Short and long fiber reinforced thermoplastics – material models in LS-DYNA

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1 Fiber reinforced thermoplastics

In the last years the demand on weight reduction in the automotive industry has led to a strong interest for various composite applications. Due to the complexity of those usually highly anisotropic materials virtual product development is one of the key factors to understand the load carrying behavior of such parts. Furthermore enhanced CAE tools and models are necessary to ensure an efficient and robust product development.

Especially fiber size and geometry have a significant influence on the part performance. Orthotropic properties increase with increasing fiber content while at the same time the effect of strain rate diminishes due to the lesser content of matrix material (figure 1 and 2). Also a strong dependence on the temperature can be seen (figure 3) especially also for the failure behavior; the test specimens become more brittle with decreasing temperatures.

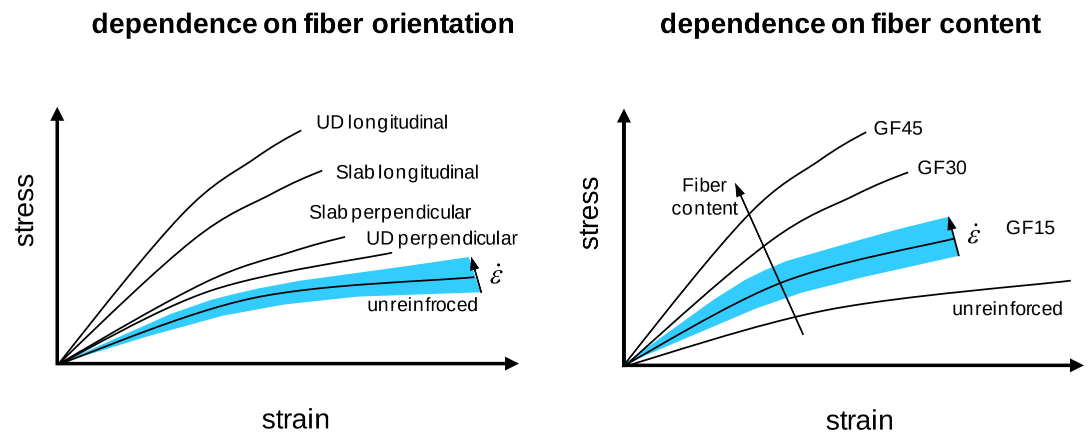

Fig.1: Influence of fiber orientation, content and strain rate on the stress-strain-behavior [1].

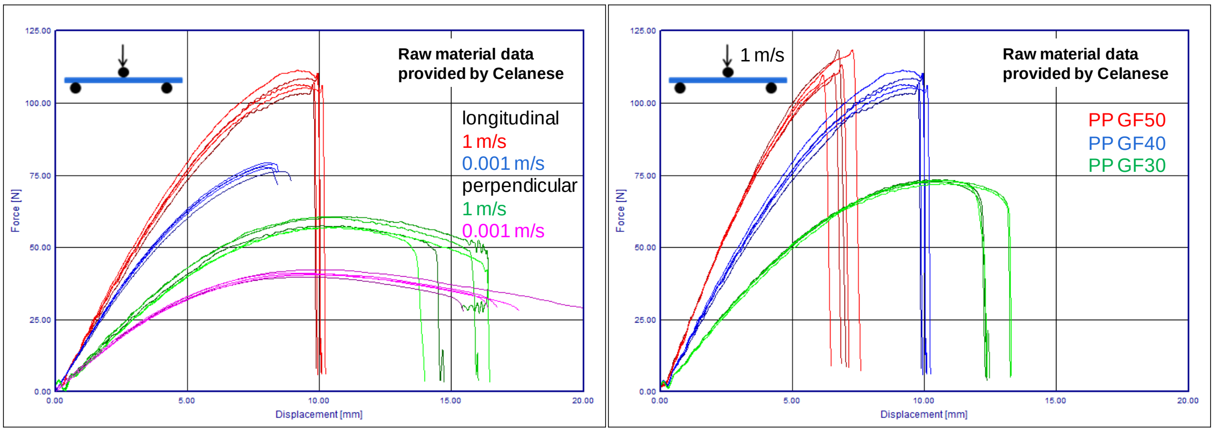

Fig.2: Influence of test velocity (left) and fiber content (right) shown on the force-displacement curves for a PP GF tested in a 3-point-bending test using 4a impetus [1].

