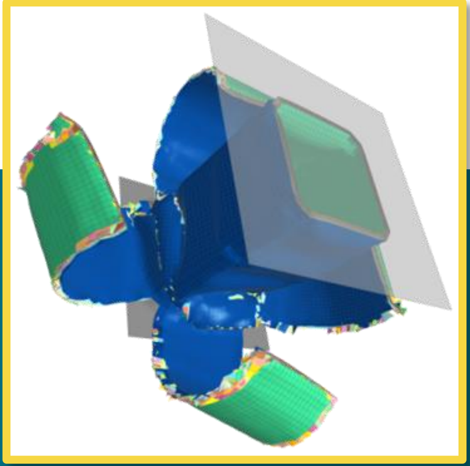

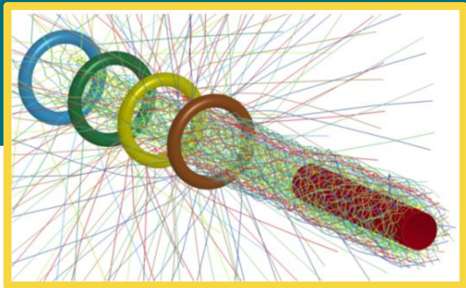

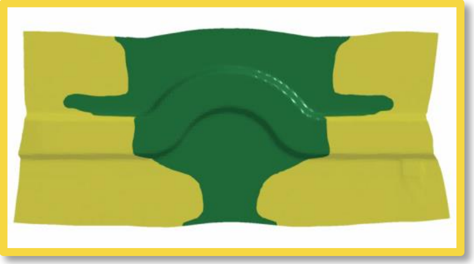

Recent developments and trends for composite modeling in LS-DYNA

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DYNAmore GmbH, Stuttgart

Fachkongress Composite Simulation

Fellbach, 26-Feb-2015

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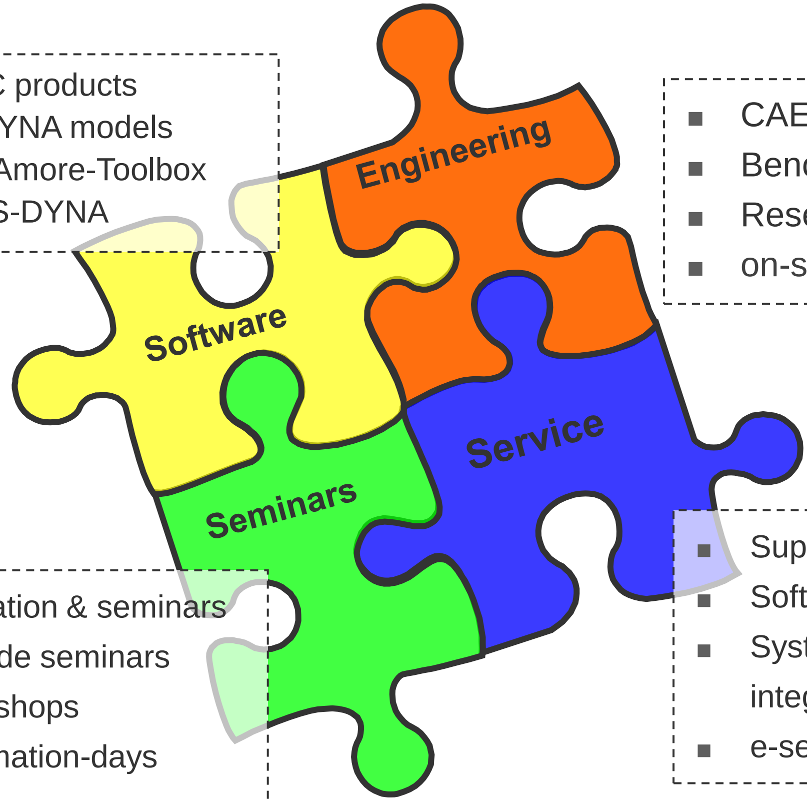
- LSTC products
- LS-DYNA models
- DYNAmore-Toolbox for LS-DYNA



- CAE services
- Benchmarks
- Research-studies
- on-site support

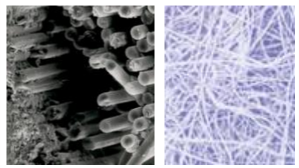
- education & seminars
- On-side seminars
- Workshops
- Information-days

- Support
- Software-development
- System- und process integration
- e-services

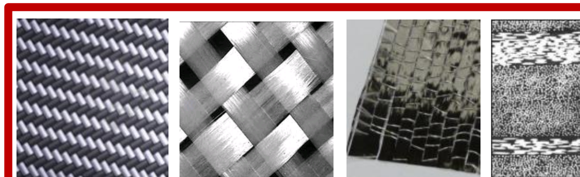
Definition & Classification

Definition: **Composite materials**, often shortened to composites or called composition materials, are **engineered** or **naturally** occurring materials made from **two or more constituent materials with significantly different physical or chemical properties** which remain separate and distinct within the finished structure.

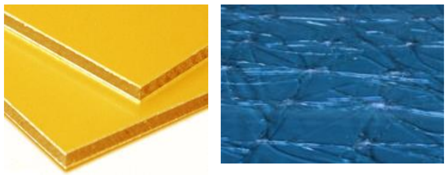
Concrete
(cement/stone/steel)



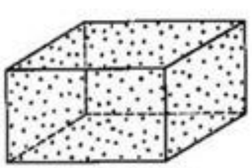
Short-/long fiber
reinforced polymers
(glass/PP)

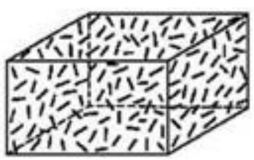


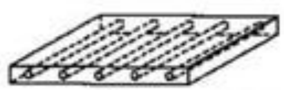
Continuous fiber
reinforced polymers
(glass/carbon/PA/PP/EP)



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







Agenda

- Modeling aspects of process simulation
  - Draping, Weaving and Braiding
  - Thermoplastic pre-pregs
  - Resin transfer molding (RTM)
  - Wet molding
  - Short/long fiber reinforced plastics

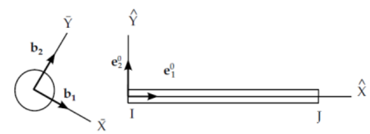
- Mapping data between the different steps along the process chain
  - Modeling aspects
  - Mapping examples

- Developments towards an increasing predictability for crushing simulations

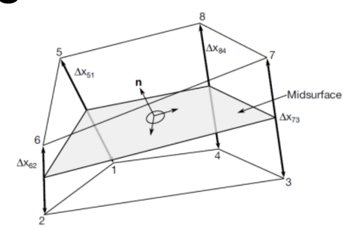
- Conclusion and Outlook

Braiding, weaving, draping

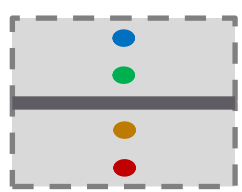
- Braiding simulation using *ELEMENT_BEAM_SOURCE for automatic element generation

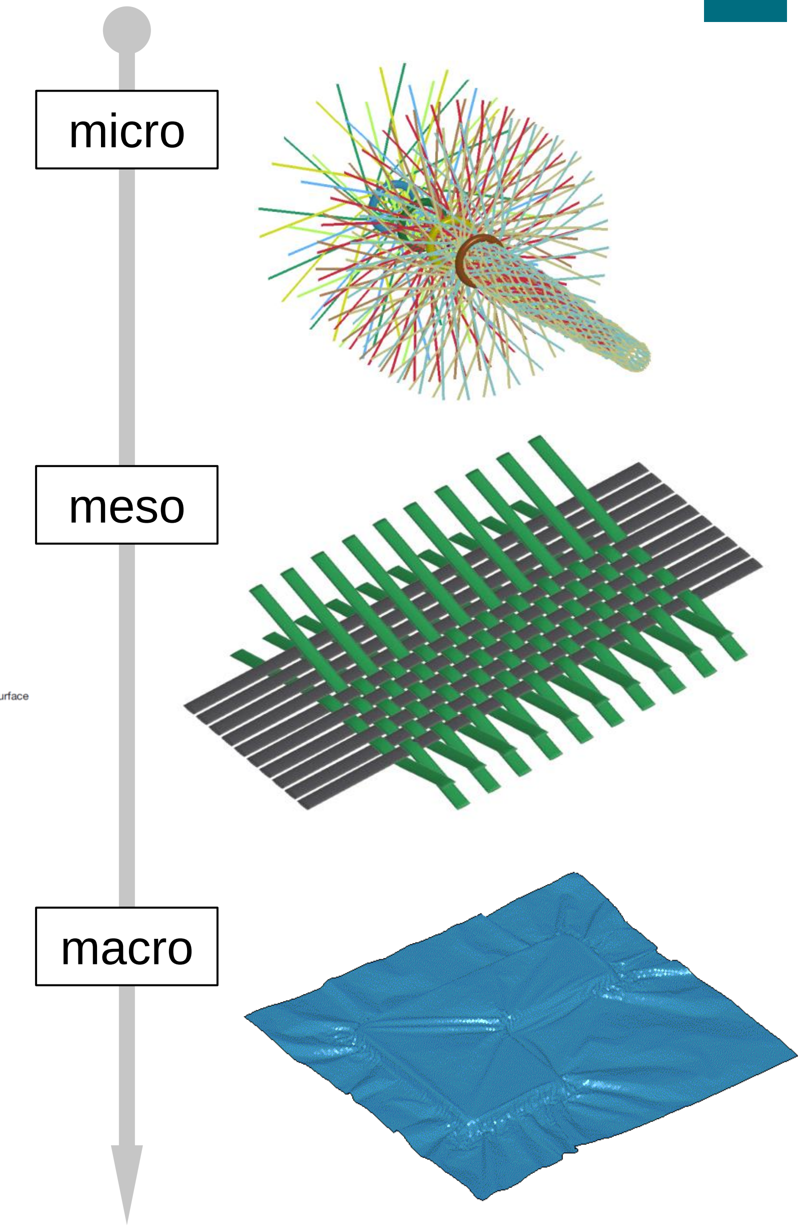


- Weaving simulation using shell- or even solid elements



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





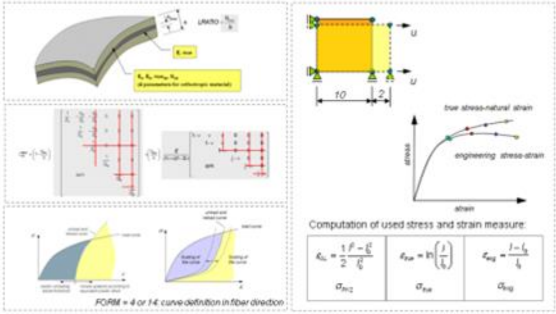
Draping

MAT_34	MAT_234	MAT_235

MAT_34

Simulation on cm-scale: MAT_FABRIC (#34)

A special membrane formulation is automatically invoked

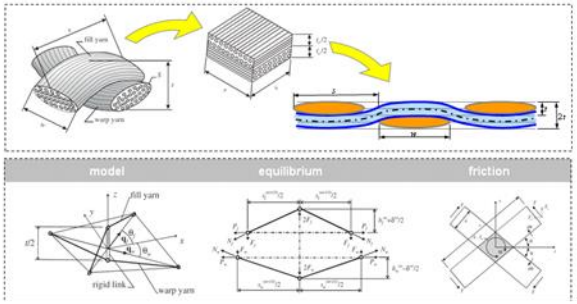


New in R7.0: bending stiffness

MAT_234

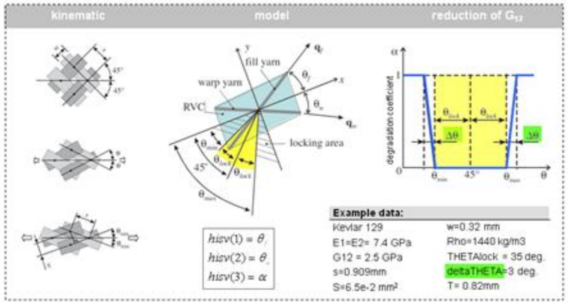
Simulation on cm-scale:
MAT_VISCOELASTIC_LOOSE_FABRIC (#234)

Micro-mechanical approach :
Mathematical description of geometry and kinematic of symmetrical woven fabric



Simulation on cm-scale:
MAT_VISCOELASTIC_LOOSE_FABRIC (#234)

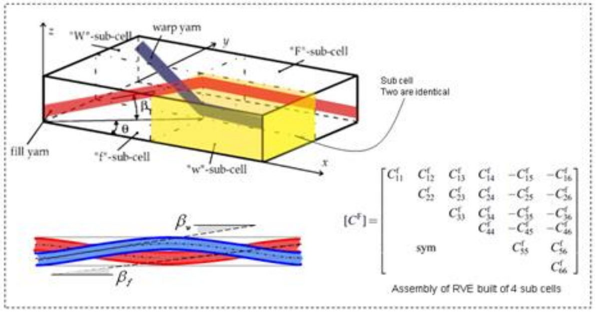
Taking locking angle through reduction factor for G_{12} into account
Visco-elastic enhancement for higher strain rates



MAT_235

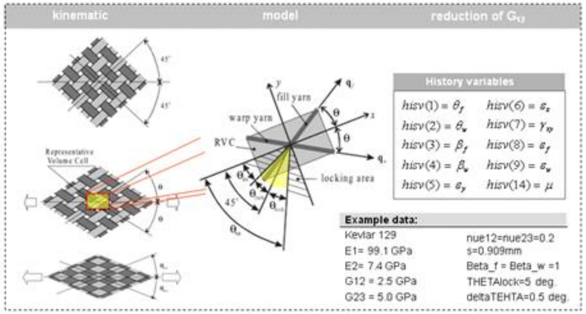
Simulation on cm-scale:
MAT_MICROMECHANICS_DRY_FABRIC (#235)

Micro-mechanical approach with homogenization strategy (RVE):
Mathematical description of symmetrically woven fabric



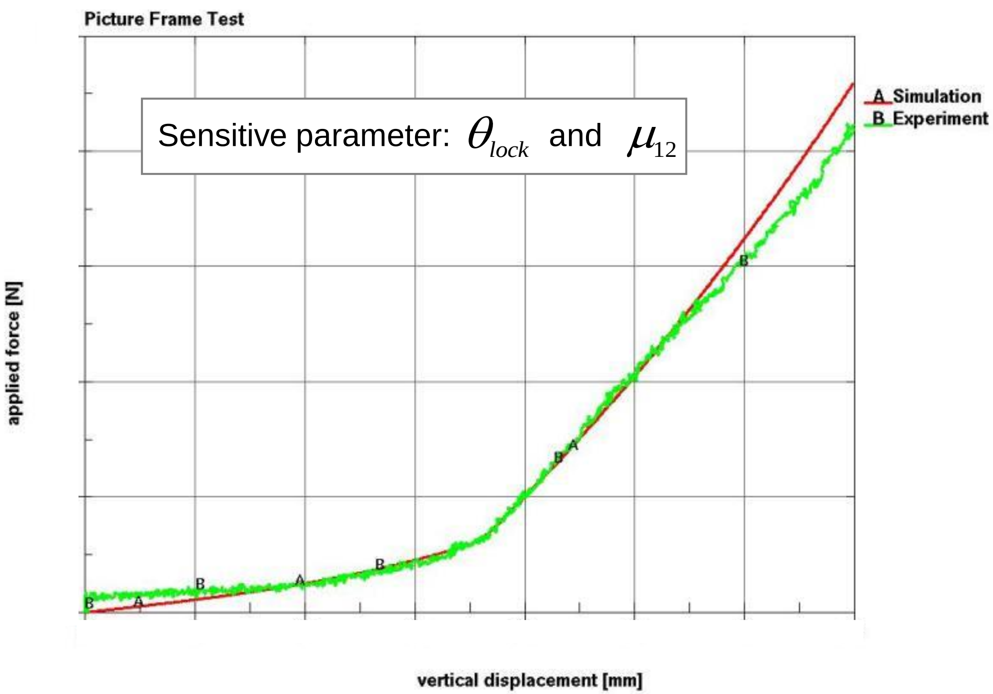
Simulation on cm-scale:
MAT_MICROMECHANICS_DRY_FABRIC (#235)

