4a impetus (PART 2): innovations – test methods, MAT_SAMP-1, anisotropy, composites and more

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4a engineering GmbH

1 Introduction - Characterizing plastics and composites using 4a impetus

In recent years plastics are substituting other materials mostly to reduce the weight of the part. As they are also carrying the same applied loads it is necessary to consider the deformation behavior (plasticity) as well as damage and failure in the material model. To characterize the dynamic deformation behavior dynamic bending tests on 4a impetus (fig. 1 left) are a cost-efficient alternative or extension compared to standard dynamic test methods. Furthermore many plastic materials have a huge difference in the tension and compression behavior. Consequently a material card generation of simple elastic-viscoplastic material models (e.g. **`*MAT_024`**) based on static and dynamic bending tests, which takes both into account, will be near to reality [1].
As a result of the processing unreinforced as well as reinforced plastics have different mechanical properties at the outer surface compared to the inner core. The bending properties (stiffness, failure behavior …) are usually favorably higher. Due to the stress distribution in bending load cases the outer highly orientated layer carry most of the load compared to the tension case. Engineering judgment based on bending material properties is therefore the better choice.

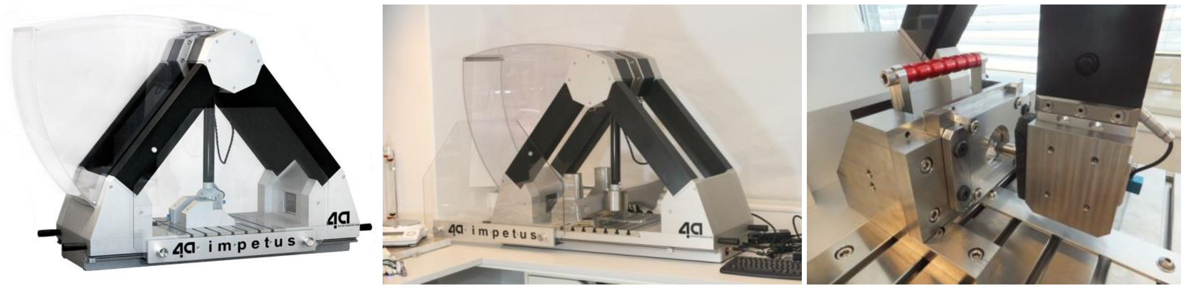


Fig.1: The actual version of 4a impetus (left); component testing in 4a impetus (middle); new puncture test and pendulum arm (right)

Nowadays more detailed material models considering complex yield surfaces (e.g. **`*MAT_124`** or **`*MAT_187`** for plastics), anisotropy (e.g. **`*MAT_157`** or **`*MAT_215`** for reinforced plastics) or complex failure models (e.g. **`*MAT_ADD_EROSION`**) are available. The objective is of course a better description of the material behavior [2, 3, 4]. The newest 4a impetus developments regard these needs - always with the focus to offer an efficient material parameter identification process (MPIP).

2 Innovations in 4a impetus - hardware

The design of 4a impetus and the pendulum arm was improved. Now it's possible to test even parts and composite materials up to an impact energy of 50J (fig. 1 middle). To characterize the dynamic behavior and failure under biaxial loading a new puncture test method was designed (fig. 1 right). It also allows testing under low or high temperatures. The implementation of a high-speed-camera (newest accessory kit) allows the visualization of dynamic behavior of the material during test (crack initiation and propagation in detail, see fig. 2).

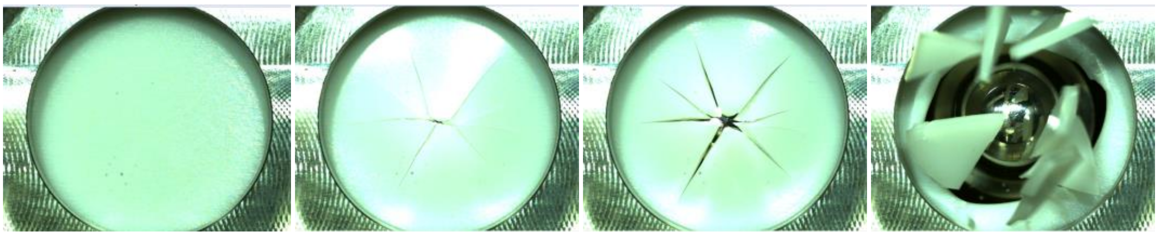


Fig.2: High speed pictures of the dynamic puncture test of a POM at different time steps

3 Innovations in 4a impetus - software

In the presentation many new features will be shown, exemplary two of them are described in this abstract in detail.

The above mentioned complex material models (fig. 3 left) as well as the most common failure models are implemented in 4a impetus GUI. The describing parameters can be directly evaluated in the material parameter identification process. For standard material cards (e.g. `*MAT_024`) an automated workflow on 3-point-bending-tests was developed and implemented as AUTOFIT process. Within a few clicks and some simulation/optimization time an accurate material card is generated by 4a impetus (fig. 3 right).

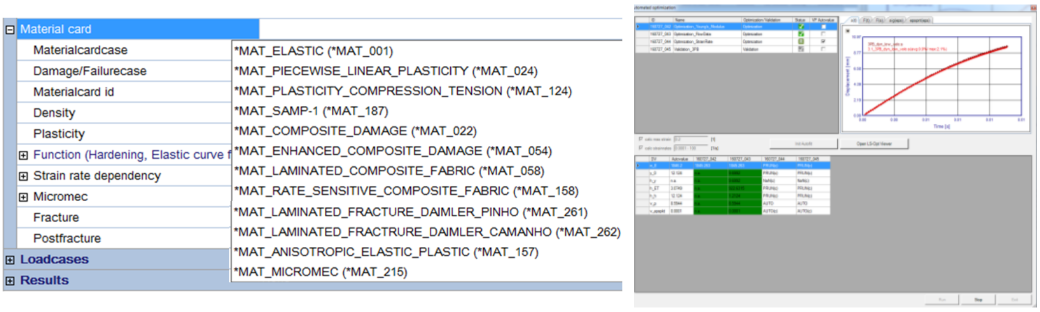


Fig.3: Available LS-DYNA material cards in 4a impetus (left); AUTOFIT process – creating material cards within a few clicks automatically (right)

For fiber reinforced plastics and composites 4a micromec is implemented as library in 4a impetus. 4a micromec is based on the Mori Tanaka Meanfield Theory and allows the user to calculate automatically the thermo elastic mechanical properties of a composite based on the information of the matrix and filler [5]. As a consequence less material parameters have to be determined in the MPIP; so the micro mechanics reduce the effort of testing and material card generation remarkable (fig. 4).

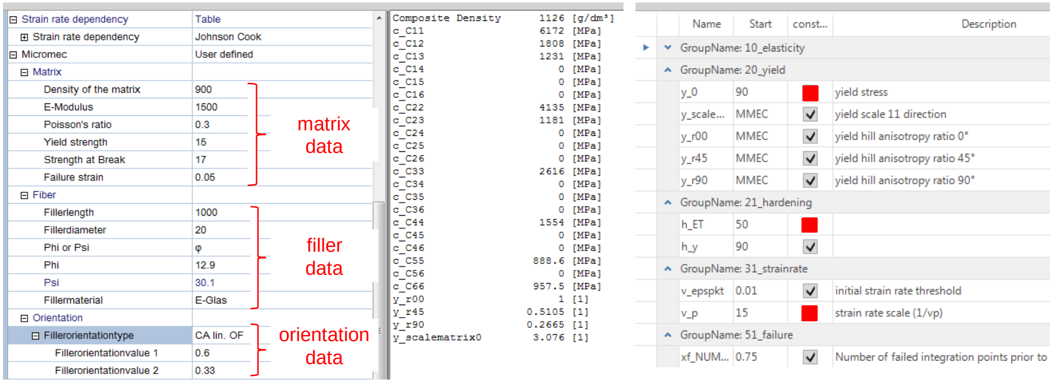


*Fig.4: Calculation of the material parameters for *MAT_157 using the 4a micromec library, this reduces the unknown material parameters down to 3 (marked in red) [5]*

4 Innovations in 4a impetus - future

In future 4a impetus hardware and software developments will continue to focus on testing and simulation trends. We will work hard to set further trend standards to ensure that the user can generate very easy, quick and cost efficient accurate validated material cards.

5 Literature

[1] Reithofer, P. et. al: *Dynamic Material Characterization Using 4a impetus*, 29th Regional Conference of the Polymer Processing Society, Graz 2015

[2] Reithofer, P. et. al: *4a impetus (PART 1): Dynamic material characterization of plastics – development in the past 10 years*, 14. LS-DYNA Anwenderforum, Bamberg 2016

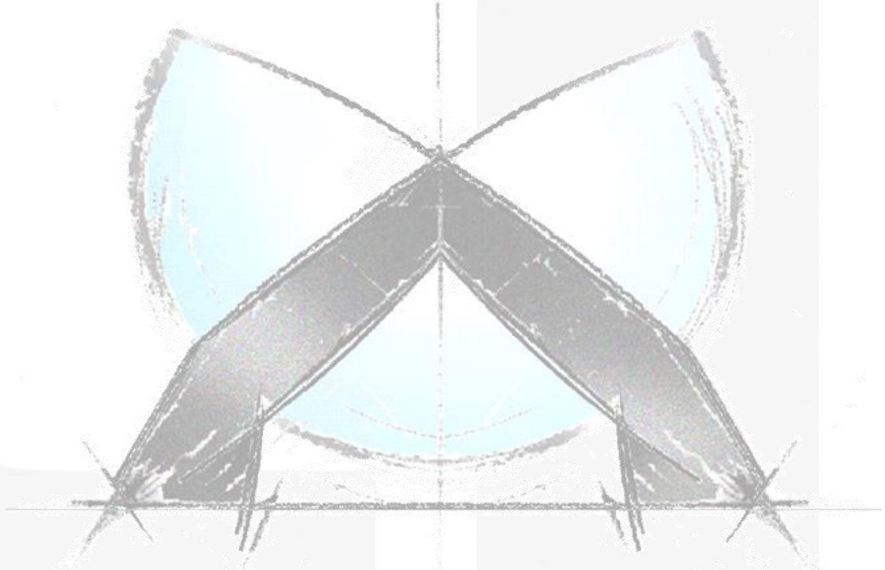
[3] Fertschej, A. et. al: *Failure models for thermoplastics in LS-DYNA*, 29th Regional Conference of the Polymer Processing Society, Graz 2015

[4] Staack, H. et. al: *Application oriented failure modeling and characterization for polymers in automotive pedestrian protection*, 8. Complas, Barcelona 2015

[5] Reithofer, P. et. al: *Material characterization of composites using micro mechanic models as key enabler,* automotive CAE Grand Challenge, Hanau 2016

4a impetus (PART 2): Innovations – test methods, anisotropy, composites, *MAT_157 and more

