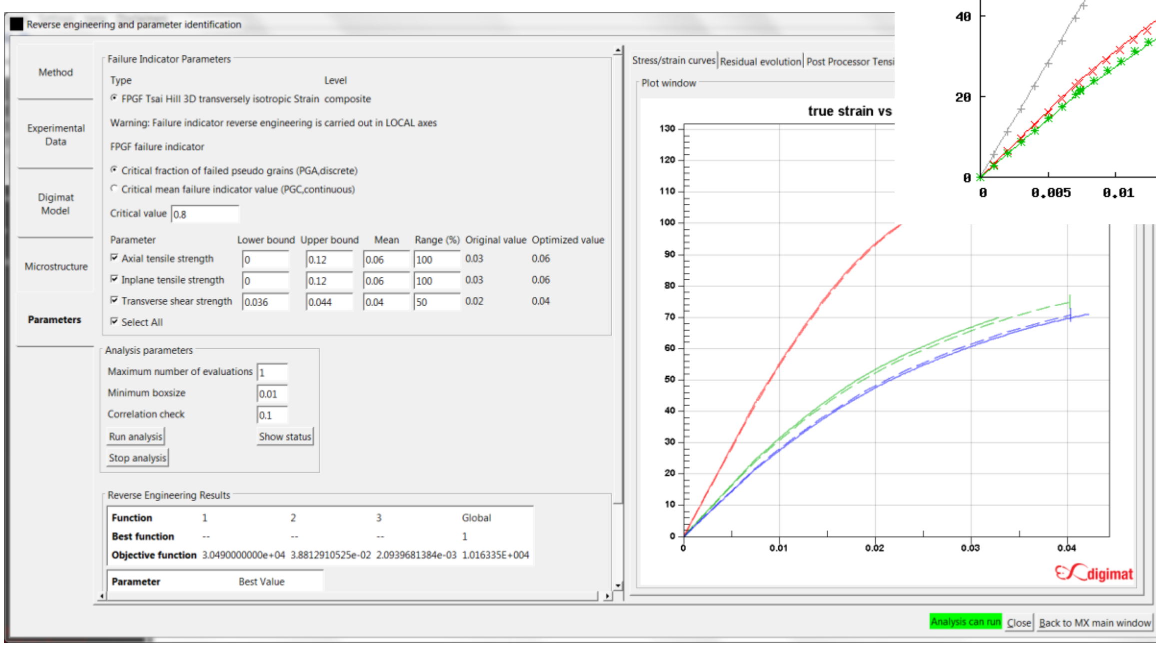
Robust/Fast/Easy

5.0.1

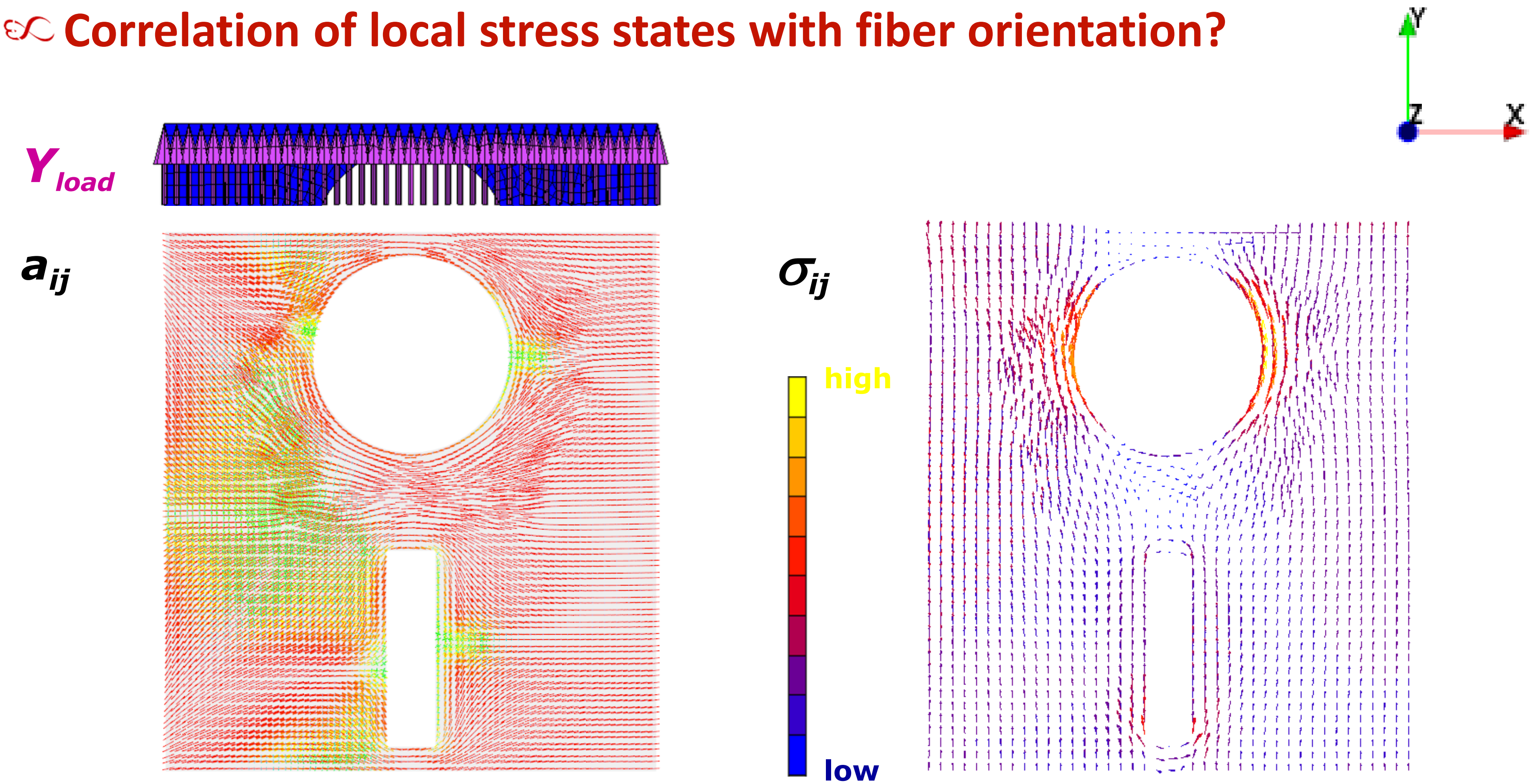
Reverse Engineering

- ✓ FPGF based failure indicators
  - Tsai-Hill 3D transversely isotropic
    - STRESS
    - STRAIN