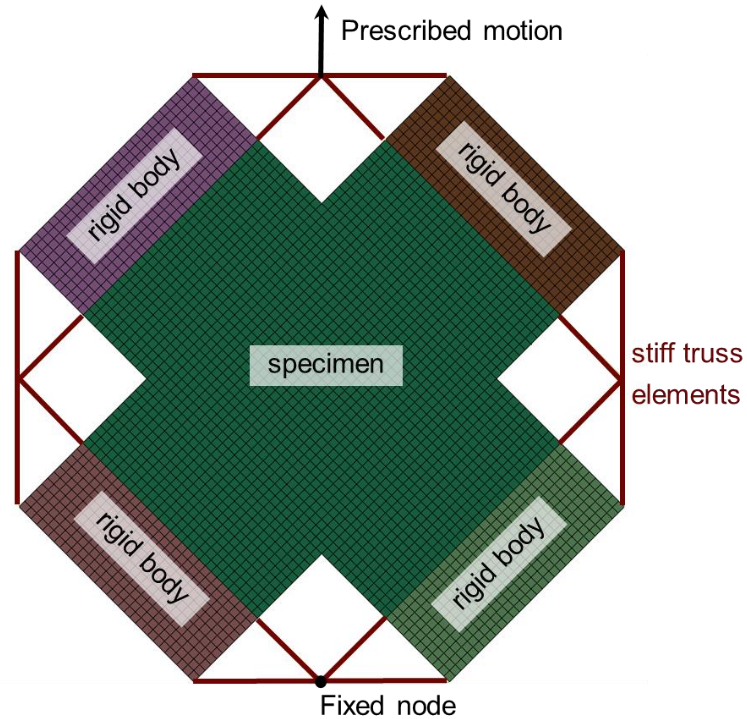
Micro-mechanical approach with homogenization strategy (RVE):
Mathematical description of symmetrically woven fabric



Draping

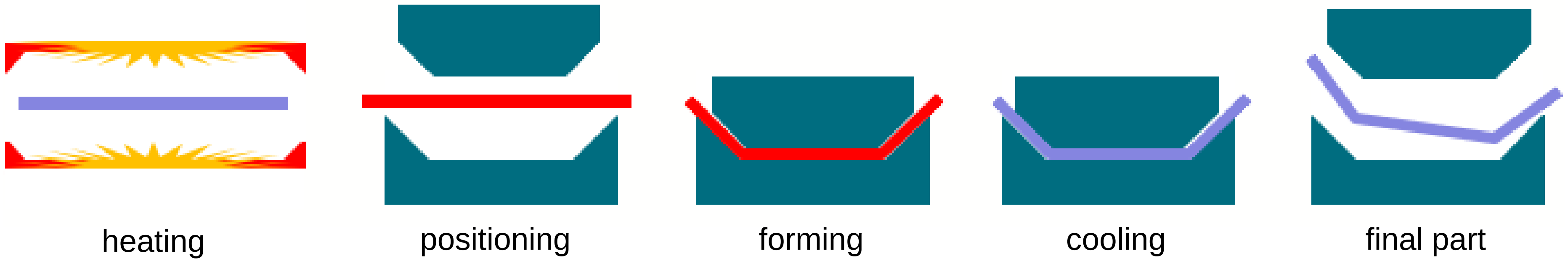
- Material characterization:





Thermoplastic pre-pregs

- 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

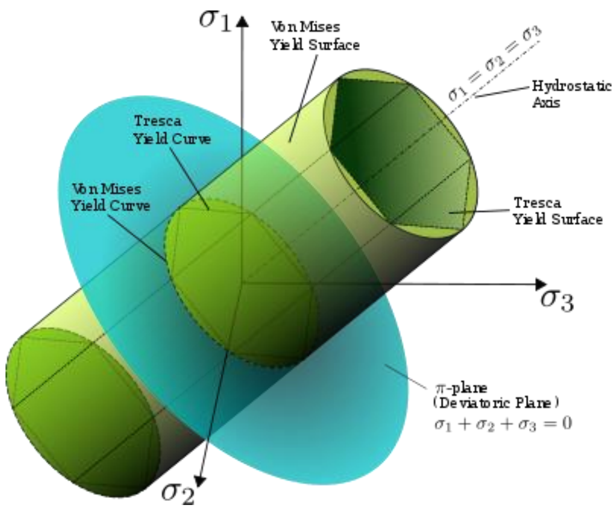


Thermoplastic pre-pregs

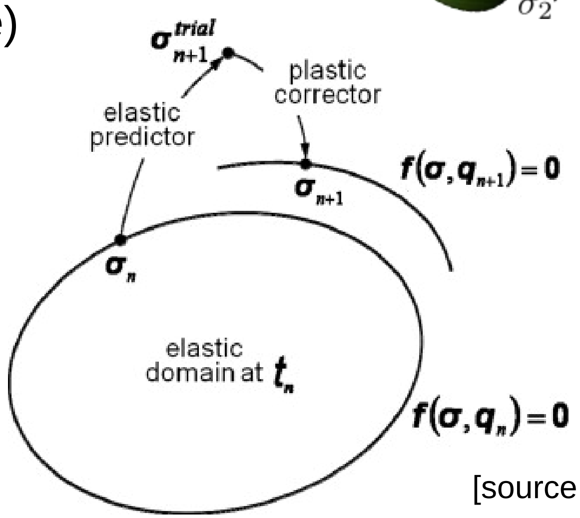
- Additive split for matrix and fiber contributions

- Matrix formulation
  - Elastic properties are defined with load curves w.r.t. to temperature (vs. strain-rate)
  - Van-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



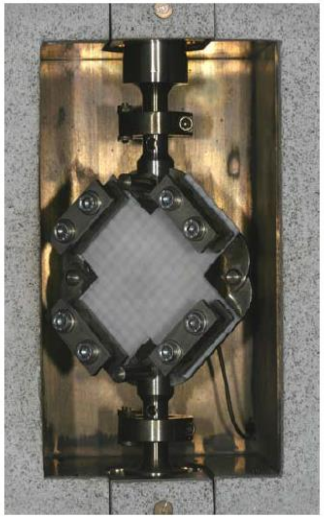
[source: www.wikipedia.de]

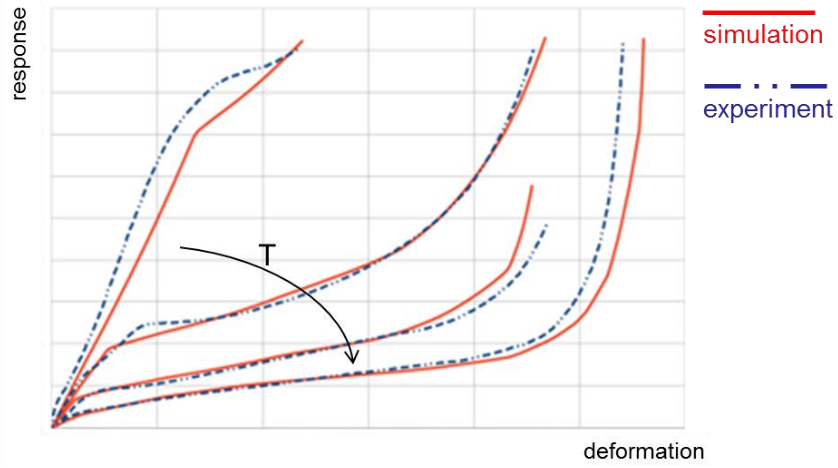


[source: Neto et al, 2008]

Thermoplastic pre-pregs

- Tool is closed within 80ms, kept closed for 3ms, and opened within 56.5ms
- Thermo-mechanical coupling between working piece and tools can be included
- Material parameters for matrix and textile from picture frame test
- 2 fiber families
  - ±45°
  - Woven structure

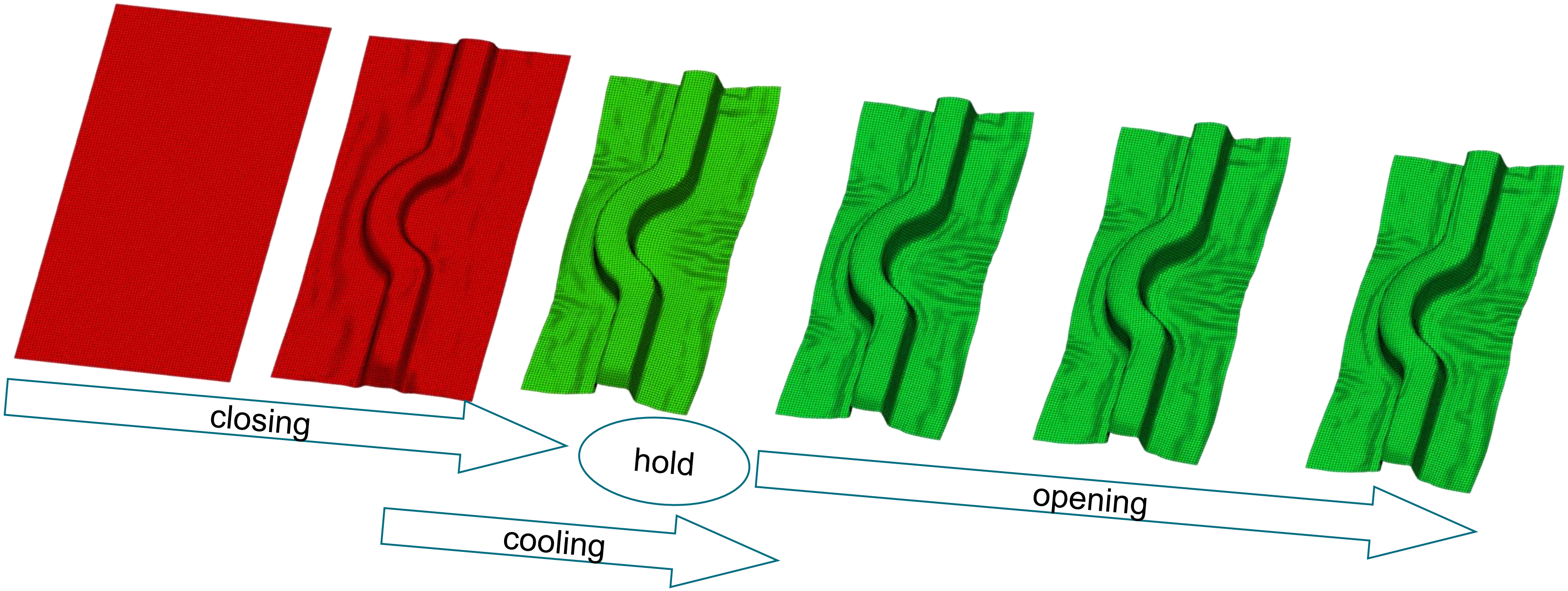




Thermoplastic pre-pregs

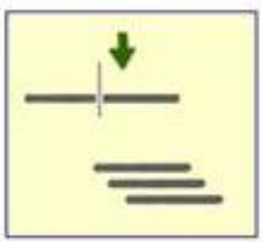
- T_m up to t=70 ms, then cooling down (13 ms) to T_c
- Opening at a constant temperature T_c

- Only few wrinkles form



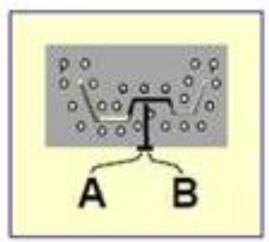
Resin transfer moulding (RTM)

- 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

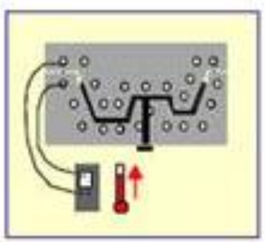


preparation of textile

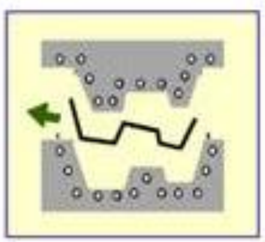
draping



infiltration



curing

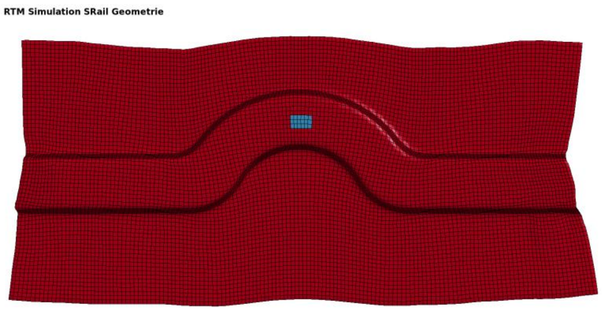


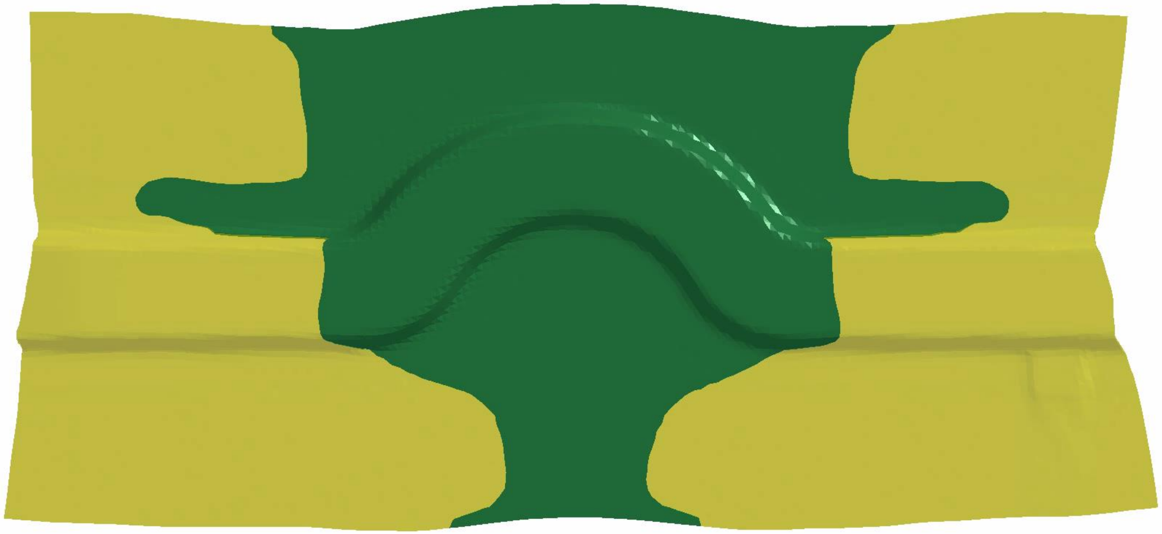
final part

[source: Benteler-SGL]