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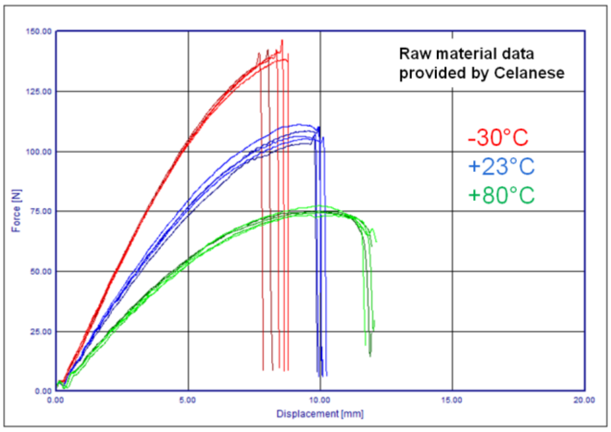

Fig.3: Influence of temperature shown on the force-displacement curves for a PP GF40 longitudinal tested in a 3-point-bending test at a velocity of 1 mps using 4a impetus [1].

LS-DYNA offers a great number of constitutive models for anisotropic materials. These models are able to consider anisotropic influences to some extent (e.g. *MAT_002, *MAT_022, *MAT_054/055, MAT_058, *MAT_103, *MAT_108, *MAT_157, etc.), shown in table 1.

The aforementioned currently available constitutive models may not be able to fulfil all of the many effects and requirements to describe the real material behavior, however most of these models are well suited to resemble the main anisotropic influence of the fiber reinforcement.

No.	Elastic	Plastic	Damage	Strain rate	Failure
2	Orthotropic / Anisotropic	None	None	None	*MAT_ADD_EROSION
22	Orthotropic	None	None	None	Orientation dependent
54	Orthotropic	None	Elastic Orthotropic	Strength	Orientation dependent
58	Orthotropic	None	Elastic Orthotropic	Strength, Stiffness	Orientation dependent
103	Isotropic	Hill	None	Plasticity	*MAT_ADD_EROSION
108	Orthotropic	Hill	None	None	*MAT_ADD_EROSION
157	Anisotropic	Hill	None	Plasticity	*MAT_ADD_EROSION
158	Orthotropic	None	Elastic Orthotropic	Viscoelasticity	Orientation dependent

Table 1: Material models in LS-DYNA for anisotropic materials [2].

Of course LS-Dyna permanently works on improvements on the existing material models. For example, for material *MAT_002 new features were recently implemented with the option *MAT_002_ANIS (see figure 4):

- Hyperelastic (total) formulation using Green-Lagrange strain
- Elastic-anisotropic behavior, stiffness matrix with 21 independent coefficients
- Several possibilities to define material directions, e.g. AOPT, ELEMENT_SOLID_ORTHO, etc.
- Use invariant node numbering is recommended

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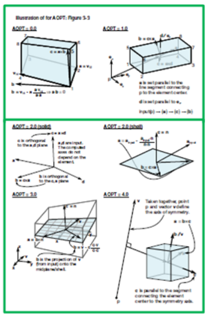
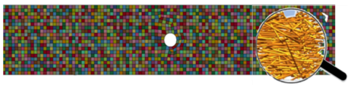
CARD #1	mid	ro	c11	c12	c22	c13	c23	c33
CARD #2	c14	c24	c34	c44	c15	c25	c35	c45
CARD #3	c55	c16	c26	c36	c46	c56	c66	aopt
CARD #4	xp	yp	zp	a1	a2	a3	macf	ihis
CARD #5	v1	v2	v3	d1	d2	d3	beta	ref



- C_{ij}: constants in the 6x6 anisotropic constitutive matrix $\sigma_{ij} = C_{ijkl}\varepsilon_{kl}$
- AOPT: usual options to define the material's coordinate system
- ihis: flag for element-wise definition of the stiffness tensor with *INITIAL_STRESS_SOLID. This allows mapping of locally anisotropic data.