Correlation of local stress states with fiber orientation?



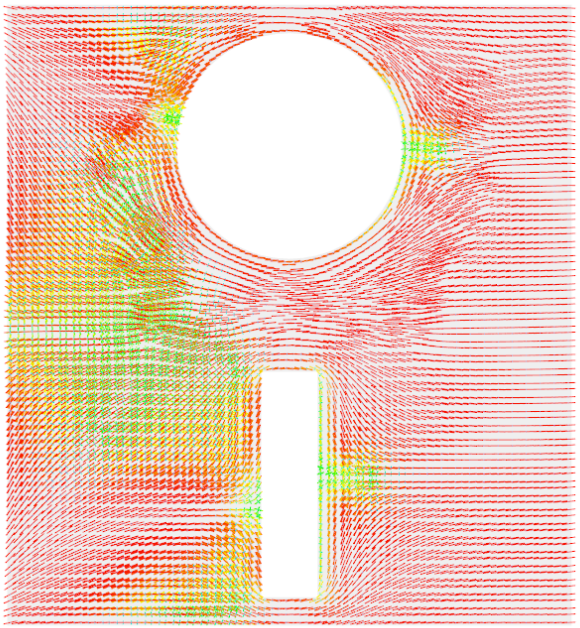
fiber orientation

stresses

First eigenvalue a_I of the orientation tensor a_{ij}

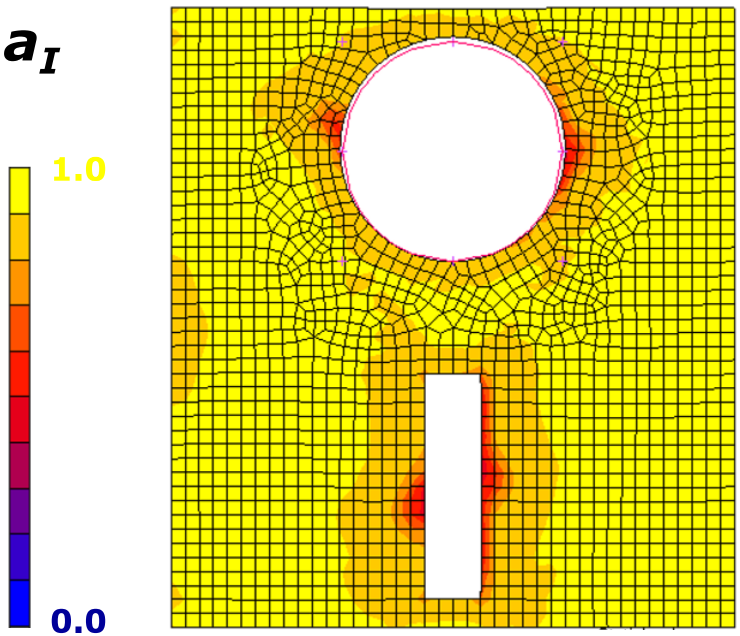
- ✓ Where do we find areas with strongly oriented fibers?