A. Fertschej, P. Reithofer, M. Rollant (4a engineering GmbH)



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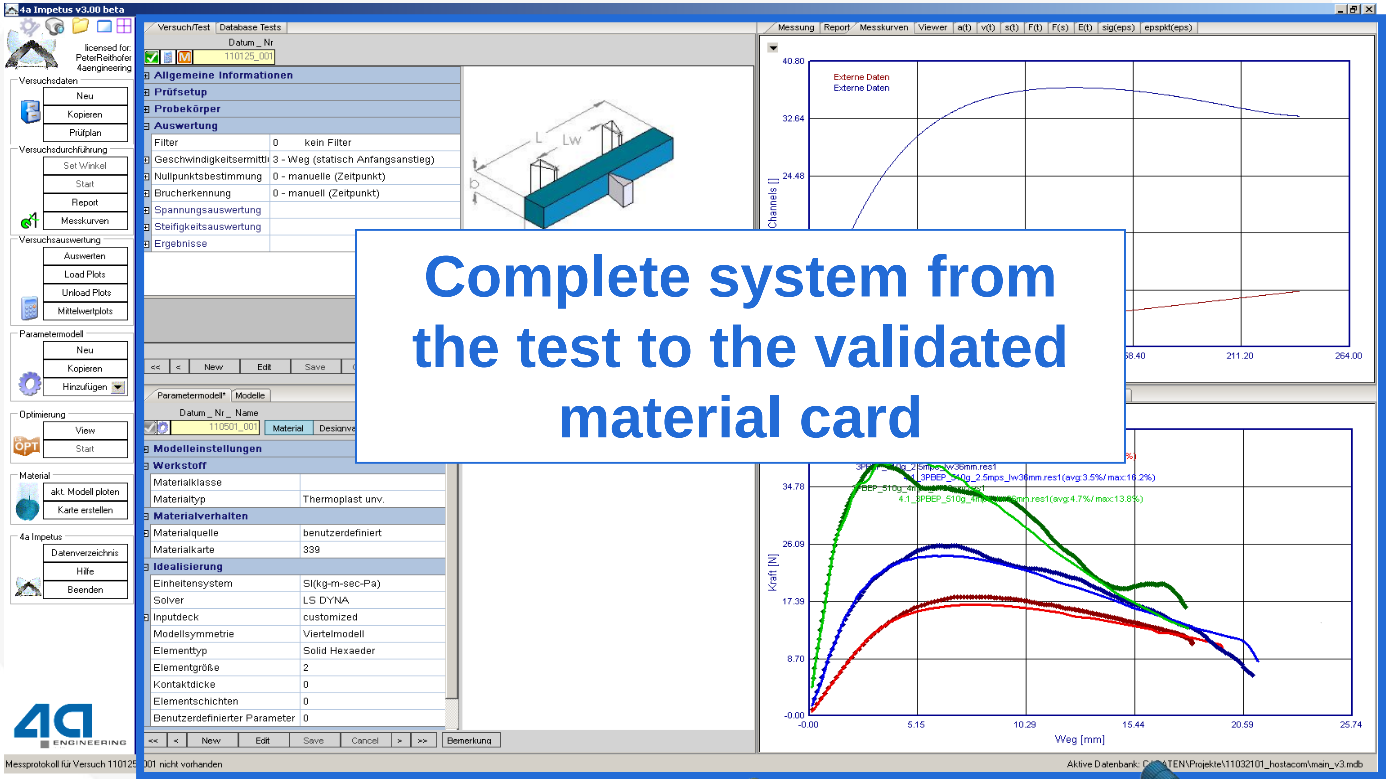
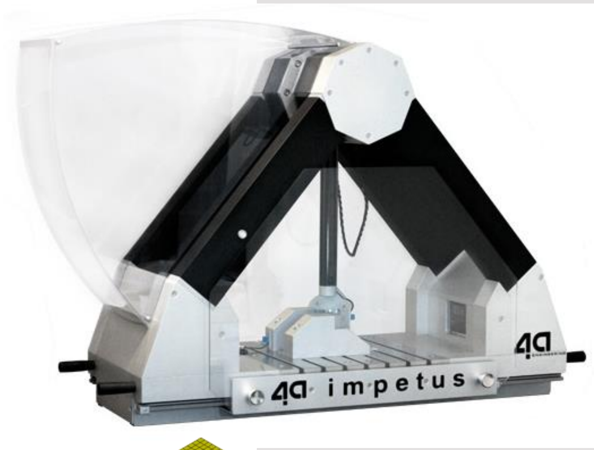
  - Hardware
    - New pendulum arm
    - New puncture test
    - High-speed camera
- Summary

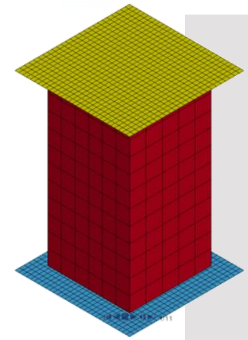
Introduction

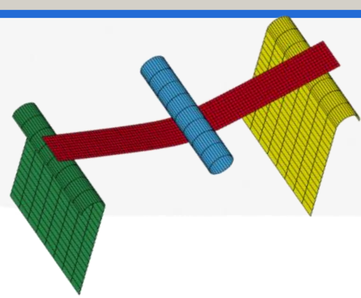
- History, basics and advantages of 4a impetus → Part 1

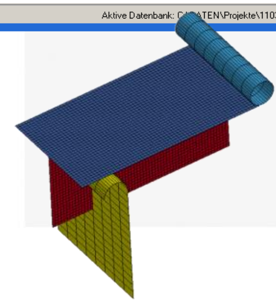


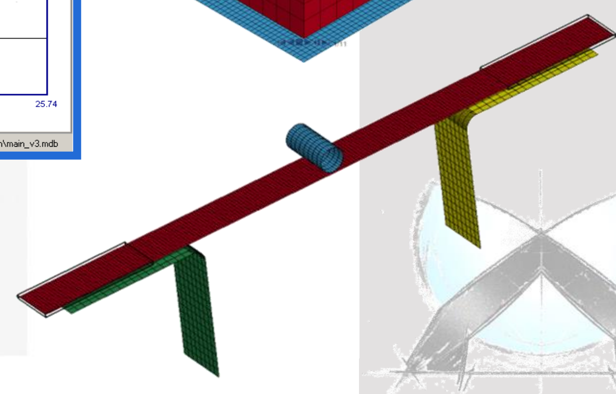
Complete system from the test to the validated material card











Introduction

4a ENGINEERING GmbH

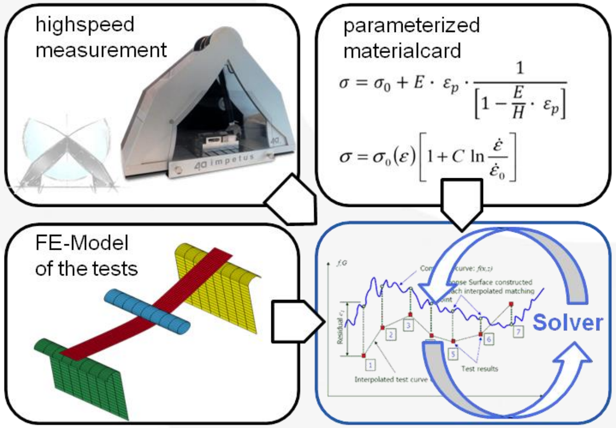
Incitement and objectives of our innovations

- **More detailed material models** are available
  → better description of the material behavior of plastics and composites
- New developments in testing are necessary
  to **measure** the needed **material behavior**
- Due to **increasing** material data and model parameters
  → automation is a key enabler
  → Focus: to offer an efficient
  material parameter identification process (MPIP)

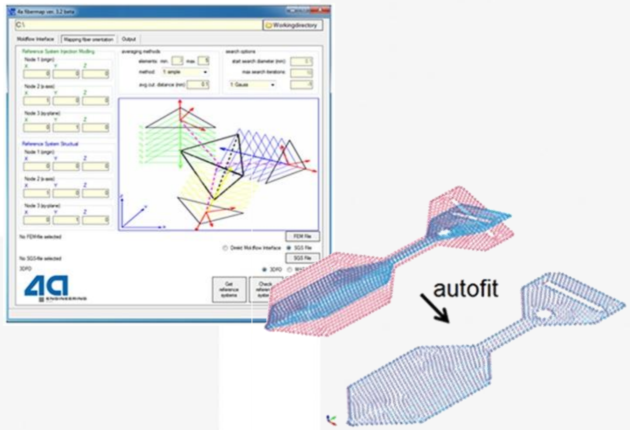
4a impetus – new software features
Licensing

- Introducing new token concept
- Software products **4a impetus, 4a fibermap, 4a micromec** and their modules are now accessible

