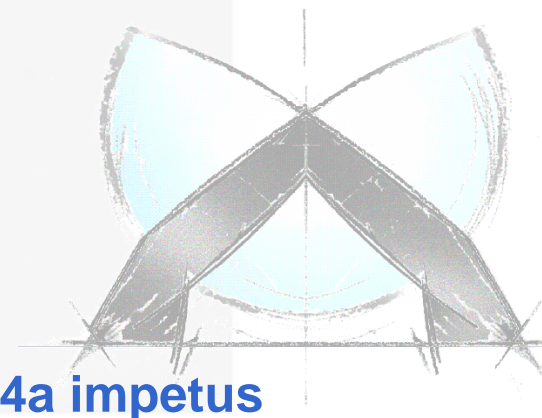


Efficient evaluation of material cards for non-reinforced and reinforced thermoplastics

A. Fertschej, P. Reithofer (4a engineering GmbH)
Th. Weninger, F. Cetin (Granta Design Ltd.)



SIMULIA COMMUNITY CONFERENCE 2015, BERLIN



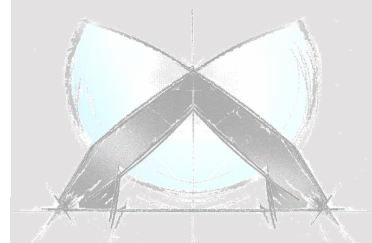
4a impetus

© by 4a engineering GmbH - intelligent testing systems

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Industriepark 1
A-8772 Traboch
reithofer@4a.co.at
++43 (0) 664 80106 601

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- 4a engineering GmbH
- 4a impetus
- Material models for thermoplastics
 - Material behavior of plastics
 - Simple material models – complex material models
- Material models for composites
 - Coupling to micro-mechanic
 - *ABQ_PLY_FABRIC
- Summary



- polymer and materials science
- numerical simulation methods
- fiber reinforced plastics and composites
- method and software development

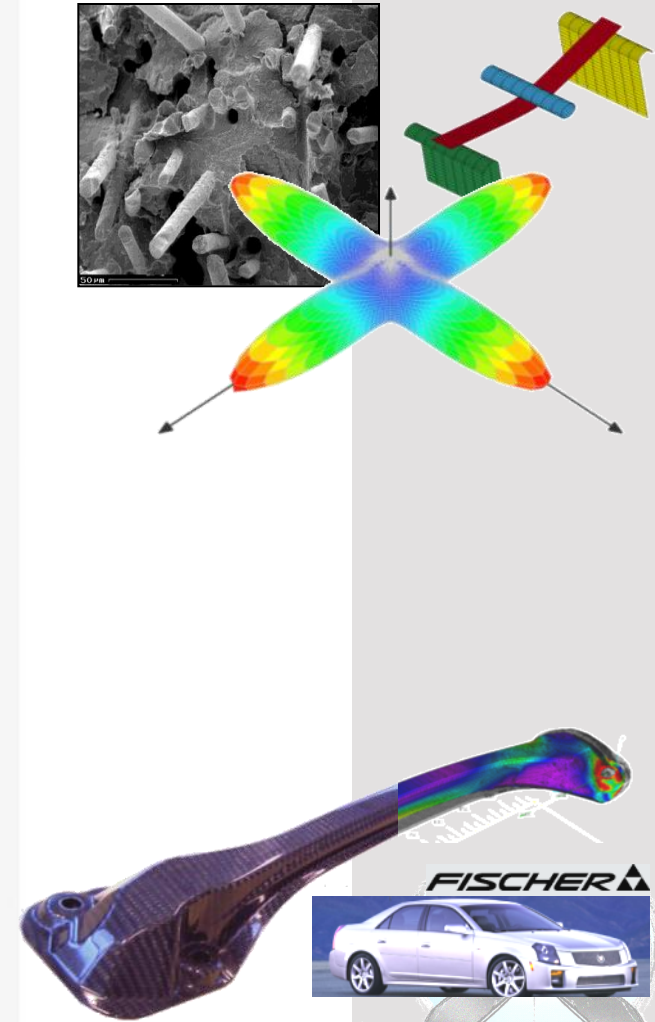
- case studies product development:



Alpine touring ski binding

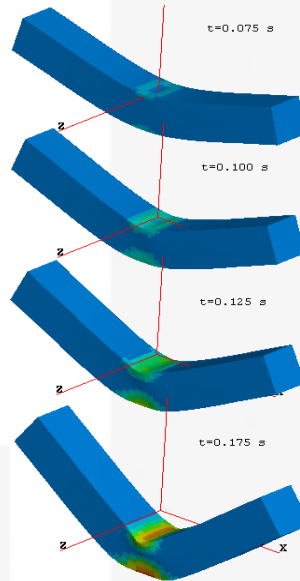


LH₂ – tank mounting



RTM – CFK – strut bar

- efficient high-dynamic testing
- crash-behaviour of plastics
- material data for simulation



source: <http://auto-kaufberatung.at>



source: <https://www.youtube.com/watch?v=TdtN9UqvZes>

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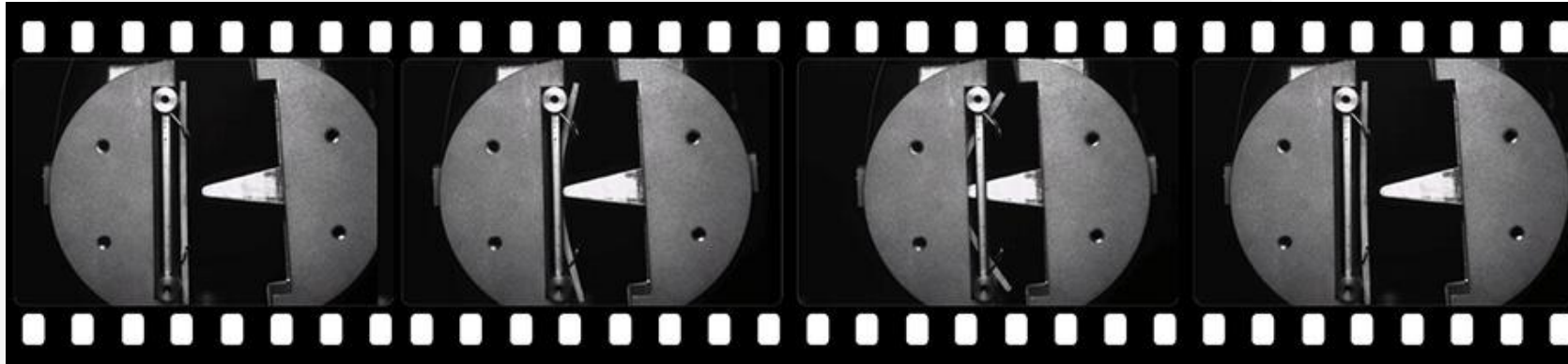
**4a impetus - intelligent testing systems
powered by 4a engineering GmbH**



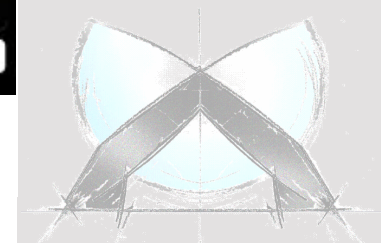
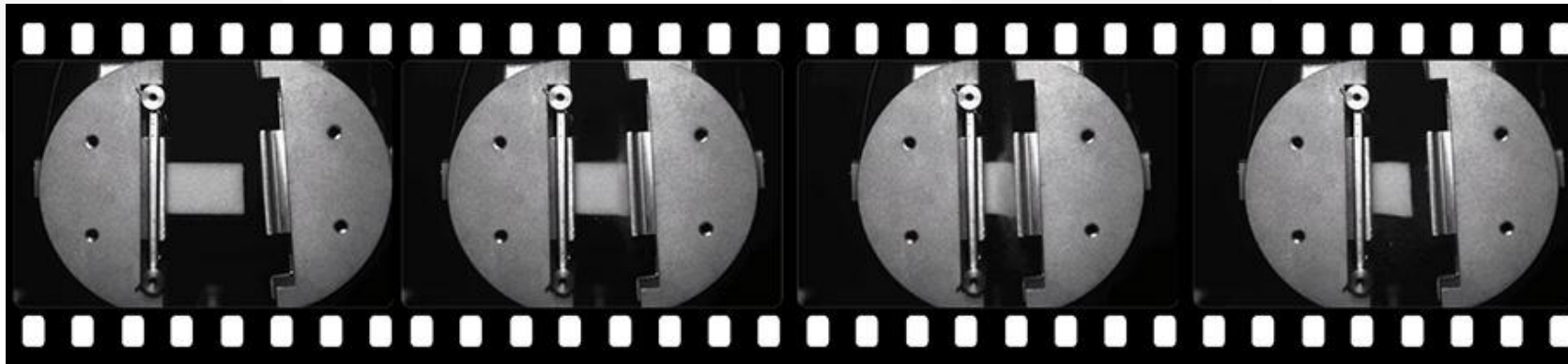
4a impetus

dynamic tests up to a velocity of 10 m/s are possible

bending test on 4a impetus double pendulum



compression test on 4a impetus double pendulum

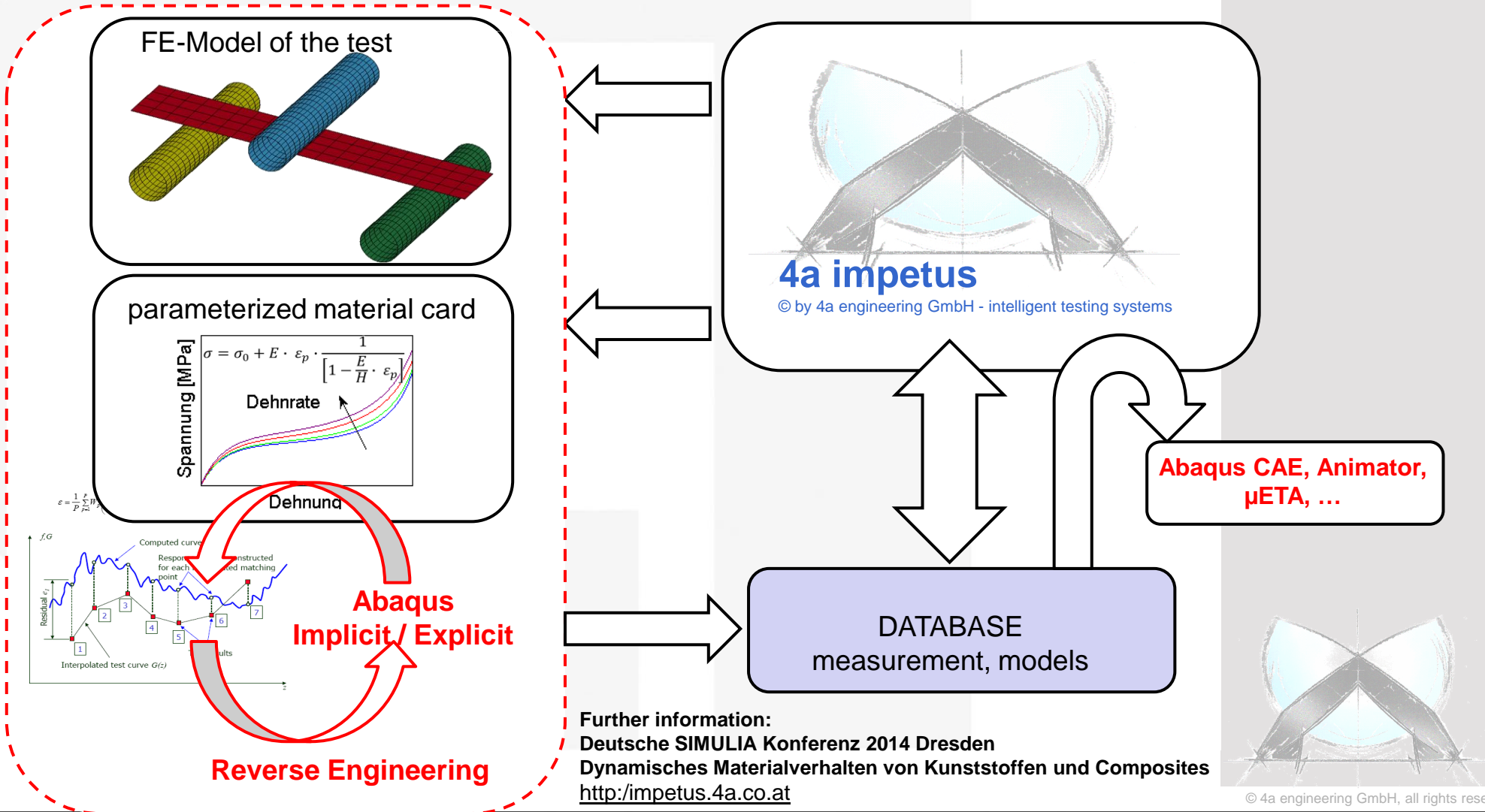


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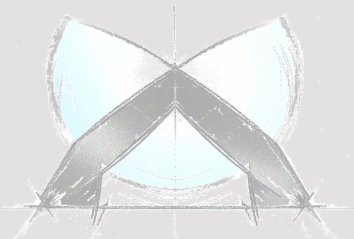
4a impetus

How does it work

Material characterization / reverse engineering



Further information:
 Deutsche SIMULIA Konferenz 2014 Dresden
 Dynamisches Materialverhalten von Kunststoffen und Composites
<http://impetus.4a.co.at>



4a impetus

How does it work

Test database

- Geometry
- Loading
- Boundary condition
- Orientation
- Measurement results
Force/Displacement
Stress/Strain

...