a_{ij}



fiber orientation

a_I

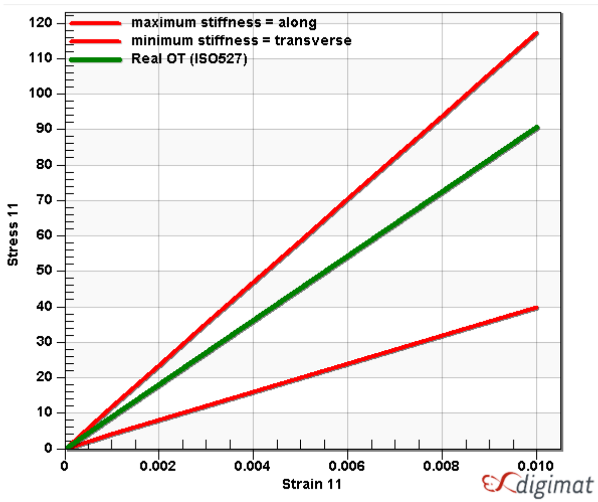


Post-Processing

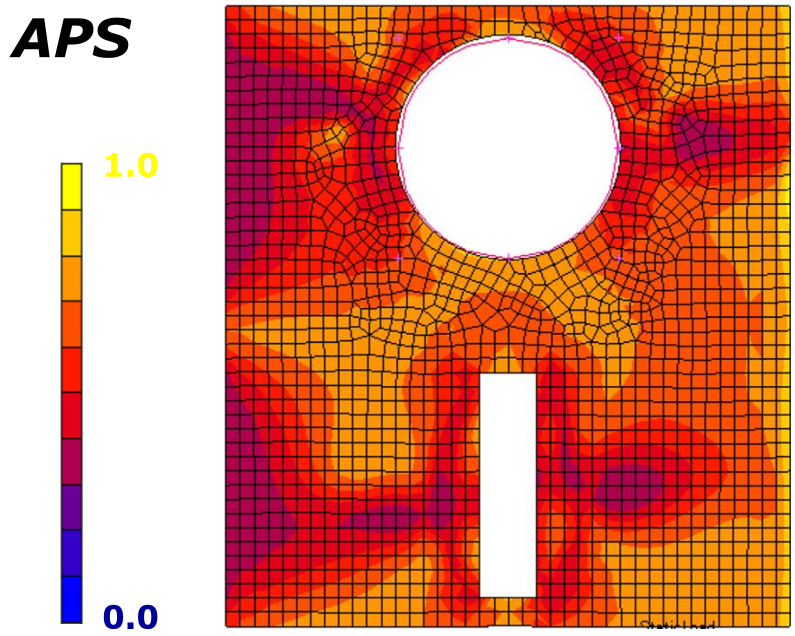
Robust/Fast/Easy

Achieved Potential Stiffness

- ✓ How much of the potential of my material am I using?



Ratio between apparent & ideal stiffness of the material

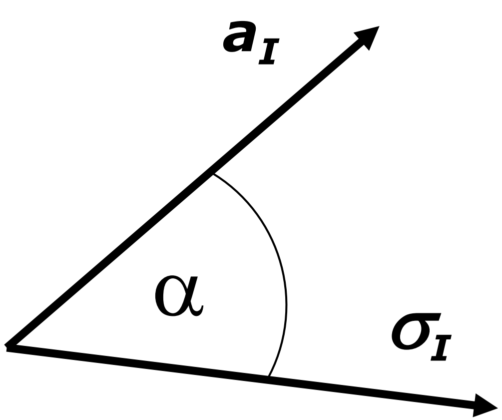


Post-Processing

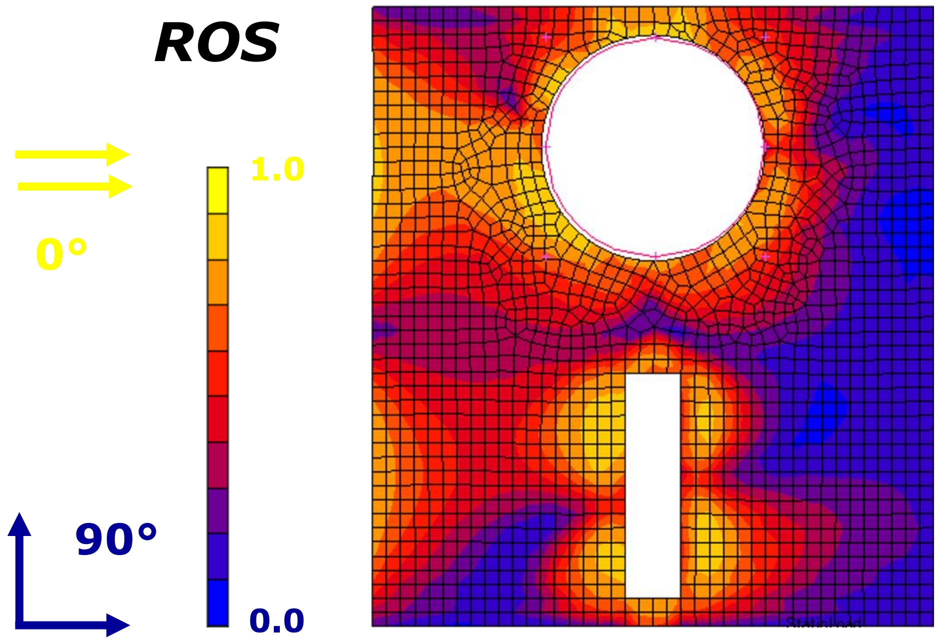
Robust/Fast/Easy

Relative Orientation State

- ✓ How strongly are stress and fiber orientation correlated?