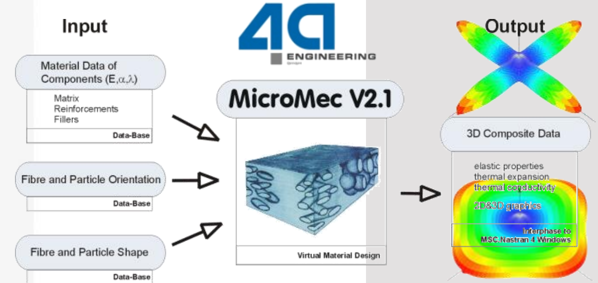
IMPETUS FIBERMAP MICROMEC



validated material cards

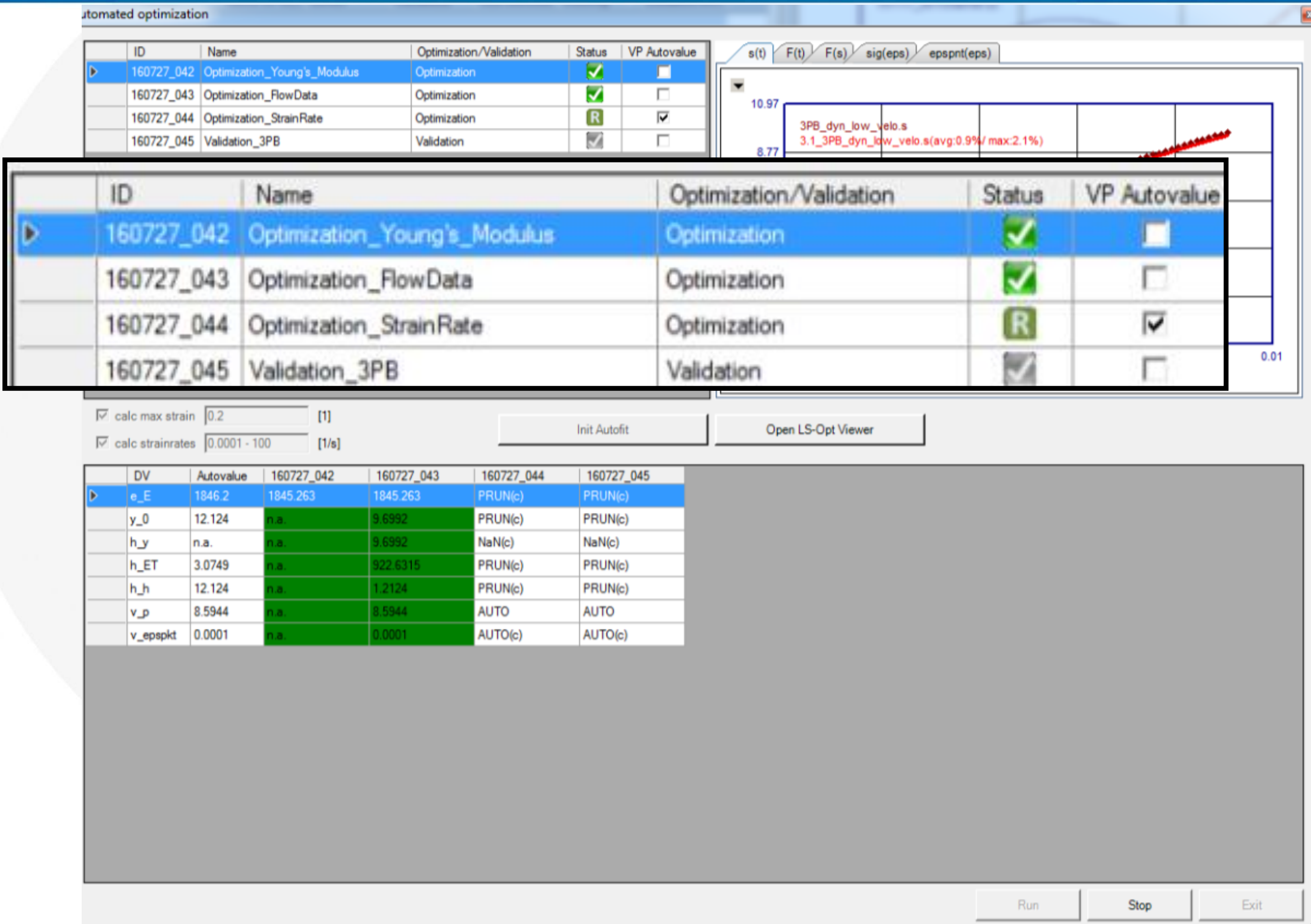


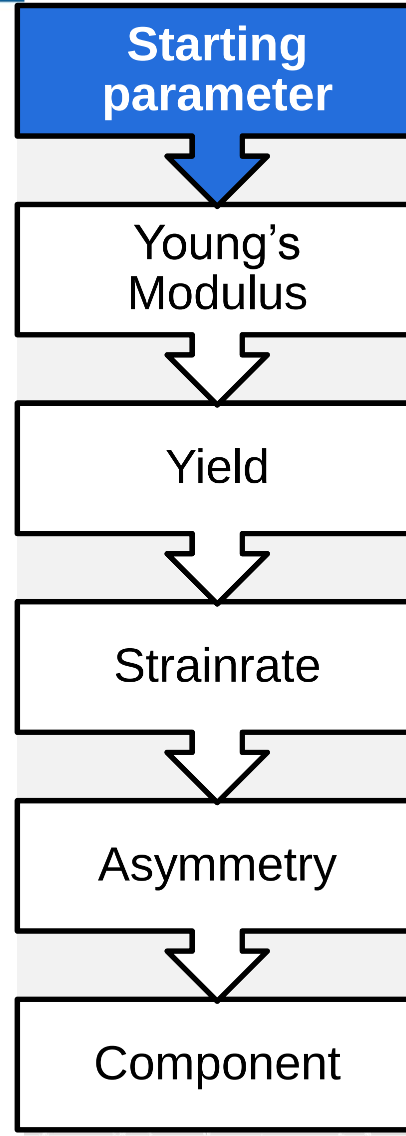
individual mapping process information



3D thermo elastic anisotropic material cards

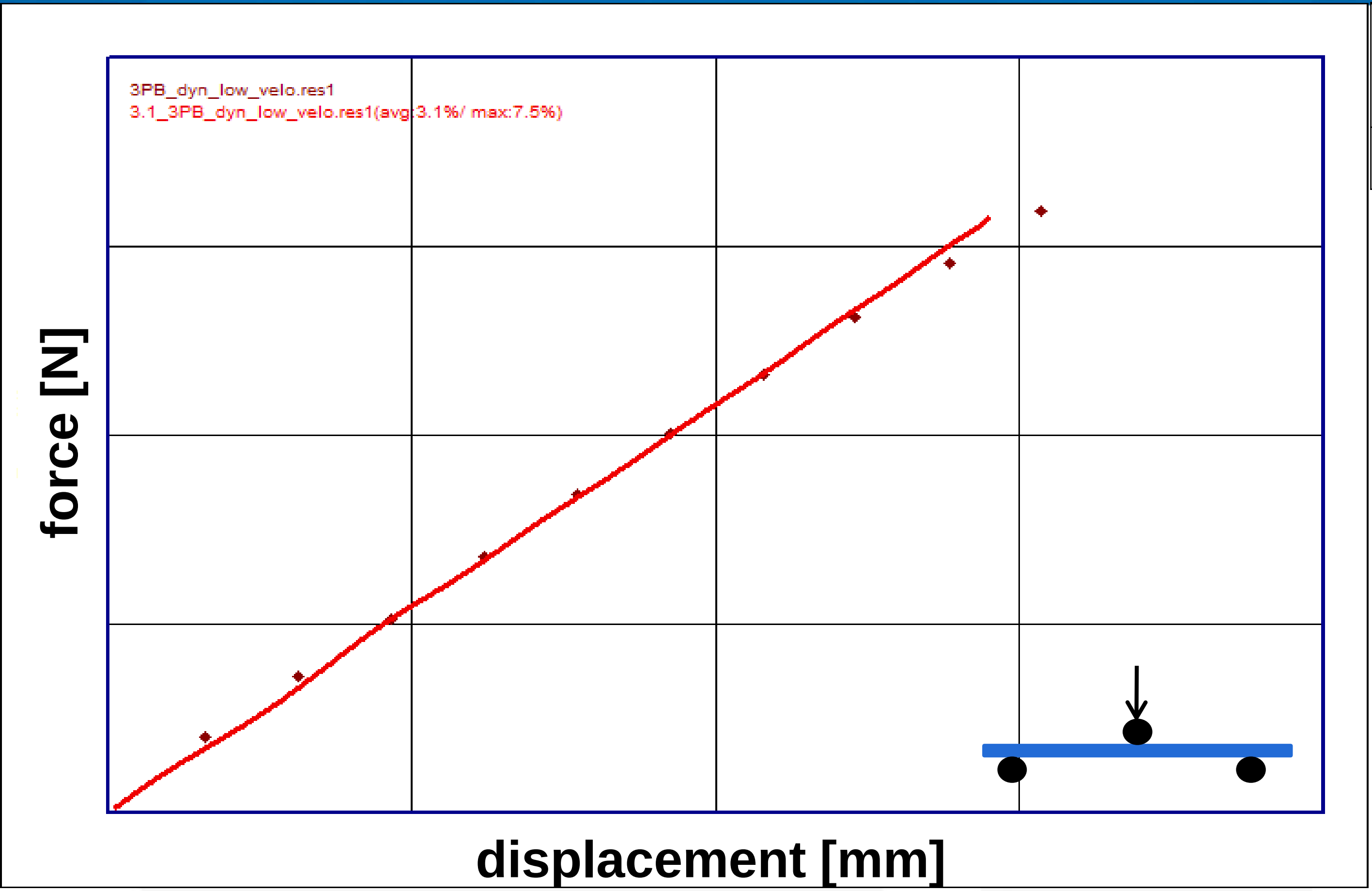
4a impetus – new software features
MPIP - Material Parameter Identification Process



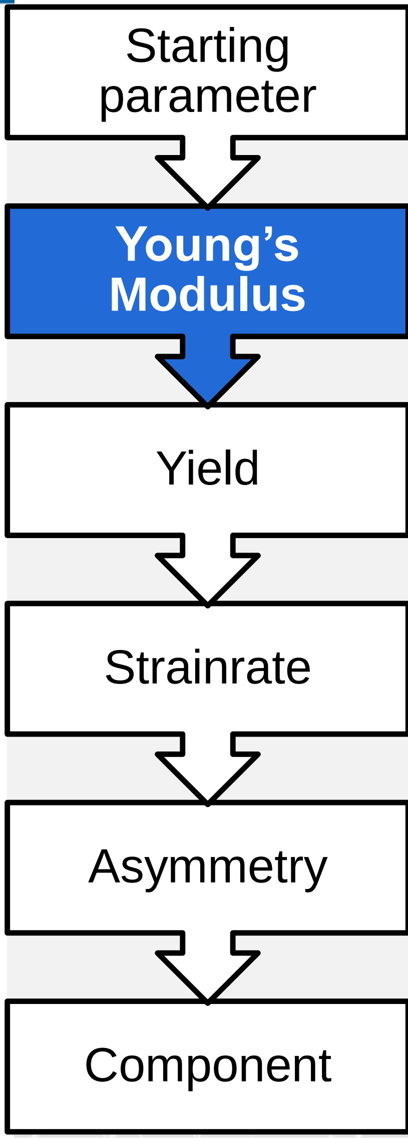


4a impetus – new software features

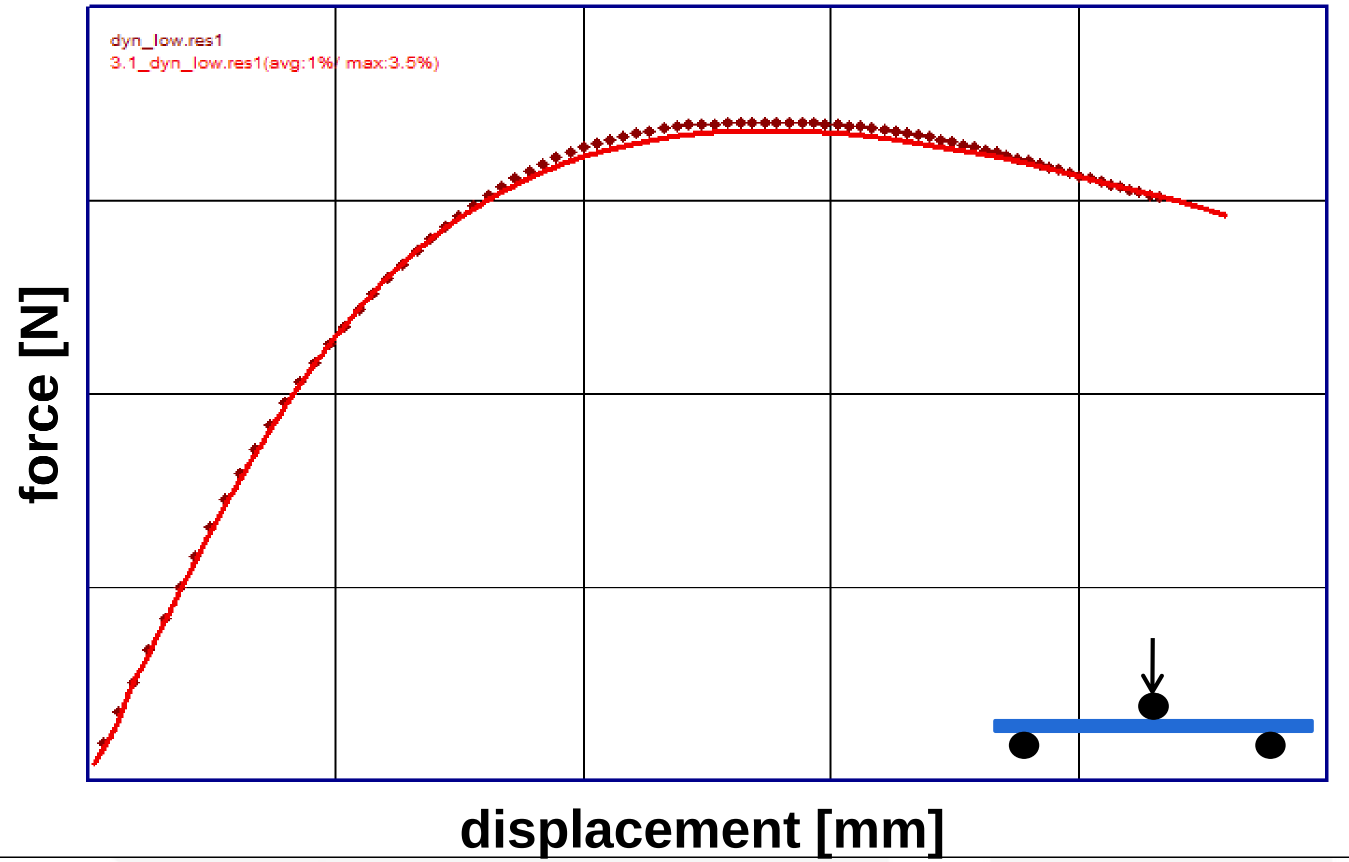
MPIP - Material Parameter Identification Process