Model database

- Optimization/Validation
- Solver
LS Dyna, Abaqus, ...
- Material model
von Mises
general yield surface
strain rate dependence
- Idealization
Shell/Solid
Meshsize

**Directly linked
to model build up**

**Evaluation
Filtering
Averaging**

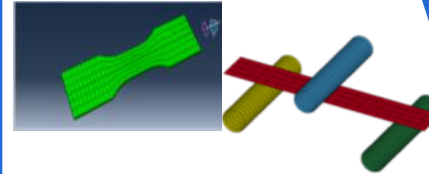
**Automatic
LS-OPT input-deck**

**Directly linked to
solver run scripts**

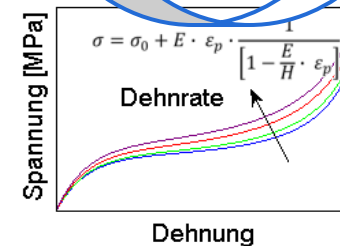
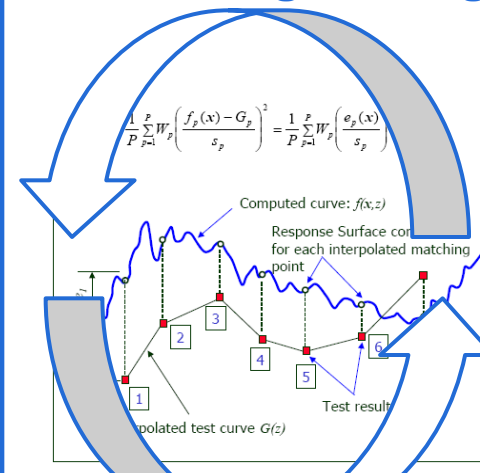
**Material optimized
parameterized
models**

**Automatic mesh
generation**

FE-Model of the test



Reverse Engineering



parameterized
material card

**validated
material
card**



4a impetus

How does it work

➤ The tests and simulations models are stored in a **data base** → easy access and user friendly

The screenshot displays the 4a impetus software interface. On the left, there is a sidebar with various toolbars for 'Test data', 'Testing', 'Evaluation of the test', 'Parameter model', 'Optimization', and 'Material'. The main window is divided into several panes:

- General information:** Includes fields for 'Date_Nr' (110125_001) and sections for 'General information', 'Test setup', 'Test specimen', and 'Evaluation'. The 'Evaluation' section contains a table with parameters like 'Filter', 'Evaluation of the velocity', 'Zero-point evaluation', 'Identification of failure', 'Stress evaluation', and 'Stiffness evaluation'.
- Test specimen:** A 3D model of a specimen with dimensions L , L_w , and b .
- Measurement curves:** A graph showing 'Channels [I]' vs. displacement. It features a blue curve labeled 'Externe Daten' and a red curve.
- Material settings:** A table with parameters such as 'System of units', 'Solver', 'Inputdeck', 'Symmetry of model', 'Idealization type', 'Element size', 'Material behaviour', 'Material source', 'Material card', 'Loadcases', and 'Casename'.
- Force-displacement curves:** A graph showing 'Force [N]' vs. 'Displacement [mm]'. It contains multiple curves in red, green, and blue, with a peak force of 32.64 N and a displacement of 18.16 mm. A label '3.1_3PBEP_498g_2.5mpa_lw36mm.res | avg 3.5% | max 7.9%' is visible.

A central text box reads: **4a impetus - complete system from the test to the validated material card**



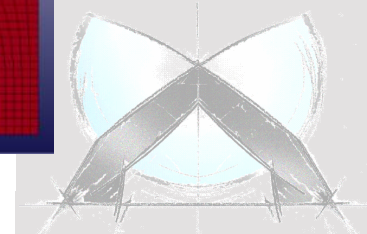
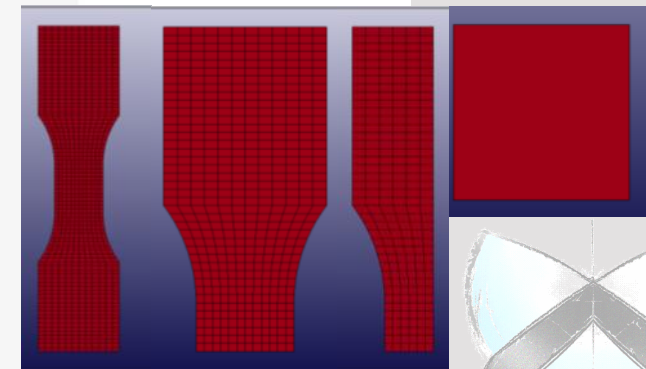
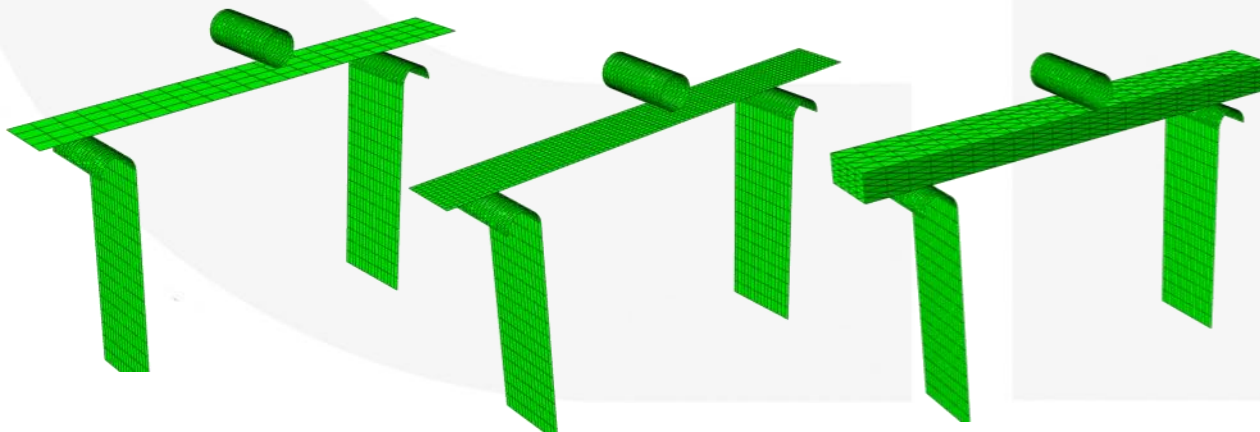
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4a impetus

Simulation - Idealization

- Can be used local or in network cluster
- Supports **Abaqus, LS-Dyna, PAM-Crash**
- Allows the idealization in **shell or solid** using the most popular element types and **an arbitrary element size** (of course it should be reasonable)
- Can consider **symmetries – simplification** down to 1-element

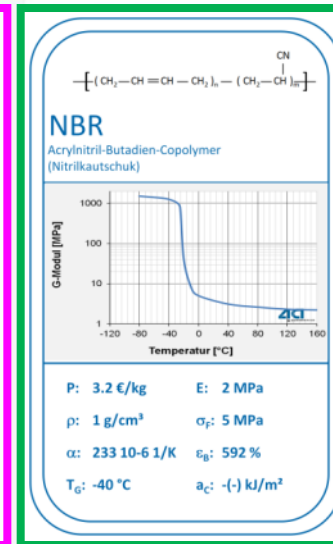
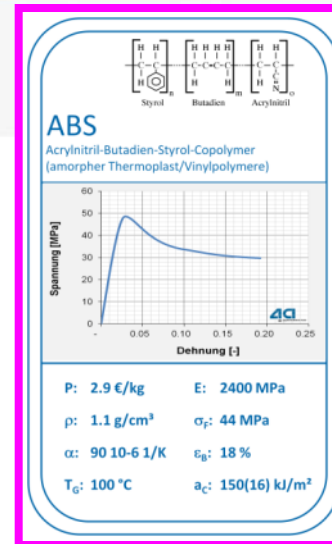
Material	
Idealization	
System of units	t-mm-sec-MPa
Solver	LS DYNA
Inputdeck	Impetus (n.a.)
Symmetry of model	NNet(LS-OPT v4.1) (a)
Idealization type	LS DYNA
Element size	PAM CRASH
Additional settings	ABAQUS
Friction coefficient	RADIOSS
Contactthickness	1
Young's Modulus of support / f	210000
Density of support / fin	7800
Time scaling	0
Solver	Selection of FE-solver



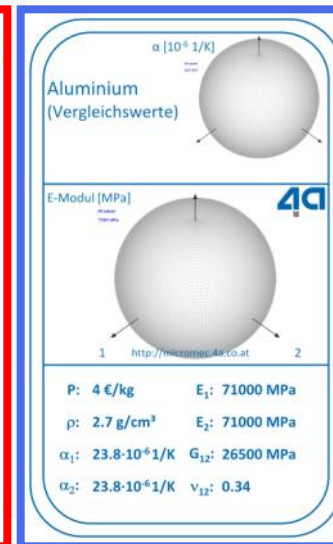
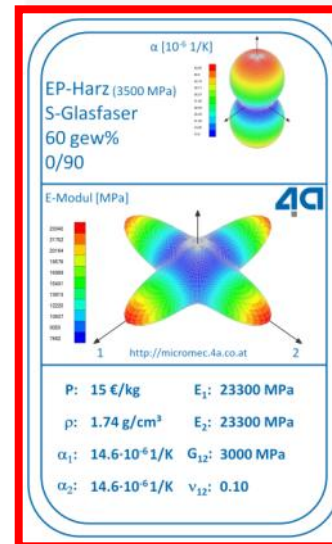
4a impetus

Tested materials

- We have already tested a wide range of
 - **thermoplastics** (ASA, ABS+PA; ABS+PC; PA6; PA6(6) GF30..50; PA66+P6; PBT GF30; PC; PE; PP; PP+ varnish; PP rubber modified; PP GF20..40; PP Impact modified; PP MX10; PP MX20; PP MX40; PP CF; PP+EPDM; MuCell-materials, ...)
 - **foams** (EPP30..80; PU RG 55, PU RG 65)
 - **rubbers** (EPDM, SILIKON)
 - **thermoset materials** (CFK, GFK with epoxy resin)
 - **metals** (aluminium, DC04, high strength steels (current tests))
 - **wood** (beech, multiplex, chipboards, MDF)



from:
4a Quartet card
game "plastics"

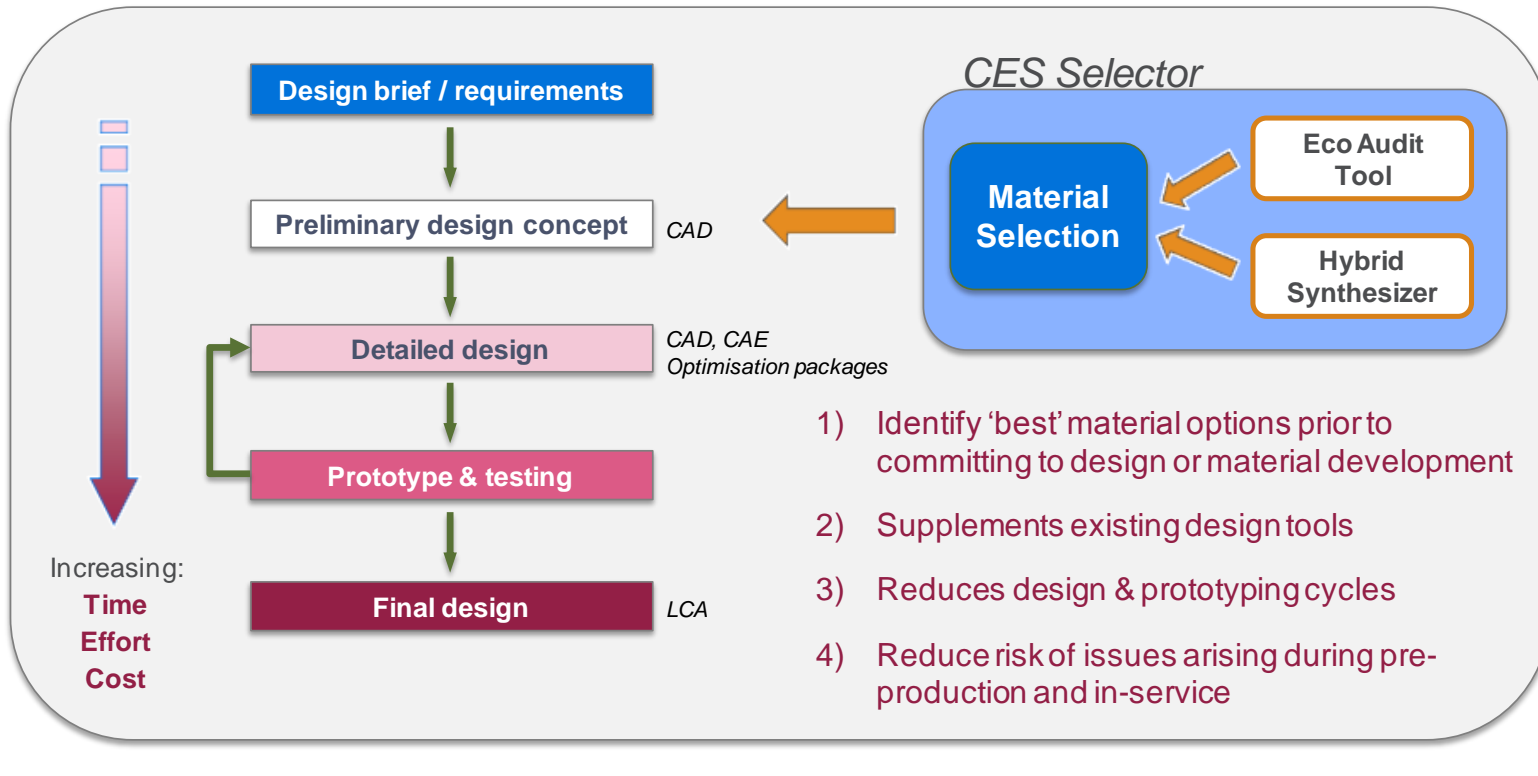


from:
4a Quartet card
game "composites"



Integration into Engineering Workflows

Typical design & development workflow



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1. Check your design

- Design requirements
- Preliminary design → first principal simulations

2. Get as much information as you can

- Material supplier / literature / in-house material information
- Get feeling for the material
(other supplier – deviation of properties)
- Material database
(Campus, IDES, GRANTA MI, CES SELECTOR)
- Influence on mechanical behavior (glass transient temperature)
- Medium resistance (oil, chemical, ...)