Scalar product between the eigenvectors of a_I and σ_I



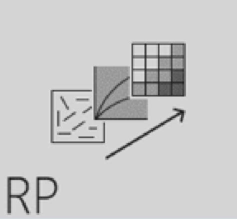
Digimat-RP

Integrated Workflow Environment
for

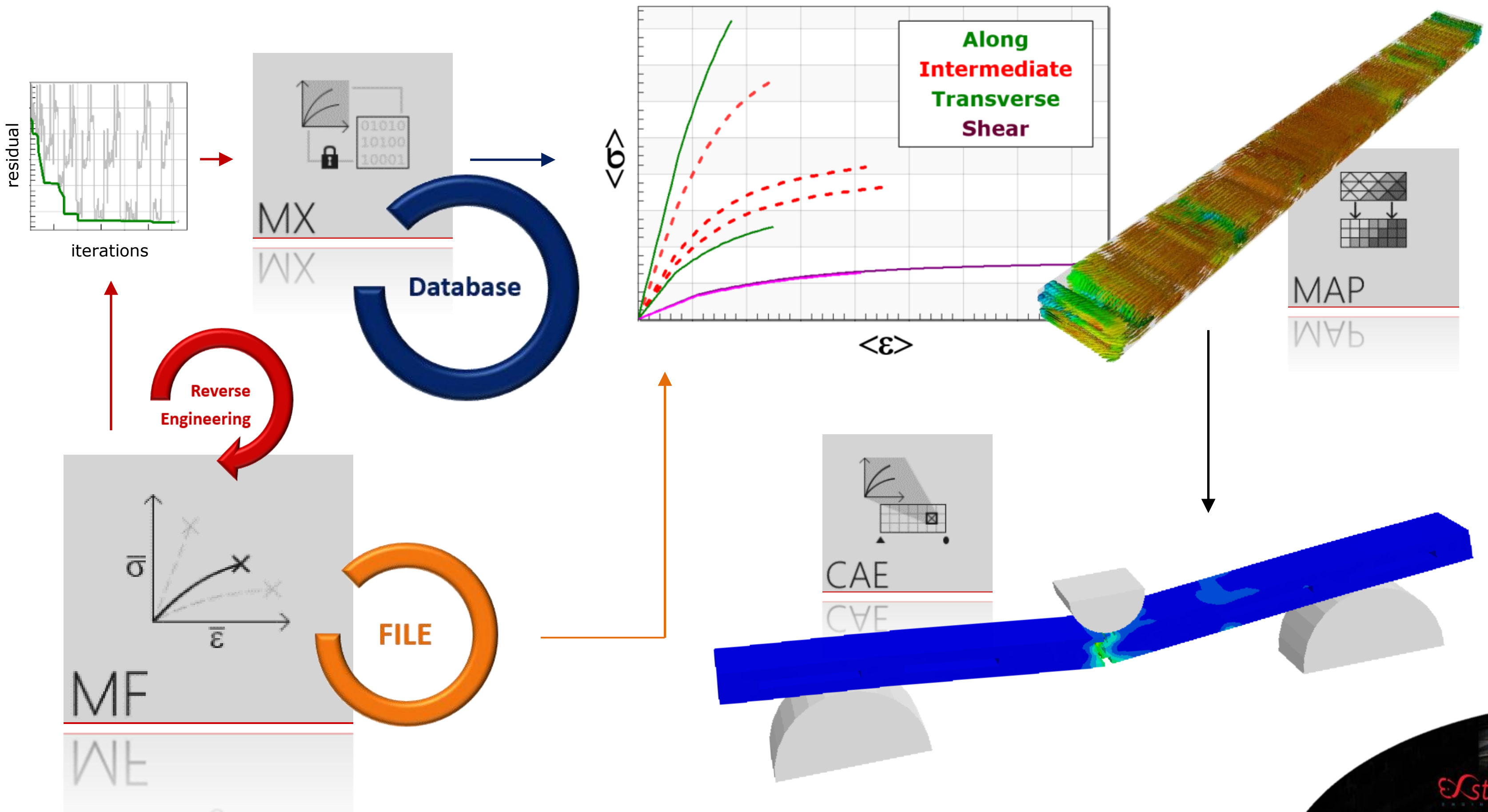
Process Chain Modeling

Tools

Digimat



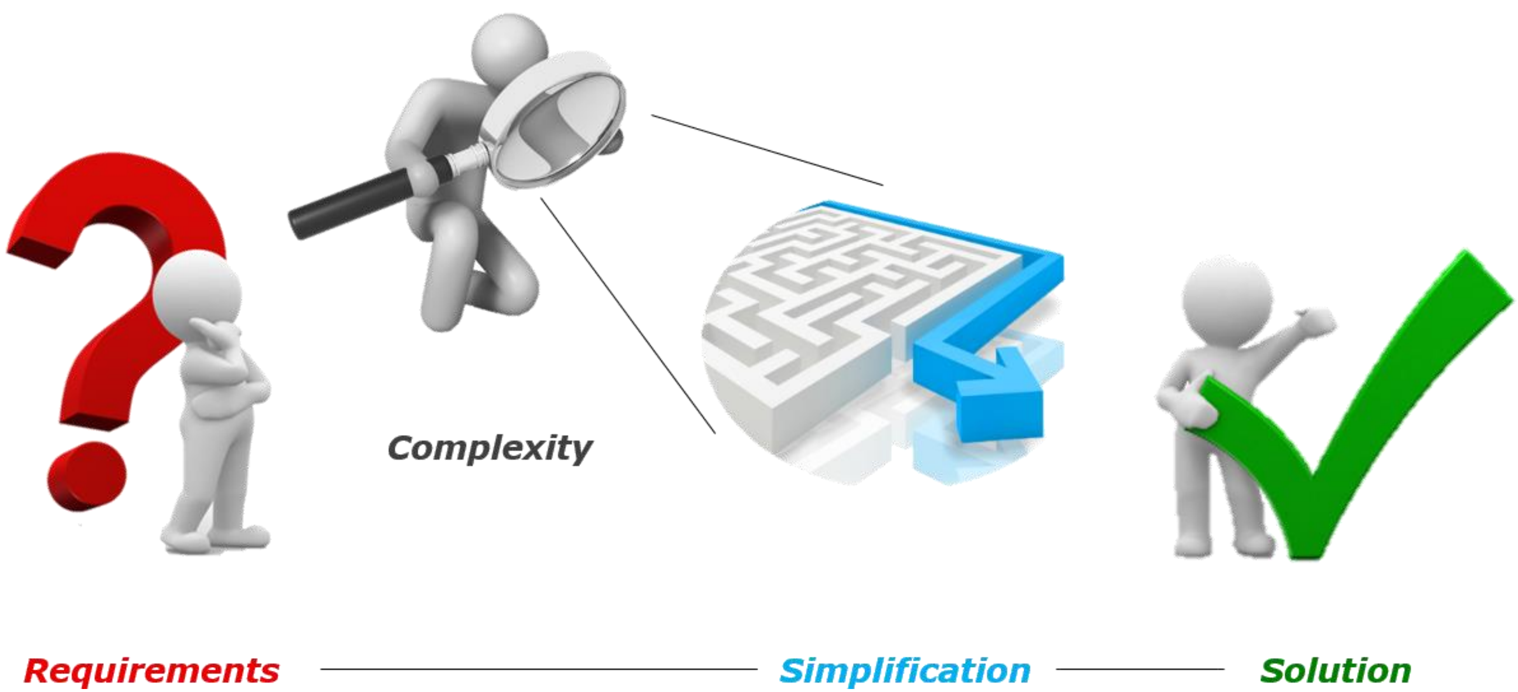
- Design of Fiber Reinforced Plastic Parts
  - ✓ **Tools** for multi-scale modeling