Old approach: each element one material card



New approach: one property
*INITIAL_STRESS_SHELL (SOLID)

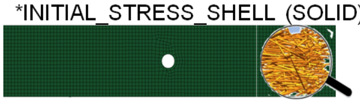


*Fig.4: New features for *MAT_002 [2].*

Also the material model *MAT_157 offers new features such as the IP-wise Initialization (figure 5).

***MAT_157: Selective mapping IHIS**

$$IHIS = a_0 + 2a_1 + 4a_2 + 8a_3$$

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

***INITIAL_STRESS_SOLID: NHISV**

- In addition to 6 stress values and eps NHISV history variables can be initialized
- NHISV must correspond to the a_i that define IHIS in *MAT_157

$$NHISV = 6a_0 + 21a_1 + 6a_2 + 1a_3$$

*Fig.5: New features for *MAT_157 [2].*

Furthermore 4a has developed a user material in LS Dyna, based on micro-mechanics (mori tanaka meanfield theory). Results and a comparison to classical material models are presented. Advantages are

- the description of the mechanical composite behavior by a matrix and fiber phase, not only in elasticity but also in visco-plasticity up to a matrix failure.
- the simplified usage in the complete simulation process chain, due to the direct usage of process induced fiber orientation and content as input parameter for the material model.

To get the best simulation results not only the best material model has to be used but also the influence of the process chain has to be considered. The fiber orientation (see figure 1 and 2) has a significant influence on the material behavior. Using 4a micromec [6] the elastic properties of a fiber reinforced material can be calculated very quick and using 4a fibermap [7] the resulting fiber orientation can be mapped from the rheological simulation into the FEM-simulation. The benefits of implementing these applications in the simulation process chain (figure 6) are clearly visible.

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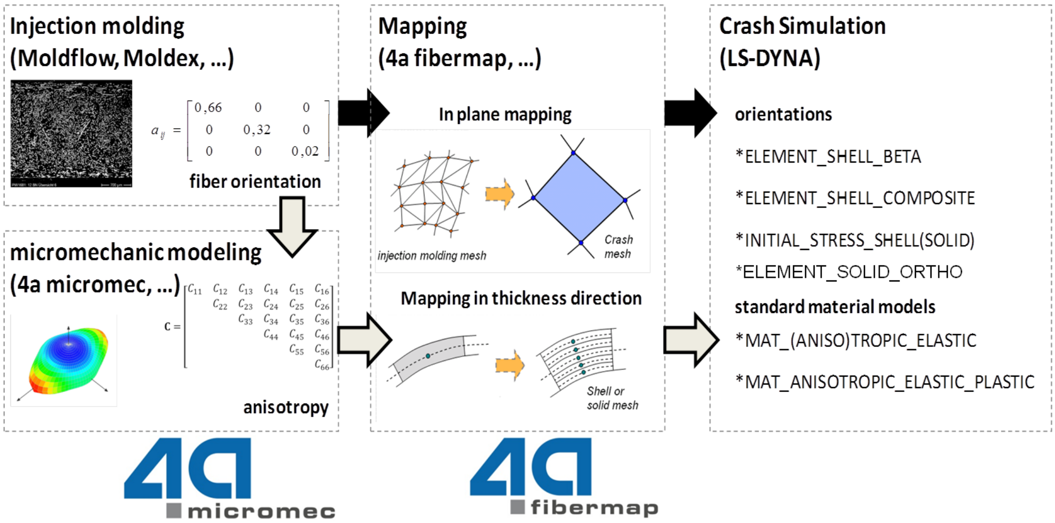

Fig.6: Available simulation process chain for injection molded parts [3].