Plastics - Material behavior

Introduction – CES SELECTOR MATERIAL UNIVERSE

CES Selector 2015 - [MaterialUniverse:\Polymers: plastics, elastomers\Plastics\Thermoplastics\PA (Polyamide/Nylon)\PA6(Unfilled)]

File Edit View Select Tools Window Feature Request Help

Browse Search Select Tools Solver Eco Audit Synthesizer Search Web Help

Database: All Editions Change...
Table: MaterialUniverse
Subset: All materials

Home PA6 (molding and extrusion) x
PA6 (molding and extrusion)
Layout: All attributes Show/Hide Find Similar

MaterialUniverse

- ▶ Ceramics and glasses
- ▶ Fibers and particulates
- ▶ Hybrids: composites, foams, honeycombs, natural materi...
- ▶ Metals and alloys
- ▶ Polymers: plastics, elastomers
 - ▶ Elastomers
 - ▶ Plastics
 - ▶ Thermoplastics
 - ▶ ABS (Acrylonitrile Butadiene Styrene)
 - ▶ Aluminum filled
 - ▶ Carbon filled
 - ▶ Glass filled
 - ▶ Stainless steel filled
 - ▶ Unfilled
 - ▶ ABS+PA blends
 - ▶ ABS+PC blends
 - ▶ ABS+PVC blends
 - ▶ ANMA (Acrylonitrile methyl acrylate copolyme...
 - ▶ ASA (Acrylic Styrene Acrylonitrile)
 - ▶ ASA+PC blends
 - ▶ ASA+PVC blends
 - ▶ CA (Cellulose Acetate)
 - ▶ CAB (Cellulose Acetate Butyrate)
 - ▶ CAP (Cellulose Acetate Propionate)
 - ▶ CN (Cellulose nitrate/Celluloid)
 - ▶ COC (Cyclic Olefin Copolymer)
 - ▶ COP (Cyclo Olefin Polymer)
 - ▶ EC (Ethyl Cellulose)
 - ▶ ECTFE (Ethylene Chlorotrifluoroethylene)
 - ▶ EMA, EEA, EBA (Ethylene acrylate copolymers)
 - ▶ ETFE (Ethylene Tetrafluoroethylene)
 - ▶ EVA (Ethylene Vinyl acetate)
 - ▶ EVOH (Ethylene Vinyl Alcohol)
 - ▶ FEP (Fluorinated Ethylene Propylene)

Mechanical properties

Young's modulus	0.944	- 1.18	GPa
Yield strength (elastic limit)	38.6	- 48.2	MPa
Tensile strength	32.9	- 40.2	MPa
Elongation	41	- 59	% strain
Elongation at yield	14.6	- 27.7	% strain
Compressive modulus	* 1.01	- 1.11	GPa
Compressive strength	* 41.6	- 46	MPa
Flexural modulus	* 0.77	- 0.923	GPa
Flexural strength (modulus of rupture)	* 43.2	- 52.7	MPa
Shear modulus	* 0.38	- 0.4	GPa
Shear strength	* 19.7	- 24.1	MPa
Bulk modulus	* 1.2	- 1.33	GPa
Poisson's ratio	0.34	- 0.36	
Shape factor	3.79		
Hardness - Vickers	* 12.4	- 13.7	HV
Hardness - Rockwell M	* 82.8	- 91.5	
Hardness - Rockwell R	* 82.8	- 91.5	
Hardness - Shore D	* 71.4	- 74.3	
Fatigue strength at 10 ⁷ cycles	* 13.9	- 15.3	MPa
Mechanical loss coefficient (tan delta)	* 0.0273	- 0.0302	

Impact & fracture properties

Fracture toughness	* 3.1	- 3.42	MPa.m ^{0.5}
Ductility index	3.97	- 4.85	
Impact strength, notched 23 °C	45.5	- 88.3	kJ/m ²
Impact strength, notched -30 °C	3.62	- 7.87	kJ/m ²
Impact strength, unnotched 23 °C	590	- 600	kJ/m ²
Impact strength, unnotched -30 °C	590	- 600	kJ/m ²

Thermal properties

Melting point	210	- 220	°C
Glass temperature	44	- 56	°C
Heat deflection temperature 0.45MPa	175	- 191	°C
Heat deflection temperature 1.8MPa	68	- 85	°C
Maximum service temperature	90	- 130	°C
Minimum service temperature	-64	- -54	°C
Thermal conductivity	0.233	- 0.253	W/m.°C

Locate in Browse Tree

Copy

Print...

Set as Reference

Add to Comparison Table

Add to Favorites

Remove from Favorites

Search Web

Export To...

- Abaqus 6
- ANSYS MAPDL v15 (ANSYS Classic)
- ANSYS Workbench v12
- MatML
- Pro/ENGINEER Wildfire 4.0 and 5.0
- SolidWorks 2011
- NastranNX

GRANTA
MATERIAL INTELLIGENCE

Plastics - Material behavior

Introduction – CES SELECTOR CAMPUS



CES Selector 2015 - [CAMPUS and M-Base Plastics:\DuPont Engineering Polymers\Zytel®]

File Edit View Select Tools Window Feature Request Help

Browse Search Select Tools Solver Eco Audit Synthesizer Search Web Help

Home Zytel® 7301 NC010 dry | PA6

Zytel® 7301 NC010 dry | PA6

Layout: All grades Show/Hide Find Similar

DuPont Engineering Polymers > Zytel® >

General

Manufacturer DuPont Engineering Polymers
 Gradename Zytel® 7301 NC010
 Issue date 21.05.2013
 Material condition dry

Composition

Polymer class Thermoplastics
 Polymer code PA6
 Polymer type PA6
 Filler type None

Characteristics

Processing Coating, Film Extrusion, Injection Molding, Other Extrusion, Profile Extrusion, Sheet Extrusion
 Delivery form Pellets

Processing and Physical properties

Density (CAMPUS ISO)	1.13e3	kg/m³
Water absorption (CAMPUS ISO)	9.5	%
Humidity absorption (CAMPUS ISO)	3	%

Mechanical properties

Tensile Modulus (CAMPUS ISO)	2.9e3	MPa
Yield stress (CAMPUS ISO)	80	MPa
Yield strain (CAMPUS ISO)	4.5	%
Nominal strain at break (CAMPUS ISO)	25	%
Charpy impact strength, +23°C (CAMPUS ISO)	600	kJ/m²
No break ✓		
Charpy impact strength, -30°C (CAMPUS ISO)	600	kJ/m²
No break ✓		
Charpy notched impact strength, +23°C (CAMPUS ISO)	6	kJ/m²

Thermal properties

Melting temperature, 10°C/min (CAMPUS ISO)	221	°C
Temp. of deflection under load, 0.45 MPa (CAMPUS ISO)	160	°C

Ready

CES Selector 2015 - [CAMPUS and M-Base Plastics:\DuPont Engineering Polymers\Zytel®]

File Edit View Select Tools Window Feature Request Help

Browse Search Select Tools Solver Eco Audit Synthesizer Search Web Help

Home Zytel® 7301 NC010 conditioned | PA6

Zytel® 7301 NC010 conditioned | PA6

Layout: All grades Show/Hide Find Similar

DuPont Engineering Polymers > Zytel® >

General

Manufacturer DuPont Engineering Polymers
 Gradename Zytel® 7301 NC010
 Issue date 21.05.2013
 Material condition conditioned

Composition

Polymer class Thermoplastics
 Polymer code PA6
 Polymer type PA6
 Filler type None

Characteristics

Processing Coating, Film Extrusion, Injection Molding, Other Extrusion, Profile Extrusion, Sheet Extrusion
 Delivery form Pellets

Mechanical properties

Tensile Modulus (CAMPUS ISO)	1.5e3	MPa
Charpy impact strength, +23°C (CAMPUS ISO)	600	kJ/m²
No break ✓		

Electrical properties

Relative permittivity, 1MHz (CAMPUS ISO)	7
--	---

Regional availability

Availability Europe, Near East/Africa

Processing notes

Profile extrusion
 PREPROCESSING Drying recommended = Yes, if moisture content of resin exceeds recommended level Drying temperature = 80°C Drying time, dehumidified dryer = 2-4 h Processing moisture content = <0.2 % PROCESSING Melt temperature optimum = 270°C Melt temperature range = 260-280°C

Further information

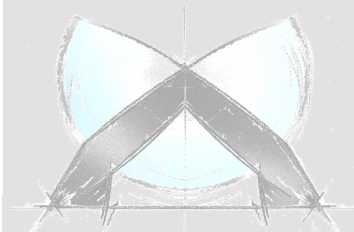
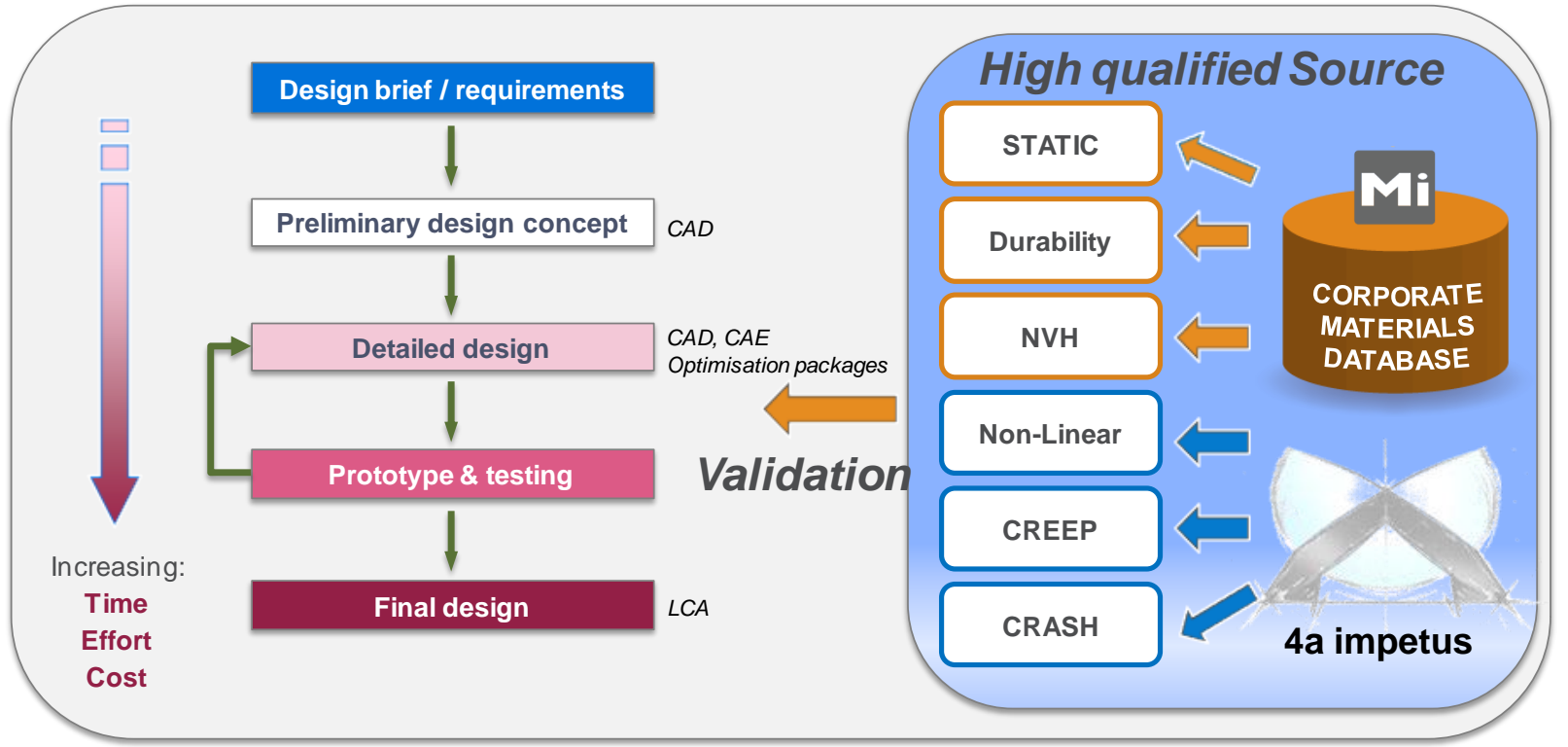
Disclaimer