Digimat
Software

Solutions

- ✓ Integrated workflow environment
- ✓ Usable for experts & non-experts alike

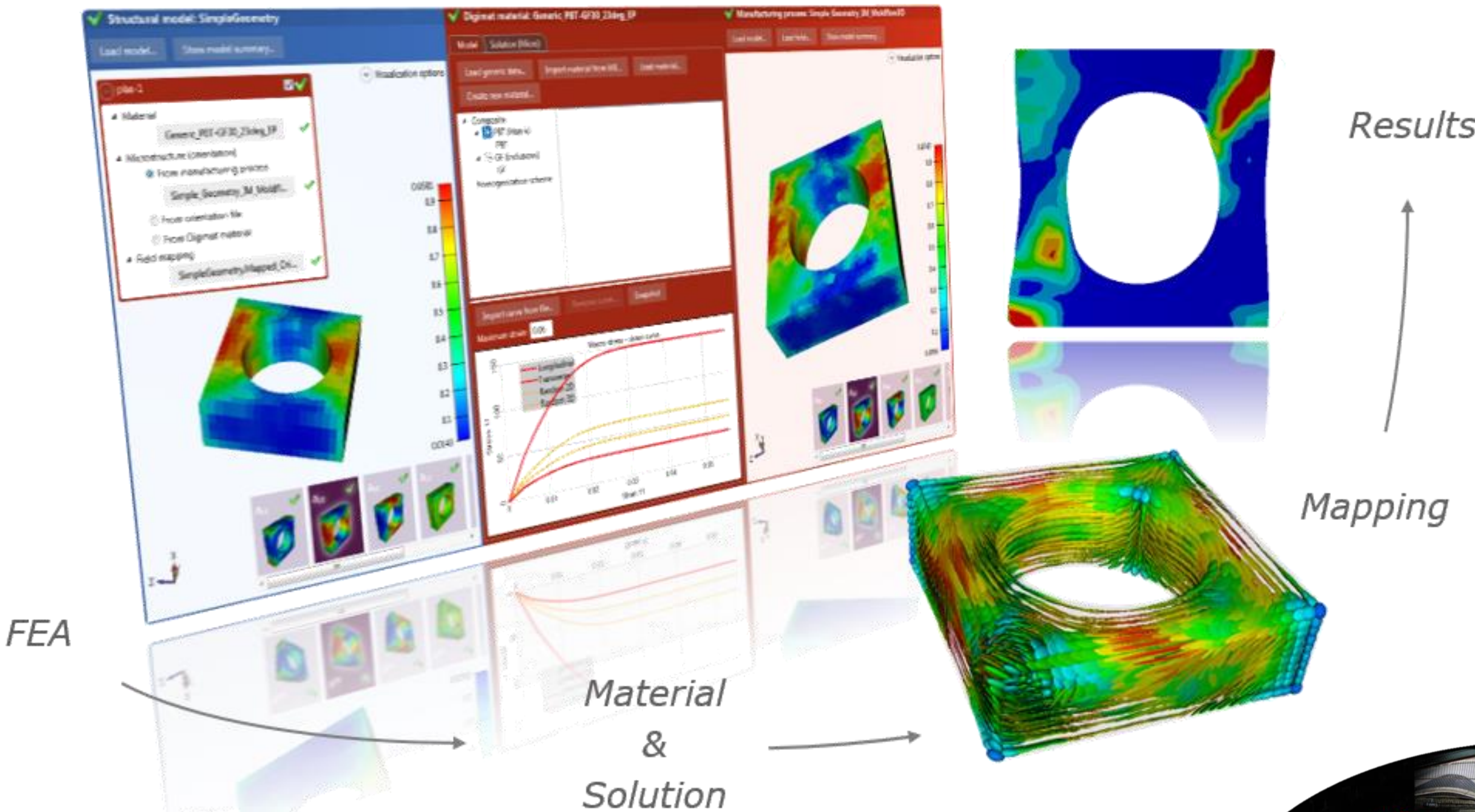


Workflow

Digimat-RP

RP

Integrated Workflow Environment



e-Xstream 10 YEARS IN MATERIALS

Workflow

Digimat-RP

RP

STRUCTURAL MODEL

✓ **Prerequisites**

- The structural model must be complete and ready to run with the targeted FEA code
- The regions of the structural FEA model where a Digimat material is to be used must have a specific material assigned