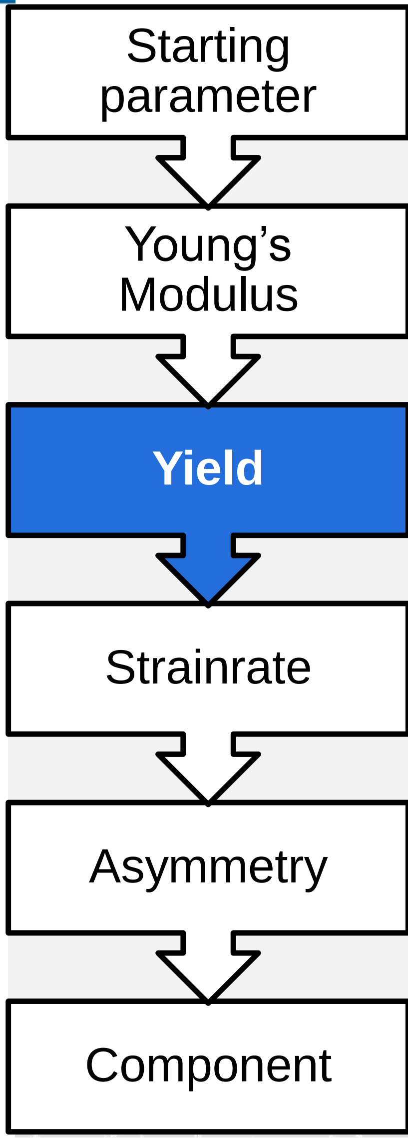
v_0 [m/s]
1



MPIP - Material Parameter Identification Process

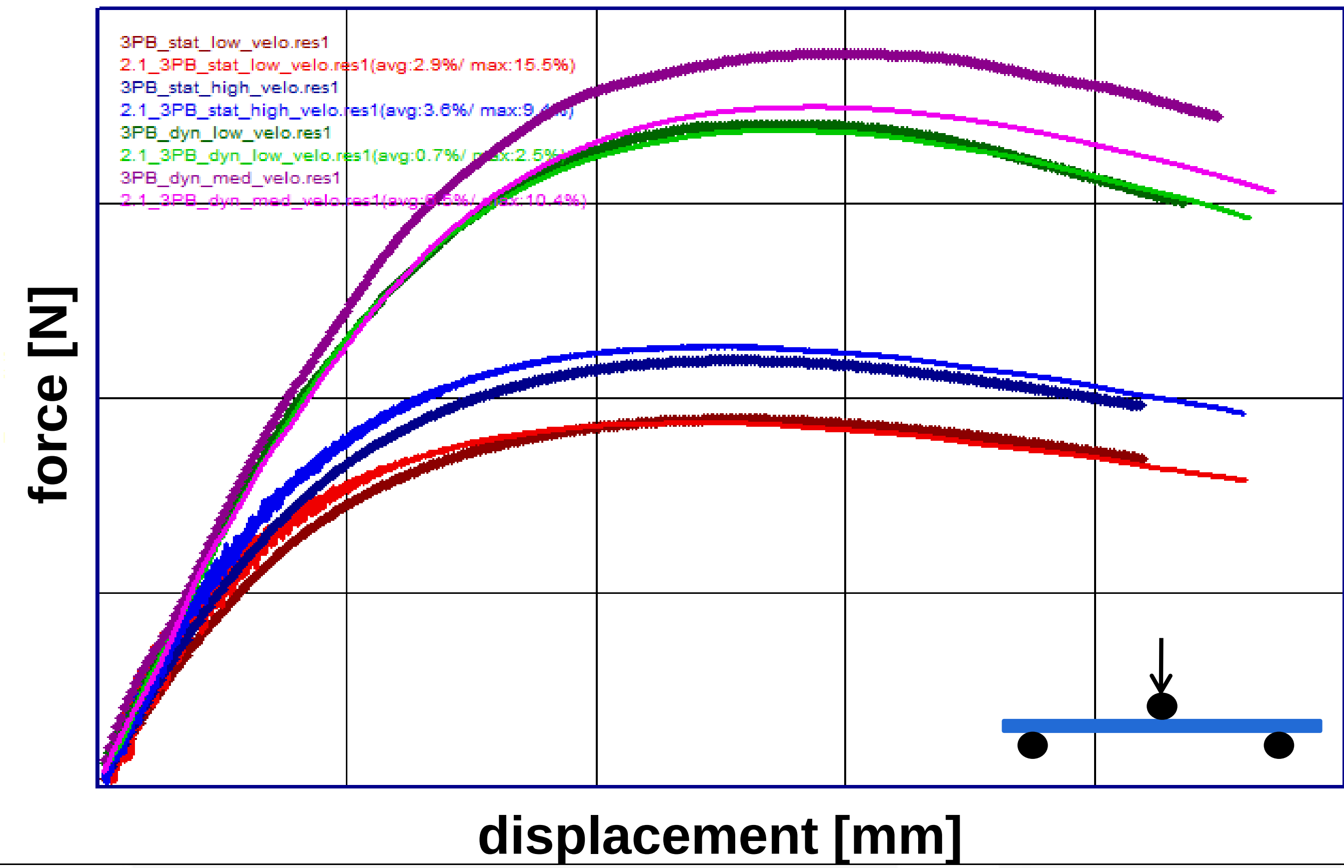


v_0 [m/s]
1



4a impetus – new software features

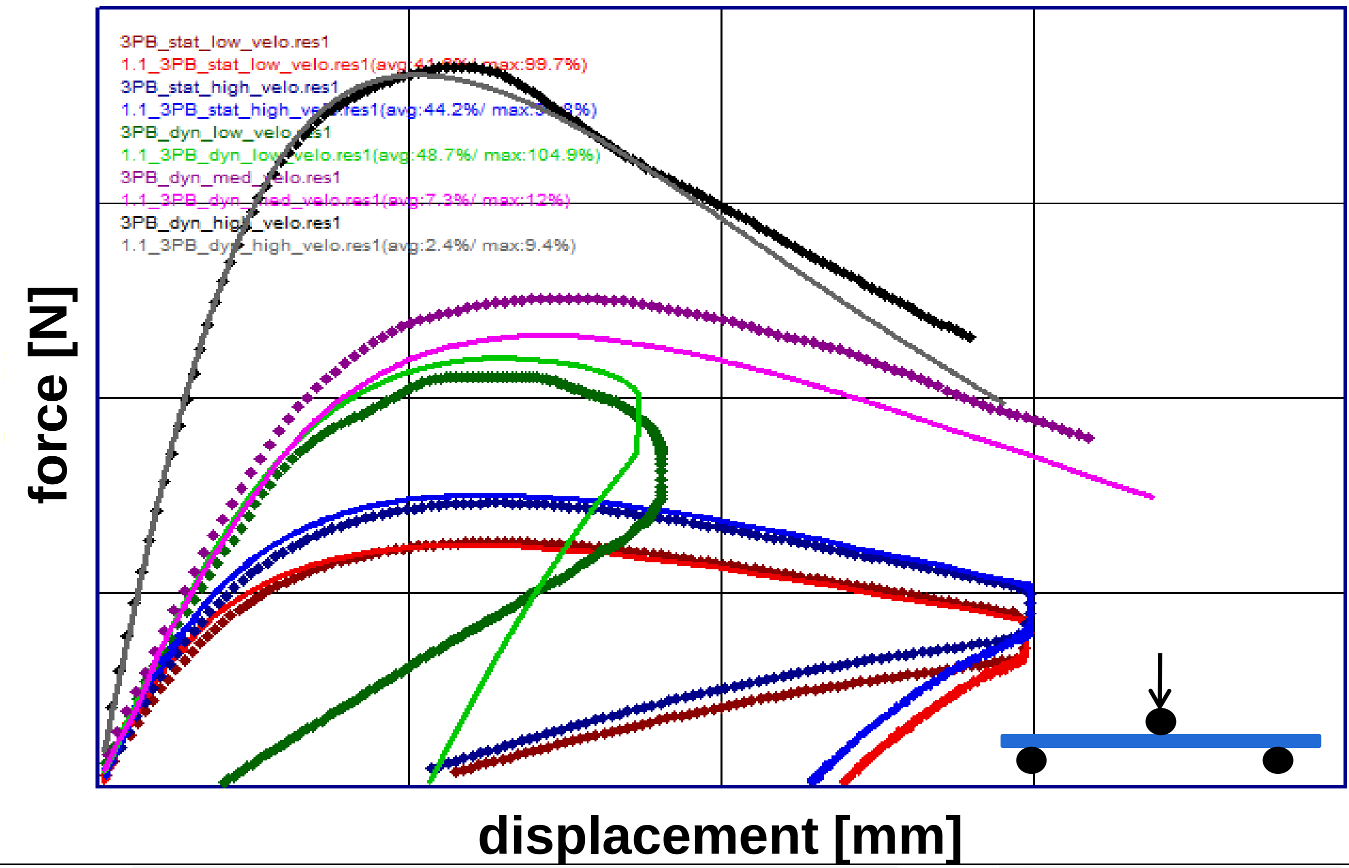
MPIP - Material Parameter Identification Process



v_0 [m/s]
0.0001
0.001
1
2.5

- Starting parameter
- Young's Modulus
- Yield
- **Strainrate**
- Asymmetry
- Component

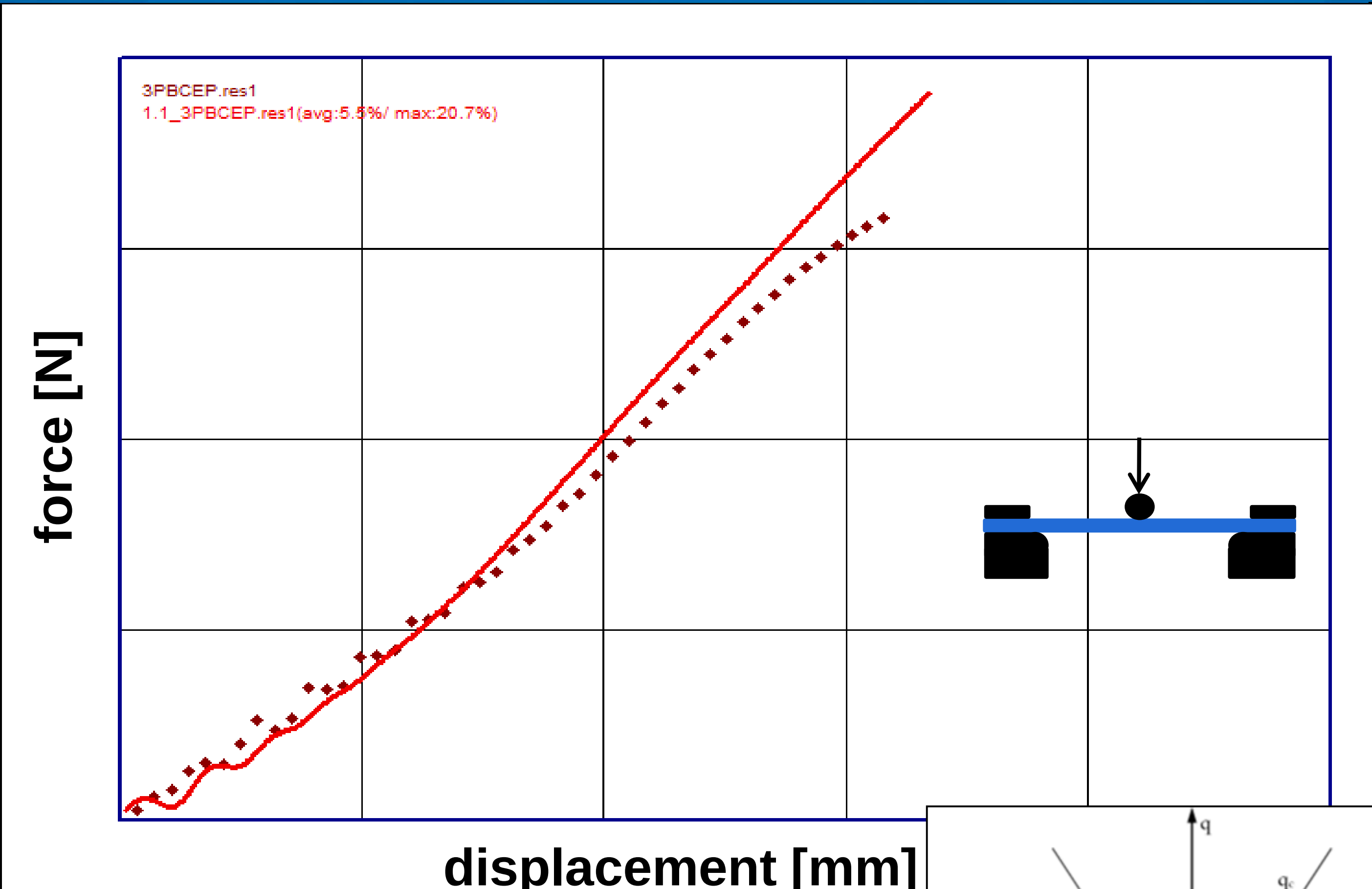
4a impetus – new software features
MPIP - Material Parameter Identification Process



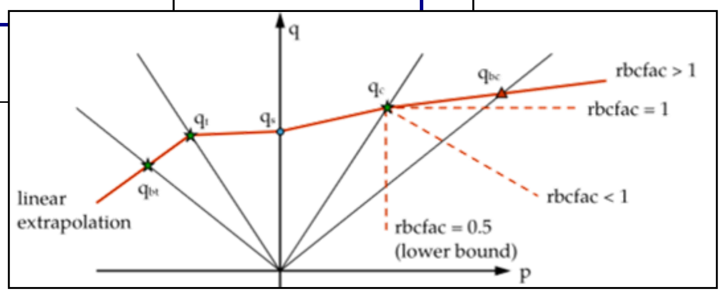
v_0 [m/s]
0.0001
0.001
1
2.5
4

- Starting parameter
- Young's Modulus
- Yield
- **Strainrate**
- Asymmetry
- Component

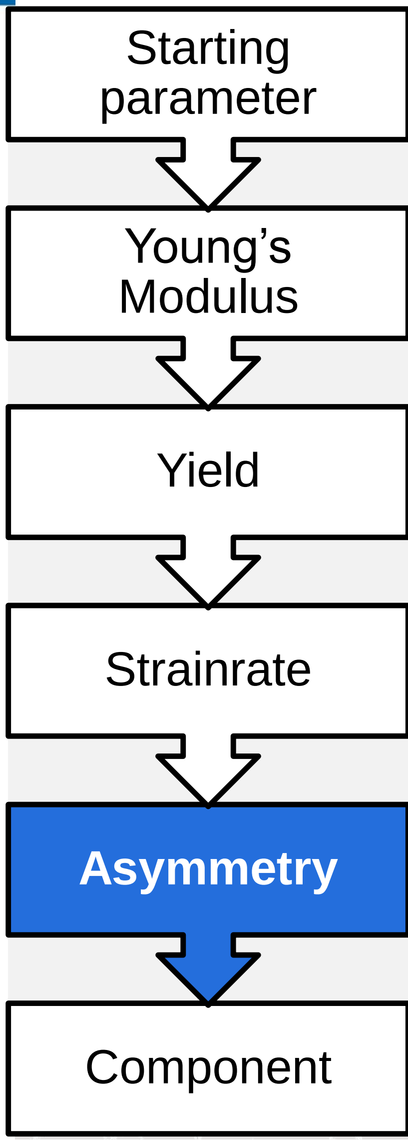
MPIP - Material Parameter Identification Process