Ready



Integration into Engineering Workflows

Typical design & development workflow



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➤ Mechanical behavior could depend on

- temperature
- strain rate (loading velocity)
- moisture content
- anisotropy (fiber reinforced)
- loading (tension, compression, shear, bending)

**ranking
through
application**

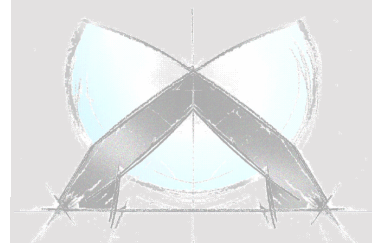
➤ Engineer's choice between

- Simple robust material model
- Complex expensive (costs + cpu) material model

➔ **Application driven**

➔ **Simulation task driven**

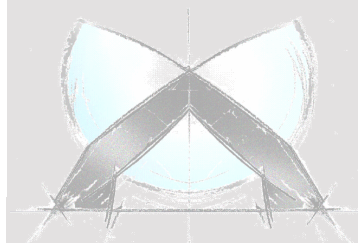
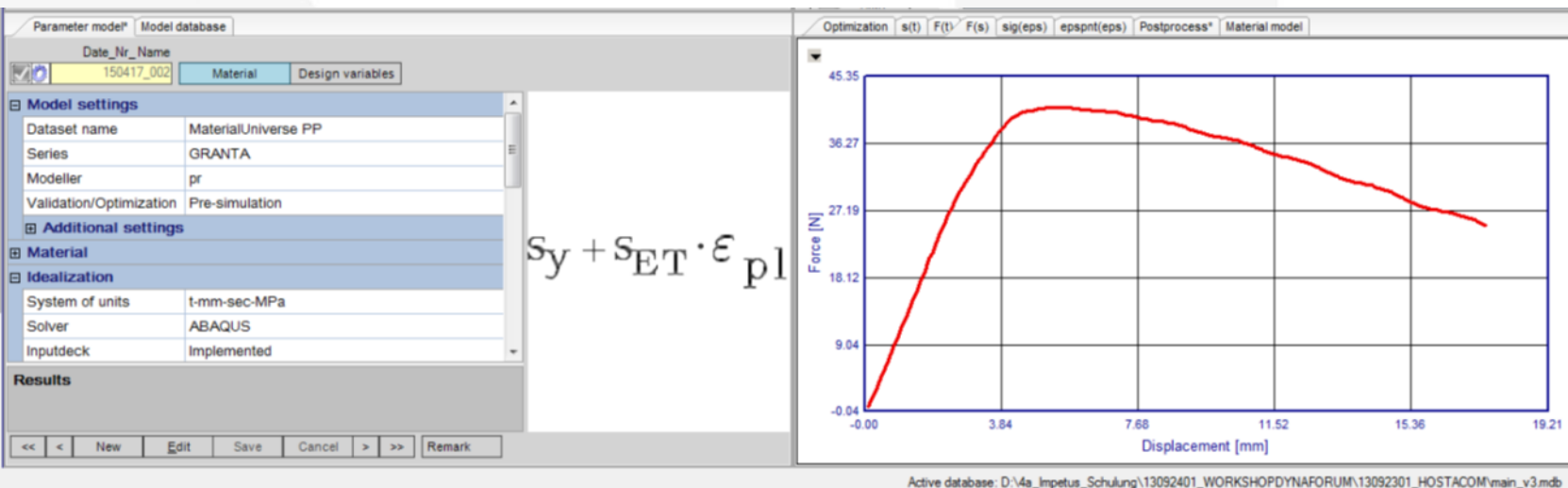
**different
requirements**



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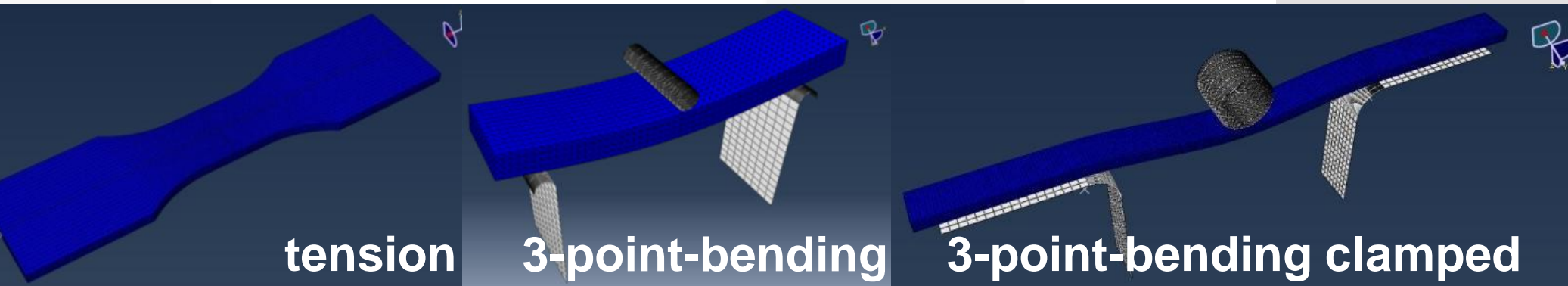
2. Get as much information as you can

- e.g. could be done with CES Selector, Granta MI, Campus, ...
- To prepare specimens (moisture, temperature, chemical resistance, ...)
 - To define test setup based on application and material requirements
 - To do pre-simulations for checking expected load conditions (acceleration, velocity, forces) to define sensors, shown in the image below



3. Testing with 4a impetus (CRASH)

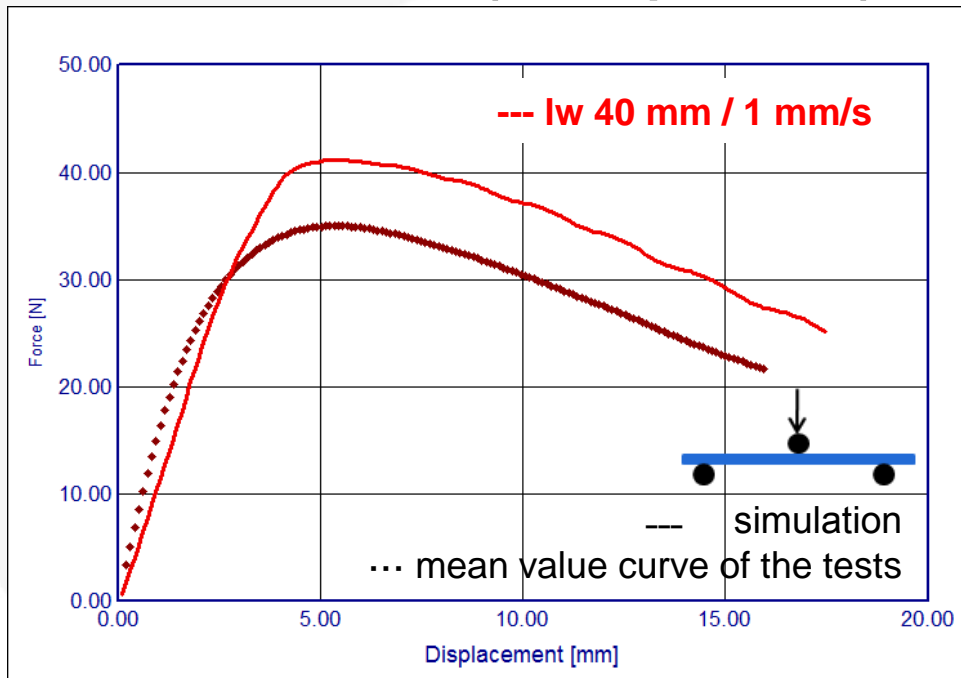
- static bending and tension (standard universal testing machine)
- dynamic bending and clamped bending (4a impetus)
- dynamic puncture test, T-Specimen (4a impetus)
-



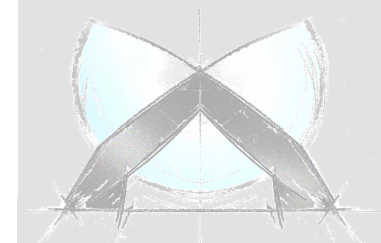
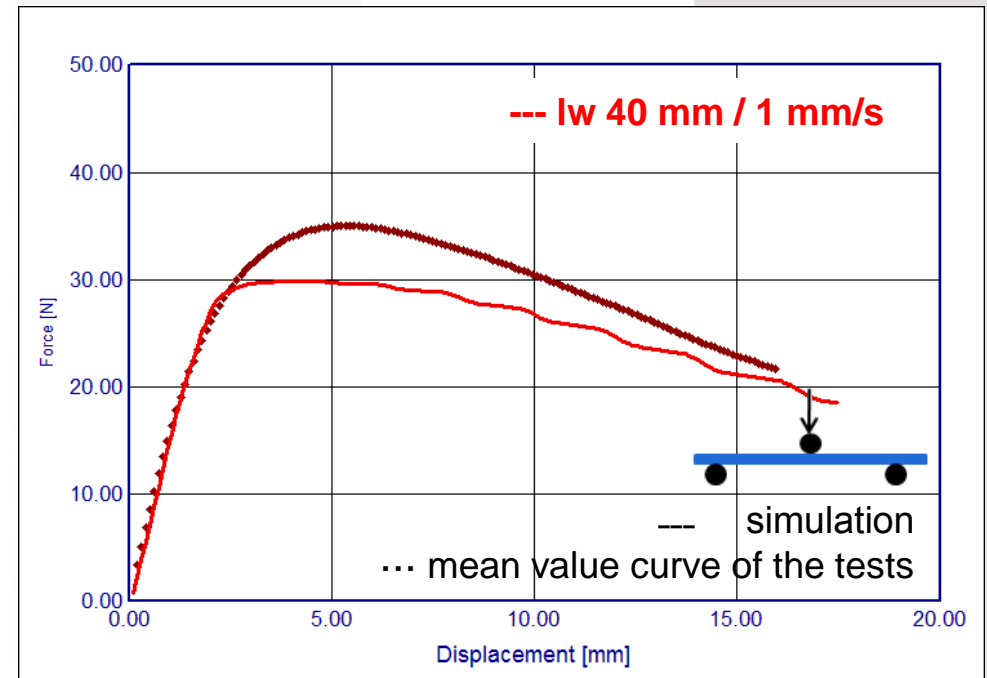
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4. Check with existing material card (CES Selector)

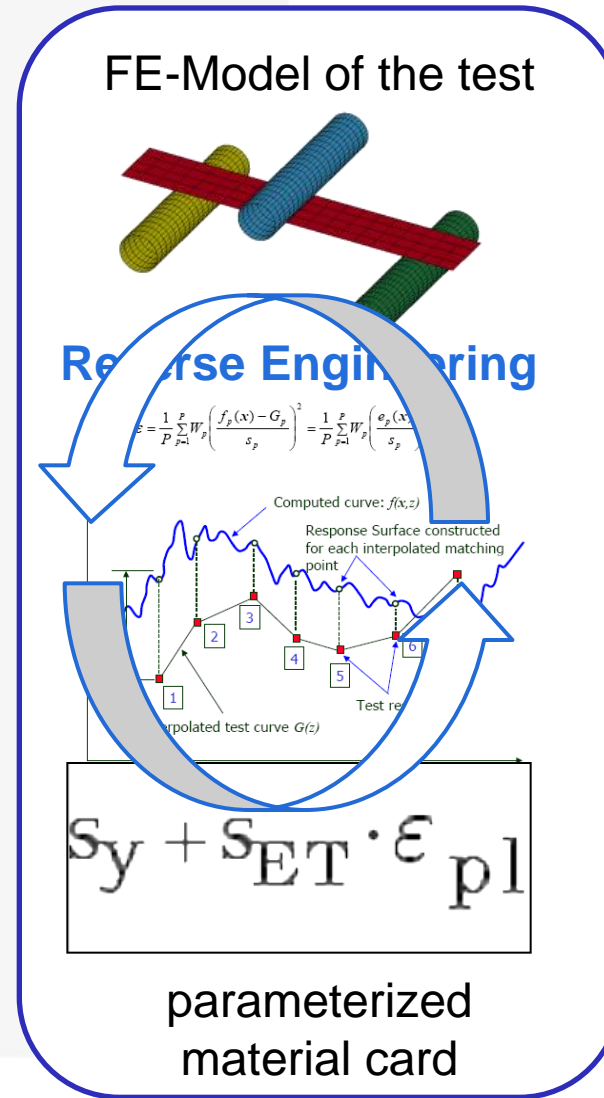
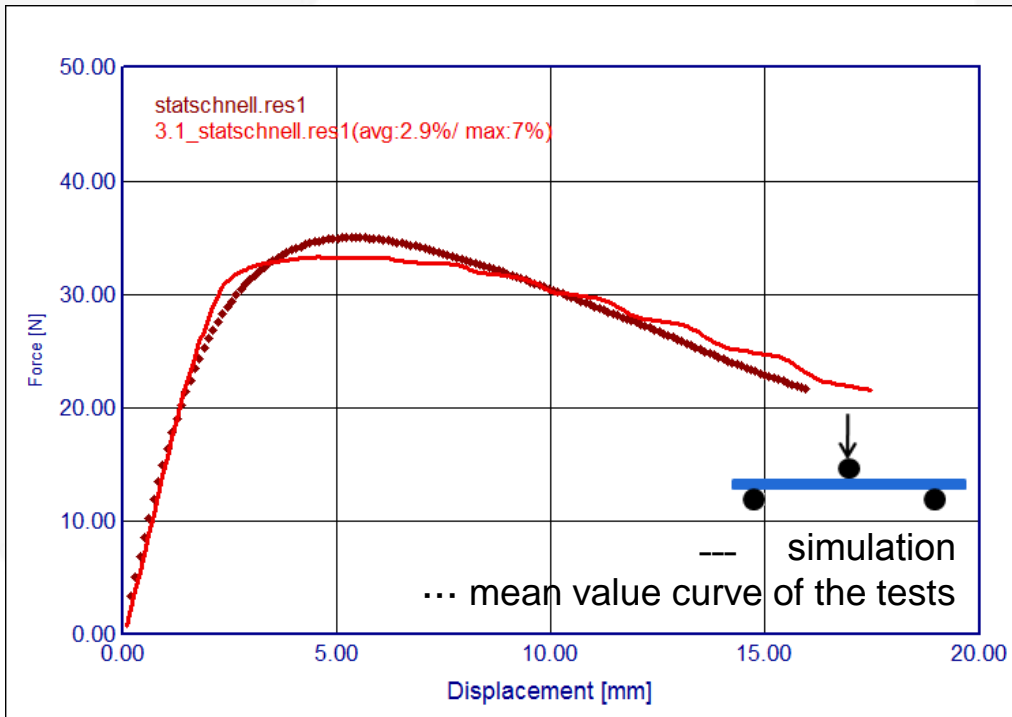
Material Universe (PP impact, UV)