  - If several different Digimat materials are to be used, then each associated region must have its own unique material

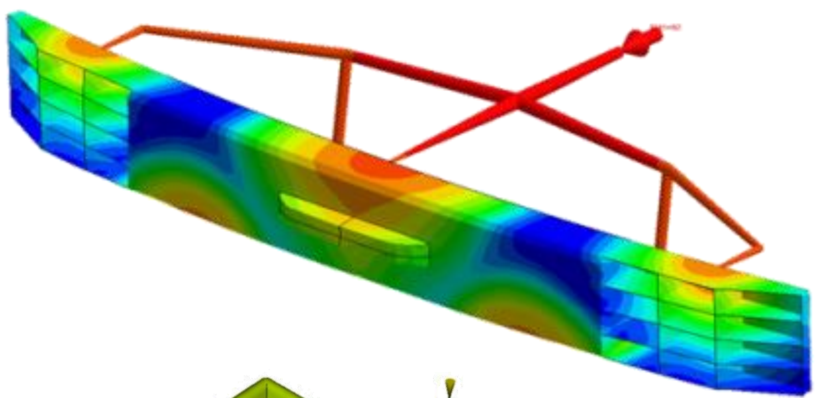
✓ **Limitations**

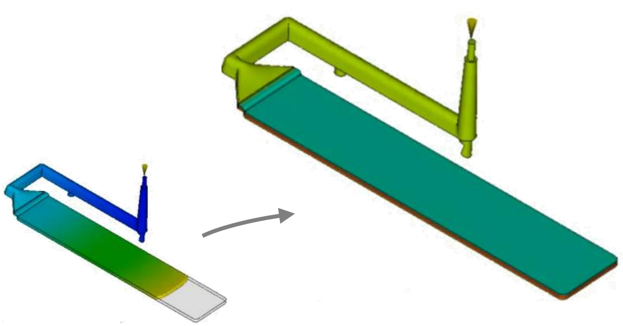
- 3D solid elements
- Bi-phase Digimat materials only
- No advanced output management

RP acts upon the material model of an existing FEA input deck!

Capabilities

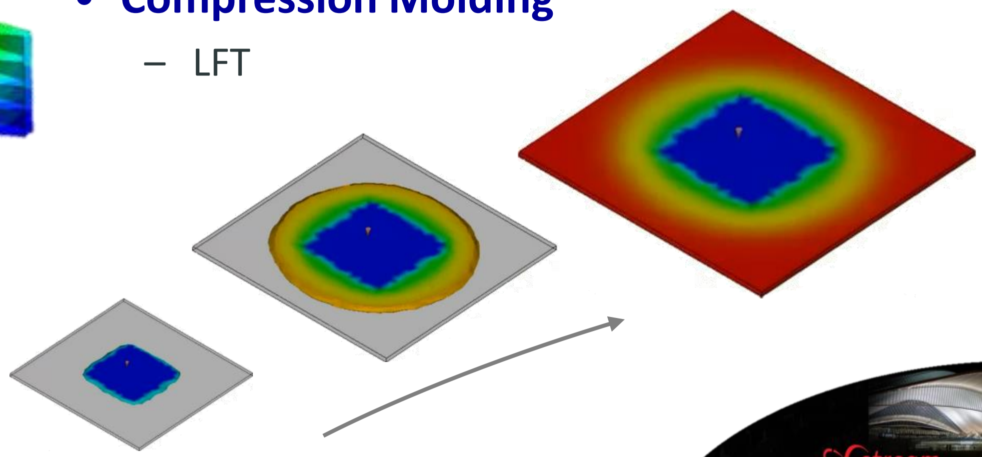
Digimat-RP





✓ **Short (& long) fiber reinforced plastics**

- **Injection Molding**
  - SFRP
- **Injection-Compression Molding**
  - SFRP / LFT
- **Compression Molding**
  - LFT