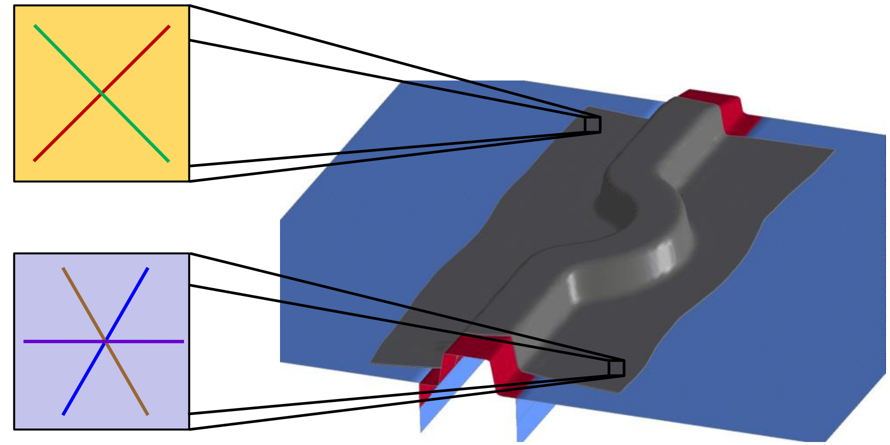
Resin transfer moulding (RTM)

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

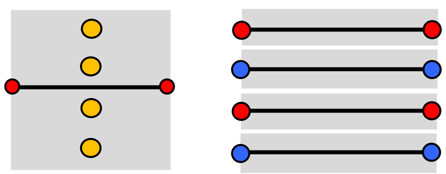




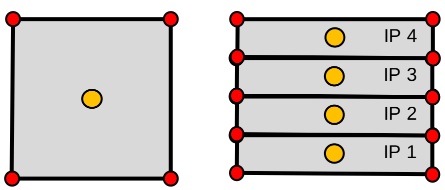
Resin transfer moulding (RTM)

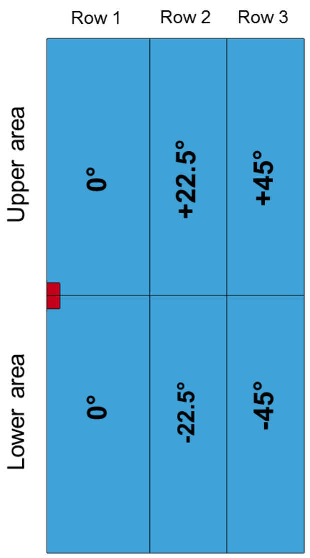


- Draping simulations are usually performed using (stacked) shell elements.



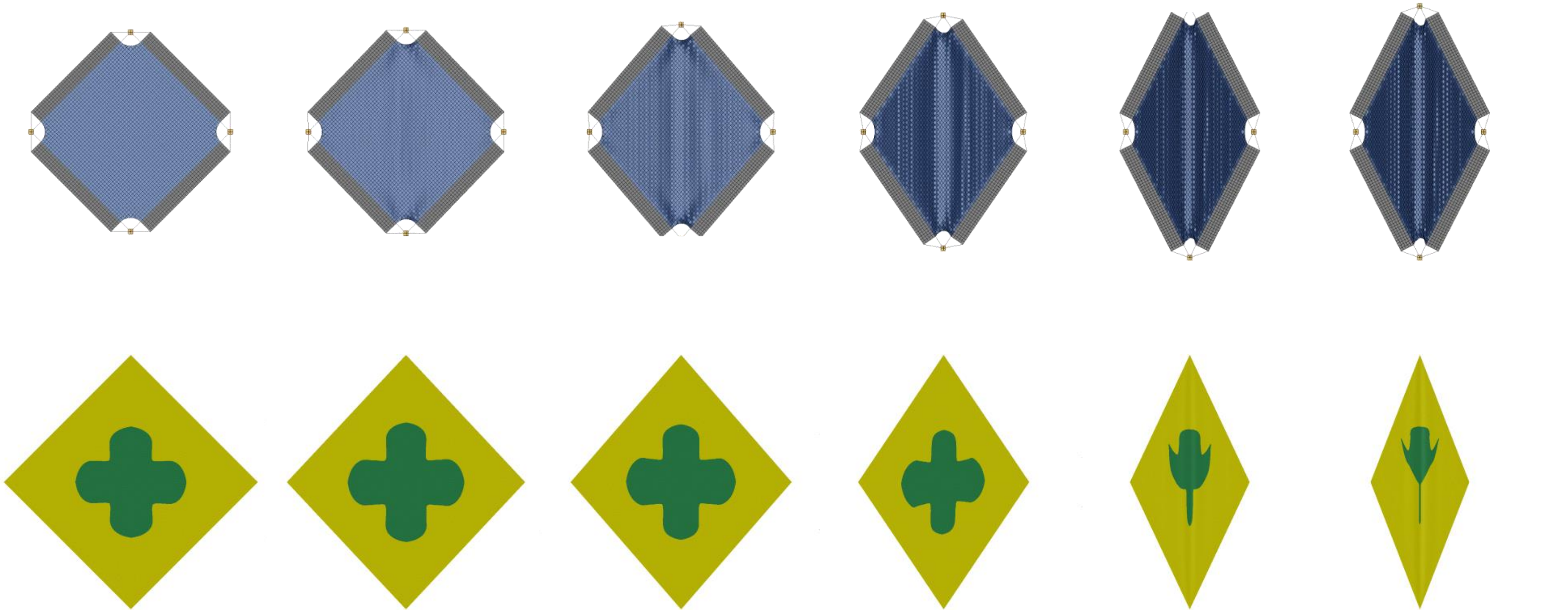
- For further infiltration with ALE, results have to be mapped on (stacked) solild elements using a porosity tensor.





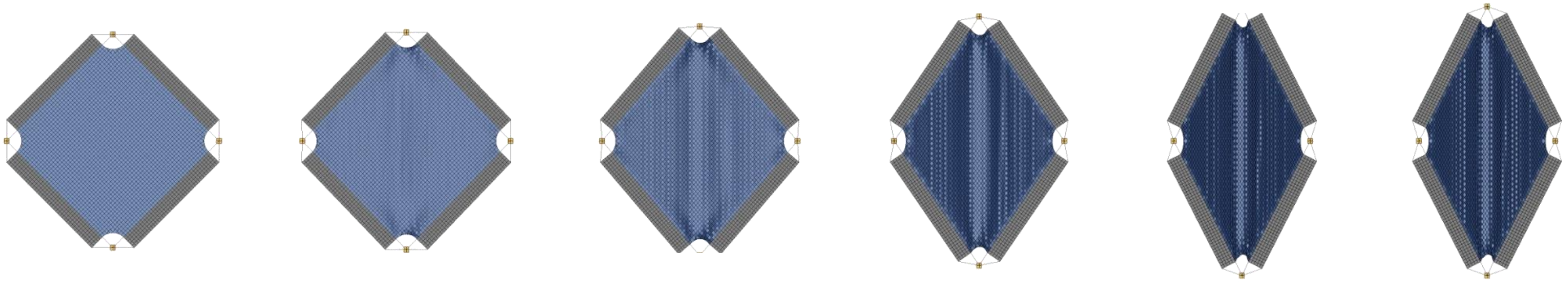
Resin Transfer Molding (RTM)

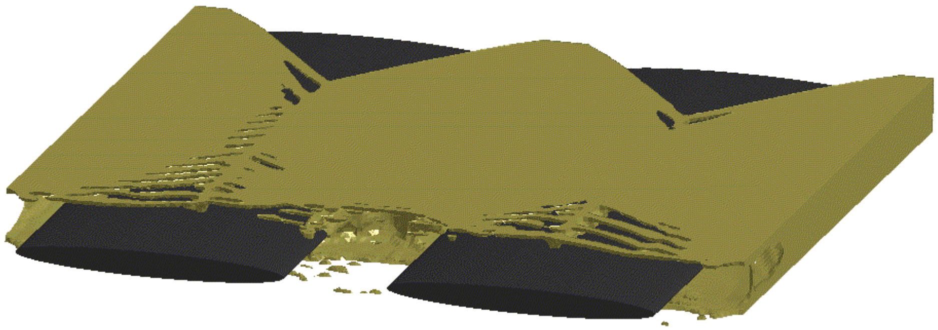
- Use results gained from picture frame tests to gain information about the behavior of the resin infusion



Resin Transfer Molding (RTM)

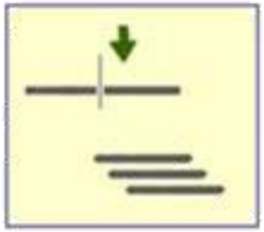
- Determine flow properties on a microstructural level using representative volume elements (RVEs)



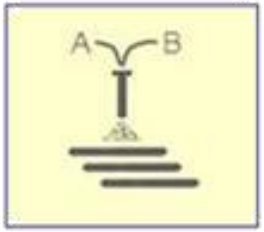


Wet moulding

- Basically, a simulation requires the same numerical tools as RTM
- Draping and injection are done in one single step
- Simulation more complex
  - Fluid-structure interaction plays an important role
  - Fluid domain, viscosity, and porosity change during the simulation
- Process overview

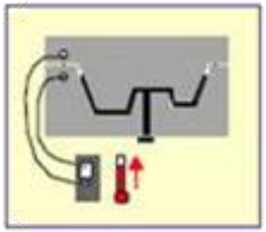


preparation of textile



impregnating

forming



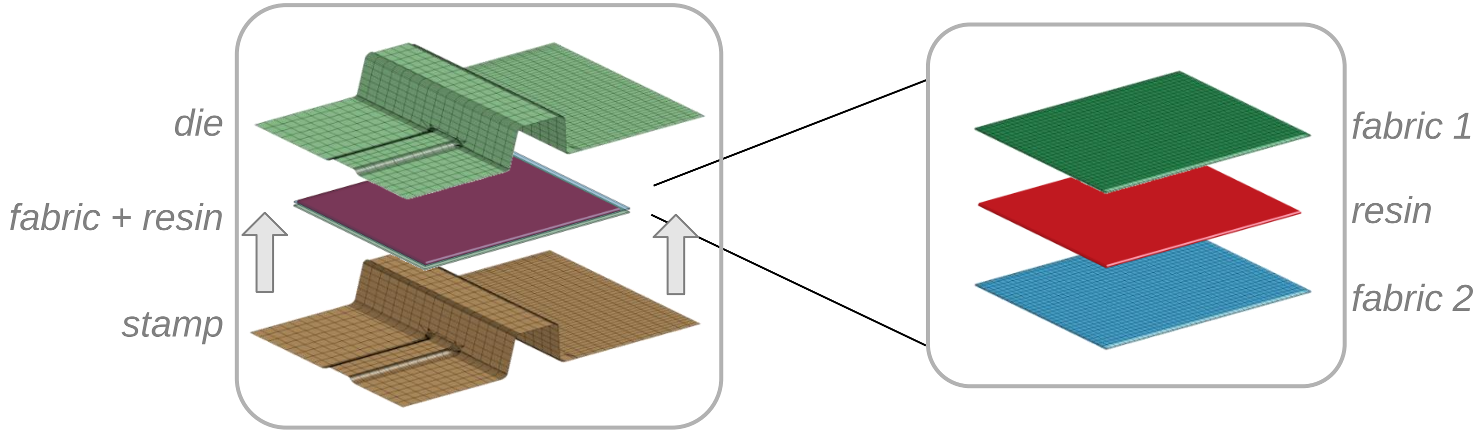
curing

final part

[source: Benteler-SGL]

Wet moulding

- Constant isotropic porosities assumed
- Cartesian background fluid grid (not shown)



Wet moulding

- Constant isotropic porosities assumed
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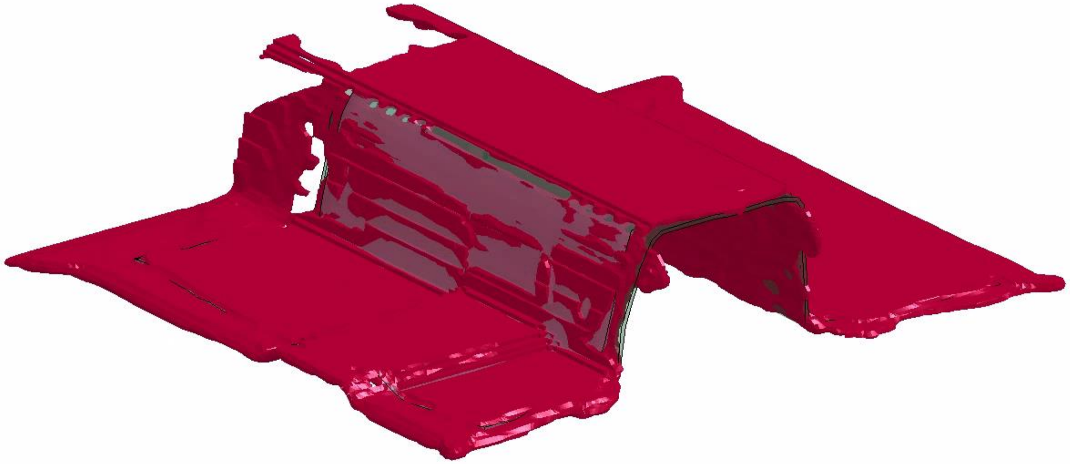
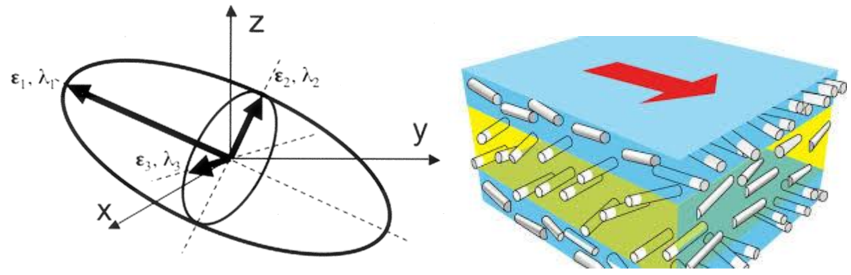
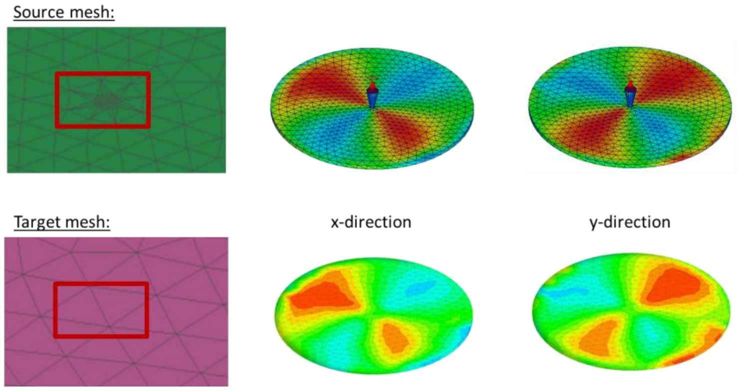


Short/long fiber reinforced plastics

- 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



[source: Fraunhofer - EMI]



Short/long fiber reinforced plastics

- mapping within the process chain (i.e. for short fiber reinforced plastics)
  - setting up an injection molding simulation using an appropriate simulation tool (i.e. Moldflow, Moldex3D, SolidWorks Plastic, …)
  - map material directions, orientation tensors, elastic properties, … (using a suitable mapping tool) onto a (re-)meshed model
    - map directly onto the integration points using (i.e. *MAT_157 - *MAT_ANISOTROPIC_ELASTIC_PLASTIC & *INITIAL_STRESS_SHELL/SOLID)
    - Solids (NHISV $= 6a_0 + 21a_1 + 6a_2 + a_3$)