Campus Hostacom XBR 169G



5. Reverse Engineering 4a impetus (*PLASTIC)

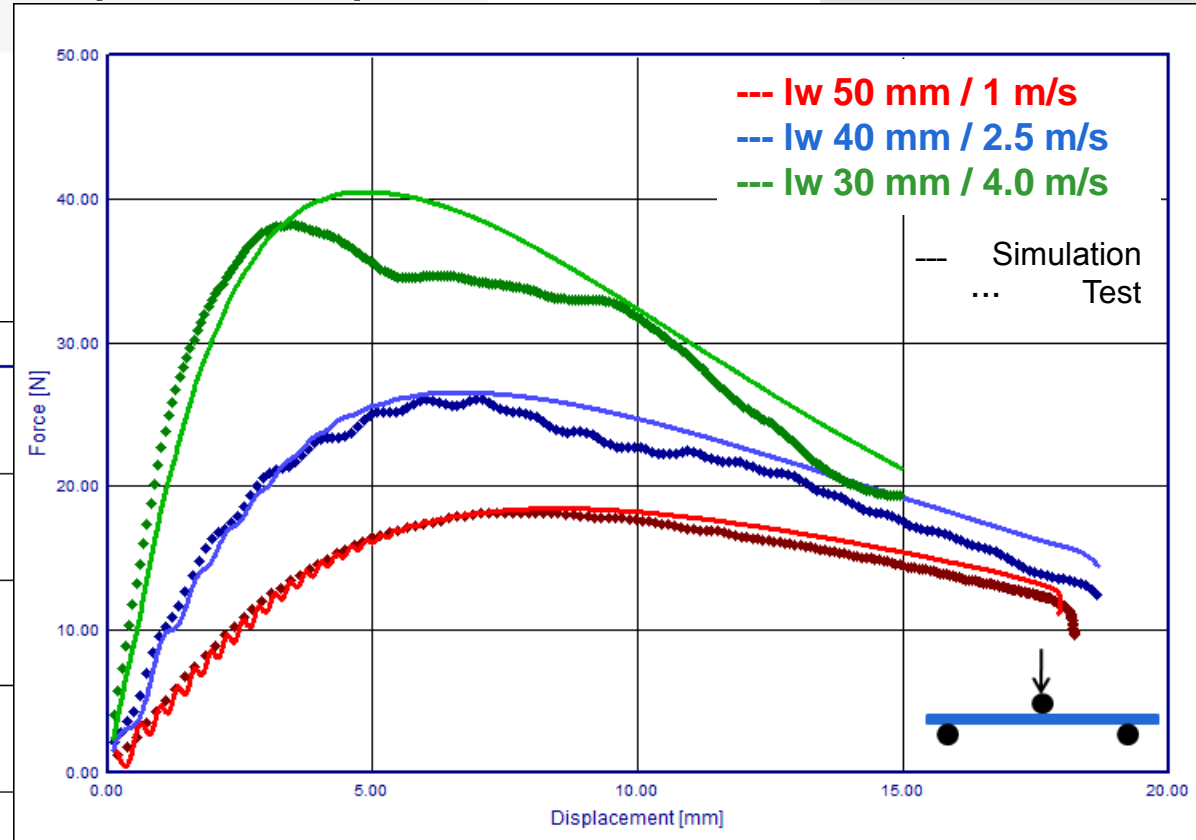
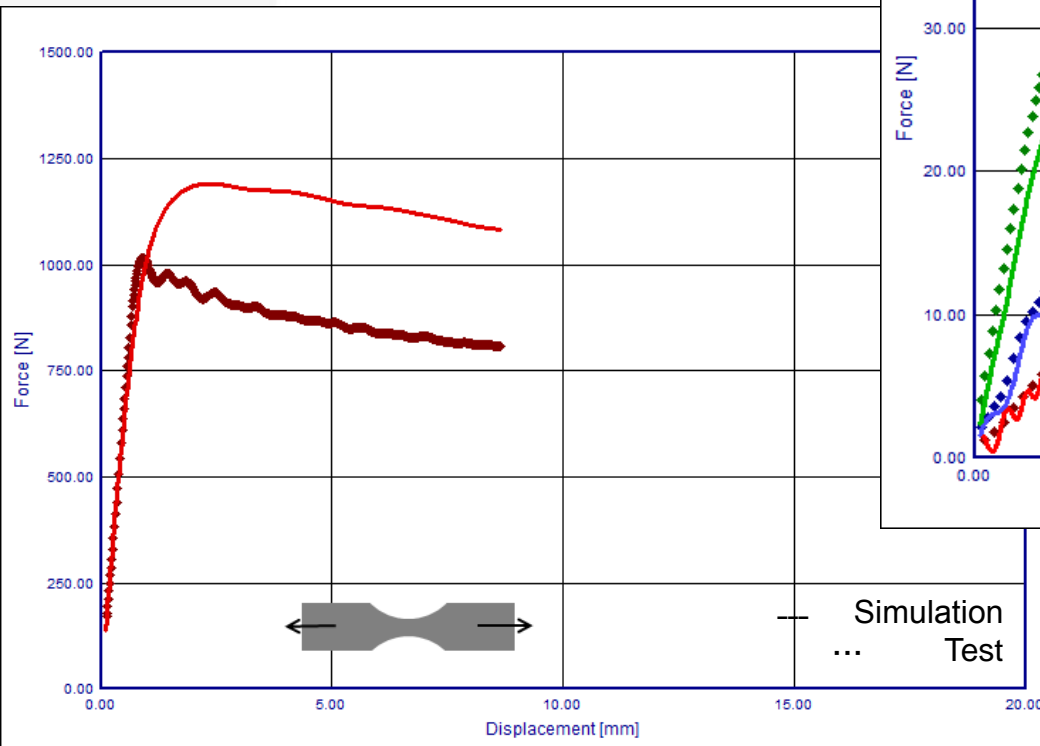