Capabilities

Digimat-RP

RP

✓ **Short (& long) fiber reinforced plastics**

- **Supported Software**
  - *3D analyses*

✓ **Moldflow**

- .xml

Autodesk Moldflow

✓ **Sigmasoft**

- .xml

SIGMASOFT

✓ **Moldex3D**

- .o2d

Moldex3D

✓ **3D Timon**

- .bou

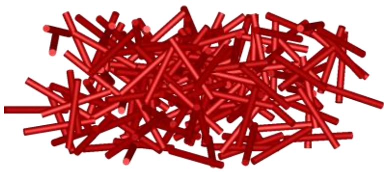
3D TIMON

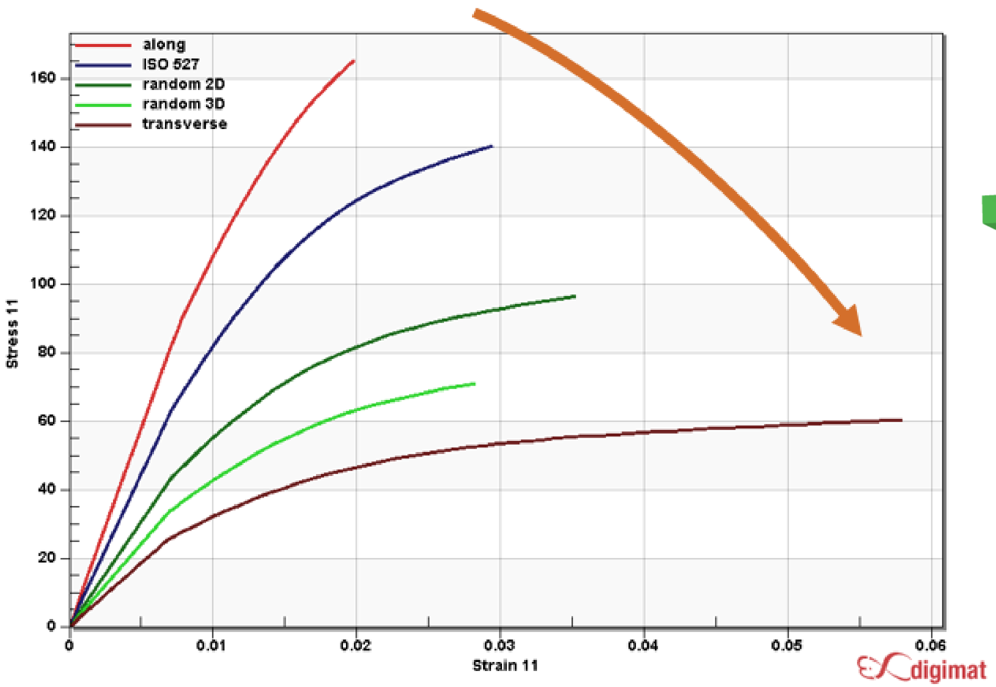
e-Xstream 10 YEARS IN MATERIALS

Capabilities

Digimat-RP

- ✓ **Short (& long) fiber reinforced plastics**
- ✓ **Properties**





Anisotropy

(Thermo-) Linear Elasticity

(Thermo-) Elastoplasticity

(Thermo-) Viscoelasticity

(Thermo-) Elasto-Viscoplasticity

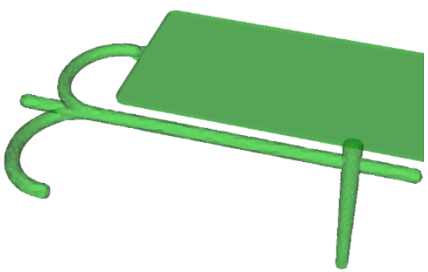
+ Failure

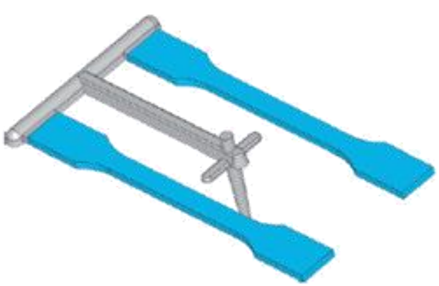
Capabilities

Digimat-RP

✓ **Short (& long) fiber reinforced plastics**

- **Levels of quality**
  - *Choice between the effort to set up the material model and accuracy of results*





- Quantitative
  - Data: based on anisotropic measurements
  - Effort: expert reverse engineering (weeks to months)
- Semi-Quantitative
  - Data: based on ISO 527 dumbbell
  - Effort: non-expert reverse engineering (~5-10 min.)
- Qualitative
  - Data: representative family curve from CAMPUS database
  - Effort: none (generic & ready to run)