Flag	Description	Variables	#
a_0	Material directions	$q_{11}, q_{12}, q_{13}, q_{31}, q_{32}, q_{33}$	6
a_1	Anisotropic stiffness	Cij	21
a_2	Anisotropic constants	F, G, H, L, M, N	6
a_3	Stress-strain Curve	LCSS	1

- Shells (NHISV $= 2a_0 + 21a_1 + 3a_2 + a_3$)

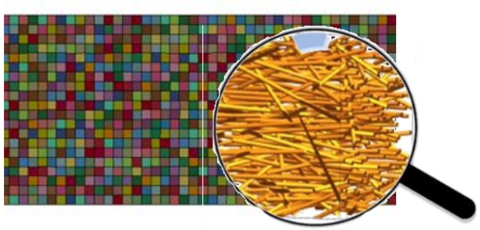
Flag	Description	Variables	#
a_0	Material directions	q_1, q_2	2
a_1	Anisotropic stiffness	Cij	21
a_2	Anisotropic constants	r_{00}, r_{45}, r_{90}	3
a_3	Stress-strain Curve	LCSS	1

Short/long fiber reinforced plastics

- mapping within the process chain (i.e. for short fiber reinforced plastics)
  - example for shells , IHIS=3 ($a_1 = 1$, $a_0 = 1$) → NHISV=2+21=23
  - *INITIAL_STRESS_SHELL

CARD 1	eid	nplane	nthick	nhisv	ntensor	large	nthint	nthhsv
CARD 2	t	sigxx	sigyy	sigzz	sigxy	sigyz	sigzx	eps
CARD 3	hisv1=q_1	hisv2=q_2	#3=C_{11}	#4=C_{12}	#5=C_{13}	#6=C_{14}	#7=C_{15}	#8=C_{16}
CARD 4	#9=C_{22}	#10=C_{23}	#11=C_{24}	#12=C_{25}	#13=C_{26}	#14=C_{33}	#15=C_{34}	#16=C_{35}
CARD 5	#17=C_{36}	#18=C_{44}	#19=C_{45}	#20=C_{46}	#21=C_{55}	#22=C_{56}	#23=C_{66}	

In material card

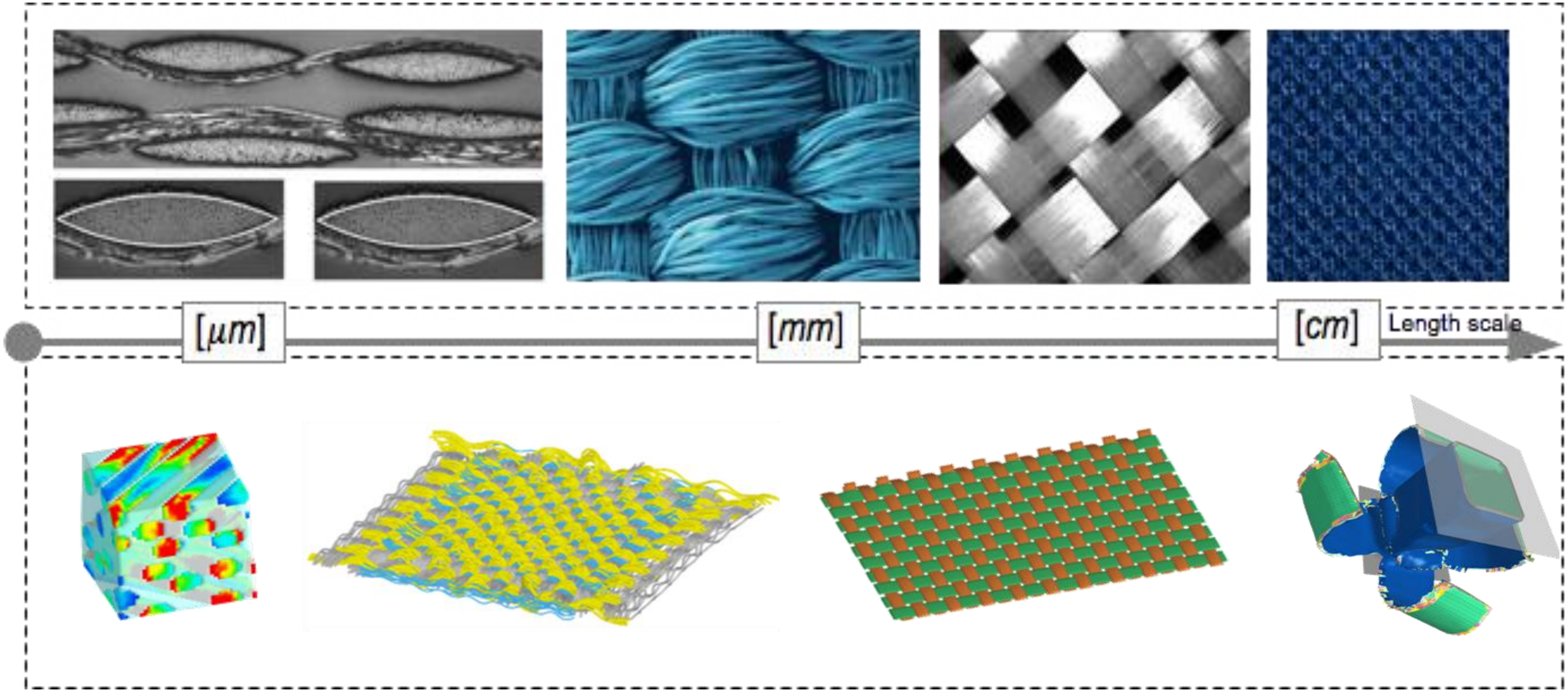


Drawback: inhomogeneous distribution (e.g. from previous short fiber filling simulation) in component needs individual part definition for every element

With *INITIAL_STRESS_SOLID

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

Modeling aspects



- For applications in mind we have to deal with complex simulations
  - Homogenized macroscopic approach is preferable
  - History variables have to be transferred properly
  - Sheets should be discretized with shell elements (~ 3 – 5 mm)

Agenda

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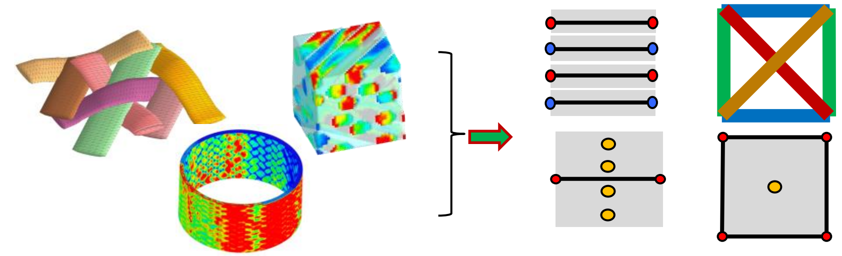
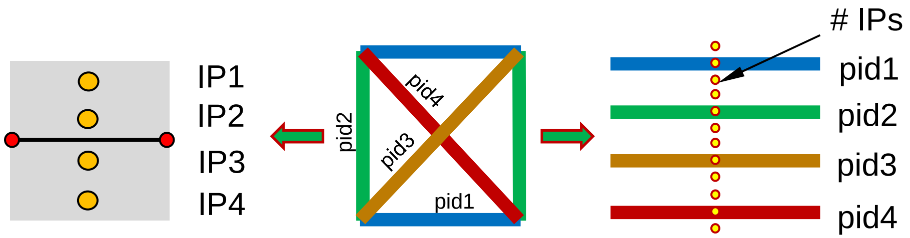
- Conclusion and Outlook

Modeling aspects - discretization

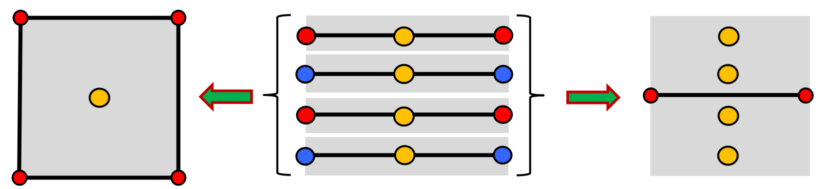
- RVE, experimental Data ➡ Shell, Stacked-Shell, Beam, Solid, Stacked-Solid…



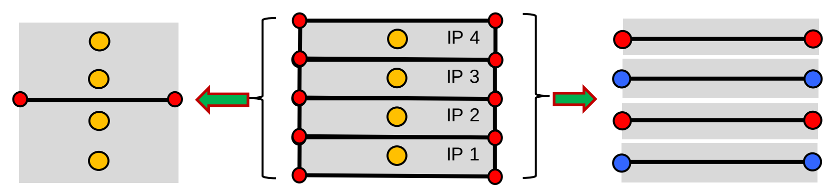
- Beam ➡ Shell, Stacked-Shell



- Stacked-Shell ➡ Solid, Shell



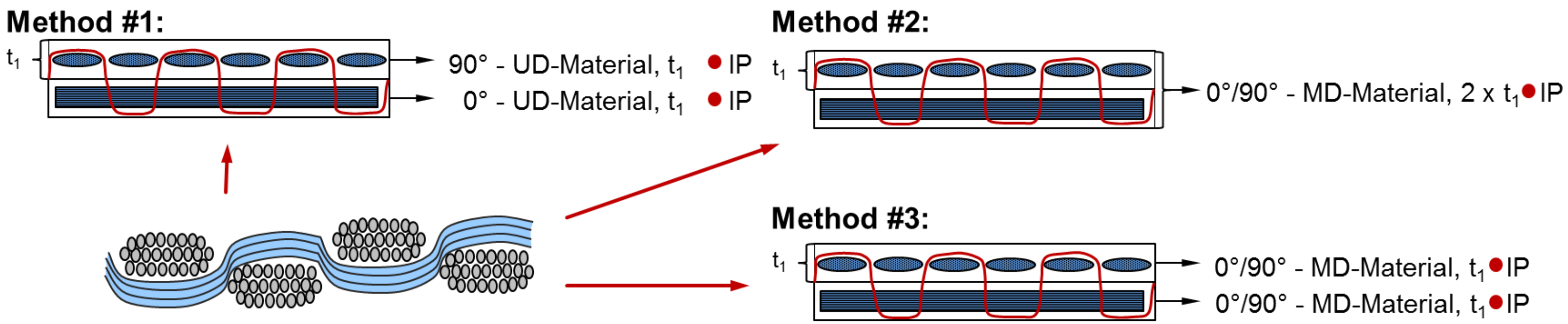
- Stacked-Solid ➡ Shell, Stacked-Shell



- and many more…

Modeling aspects – material properties

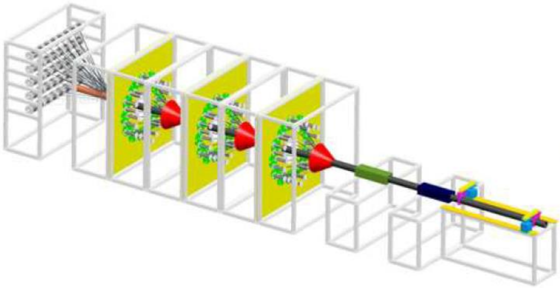
- Different approaches to model the different materials (e.g. woven & non-crimp fabric)
- Material parameters can be smeared over several layers or can be considered seperately



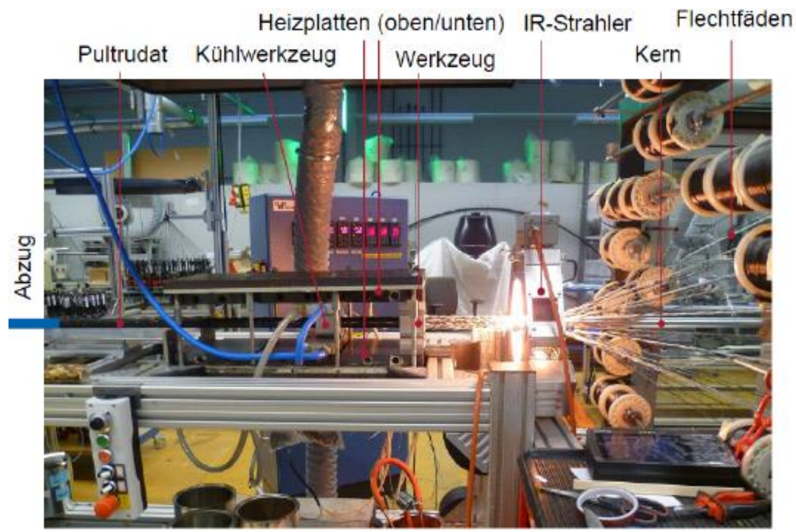
Braiding process chain (TPult)

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

- Why run braiding simulations?
  - Predict the roving layup prior the actual braiding process
  - Get information about the influence of roving pre-tensioning and friction btw. the rovings and the core/braiding rings

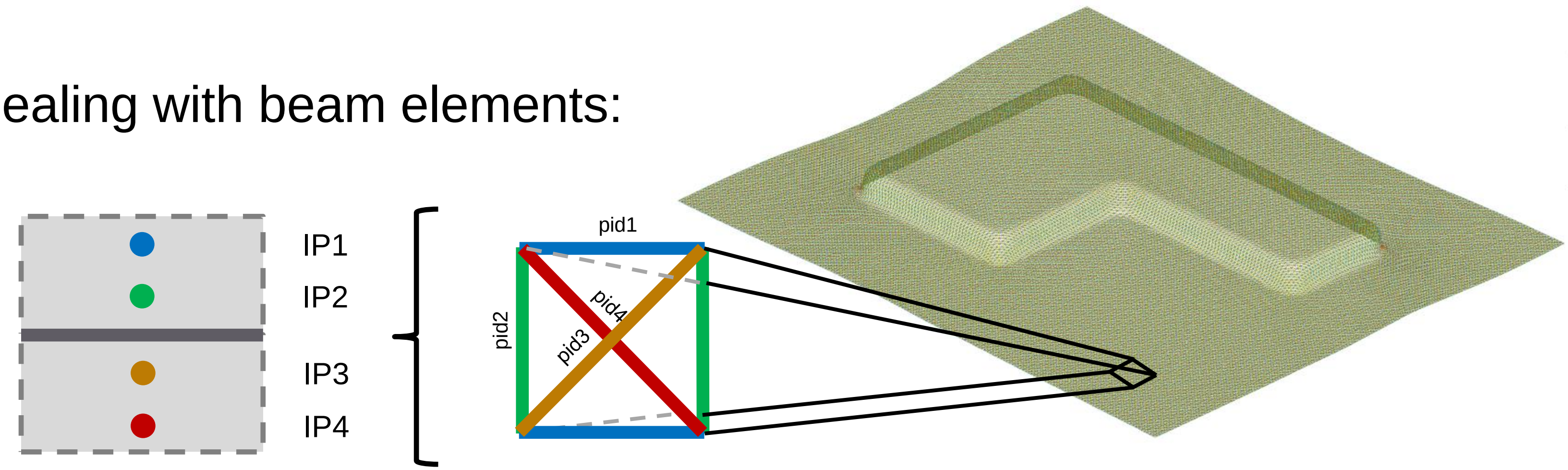


- Government funded research-project TPult:
  - Braiding on one core with four braiding machines in a row with rovings using a thermoplastic resin
  - Re-heating of the resin for further forming steps