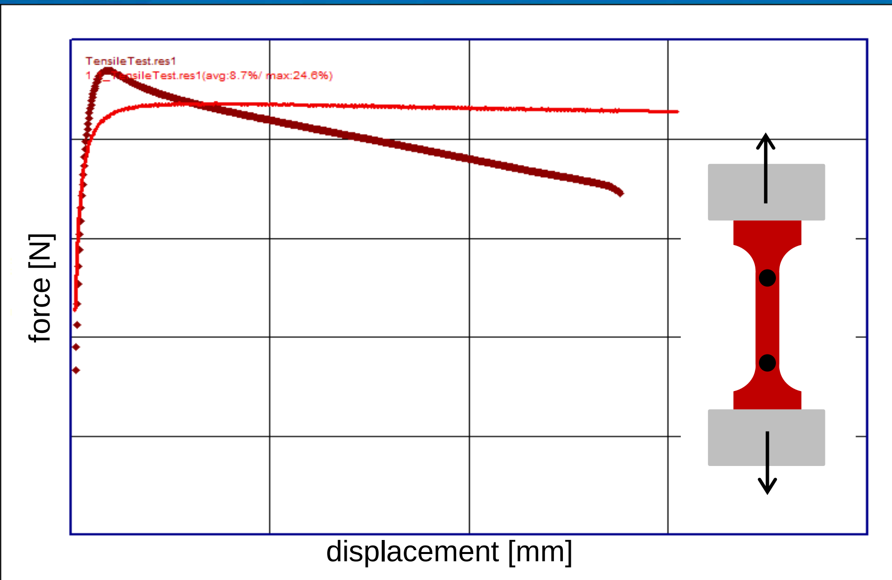
v_0 [m/s]
4



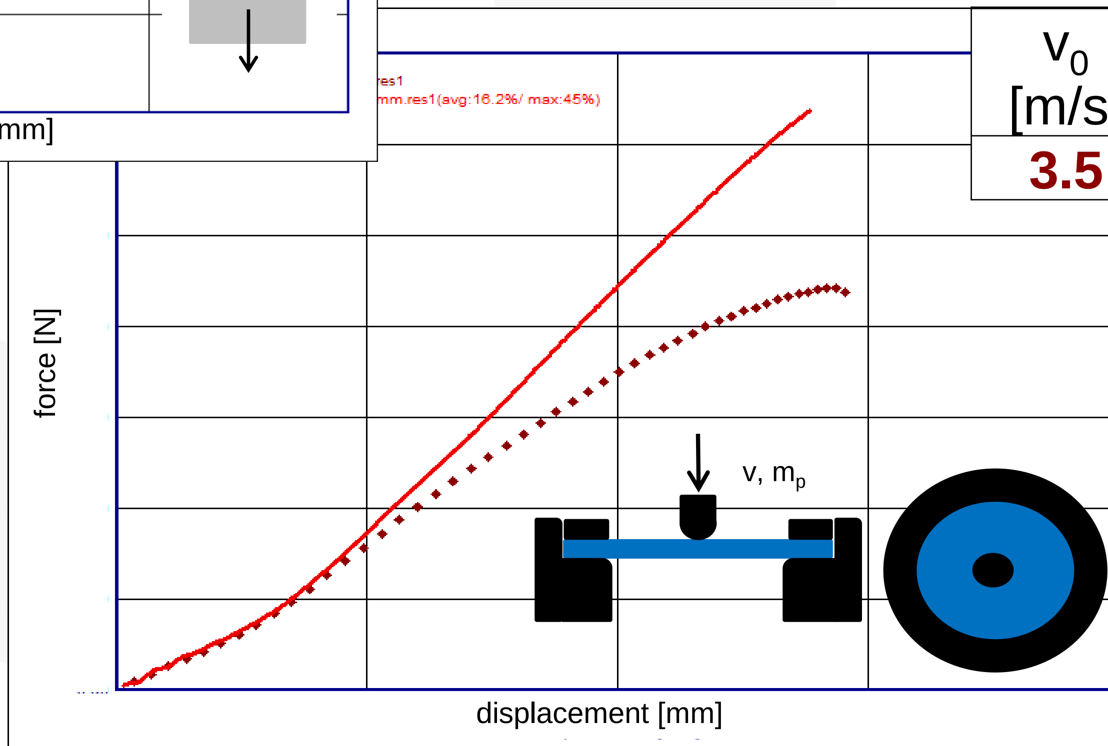
[LSDYNA MANUAL]



4a impetus – new software features
MPIP - Material Parameter Identification Process



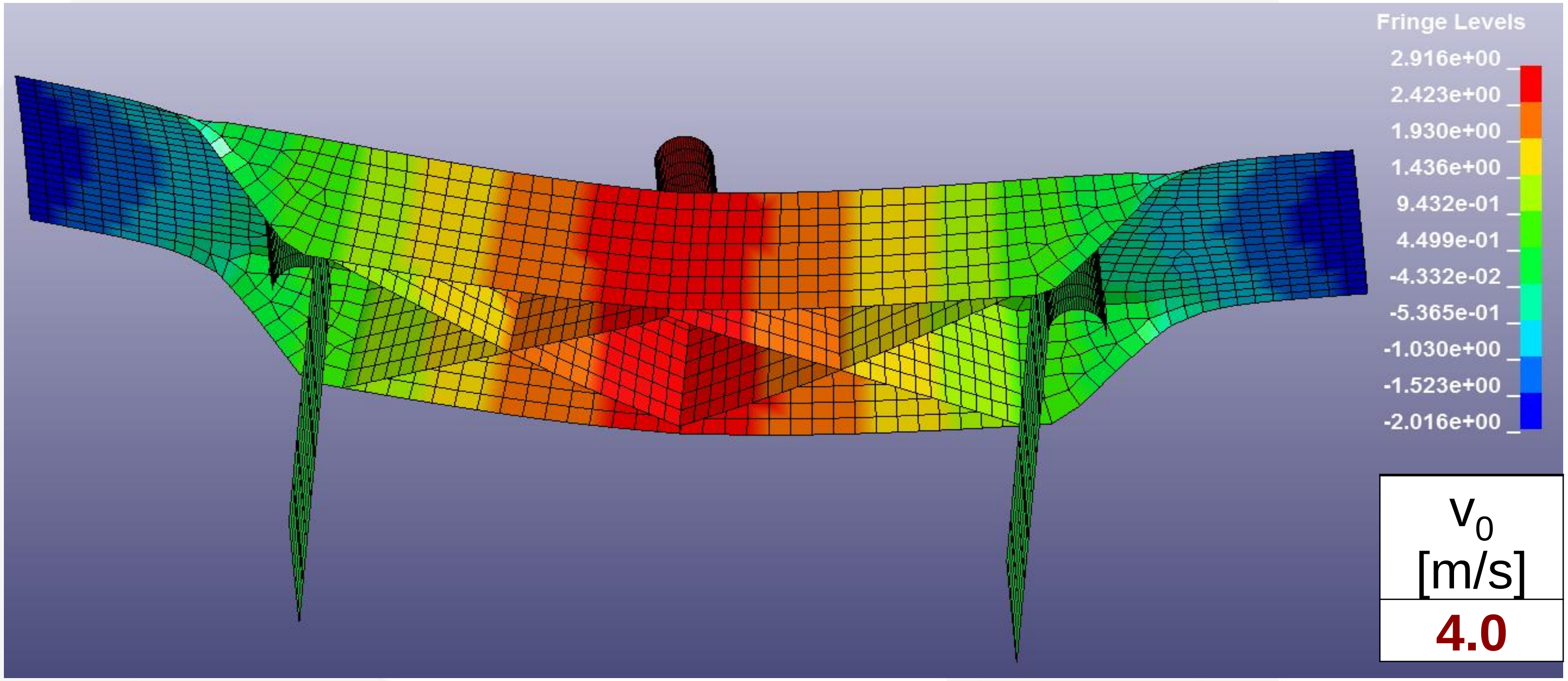
v_0 [m/s]
0.001



v_0 [m/s]
3.5

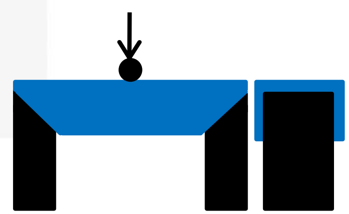
- Starting parameter
- Young's Modulus
- Yield
- Strainrate
- Validation
- **Asymmetry**
- Component

4a impetus – new software features
MPIP - Material Parameter Identification Process



v_0 [m/s]

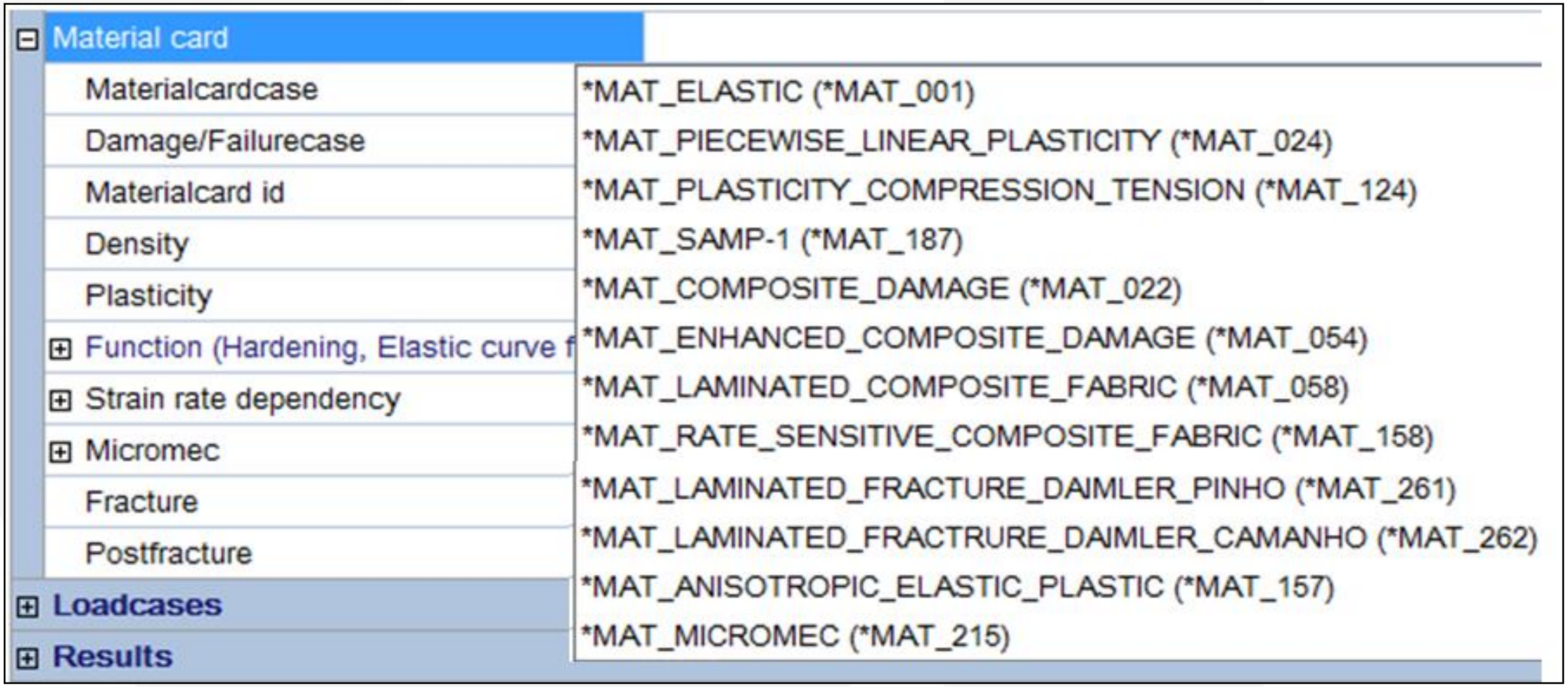
4.0



Starting parameter
↓
Young's Modulus
↓
Yield
↓
Strainrate
↓
Asymmetry
↓
Component

4a impetus – new software features
Material model

- Plenty of direct implemented **LS-Dyna material models** (also Abaqus, PamCrash)



- Whole number of LS-Dyna material models is available through userdefined inputdeck

4a impetus – new software features
Material model – XML, filter

⊞ **Model settings**	
⊟ **Material**	
Material preset	MAT215
Material name	GLASS
⊟ **Idealization**	
System of units	t-mm-sec-MPa
Solver	LS DYNA
Inputdeck	Implemented
Symmetry of model	1-Element or more complex
Idealization type	Shell
Element size	1
⊞ **Additional settings**	
⊟ **Material behaviour**	
⊟ Material source	Implemented
Elasticity	Not isotropic elastic
Plasticity	Not selected
Failure/Damage	Not selected
⊟ Material card	*MAT_COMPOSITE_DAMAGE (*MAT_022)
Materialcardcase	7500_MAT22
Damage/Failurecase	None
Materialcard id	1000000
Density	910
Plasticity	None
Function (Hardening, Elastic curve form)	
Strain rate dependency	None
⊟ Micromec	Endless fiber reinforced plastics
⊟ Matrix	

Function (Hardening, Elastic curve form)