5. Reverse Engineering 4a impetus (*PLASTIC)

No tension/compression asymmetry

→ good conformity for bending

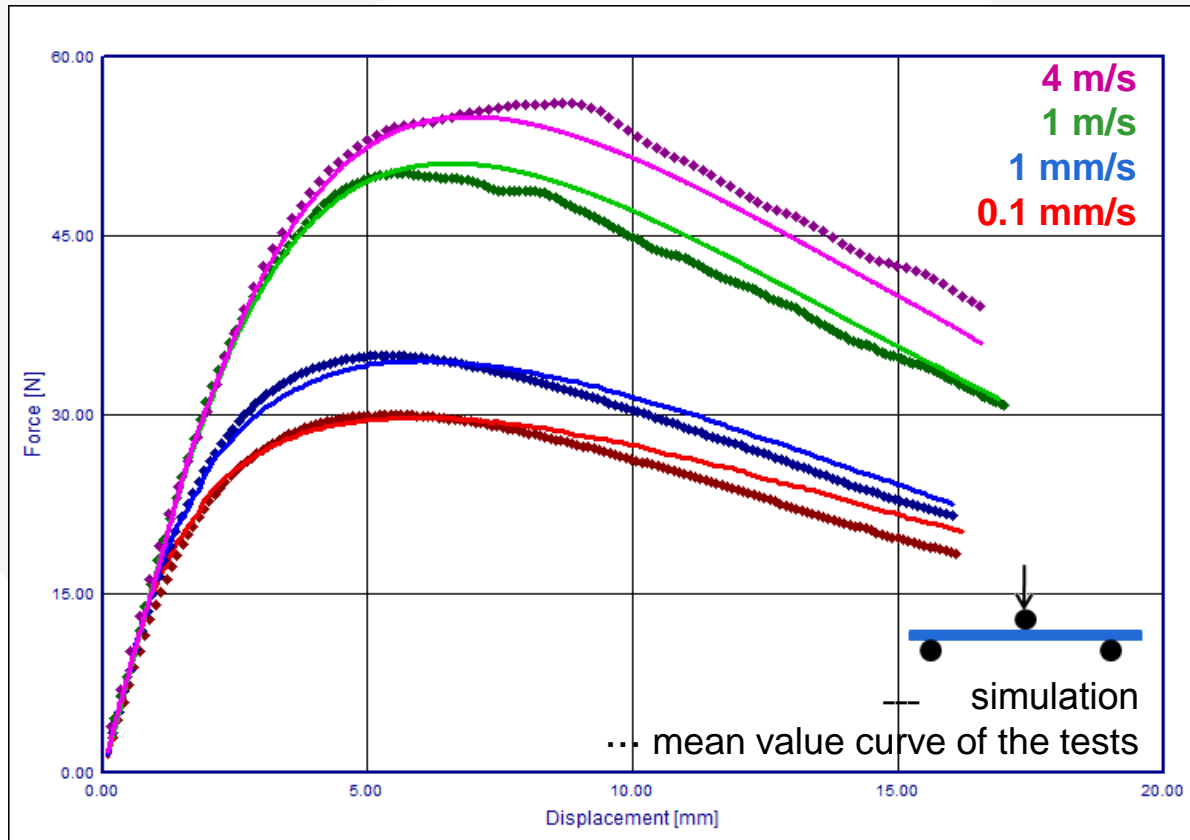
→ poor conformity for tension



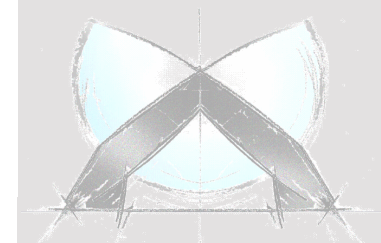
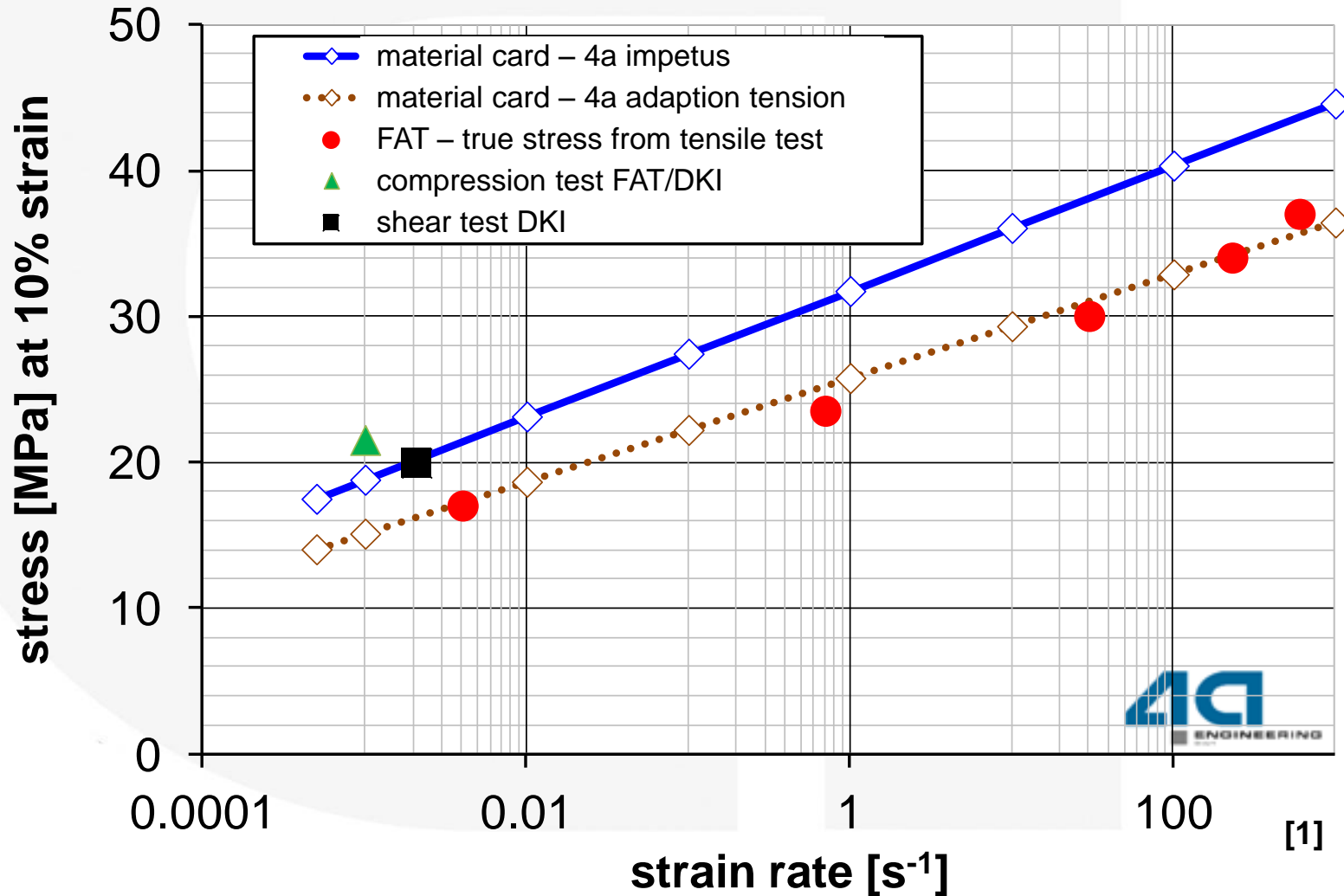
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5. Reverse Engineering 4a impetus (*PLASTIC)

Dynamic loadcases



Comparison classical approach vs. 4a impetus



Supported Abaqus models for isotropic materials

- **PLASTIC*
- **DRUCKER PRAGER*
- **USERMATERIAL, name=ABQ_MOLDED_PLASTIC [2]*

von Mises

Drucker Prager

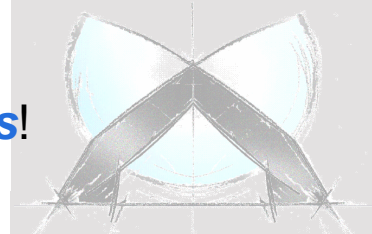
general yield surface

Material behaviour	
Material source	Implemented
Density	-1020.83
Poisson's ratio	0.3
Failure strain	0
Elasticity	Linear elastic
Plasticity	vonMises
Curve 1	4a Model A
Strain rate dependency	Table
Strain range upto	0.25
Sampling points	50
Bias factor	10

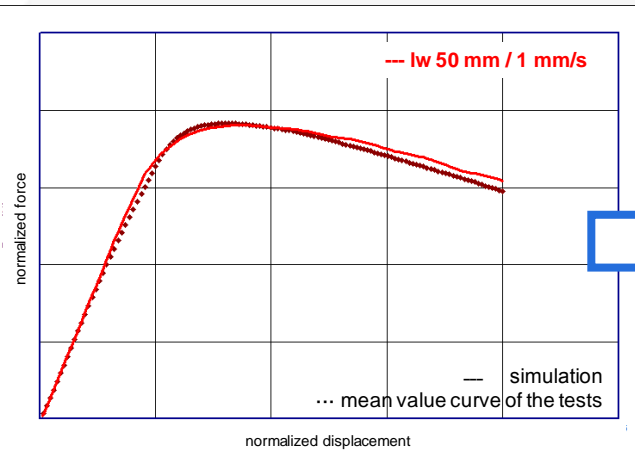
Material behaviour	
Material source	Implemented
Density	-1020.83
Poisson's ratio	0.3
Failure strain	0
Elasticity	Linear elastic
Plasticity	Drucker-Prager
Curve 1	4a Model A
Curve 2	Kurve 1 skaliert
Strain rate dependency	Table
Strain range upto	0.25
Sampling points	50
Bias factor	10

Material behaviour	
Material source	Implemented
Density	-1020.83
Poisson's ratio	0.3
Failure strain	0
Elasticity	Linear elastic
Plasticity	general yield surface (3 curves)
Curve 1	4a Model A
Curve 2	Kurve 1 skaliert
Curve 3	Kurve 1 skaliert
Strain rate dependency	Table
Strain range upto	0.25
Sampling points	50
Bias factor	10

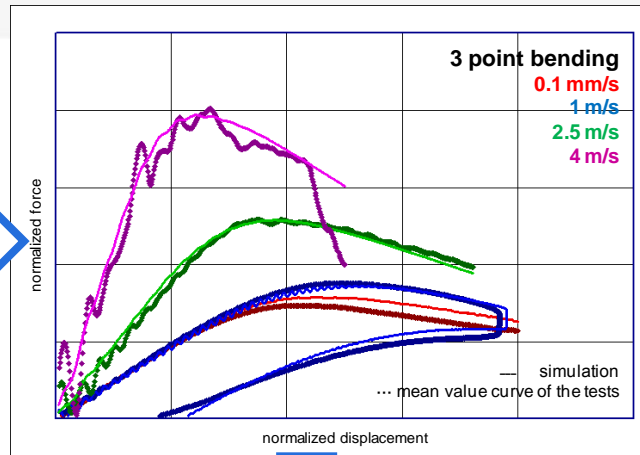
- All ABAQUS material cards are available *using user defined interfaces!*
- Same possibilities for the *other solvers* (e.g. LS-DYNA, Pam-Crash,...)



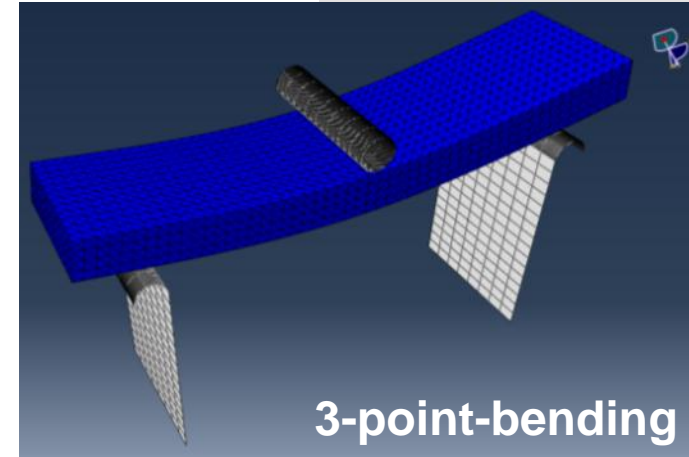
Reverse Engineering 4a impetus (*ABQ_MOLDED_PLASTIC)



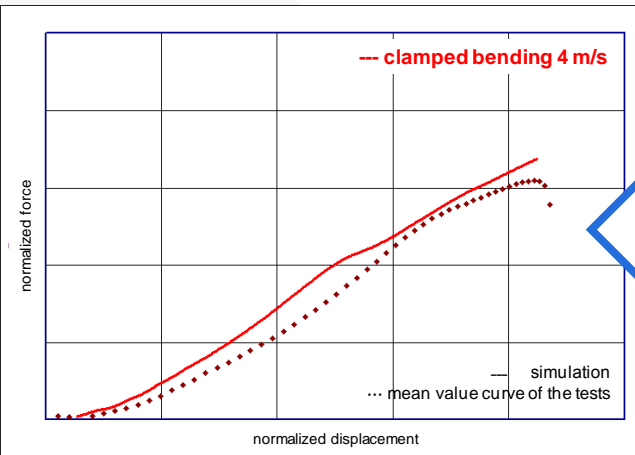
static behavior - yield



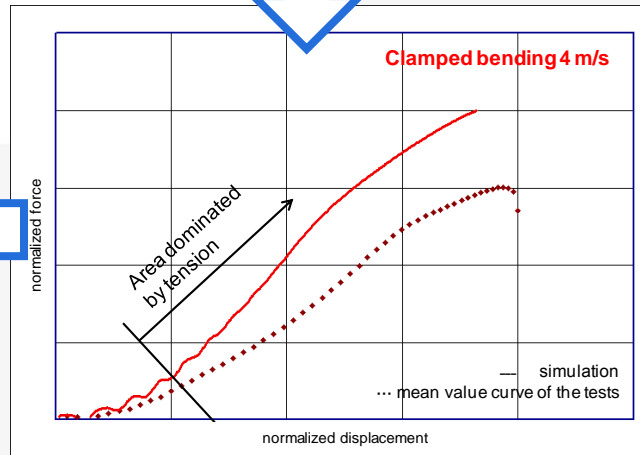
dynamic behavior – strain rate



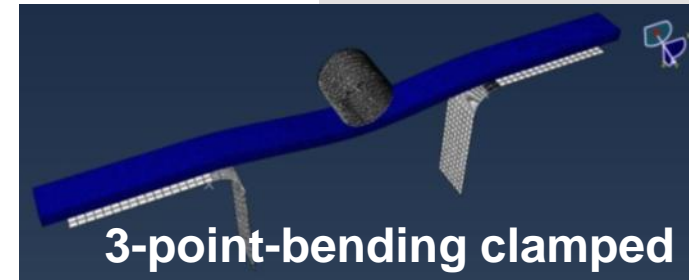
3-point-bending



fit compression/tension behavior



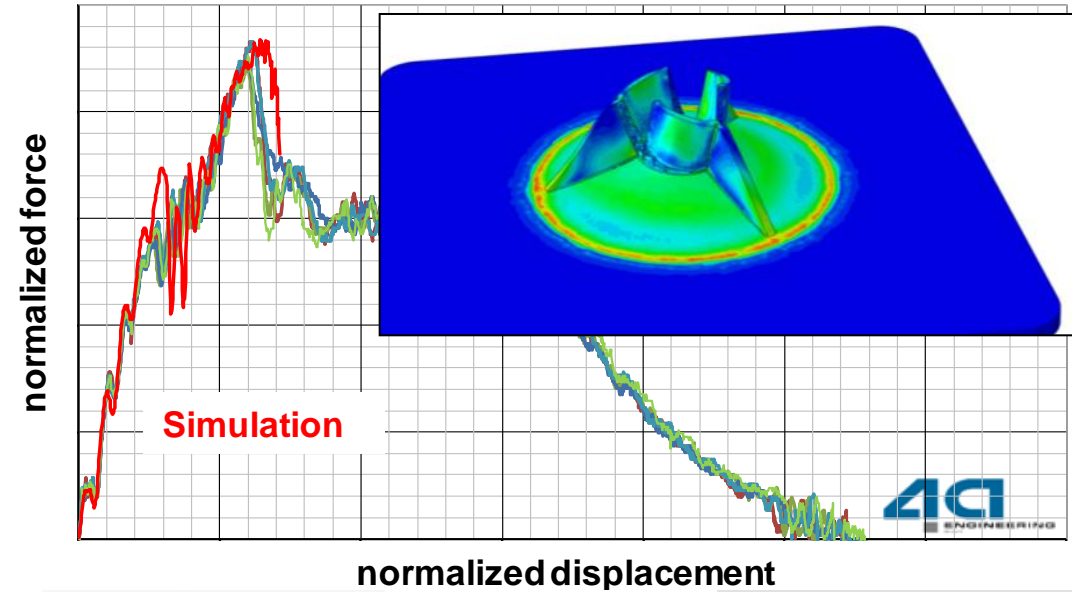
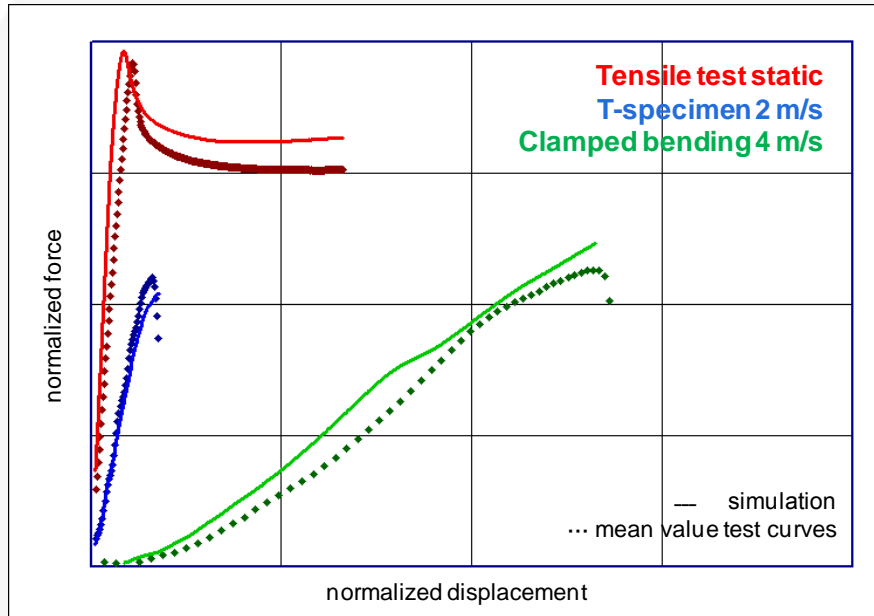
check compression/tension behavior