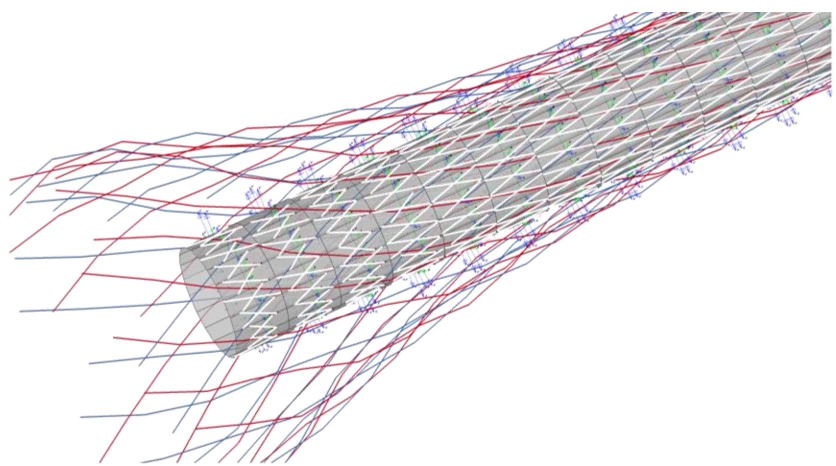


Mapping example

- Dealing with beam elements:

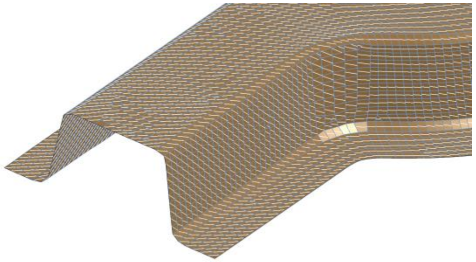


- Mapping can be performed in different ways
  - One direction for each integration point
  - Usage of a multi-directional material

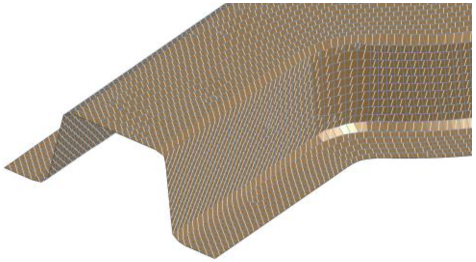


Mapping example

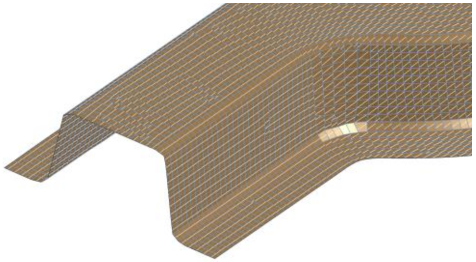
Layer #1:



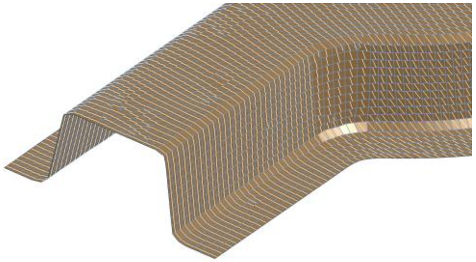
Layer #2:

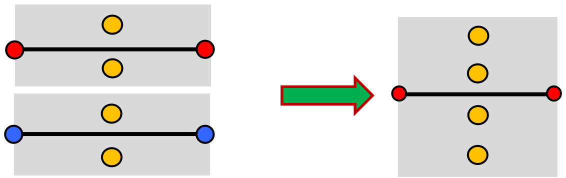


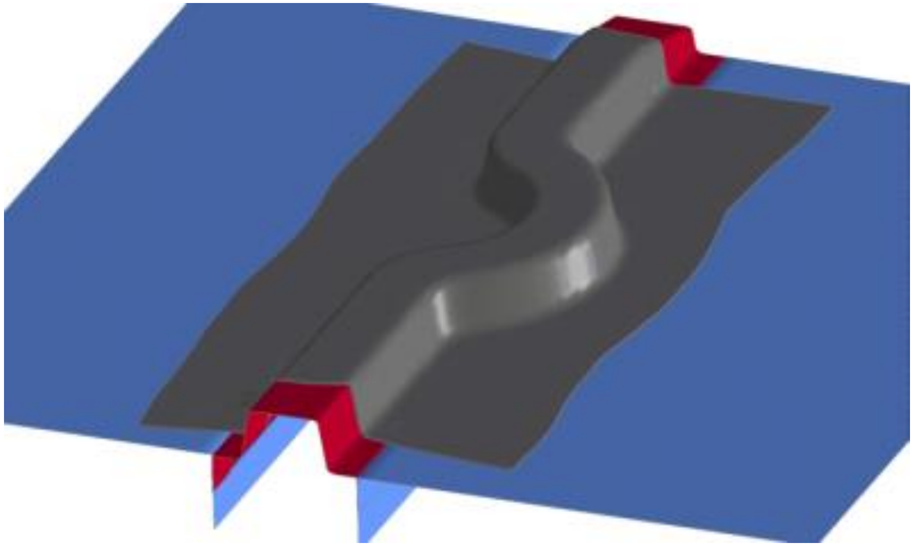
Layer #3:



Layer #4:

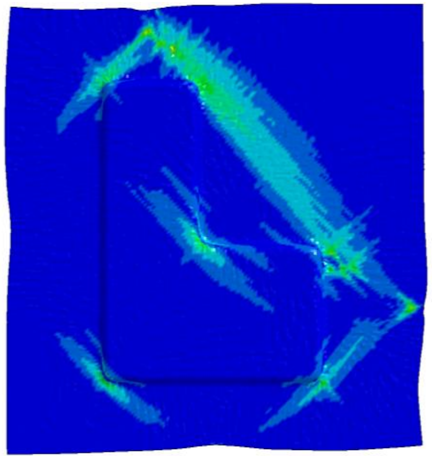


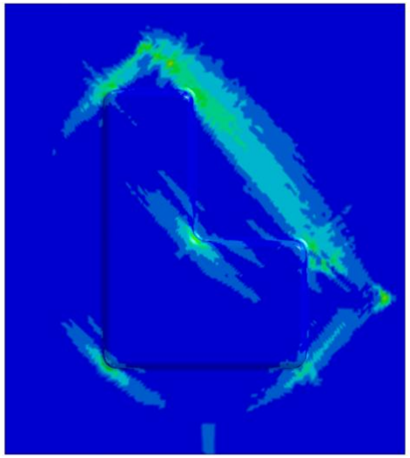


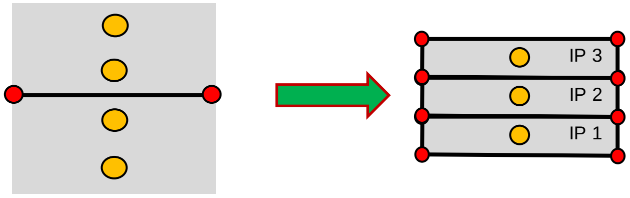


Mapping example

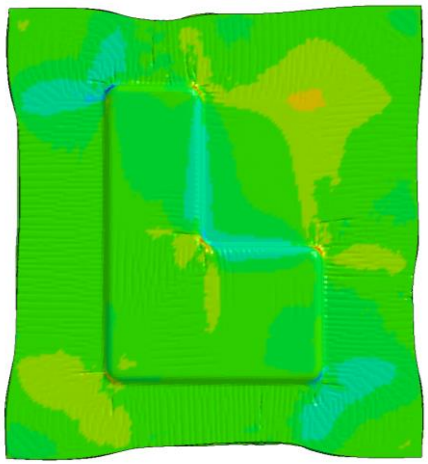
v. Mises Stress:

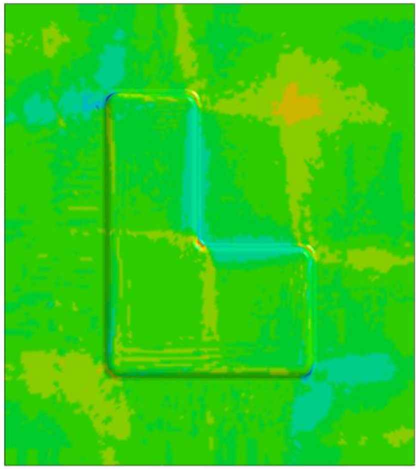


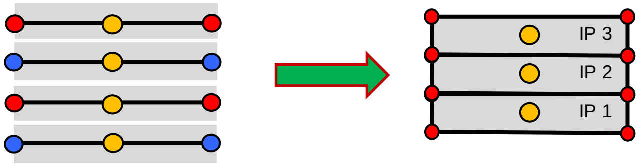




HISV #1:

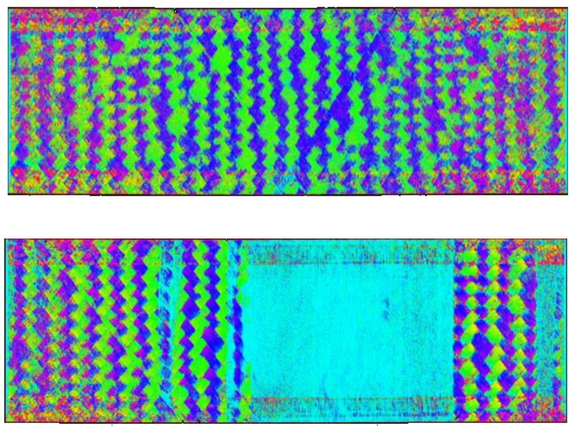




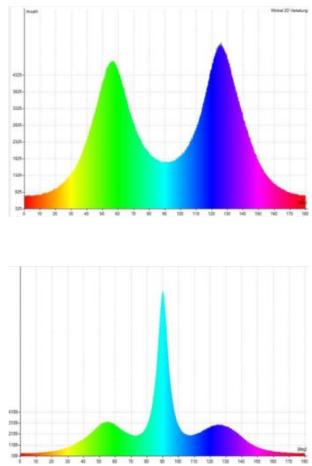


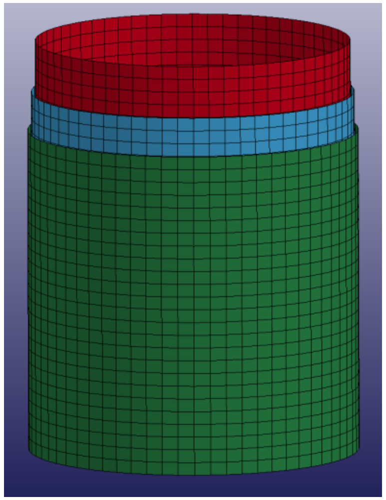
Mapping of CT-data

- Consider fiber orientations gained from CT-scans



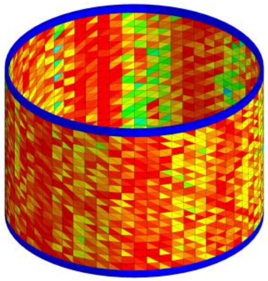
Orientation distribution



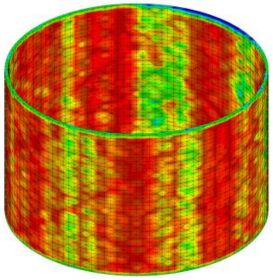


- Qualitiy of the results is mesh size dependent

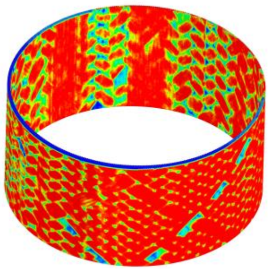
Coarse Mesh

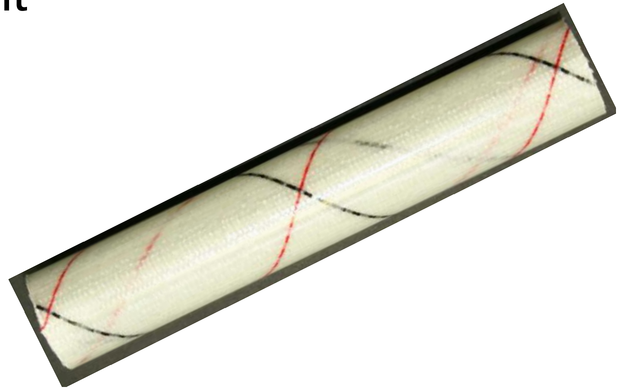


Mean Mesh



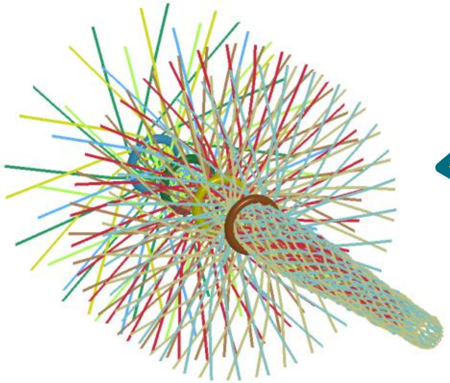
Fine Mesh



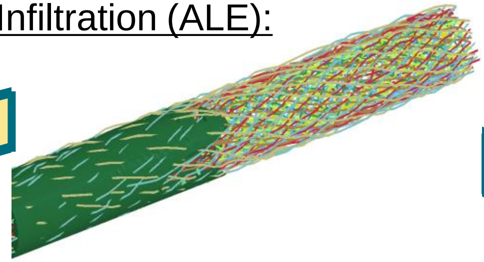


Process chain

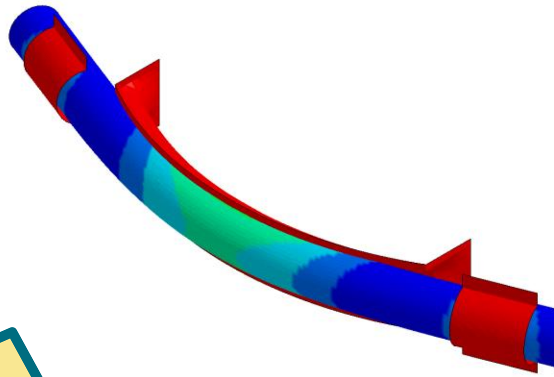
Braiding:



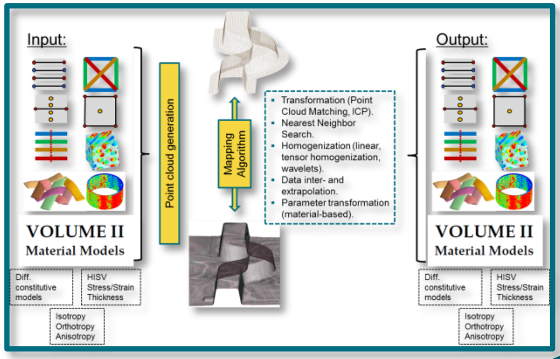
Infiltration (ALE):



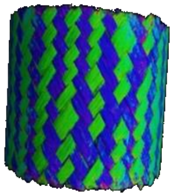
Forming (MAT_249):

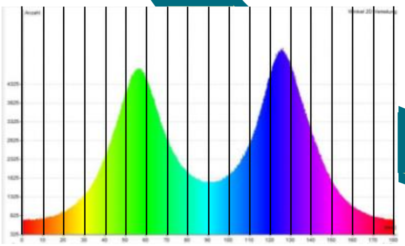


Mapping:

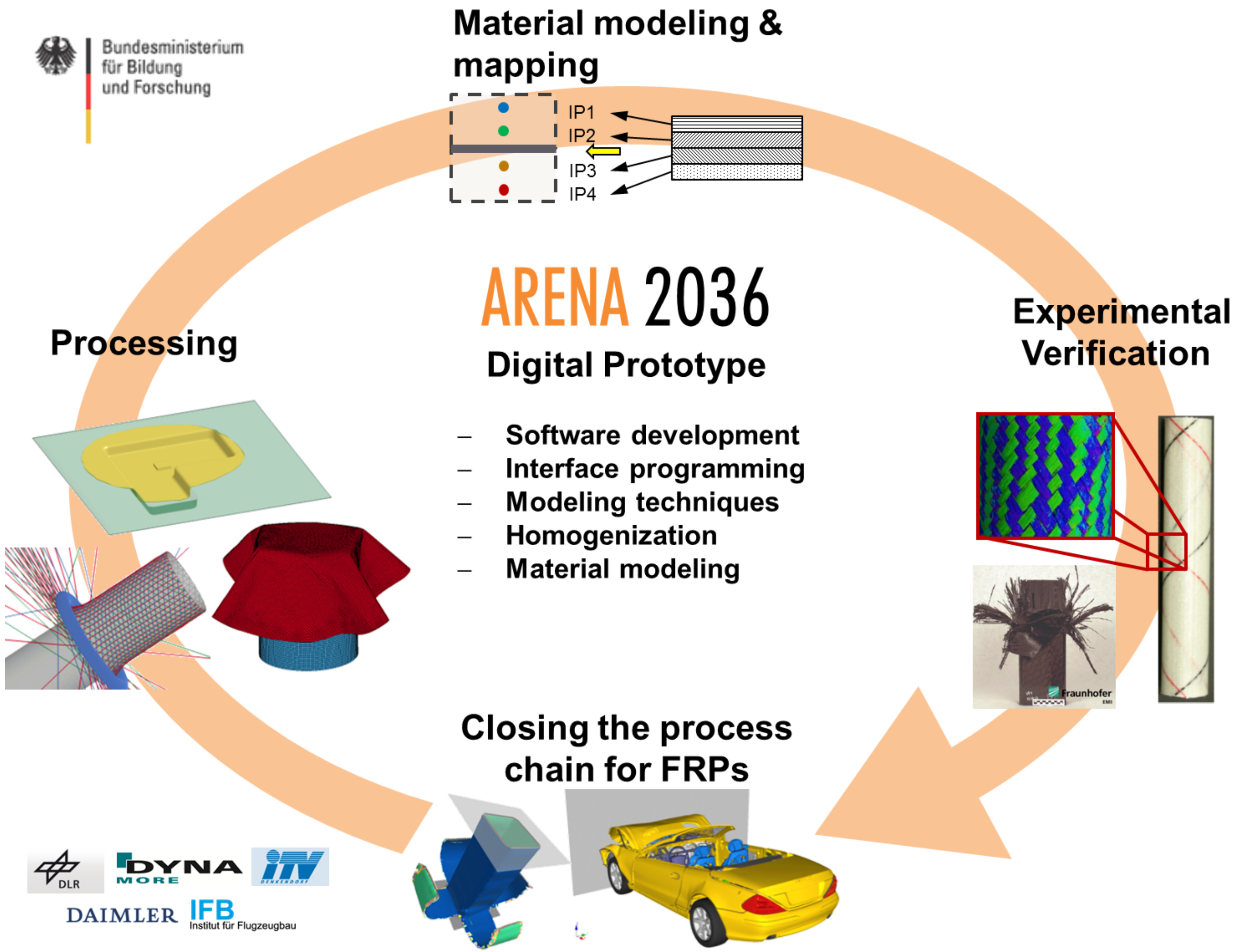


Experimental validation:



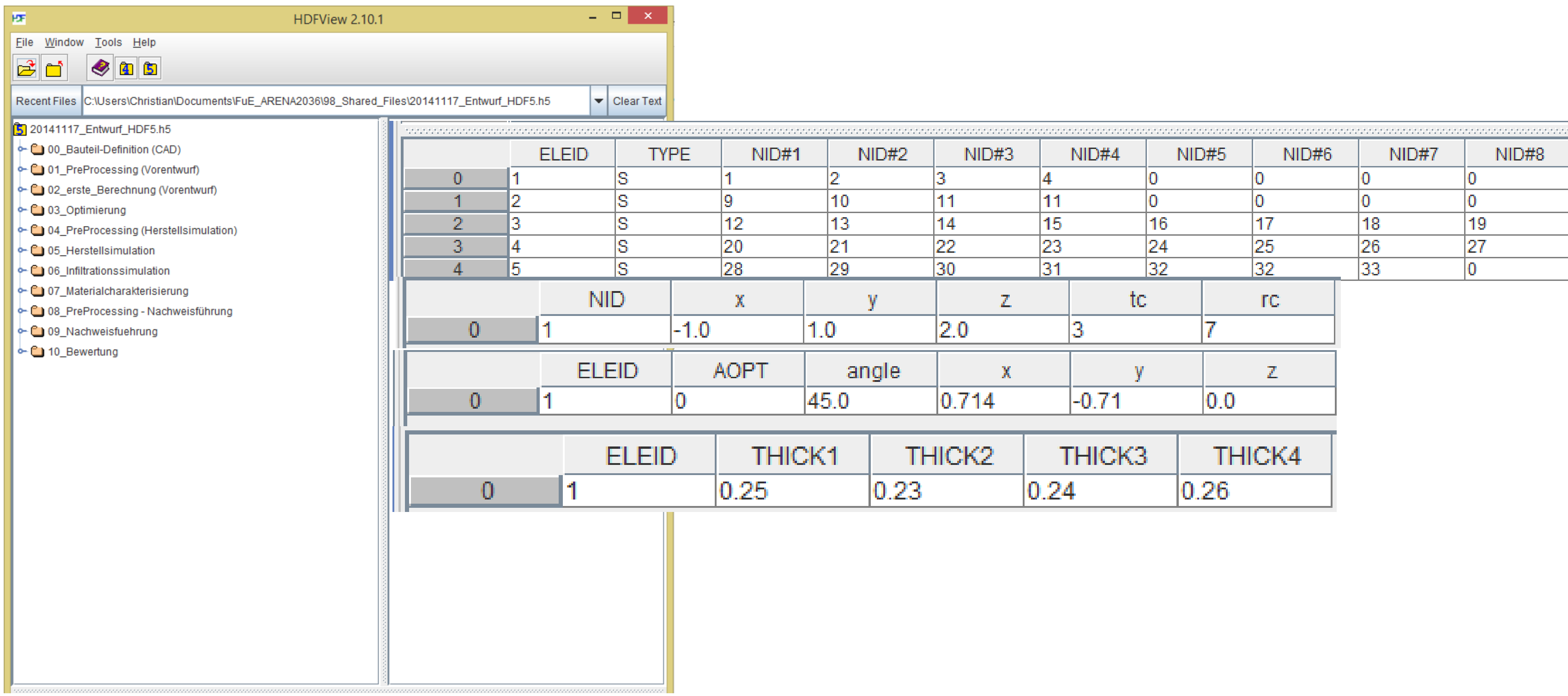


The digital prototype (ARENA 2036)



The digital prototype (ARENA 2036)

- Definition of a unified data exchange format accessible for all the project partners
- Exchange format is based on the binary open source HDF5 – data format, which can be easily accessed with HDFView



	ELEID	TYPE	NID#1	NID#2	NID#3	NID#4	NID#5	NID#6	NID#7	NID#8
0	1	S	1	2	3	4	0	0	0	0
1	2	S	9	10	11	11	0	0	0	0
2	3	S	12	13	14	15	16	17	18	19
3	4	S	20	21	22	23	24	25	26	27
4	5	S	28	29	30	31	32	32	33	0

	NID	x	y	z	tc	rc
0	1	-1.0	1.0	2.0	3	7

	ELEID	AOPT	angle	x	y	z
0	1	0	45.0	0.714	-0.71	0.0

	ELEID	THICK1	THICK2	THICK3	THICK4
0	1	0.25	0.23	0.24	0.26

Agenda

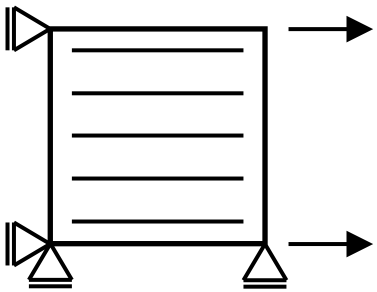
- Modeling aspects of process simulation
  - Draping, Weaving and Braiding
  - Thermoplastic pre-pregs
  - Resin transfer molding (RTM)
  - Wet molding
  - Short/long fiber reinforced plastics
- Mapping data between the different steps along the process chain
  - Modeling aspects
  - Mapping examples
- Developments towards an increasing predictability for crushing simulations
- Conclusion and Outlook

Available material models in LS-DYNA

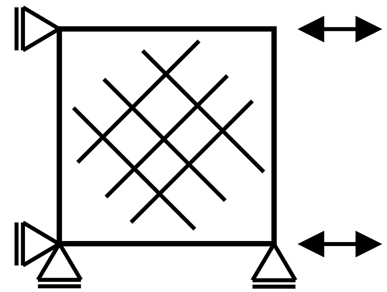
	Element	Failure criteria	Rate dependency	Remarks
***MAT_022:** COMPOSITE_DAMAGE	Shell, Tshell, Solid	Chang-Chang	-	ALPH doesn't affect stress vs. strain relationship. (same for 054/055)
***MAT_054/055:** ENHANCED_COMPOSITE_DAMAGE	Shell, Tshell, Solid	54: Chang 55: fiber: Chang matrix: Tsai-Wu	rate dependent 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

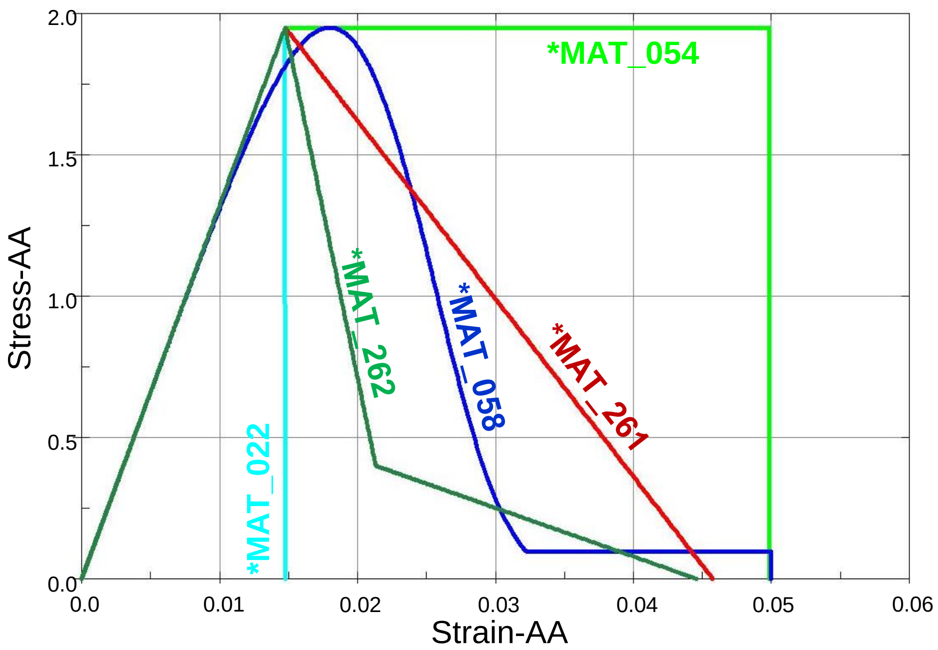
- comparison of the material models
  - 1-Element-Test, Single-Layer (‚SHELL‘, ELFORM=2)

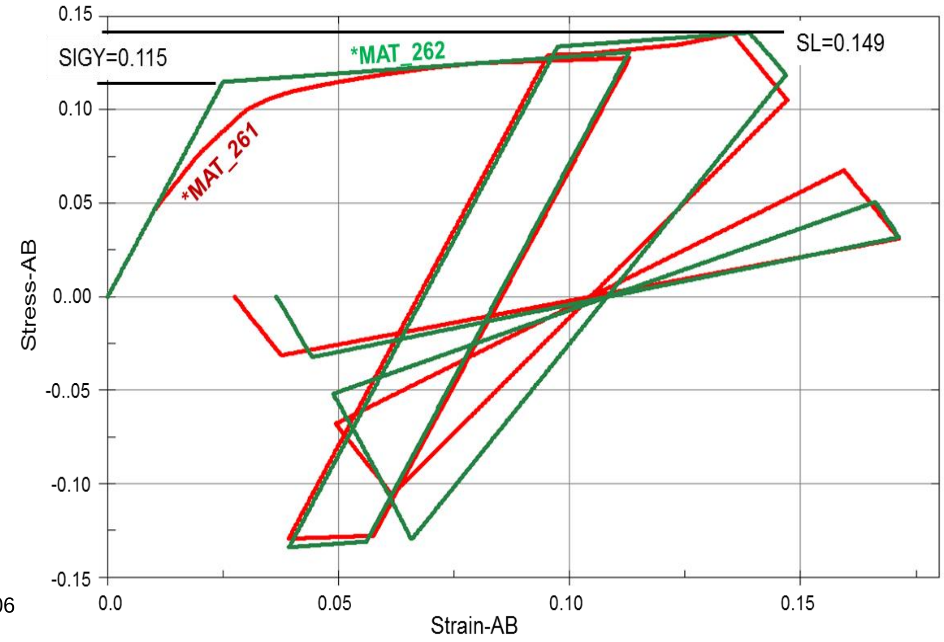
fiber tensile load (A-E)



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







○ *MAT_LAMINATED_COMPOSITE_FABRIC (*MAT_058)

		1	2	3	4	5	6	7	8
elastic, orthotropic parameters	Card 1	MID	RO	EA	EB	(EC)	PRBA	TAU1	GAMMA1
	Card 2	GAB	GBC	GCA	SLIMT1	SLIMC1	SLIMT2	SLIMC2	SLIMS
material coos	Card 3	AOPT	TSIZE	ERODS	SOFT	FS	**EPSF**	**EPSR**	**TSMD**
	Card 4	XP	YP	ZP	A1	A2	A3		
	Card 5	V1	V2	V3	D1	D2	D3	BETA	
model parameter	Card 6	E11C	E11T	E22C	E22T	GMS			
	Card 7	XC	XT	YC	YT	SC			
new model parameter (optional)	(opt) 8	**LCXC**	**LCXT**	**LCYC**	**LCYT**	**LCSC**	**LCTAU1**	**LCGAM1**	**DT**
	(opt) 9	**LCE11C**	**LCE11T**	**LCE22C**	**LCE22T**	**LCGMS**			

EPSF	Damage initiation transverse shear strain
EPSR	Final rupture transverse shear strain
TSMD	Transverse shear maximum damage

Parameters related to transverse shear (starting 971-R7.1)

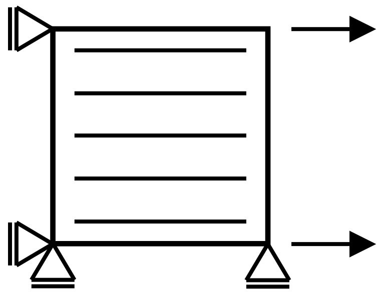
LCXC	Load curve ID for XC vs. strain rate (XC is ignored with that option), available in log-scale
LCXT	Load curve ID for XT vs. strain rate (XT is ignored with that option), available in log-scale
LCYC	Load curve ID for YC vs. strain rate (YC is ignored with that option), available in log-scale
LCYT	Load curve ID for YT vs. strain rate (YT is ignored with that option), available in log-scale
LCSC	Load curve ID for SC vs. strain rate (SC is ignored with that option), available in log-scale
DT	Strain rate averaging option