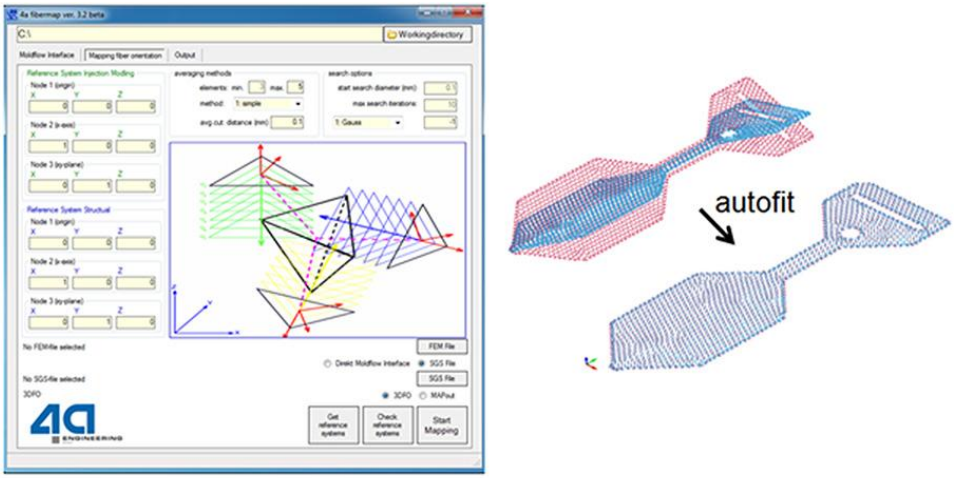

Fig.7: 4a fibermap for mapping informations like fiber orientation, temperature, ...
Autofit feature - to find automatically coordinate transformation from process to structural mesh

Figure 8 shows a comparison of the test results to the simulation results on PP GF40. The orthotropic material model without plasticity or damage (*MAT_002) can reproduce the longitudinal direction, but is too stiff in perpendicular direction.

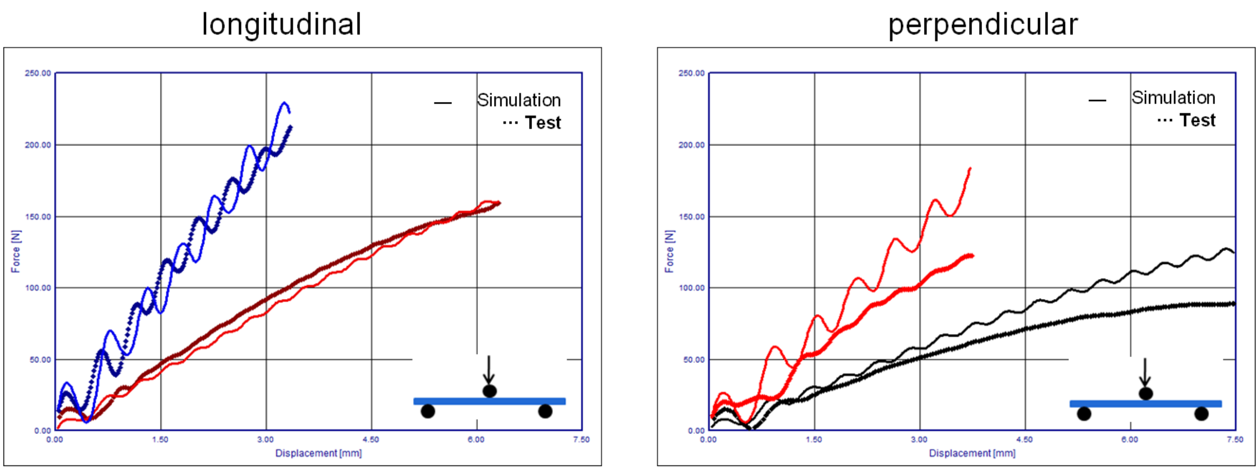

*Fig.8: Comparison of test and simulation results on PP GF40 (3-point-bending, two velocities, *MAT_002) [1].*

Figure 9 shows the results for *MAT_157, which is an orthotropic material model with visco plasticity based on a HILL yield function, this material model can reproduce both directions.
For this example

- the resulting fiber orientation of the test specimens were mapped by using 4a fibermap,
- the elastic properties were calculated by using 4a micromec and
- the visco plasticity and failure behavior were determined by reverse engineering with 4a impetus.

The implementation of the process chain (shown in figure 6) into the 4a impetus process is shown in figure 10 and leads to very good and near to reality results.