Solver

Filter

Material card

4a impetus – new software features
Material model – design variable table

Parameter model* | Model database

160623_007 | Material | Designvariablen | Layers

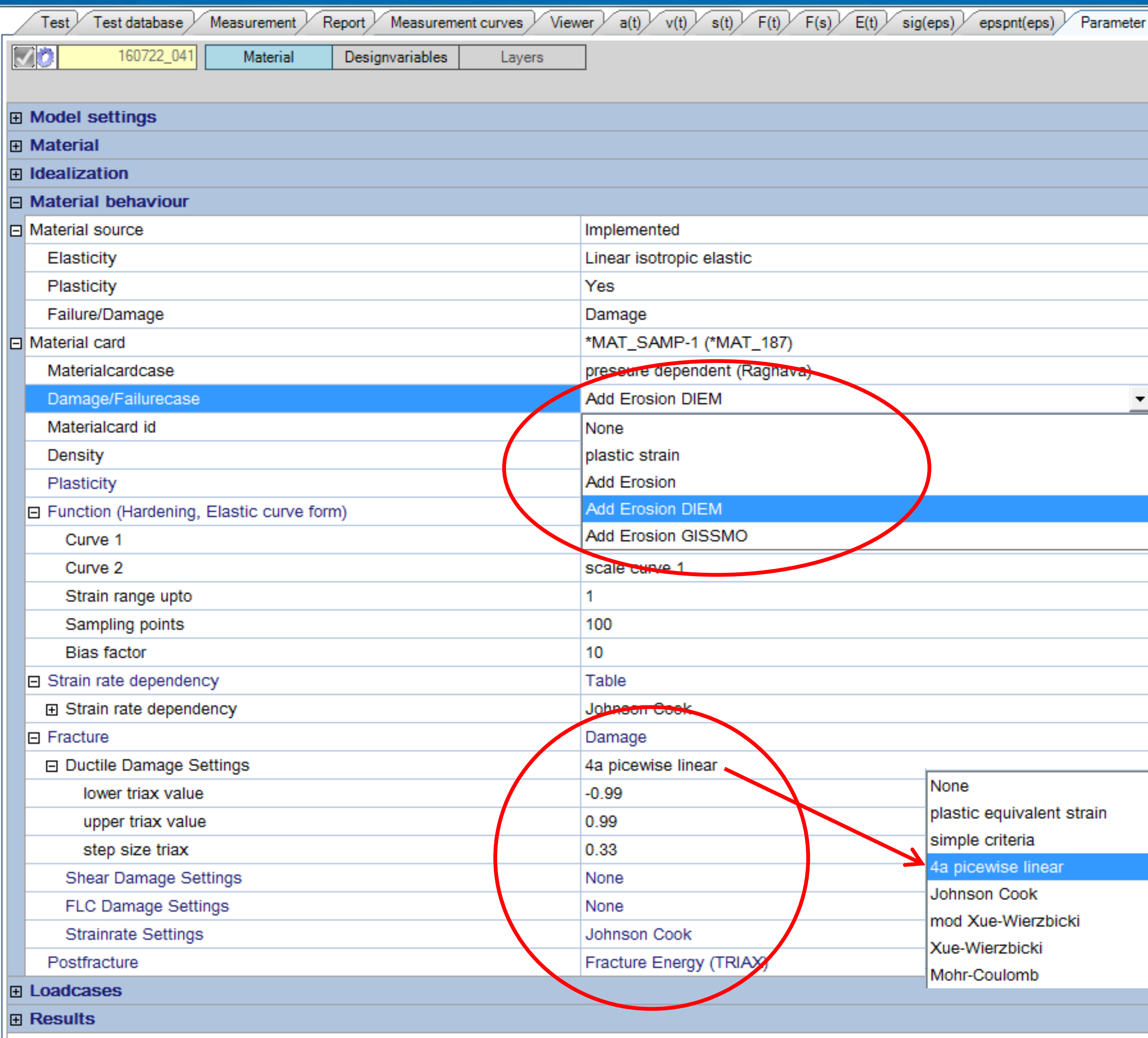
	Name	Start	const...	from	to	Variance	Condit...	Description
GroupName: 10_elasticity								
	e_E	1500	☑					youngs modulus
GroupName: 20_yield								
	y_0	12	☐	5	150	50		yield stress
GroupName: 21_hardening								
	h_y	12	☑	5	150	50	=y_0	hardening yield stress
	h_ET	150	☑	0	150	(NULL)	<e_E	tangent modulus
GroupName: 31_strainrate								
	v_p	12	☑	1	500			strain rate scale (1/vp)
	v_epspkt	0.001	☑	0.001	1			initial strain rate threshold
GroupName: 51_failure								
▶	xf_NUM...	-65	☑	(NULL)	(NULL)	(NULL)		Number of failed integration p...
	xf_FAILM	0	☑	(NULL)	(NULL)	(NULL)		option matrix failure
	xf_FAILF	0.0	☑	(NULL)	(NULL)	(NULL)		option fiber failure
	fd_BC	2.0	☑	(NULL)	(NULL)	(NULL)		plastic equivalent failure strain (...

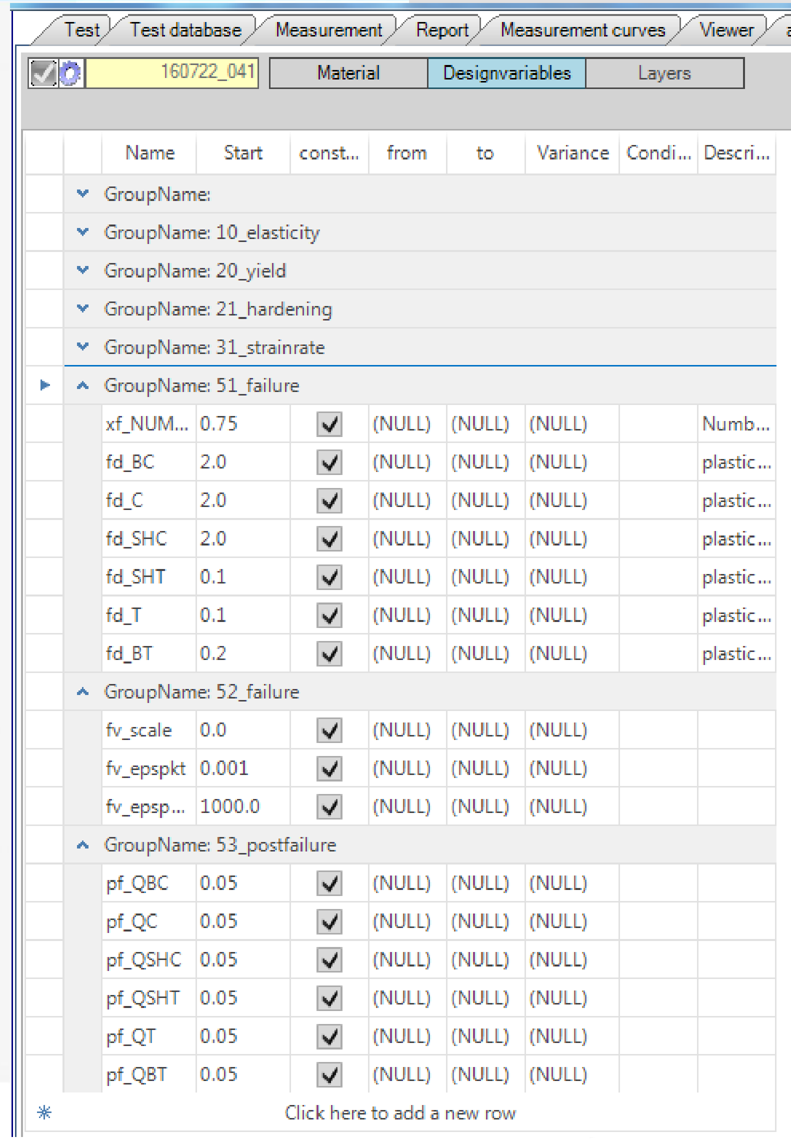
<< | < | New | Edit | Save | Cancel | > | >>

- classifying by mechanical behavior
- description

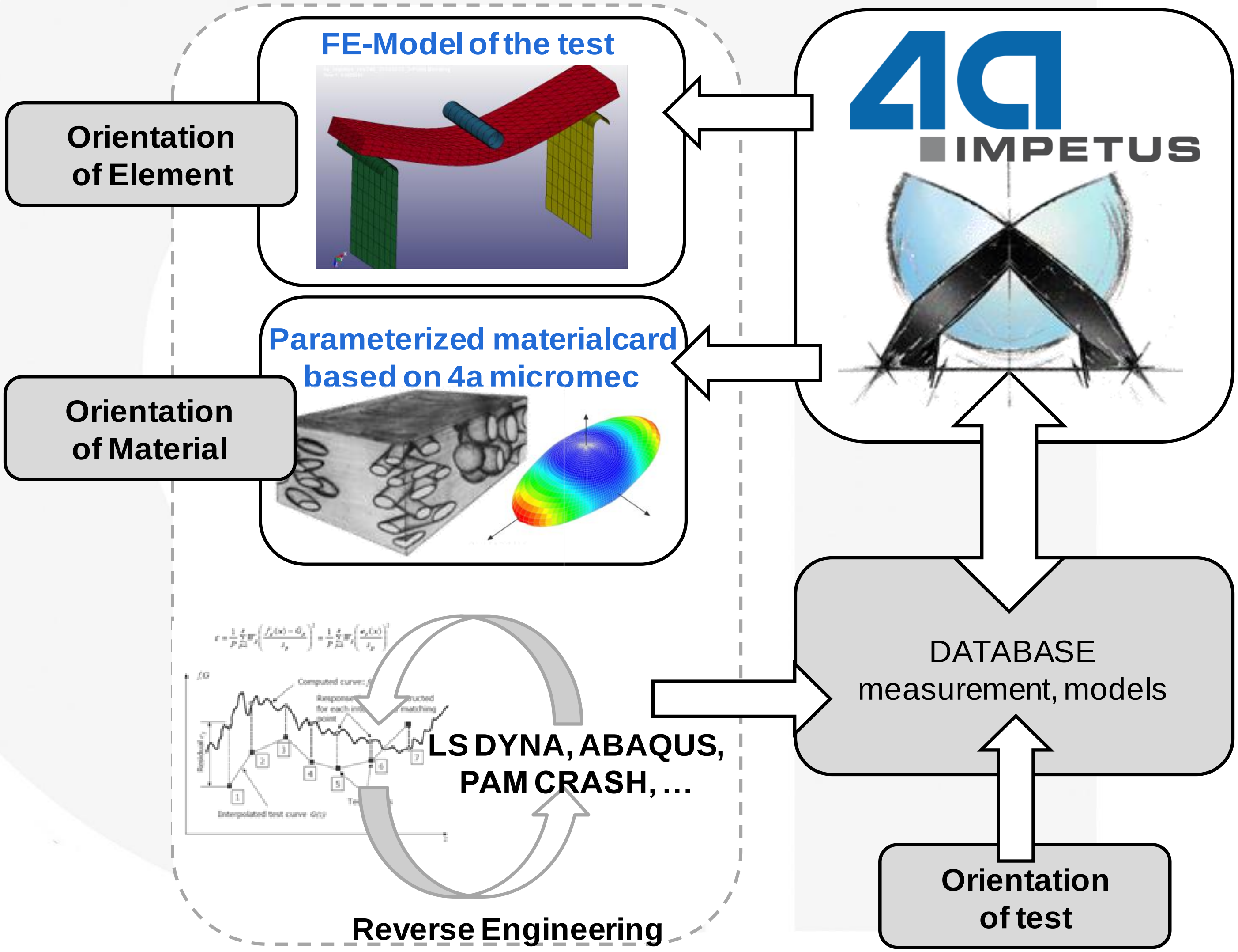
4a impetus – new software features

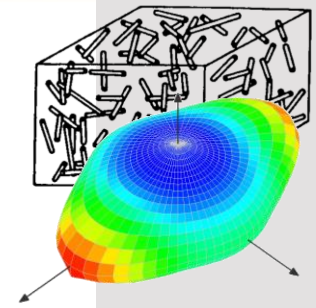
Material model – failure models





4a impetus – new software features
Anisotropy – Composites





4a impetus – new software features
Anisotropy – Composites

160223_006 | Material | Designvariablen | Layers

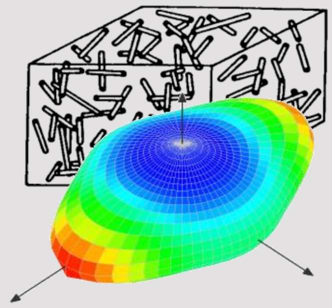
⊟ Strain rate dependency	Table
⊞ Strain rate dependency	Johnson Cook
⊟ Micromec	User defined
⊟ Matrix	
Density of the matrix	900
E-Modulus	1500
Poisson's ratio	0.3
Yield strength	15
Strength at Break	17
Failure strain	0.05
⊟ Fiber	
Fillerlength	1000
Fillerdiameter	20
Phi or Psi	φ
Phi	12.9
Psi	30.1
Fillermaterial	E-Glas
⊟ Orientation	
⊟ Fillerorientationtype	CA lin. OF
Fillerorientationvalue 1	0.6
Fillerorientationvalue 2	0.33

matrix data

filler data

orientation data

Composite Density	1126	[g/dm³]
c_C11	6172	[MPa]
c_C12	1808	[MPa]
c_C13	1231	[MPa]
c_C14	0	[MPa]
c_C15	0	[MPa]
c_C16	0	[MPa]
c_C22	4135	[MPa]
c_C23	1181	[MPa]
c_C24	0	[MPa]
c_C25	0	[MPa]
c_C26	0	[MPa]
c_C33	2616	[MPa]
c_C34	0	[MPa]
c_C35	0	[MPa]
c_C36	0	[MPa]
c_C44	1554	[MPa]
c_C45	0	[MPa]
c_C46	0	[MPa]
c_C55	888.6	[MPa]
c_C56	0	[MPa]
c_C66	957.5	[MPa]
y_r00	1	[1]
y_r45	0.5105	[1]
y_r90	0.2665	[1]
y_scalematrix0	3.076	[1]