LCE11C	Load curve ID defining E11C vs. strain rate (E11C is ignored with that option)
LCE11T	Load curve ID defining E11T vs. strain rate (E11T is ignored with that option)
LCE22C	Load curve ID defining E22C vs. strain rate (E22C is ignored with that option)
LCE22T	Load curve ID defining E22T vs. strain rate (E22T is ignored with that option)
LCGMS	Load curve ID defining GMS vs. strain rate (GMS is ignored with that option)

Parameters related to strain rate dependent element elimination (starting 971-R7.1)

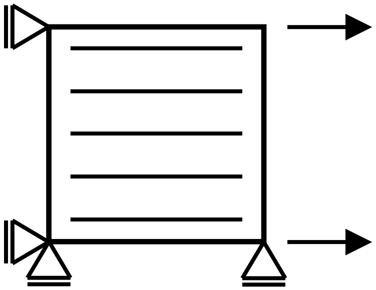
- *MAT_LAMINATED_COMPOSITE_FABRIC (*MAT_058)
  - 1-Element-Test, Single-Layer (‚SHELL‘, ELFORM=2, FS=0.0)

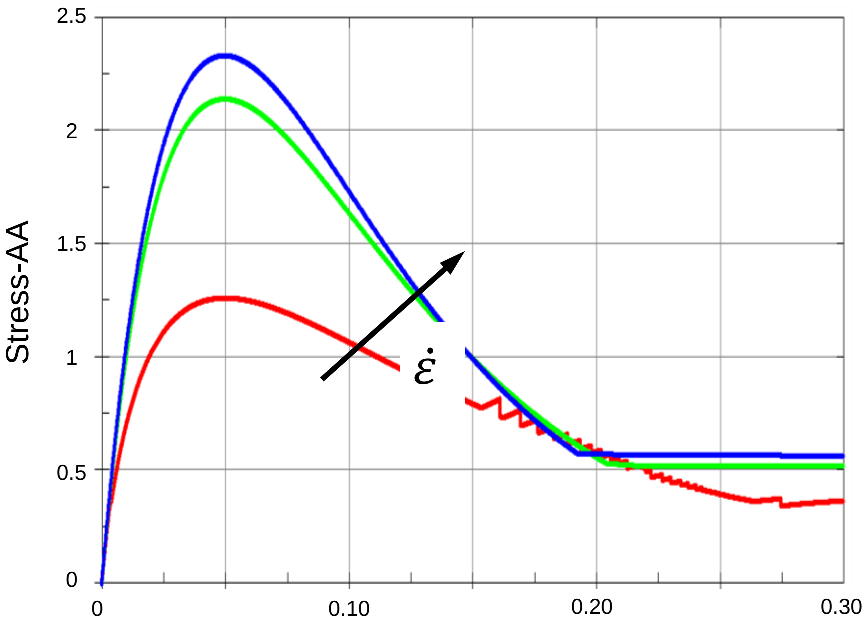
fiber tensile load

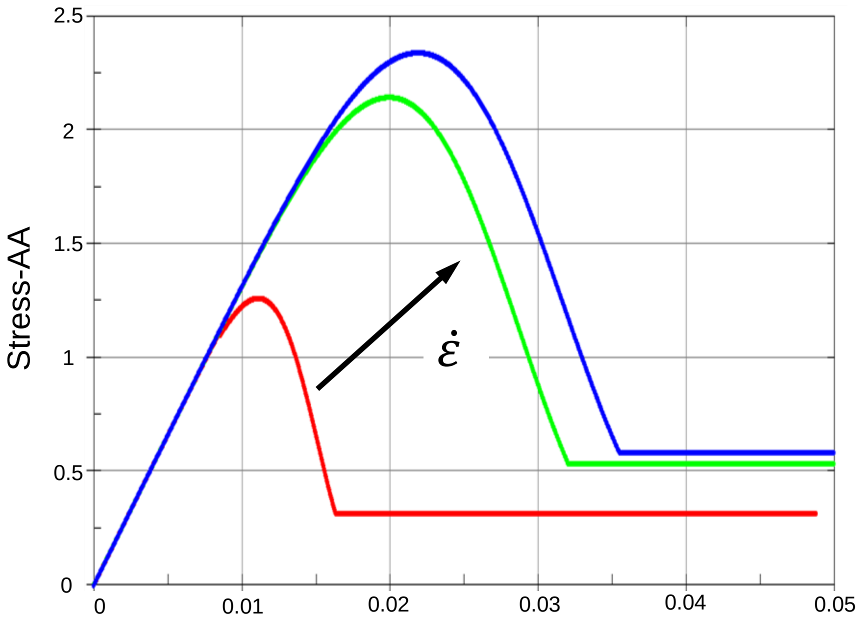


Material Parameter:
EA= 132.0 [kN/mm²]
LCXT= …
LCE11T=…
XT=1.950
E11T=0.050
SLIMT1=0.25

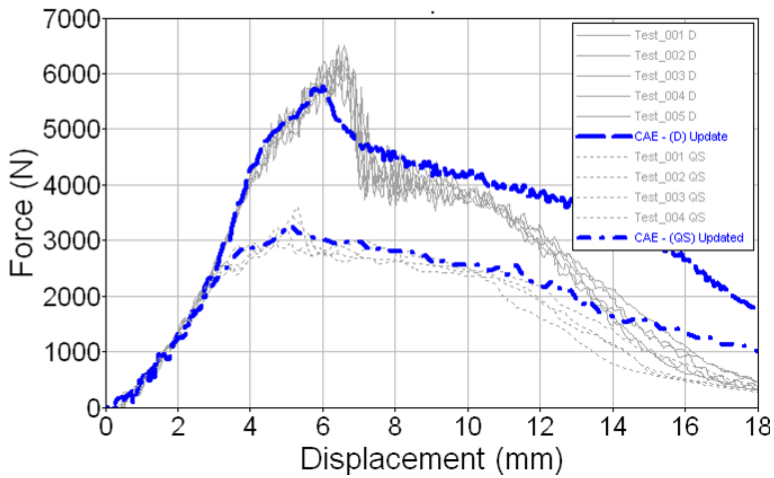
fiber tensile load

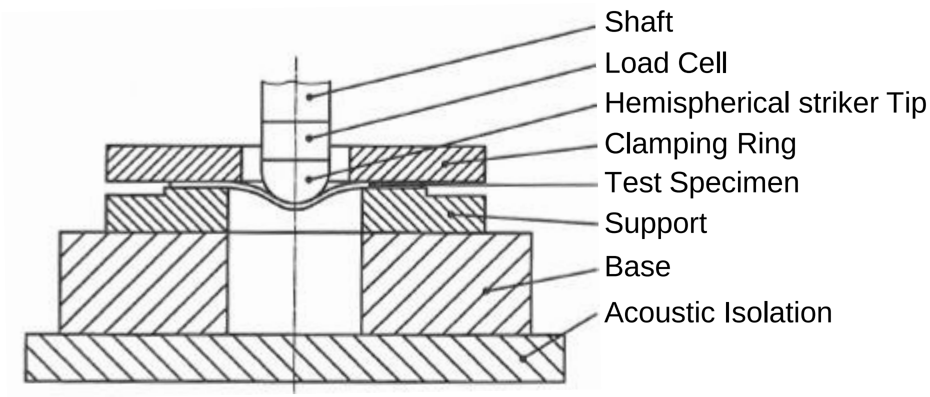




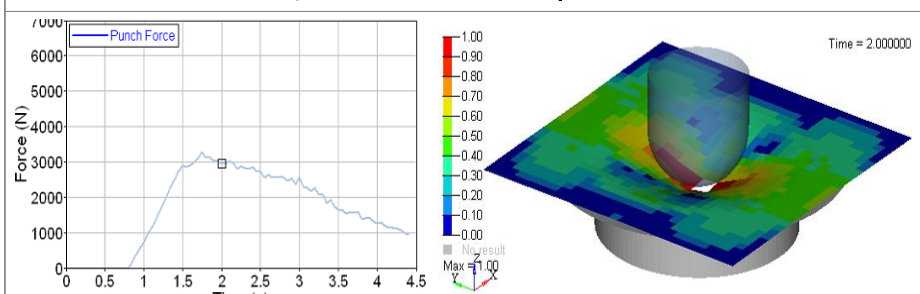
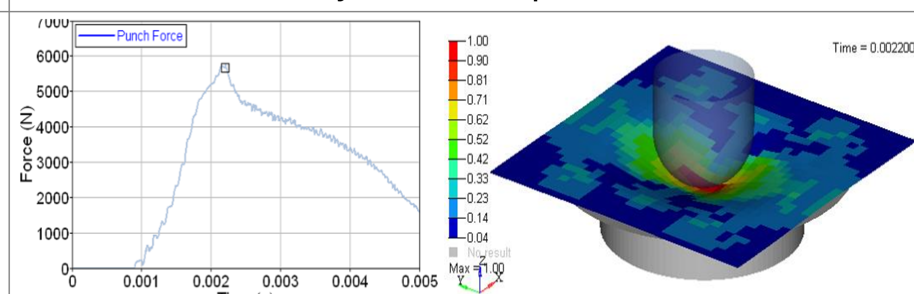


- *MAT_LAMINATED_COMPOSITE_FABRIC (*MAT_058)
  - Example: Punch Test (DIN EN ISO 6603-2)
    - PA6 GF46 Organo-sheet
    - Loading speed:
      a) Quasi-static: $\dot{\varepsilon} \sim 0.001\ [1/s]$
      b) Dynamic: $\dot{\varepsilon} \sim 200\ [1/s]$





Disc Punch Test Configuration

Quasi-Static Response	Dynamic Response
	

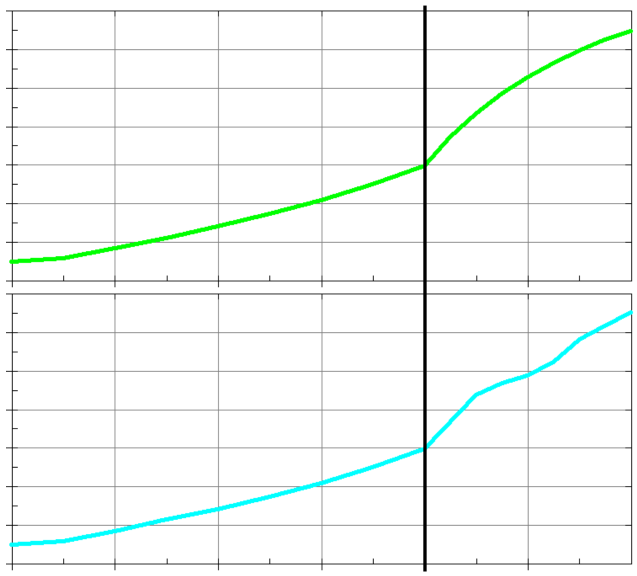
Damage in 0°

Damage in 0°

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

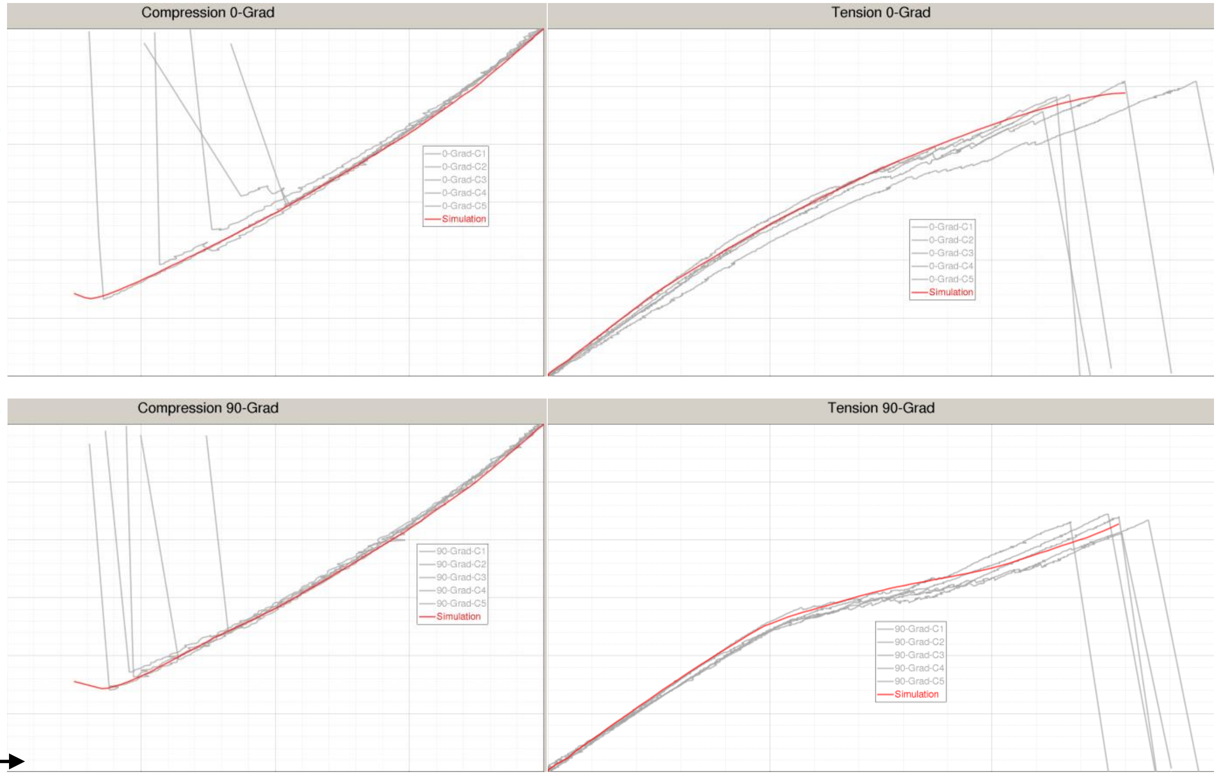
- *MAT_LAMINATED_COMPOSITE_FABRIC (*MAT_058)
    - Example: Adjusting non-linear material properties for woven composite