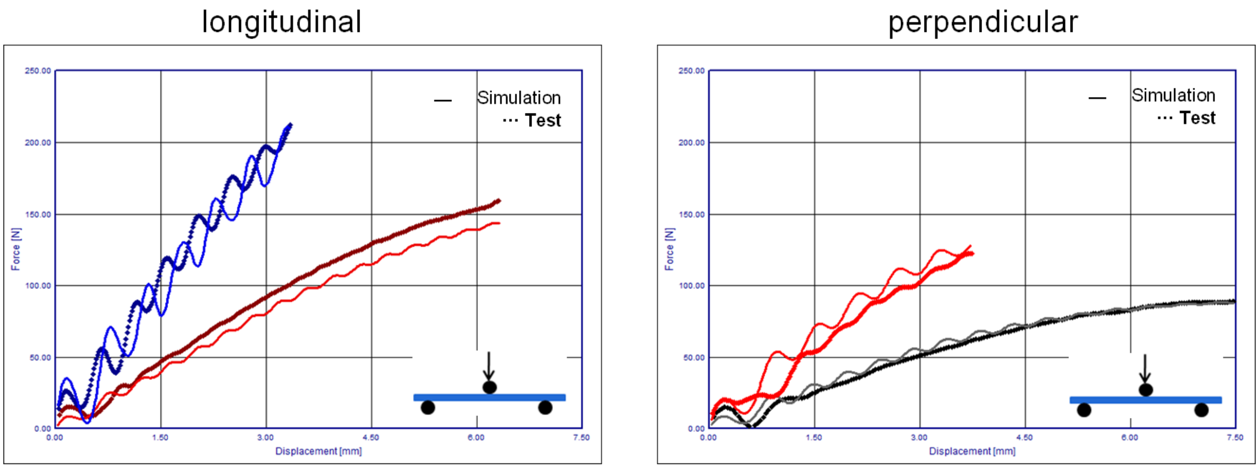

*Fig.9: Comparison of test and simulation results on PP GF40 (3-point-bending, two velocities, *MAT_157) [1].*

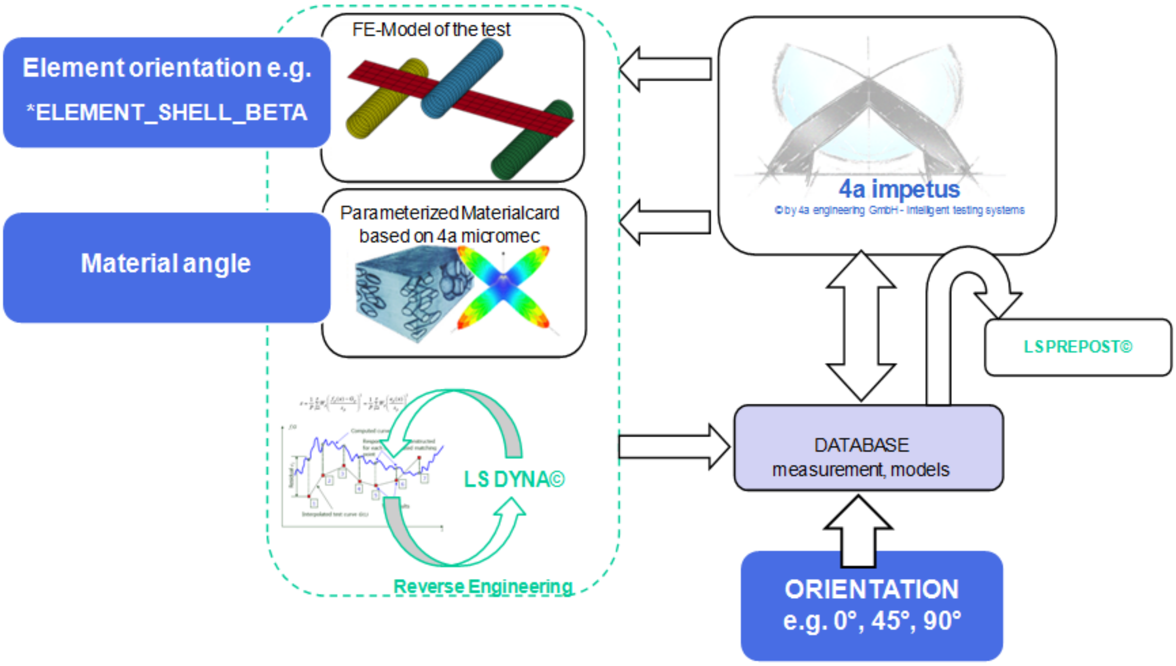

Fig.10: 4a impetus process for fiber materials [4].