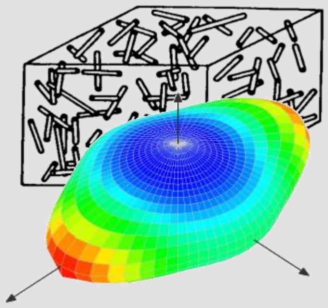
4a impetus – new software features
Anisotropy – Composites

160223_006	Material	Designvariablen	Layers

Name	Start	const...	Description
GroupName: 10_elasticity			
c_C11	MMEC	✓	constitutive matrix 11
c_C12	MMEC	✓	constitutive matrix 12
c_C13	MMEC	✓	constitutive matrix 13
c_C14	MMEC	✓	constitutive matrix 14
c_C15	MMEC	✓	constitutive matrix 15
c_C16	MMEC	✓	constitutive matrix 16
c_C22	MMEC	✓	constitutive matrix 23
c_C23	MMEC	✓	constitutive matrix 23
c_C24	MMEC	✓	constitutive matrix 24
c_C25	MMEC	✓	constitutive matrix 25
c_C26	MMEC	✓	constitutive matrix 26
c_C33	MMEC	✓	constitutive matrix 33
c_C34	MMEC	✓	constitutive matrix 34
c_C35	MMEC	✓	constitutive matrix 35
c_C36	MMEC	✓	constitutive matrix 36
c_C44	MMEC	✓	constitutive matrix 44
c_C45	MMEC	✓	constitutive matrix 45
c_C46	MMEC	✓	constitutive matrix 46
c_C55	MMEC	✓	constitutive matrix 55
c_C56	MMEC	✓	constitutive matrix 56
c_C66	MMEC	✓	constitutive matrix 66

160223_006	Material	Designvariablen	Layers

Name	Start	const...	Description
GroupName: 10_elasticity			
GroupName: 20_yield			
y_0	90	(red)	yield stress
y_scale...	MMEC	✓	yield scale 11 direction
y_r00	MMEC	✓	yield hill anisotropy ratio 0°
y_r45	MMEC	✓	yield hill anisotropy ratio 45°
y_r90	MMEC	✓	yield hill anisotropy ratio 90°
GroupName: 21_hardening			
h_ET	50	(red)	
h_y	90	✓	
GroupName: 31_strainrate			
v_epspkt	0.01	✓	initial strain rate threshold
v_p	15	(red)	strain rate scale (1/vp)
GroupName: 51_failure			
xf_NUM...	0.75	✓	Number of failed integration points prior to

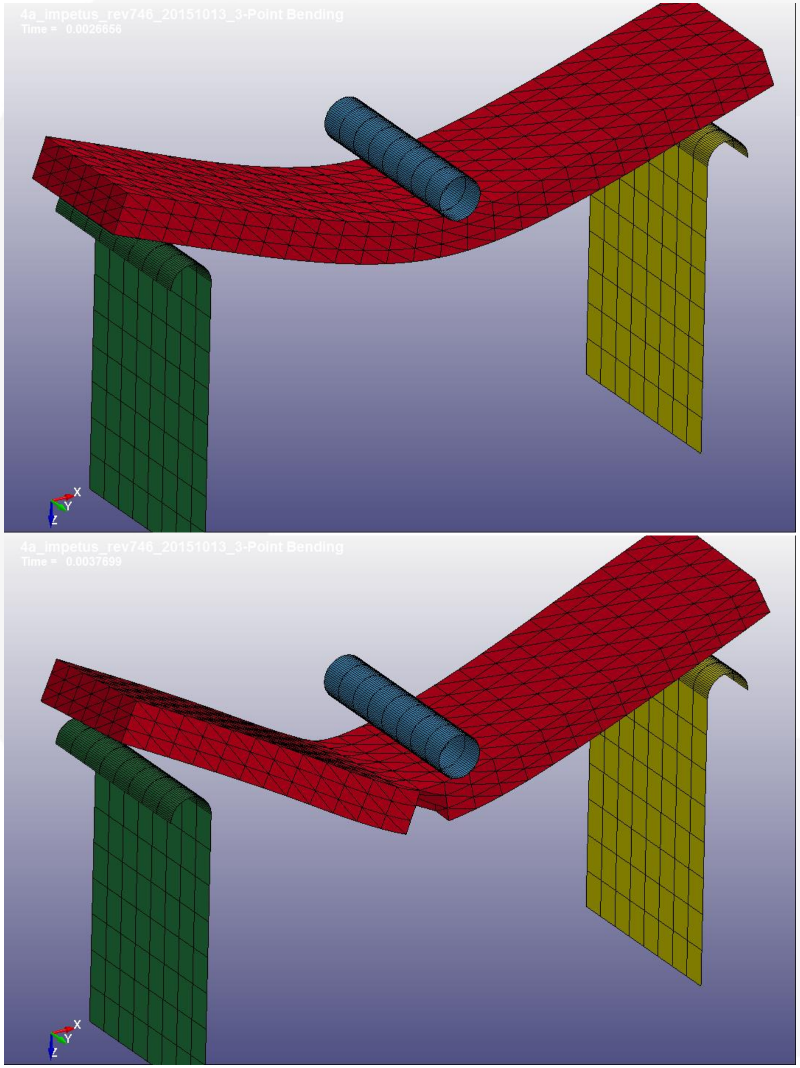


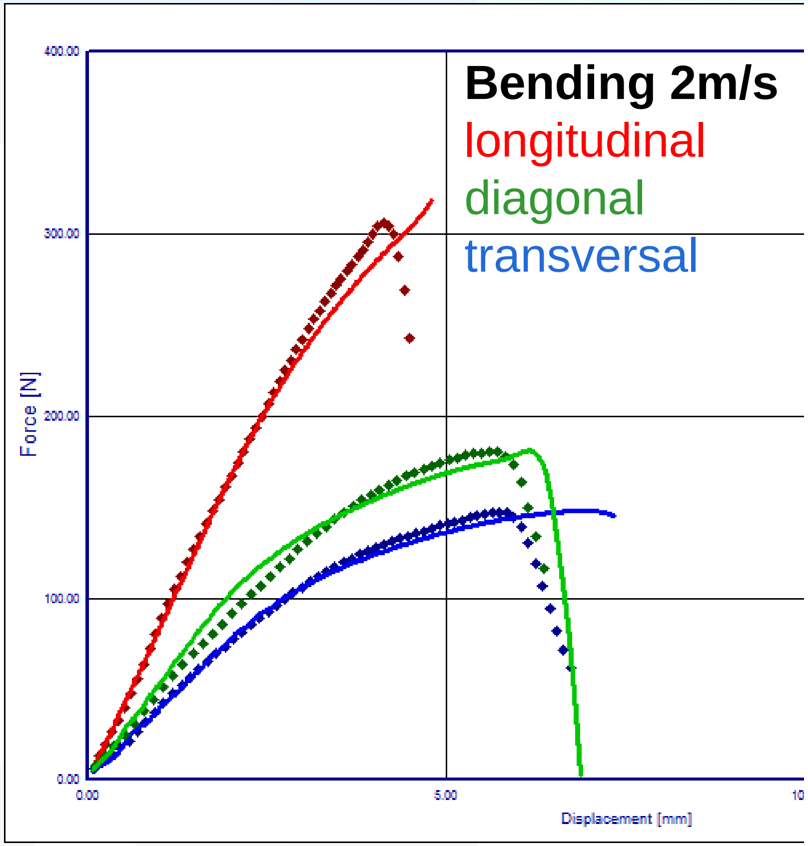
e.g.: 30 design variables for ***MAT_157**

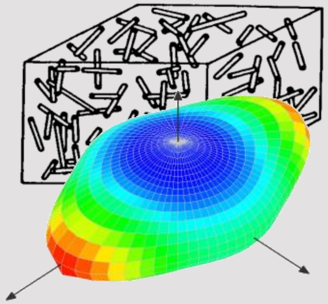
MMEC – design variable calculated by micro mechanic model

Less free design variables left for material parameter identification

4a impetus – new software features
Anisotropy – Composites



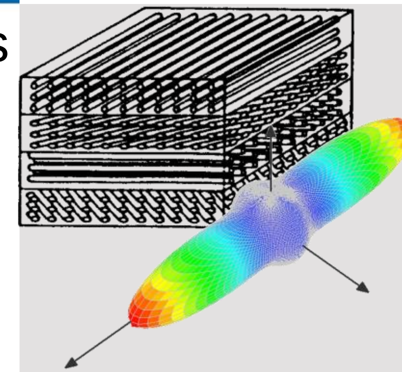




[P. Reithofer et al - Material characterization of composites using micro mechanic models as key enabler, CAE Grand Challenge 2016, Hanau]

Anisotropy – Composites

- Additional possibility **to define LAYUP** in 4a impetus for composites
- **Sample orientation** from test database



Parameter model*

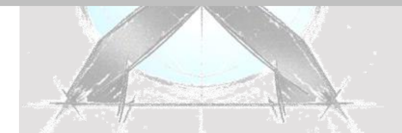
160708_001 | Material | Designvariablen | Layers

Additional settings	
Friction coefficient	0.1
Contactthickness	1
Young's Modulus of support / fin	210000
Density of support / fin	7800
Time scaling	1
Number of element layers	9
Write part/section	Composite
Scale the thickness to the measure	Yes
Element type	16: Fully integrated shell ele
User defined parameter	0
Shell thickness update	no change in thickness
Material behaviour	
Material source	Implemented
Elasticity	Not isotropic elastic
Plasticity	Not selected
Failure/Damage	Not selected
Material card	*MAT_COMPOSITE_DAMAGE (*MAT_022)
Materialcardcase	7500_MAT22

Parameter model*

160708_001 | Material | Designvariablen | Layers

MaterialID	Thickness	angle
1000000	0.2	0
1000000	0.2	90
1000000	0.2	0
1000000	0.2	90
1000000	0.2	90
1000000	0.2	0
1000000	0.2	90
1000000	0.2	0



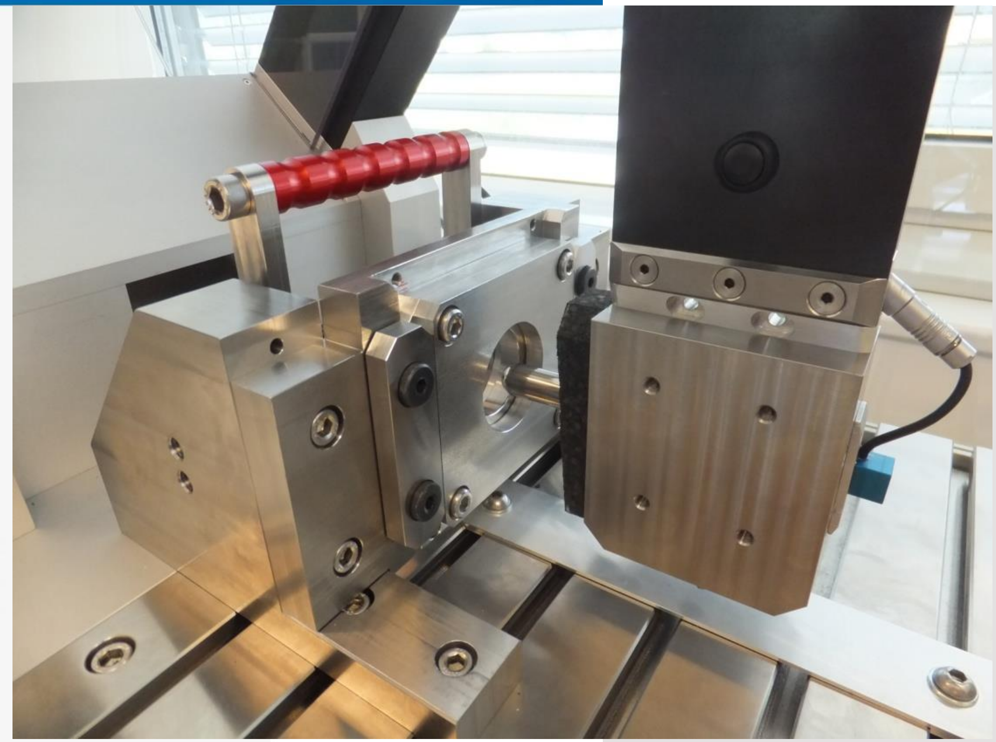
4a impetus – new hardware features
New pendulum arm