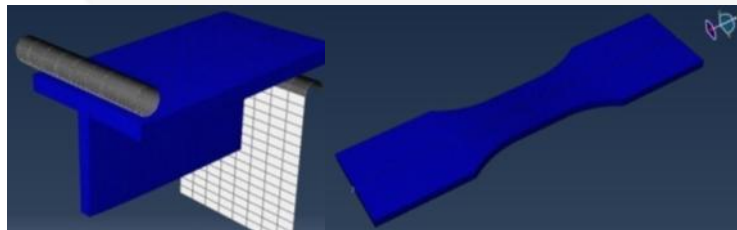
3-point-bending clamped



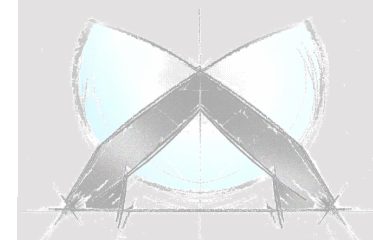
Validation 4a impetus (*ABQ_MOLDED_PLASTIC)



Static tension test dynamic T-specimen



Dynamic puncture test with the part The test curves are matched very well



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7. Delivery / Storage

“Too expensive to throw it into the waste basket”

- **Delivery to customer**
 - ASCII File
 - Loss of information (measurement results)
- **Store in Material Information Database**
 - Link between material card and tests → 4a impetus
 - Workgroup solution → 4a impetus
 - Company wide solution (security) → e.g. Granta MI
- **Further usage (4a impetus)**
 - other solvers
 - mesh type / mesh size / solver settings
 -

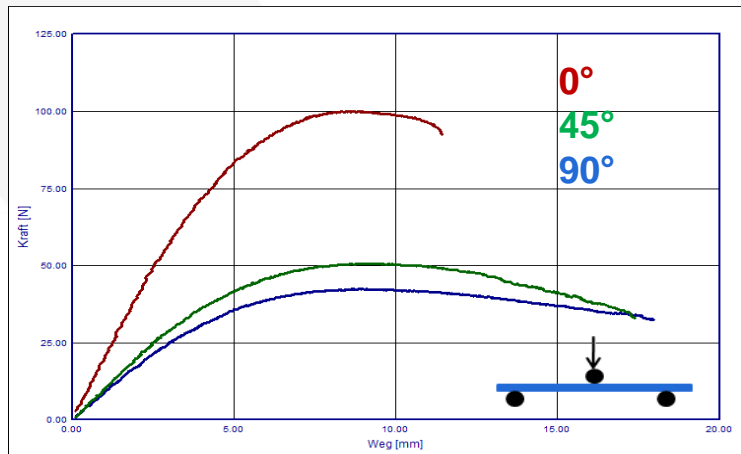
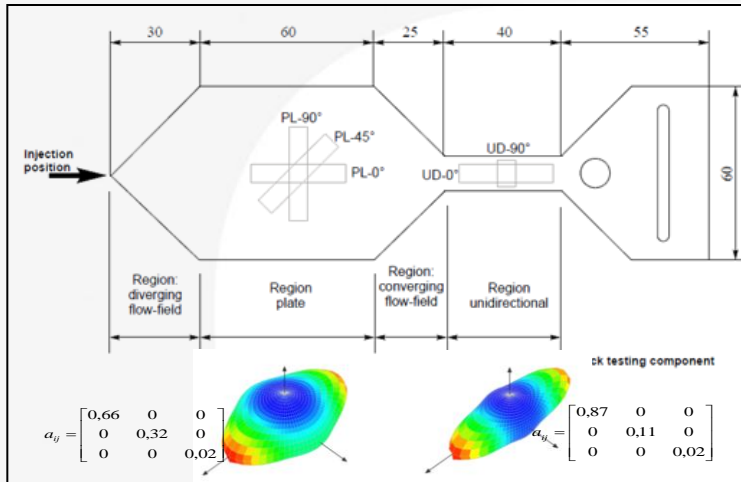


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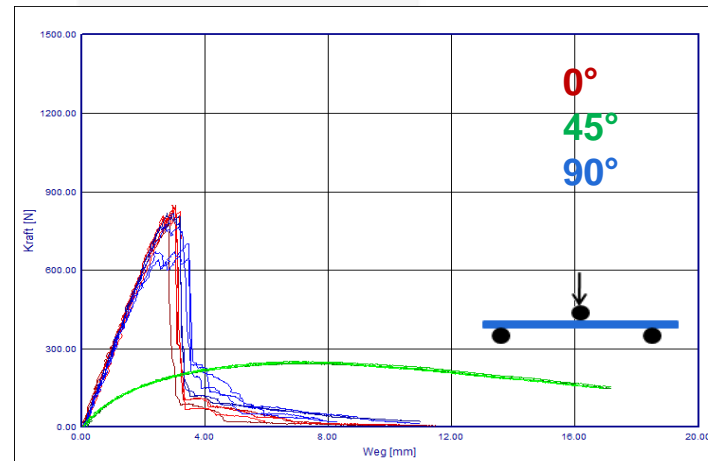
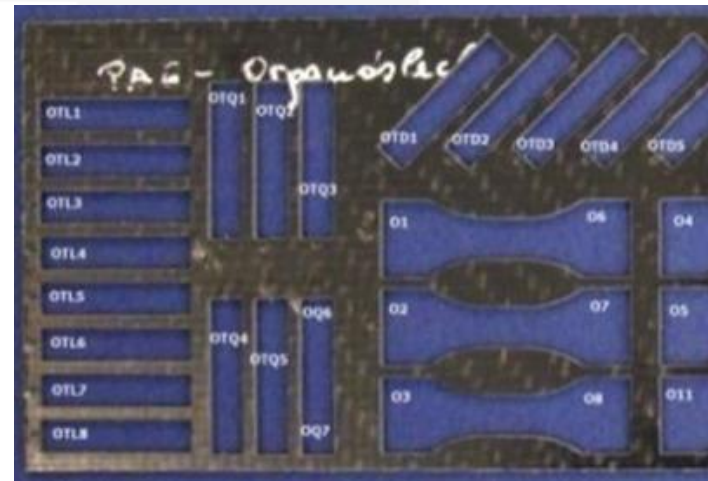
Composites

Influence of the orientation

Short fiber reinforced thermoplastic [3]



Composite – organic sheet [4]



➤ * VUMAT ABQ_PLY_FABRIC: typical input [5]

```
*MATERIAL, NAME= ABQ_PLY_FABRIC
```

```
*DENSITY
```

```
 $\rho$ 
```

```
*USER MATERIAL, CONSTANTS=40
```

```
** Line 1:
```

```
 $E_{1+}$ ,  $E_{2+}$ ,  $\nu_{12+}$ ,  $G_{12}$ ,  $E_{1-}$ ,  $E_{2-}$ ,  $\nu_{12-}$  ←
```

```
** Line 2:
```

```
 $X_{1+}$ ,  $X_{1-}$ ,  $X_{2+}$ ,  $X_{2-}$ ,  $S$  ←
```

```
** Line 3:
```

```
 $G_f^{1+}$ ,  $G_f^{1-}$ ,  $G_f^{2+}$ ,  $G_f^{2-}$ ,  $\alpha_{12}$ ,  $d_{12}^{\max}$  ←
```

```
** Line 4:
```

```
 $\tilde{\sigma}_{y0}$ ,  $C$ ,  $p$  ←
```

```
** Line 5:
```

```
lDelFlag,  $d_{\max}$ ,  $\bar{\epsilon}_{\max}^{pl}$ ,  $\hat{\epsilon}_{\max}$ ,  $\hat{\epsilon}_{\min}$  ←
```

```
*DEPVAR, DELETE=16
```

```
16
```

Young's Modulus in 0° (tension), Young's Modulus in 90° (tension), Poisson's ratio ν_{12} (tension), Shear Modulus, Young's Modulus in 0° (compression), Young's Modulus in 90° (compression), Poisson's ratio ν_{12} (compression),

strength in 0° (tension), strength in 0° (compression), strength in 90° (tension), strength in 90° (compression), shear strength

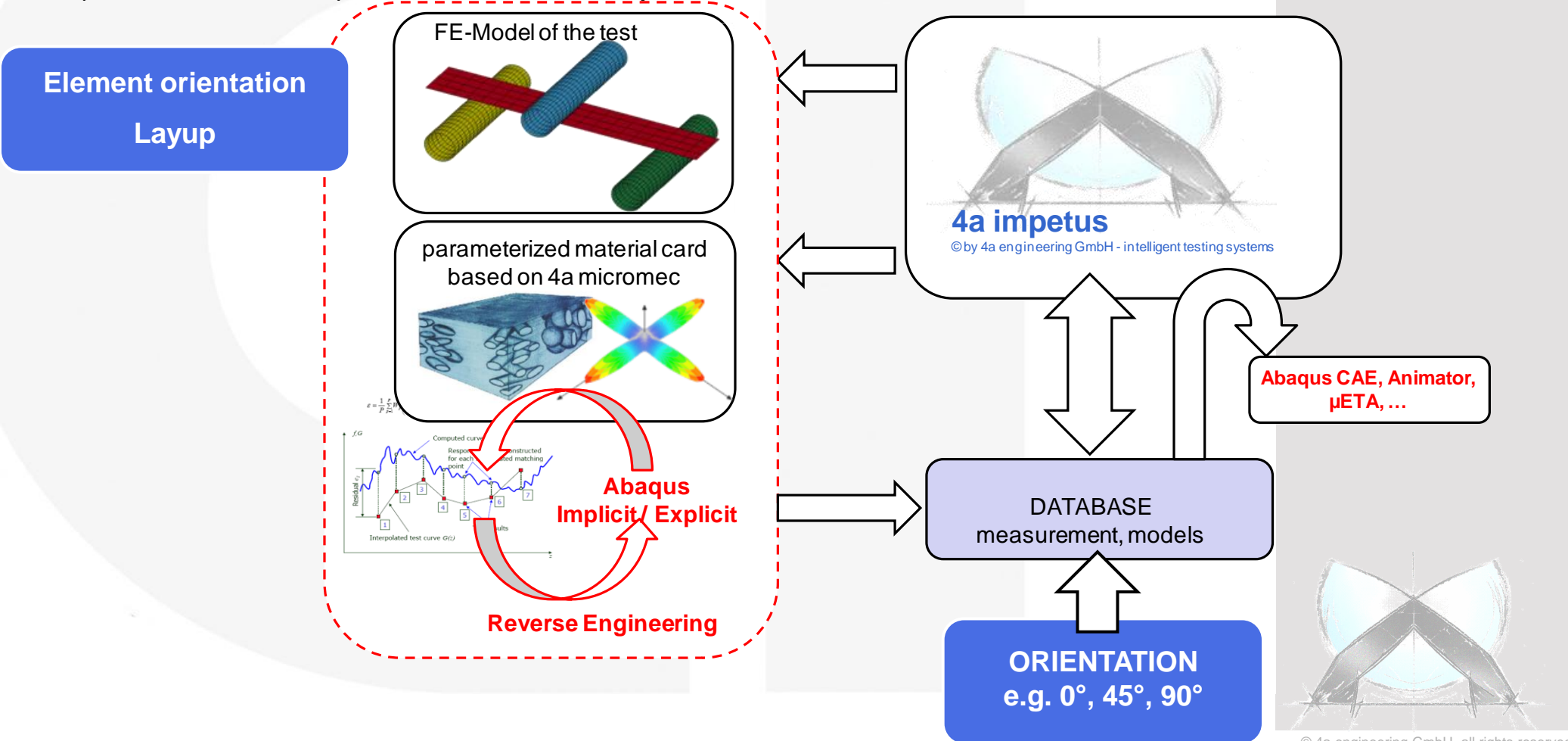
damage parameter

shear hardening data

data for element erosion



- The influence of the manufacturing process on the material behavior (fiber orientation) is included in the process chain.