Figure 11 shows a casestudy of the so called "Nutini box". As mentioned before the fiber orientation was mapped on the LS-DYNA simulation model, by using the LS-DYNA input key ***ELEMENT_SHELL_BETA**. Together with one average *MAT_157 the simulation results including the consideration of failure were quite accurate.

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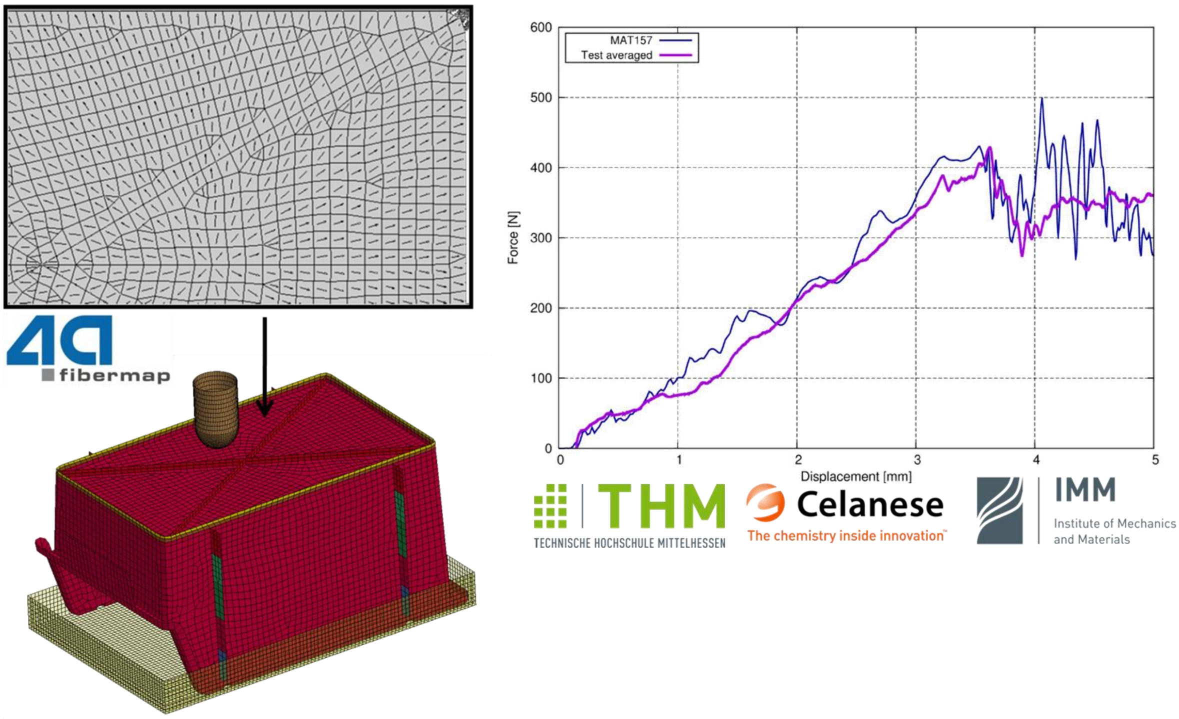

Fig.11: Crash of the Nutini box; results were achieved using the 4a impetus process [5].

2 Summary

LS-DYNA offers a great number of constitutive models for anisotropic materials, but they may not be able to fulfil all of the many effects and requirements to describe the real material behavior. So permanently improvements on the existing material models are done.

Orthotropic material models without plasticity or damage (*MAT_002, *MAT_022) can reproduce the longitudinal direction, but are too stiff in perpendicular direction. Orthotropic material models with plasticity (*MAT_108) can reproduce both directions, but since plastics are rate dependent there is a need to take an average strain rate for the material parameters. Orthotropic material models with plasticity and rate dependence (*MAT_157) can reproduce both directions and are the optimal choice to describe the mechanical composite behavior. To separate matrix and fiber phase especially a micro mechanical material model is needed for describing effects like matrix failure. Considering the complete process chain in the 4a impetus process leads to accurate and near to reality results.

3 Literature

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[7] http:// fibermap.4a.co.at

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