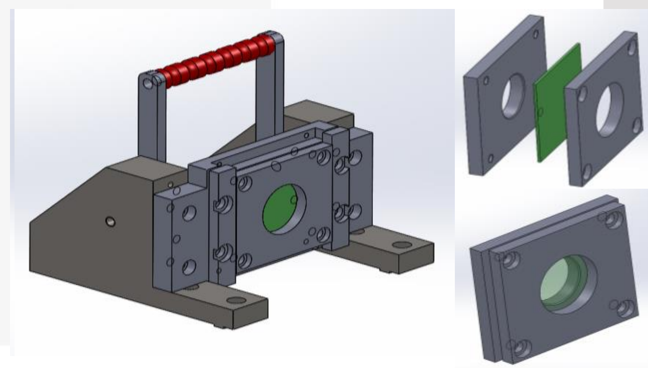
- Dynamic 3-point-bending **tests of composite materials** or puncture tests of thermoplastic materials
- Usable up to an **impact energy of 50 J**
- Vibration reduced pendulum arm made of **carbon**, aluminum and steel alloy
- Plugable acceleration sensors
- Mounting of additional masses possible (mass: 1 – 4 kg)

4a impetus – new hardware features

New puncture test

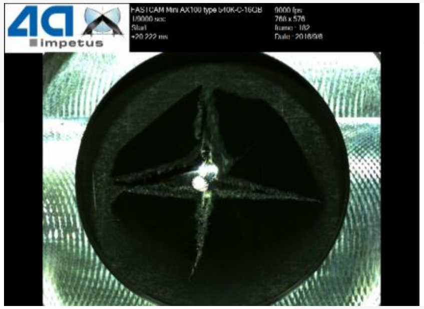
- Loosely based on DIN EN ISO 6603-2
- Easy mounting on 4a impetus
- Various inserts and impactor diameter
- Additional masses possible
- Quick change of inserts → possibility for testing at **low or high temperatures**
- Maximum energy: 50 J
- Investigation of **flow behavior and failure under biaxial load**

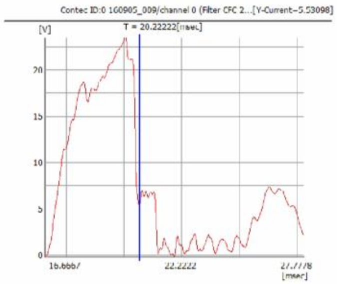


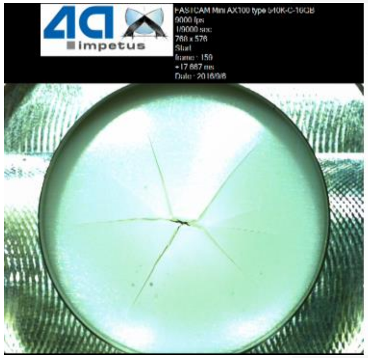


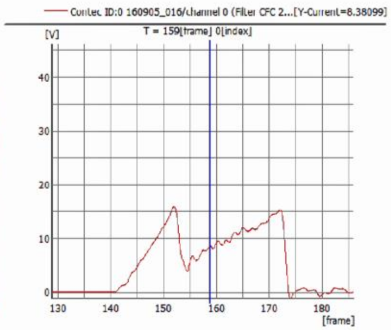
New puncture test

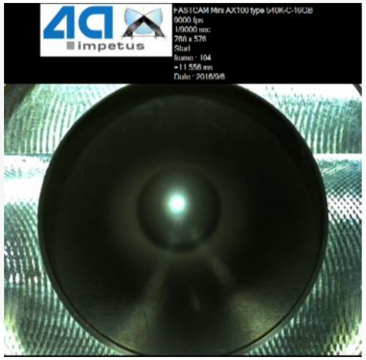
- Test results:

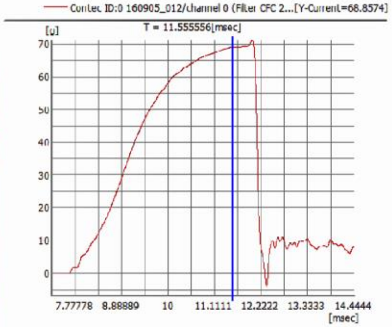






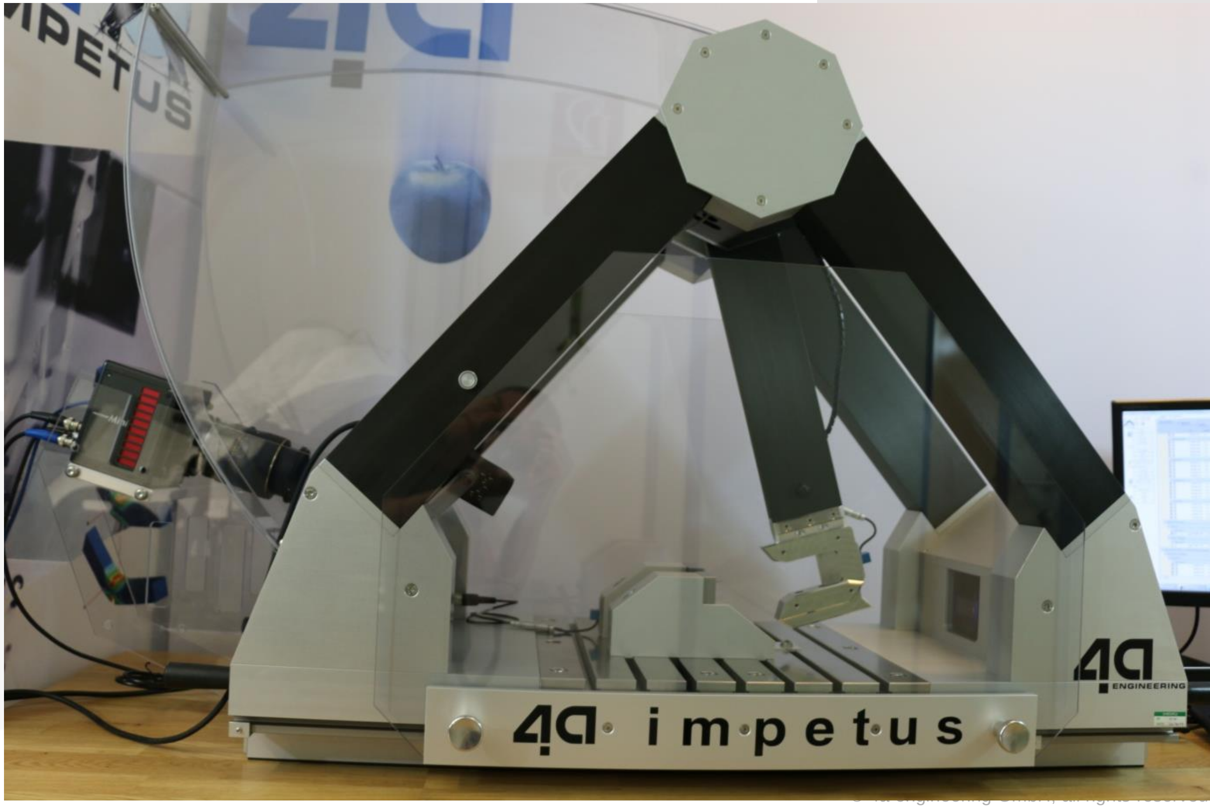






- **Visualization of dynamic behavior** of the material during test (crack initiation and propagation)
- Easy view, different angles possible
- Trigger signal from 4a impetus

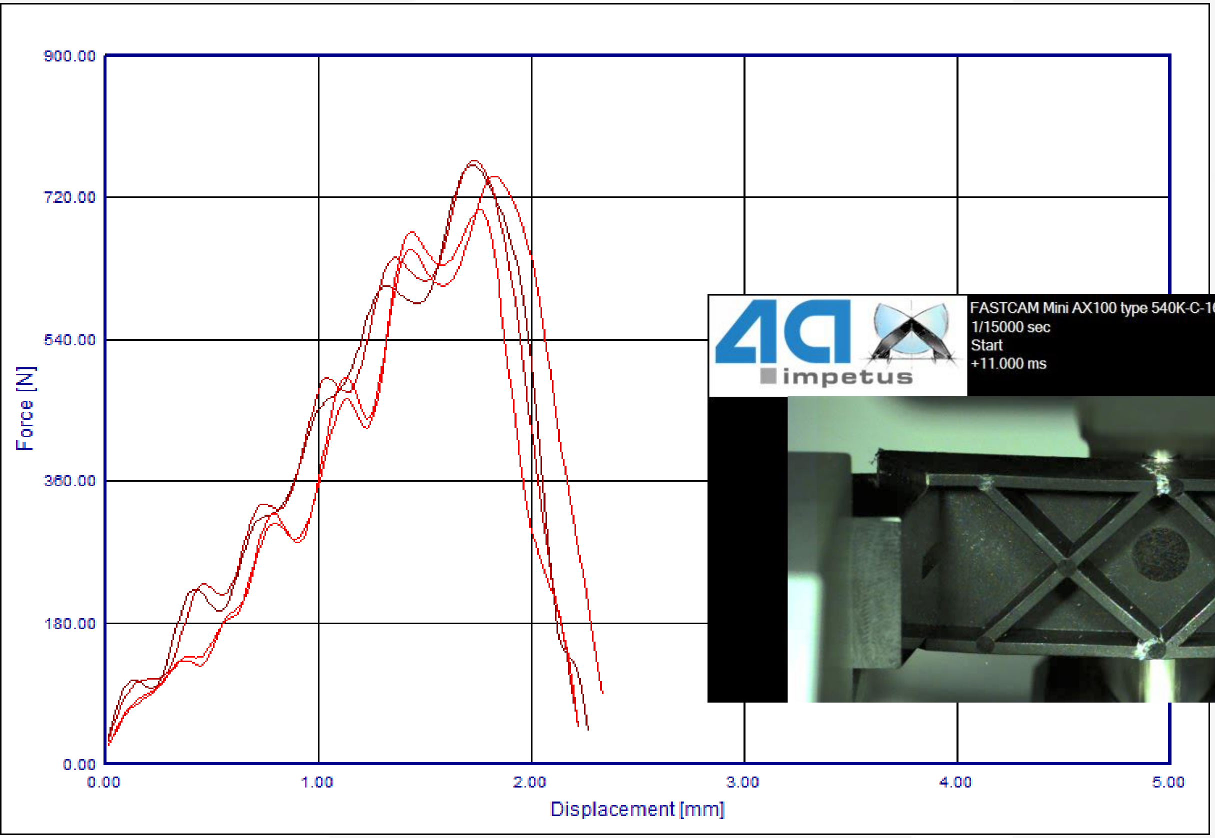
  → **synchronizing**

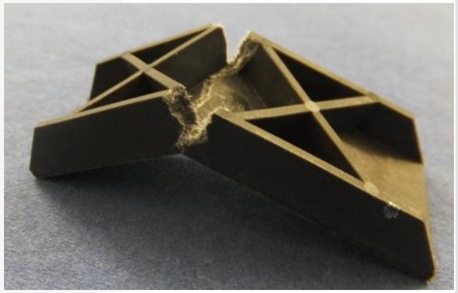


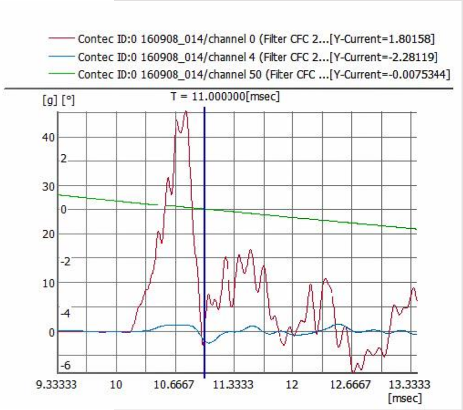
4a impetus – new hardware features
High-speed camera

- Example: XX-rib, PP LGF30, dynamic 3-point bending @ 3 mps

  force-displacement curves by 4a impetus







Summary

- **Complex material models**

  → accurate description of plastics and composites

- **Appropriate test methods**

  → get access to the material model parameters

  → time and cost efficient

- **MPIP - Material Parameter Identification Process**

  → to fit the material model parameters

  → time and cost efficient

- **Continuous improvements in 4a impetus** hard- and software

  → easy, time & cost efficient

  → accurate **validated material cards**

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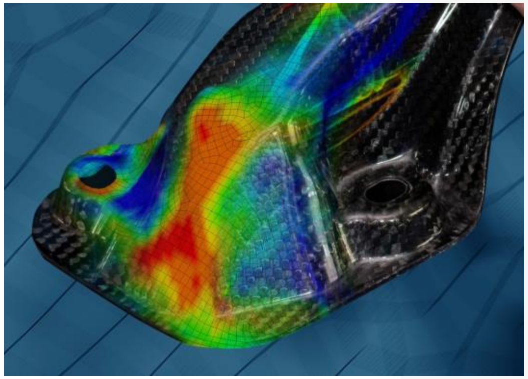
Thank you for your attention!



14th TECHNOLOGIETAG

23.- 24. March 2017
in Schladming, Austria

„Light weight applications & Composites"
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