Curve-definition for EA



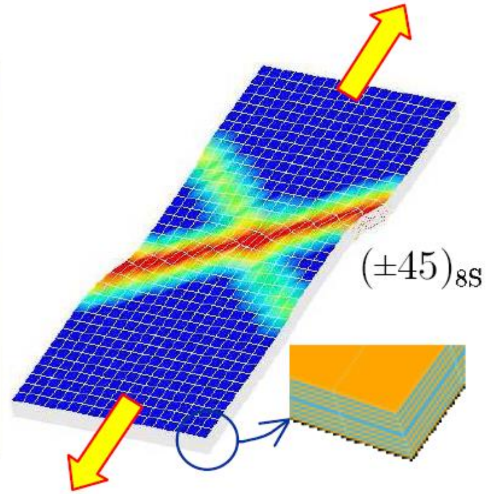
Curve-definition for EA

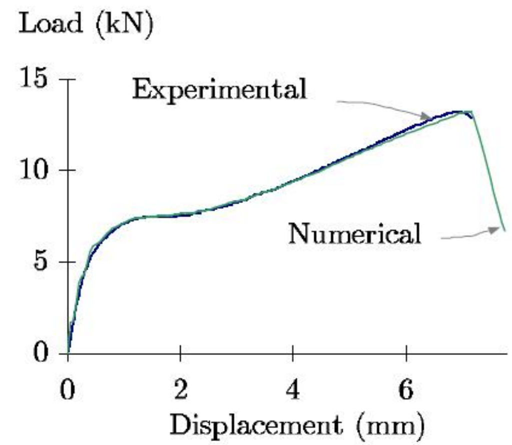
compression tension



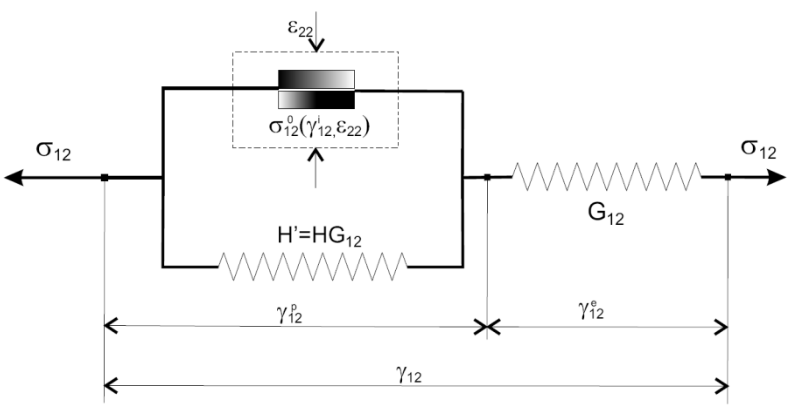
- Non-linear elastic, orthotropic material properties for EA, EB via *DEFINE_CURVE

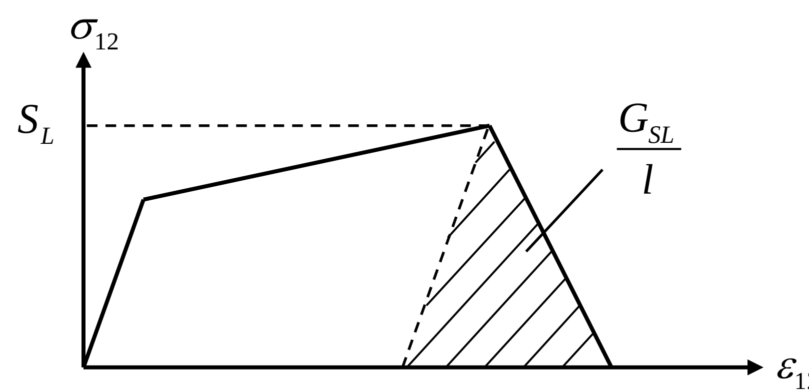
- *MAT_LAMINATED_FRACTURE_DAIMLER_CAMANHO (*MAT_262)
  - in-plane shear behavior





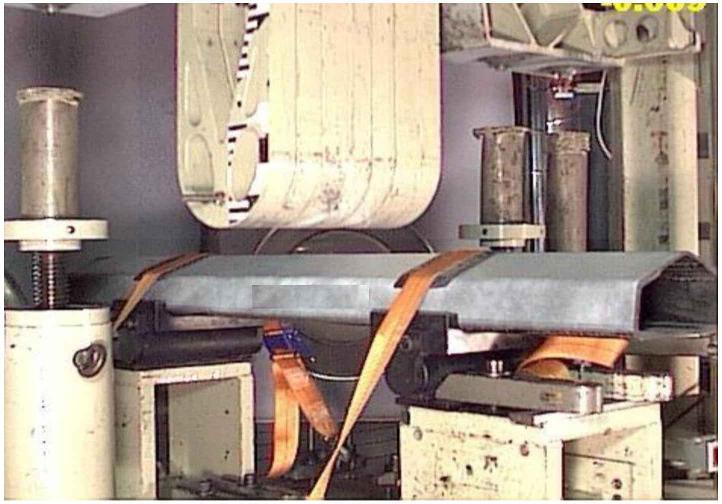
1D-plasticity model with combined iso/kin hardening – coupled with linear damage evolution (softening)

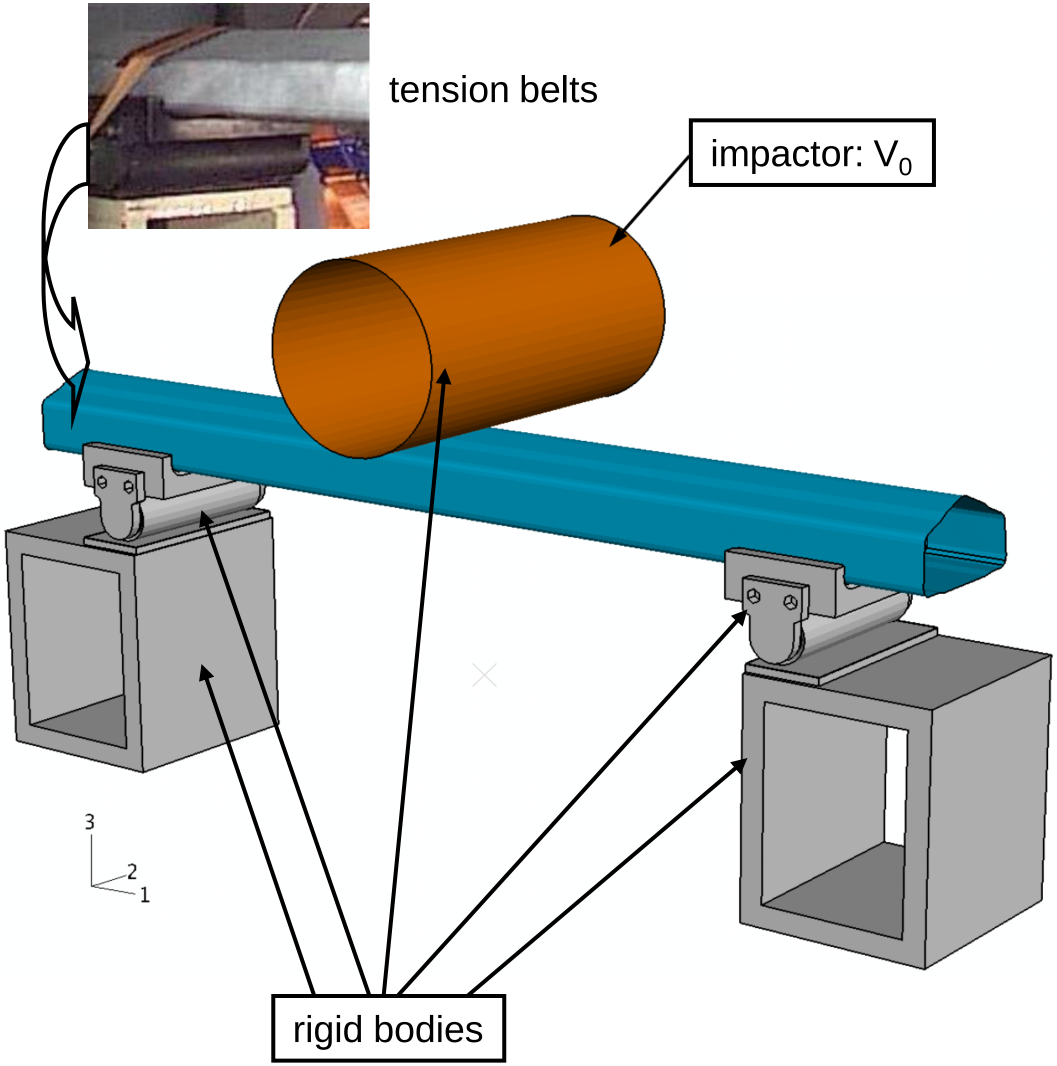




3-point-bending

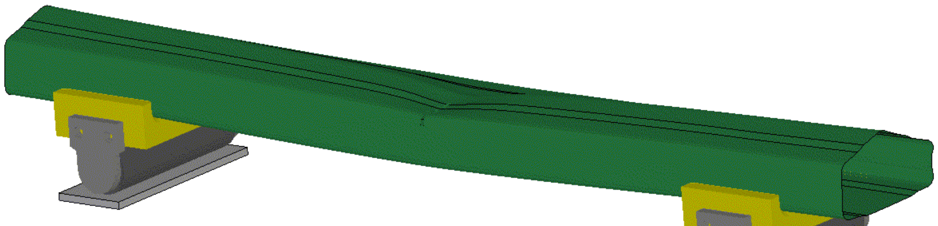
- support and impactor as rigid bodies
- tension belts with pre-stressed beams
- girder with layered shell elements (12 layers, *ELFORM=2*) and material model from P. Camanho



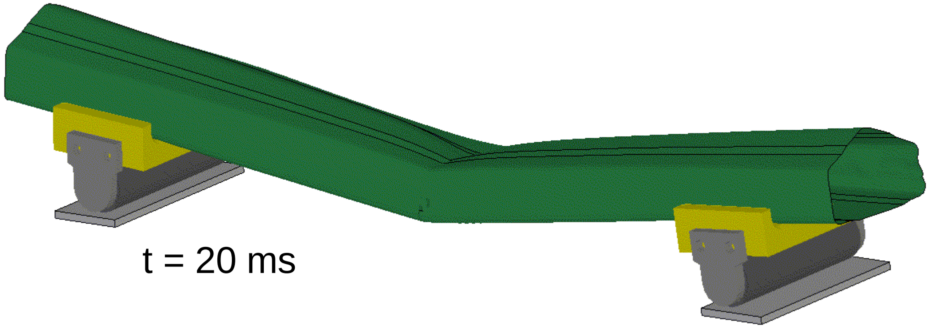


3-point-bending

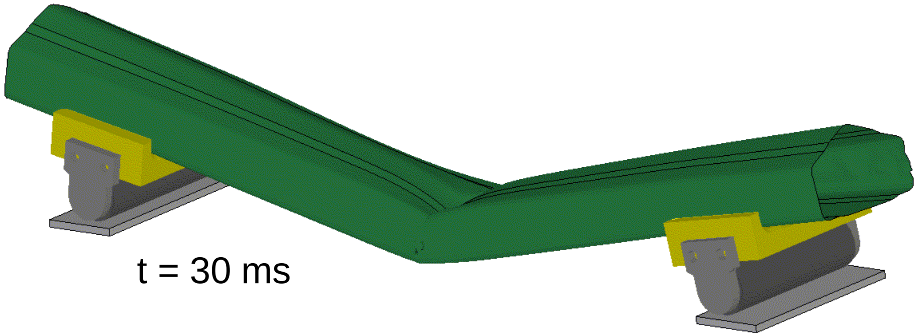
LS-DYNA with material model from P. Camanho (UserMat)



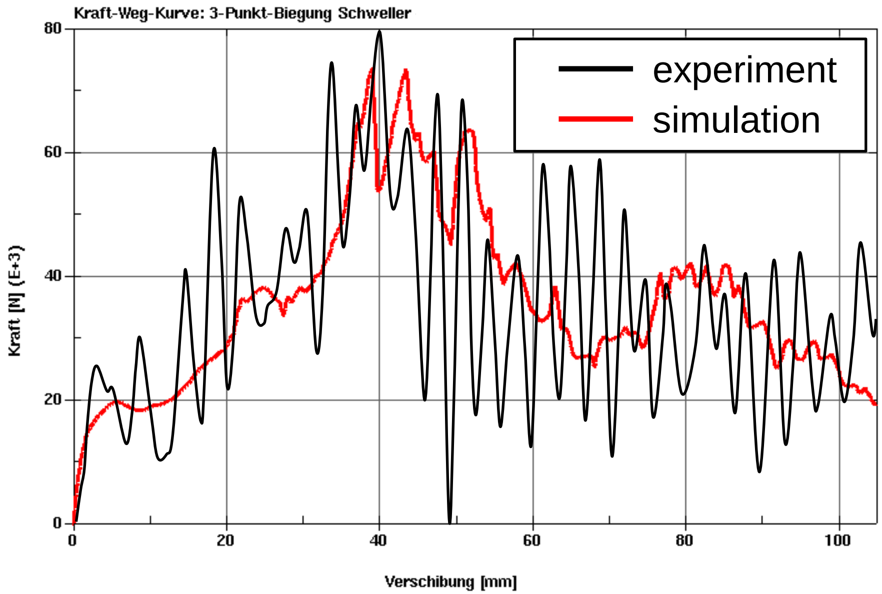
t = 10 ms

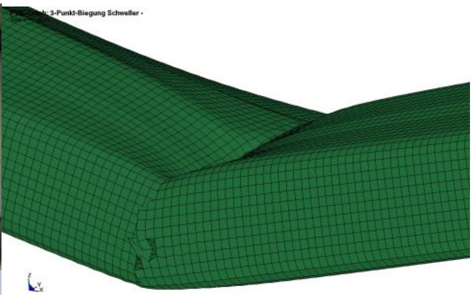


t = 20 ms



t = 30 ms





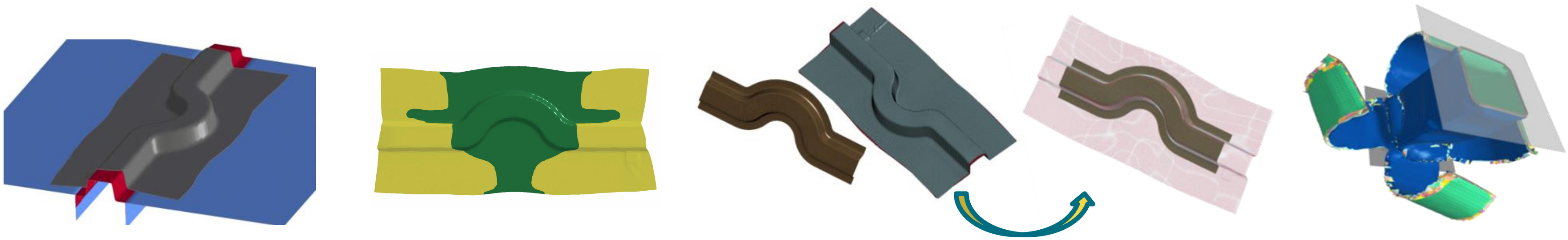
Agenda

- Modeling aspects of process simulation
  - Draping, Weaving and Braiding
  - Thermoplastic pre-pregs
  - Resin transfer molding (RTM)
  - Wet molding
  - Short/long fiber reinforced plastics
- Mapping data between the different steps along the process chain
  - Modeling aspects
  - Mapping examples
- Developments towards an increasing predictability for crushing simulations
- Conclusion and Outlook

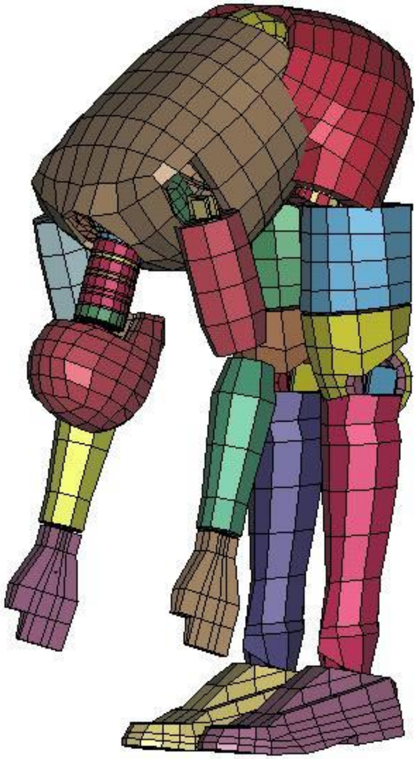
Conclusion and Outlook

- 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.



Thank you for your attention!



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