Capabilities

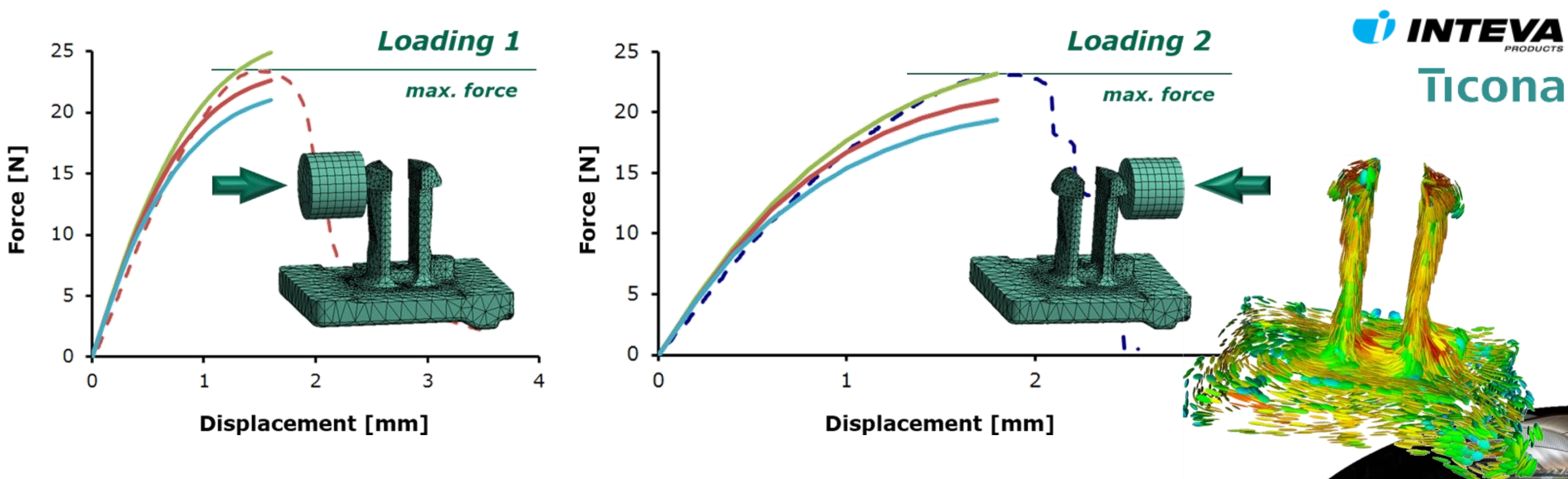
Digimat-RP

RP

✓ **Short (& long) fiber reinforced plastics**

- **Levels of quality**
  - *Choice between the effort to set up the material model and accuracy of results*

QUALITATIVE / SEMI-QUANTITATIVE / QUANTITATIVE



Capabilities

Digimat-RP

✓ **Short (& long) fiber reinforced plastics**

- **Input**
  - *Encryption/Decryption of material properties fully supported*

✓ **Internal**

- Generic grades
  - » Linear elastic

✓ **From Tools**

- **Digimat-MX**
  - Material suppliers' grades
  - Generic grades
    - » (Thermo-) Linear elastic
    - » (Thermo-) Elastoplastic

✓ **From File**

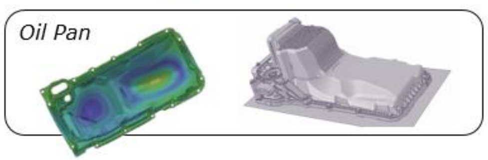
- **Digimat-MF (.daf)**
  - Build, save & use material model
    - » Any type
- **Digimat-CAE (.mat)**
  - Re-use previous analyses
    - » Any type
  - Use encrypted
    - » Any type

Capabilities

Digimat-RP

✓ **Short (& long) fiber reinforced plastics**

- **Performances**



RENAULT

INTEVA PRODUCTS

Ticona

TrelleborgVibracoustic

SOLVAY asking more from chemistry | Plastics

GM

NVH

E	- Linear Elastic

Stiffness (quasi-static)

E/EP	- Linear elastic / Elastoplastic
TE/TEP	- Temperature dependent

Impact & Failure

VE/EVP	- Viscoelastic / Elasto-Viscoplastic
+ FPGF	- Failure of SFRP

(Thermal) Creep

VE / TVE	- Viscoelastic
EVP / TEVP	- Elasto-Viscoplastic

Capabilities

Digimat-RP

✓ **Short (& long) fiber reinforced plastics**

- **Solution Methods**
  – *Choice between accuracy of results and performance of the computation (CPU)*

✓ **MACRO**

- Linear elastic weak coupling
- High efficiency in CPU

✓ **MICRO**

- Nonlinear strong coupling
- Highest accuracy in stiffness

✓ **HYBRID**

- Nonlinear weak coupling
- High efficiency in CPU
- High accuracy in stiffness
  – E, EP, EVP, TE, TEP
- Highest accuracy in failure of SFRP

Capabilities

Digimat-RP

RP

✓ **Short (& long) fiber reinforced plastics**

- **IMPLICIT – Supported software**
  - *3D analyses*

✓ **MSC Nastran SOL400**

.bdf / .dat

MSC Software

✓ **Abaqus STD**

.inp

SIMULIA

✓ **Marc**

.dat

MSC Software

✓ **Ansys**

.cdb / .inp / .dat

ANSYS

Capabilities

Digimat-RP

✓ **Short (& long) fiber reinforced plastics**

- **EXPLICIT – Supported software**
  - *3D analyses*

✓ **MSC Nastran SOL700**

.bdf / .dat

✓ **Abaqus Explicit**

.inp

✓ **LS-Dyna**

.k / .key

Capabilities

Digimat-RP

Summary

- ✓ **FEA**
  - Marc, MSC Nastran (SOL400 /700), Abaqus (Standard/Explicit), Ansys, LS-Dyna (Implicit/Explicit)
- ✓ **Material**
  - Generic / File (.daf & .mat) / Digimat-MX / Digimat-MF
  - Support of encryption
- ✓ **Solutions**
  - Macro, Micro, Hybrid + User defined templates
- ✓ **Manufacturing**
  - Moldflow3D, Moldex3D, Sigmasoft, Timon3D
- ✓ **Job management** (submission & monitoring)

Further Information

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