Input

Material Data of Components (E, α, λ)

Matrix
Reinforcements
Fillers

Data-Base



Fibre and Particle Orientation

Data-Base

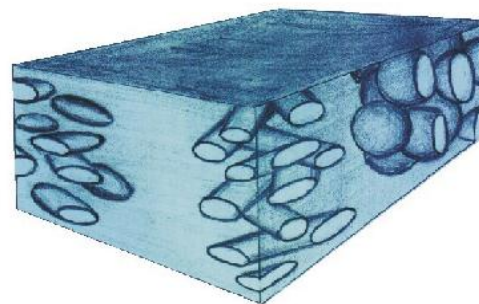


Fibre and Particle Shape

Data-Base



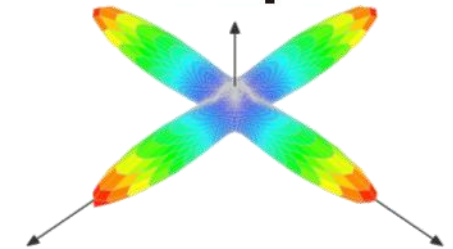
4a micromec



Virtual Material Design



Output



3D Composite Data

elastic properties
thermal expansion
thermal conductivity

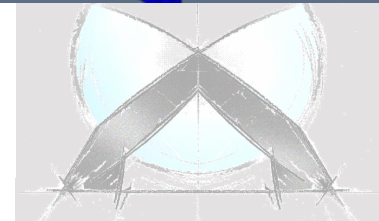
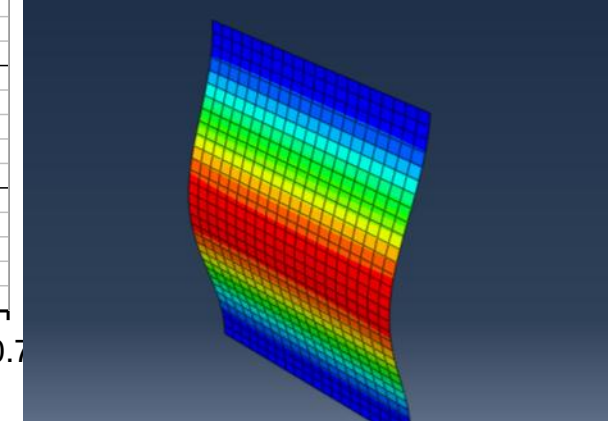
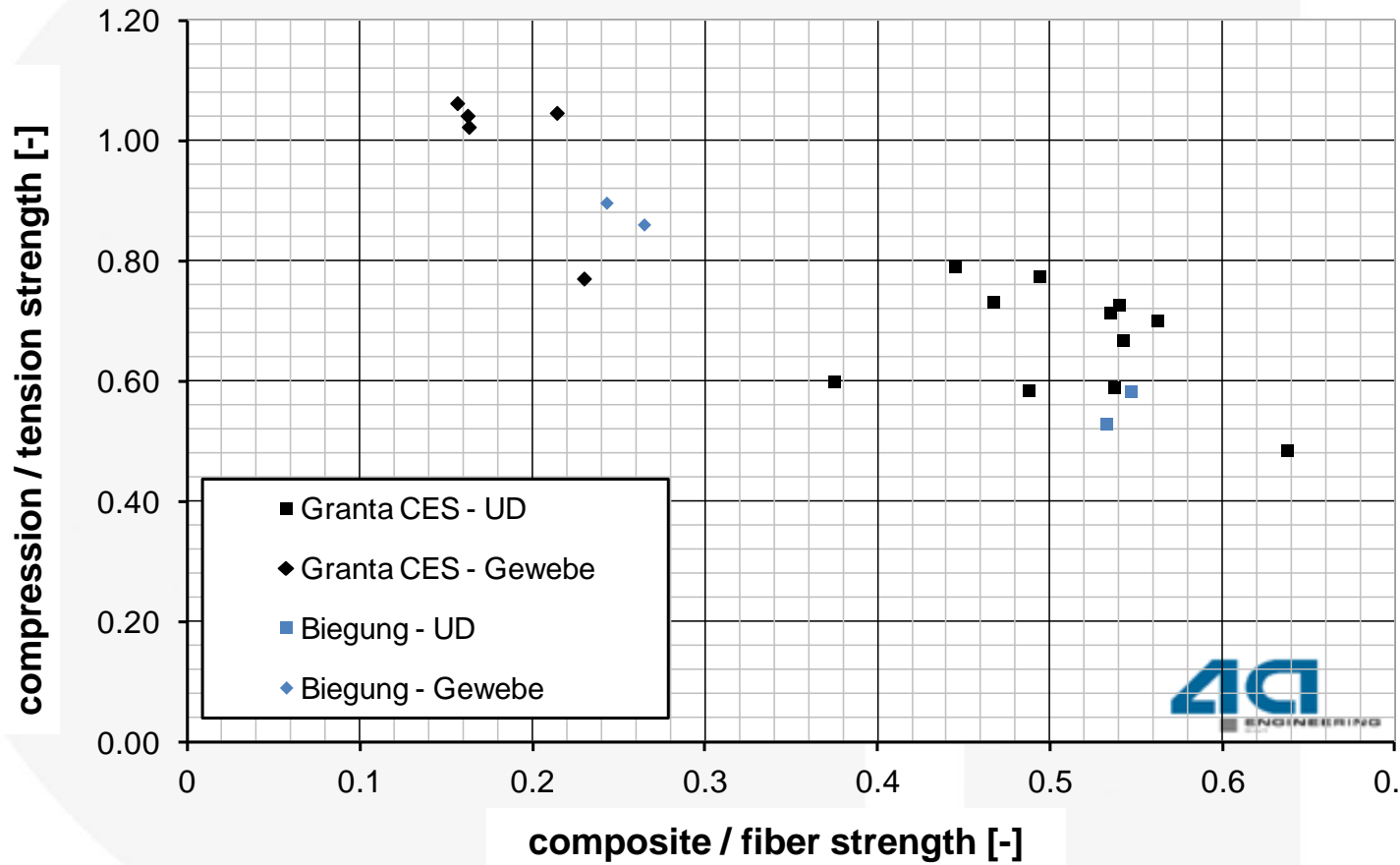
2D&3D graphics

Interphase to
MSC.Nastran 4 Windows

- Usage for SFRT, LFRT, CFRP, GFRP,
- Stand-Alone-Solution available (3D thermo-elastic properties)
- User Material (orthotropic elastic visco-plastic including failure)



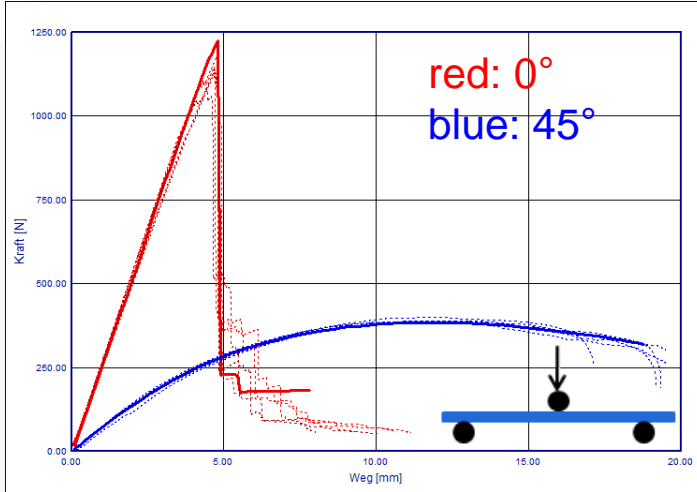
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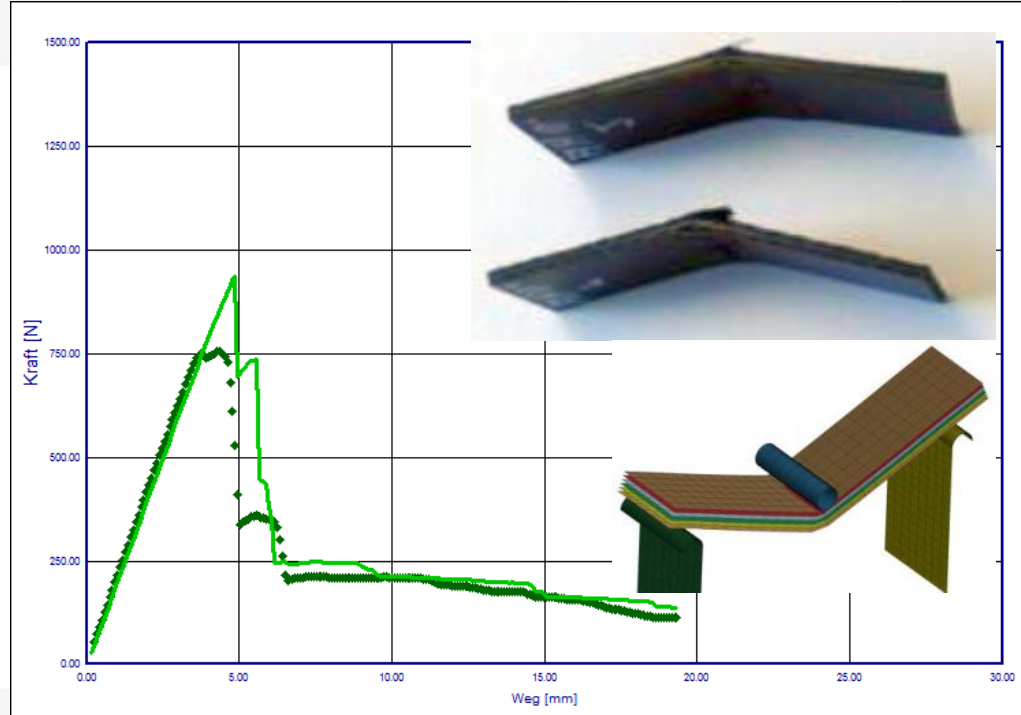
Results with kindly permission of
MAGNA STEYR Fahrzeugtechnik AG & Co KG [6]

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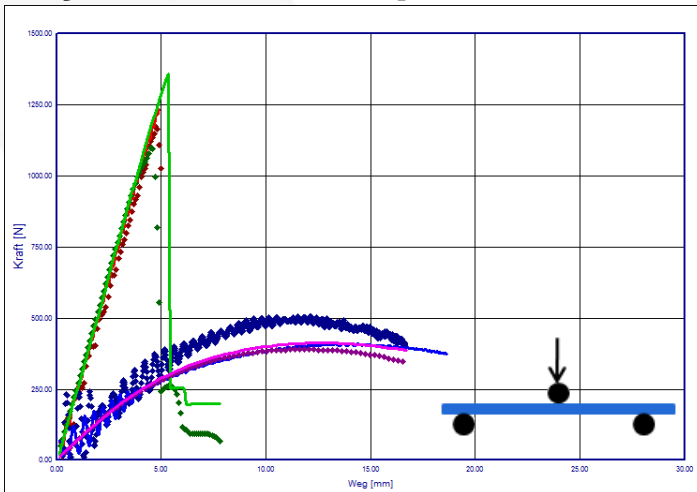
Orientation



Multilayer Setup



Dynamic 4a impetus



.... test
— simulation

Results with kindly permission of
MAGNA STEYR Fahrzeugtechnik AG & Co KG [6]



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- **Abaqus** offers a multitude of material models to describe the dynamic material behavior of **plastics and composites** very well.
- With **increasing complexity** the accurateness of the characterization as well as the effort to adapt the material models rises. Therefore it is essential to **stay focused** on the **significant influences**.
- **Material information systems** (like CES Selector™, GRANTA MI™) are a helpful extension in the material card generation process, to enable full traceability and management of the information especially **at the start** and **end of the process**.
- Tools like **4a impetus** or **4a micromec** ensure **quality and reproducibility** in the **process of generating material cards**, especially as the material card is linked to the chosen idealization (solver, element type, element size, ...).
- As plastics will be used much more for mechanical loaded parts, **modeling of failure** will be the **next challenge in future**.



.. in physics we trust



[1] **Materialmodelle für Kunststoffe, komplexe Fließflächen und Versagen**

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

11. 4a Technologietag 2014

http://technologietag.4a.co.at/images/tt2014/s2v1_Reithofer.pdf

[2] **VUMAT for Molded Plastics**, Simulia - Dassault Systèmes,

<http://simulia.custhelp.com>

[3] **4a micromec für die integrative Simulation faserverstärkter Kunststoffe**

A. Fertschej, B. Jilka, P. Reithofer (4a engineering GmbH)

11. LS-DYNA Forum 2012, Ulm

<http://www.dynamore.de/de/download/papers/ls-dyna-forum-2012/documents/materials-3-4>



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[4] Dynamische Materialcharakterisierung von Composites mit 4a impetus

A. Dietrich, M. Fritz, B. Jilka, P. Reithofer (4a engineering GmbH)

B. Hofer, B. Fellner (MAGNA STEYR Fahrzeugtechnik AG & Co KG)

10. 4a Technologietag 2013, Schladming

http://technologietag.4a.co.at/images/tt2013/s5bv2_Reithofer.pdf

[5] VUMAT for Fabric Reinforced Composites , Simulia - Dassault Systèmes;

<http://simulia.custhelp.com>

[6] Dynamische Materialcharakterisierung von Composites mit 4a impetus

A. Dietrich, M. Fritz, B. Jilka, P. Reithofer (4a engineering GmbH)

B. Hofer, B. Fellner (MAGNA STEYR Fahrzeugtechnik AG & Co KG)

10. 4a Technologietag 2013, Schladming

http://technologietag.4a.co.at/images/tt2013/s5bv2_Reithofer.pdf



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[7] Möglichkeiten und Grenzen der integrativen Simulation von kurz- und langglasfaserverstärkten Kunststoffen

A. Fertschej, B. Jilka, P. Reithofer (4a engineering GmbH)

NAFEMS 2014, Leipzig

[8] Dynamisches Materialverhalten von Kunststoffen und Composites

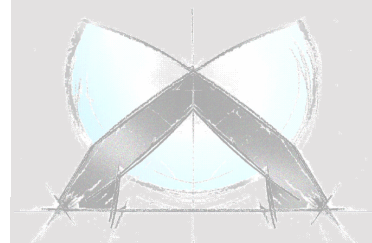
A. Fertschej, P. Reithofer (4a engineering GmbH)

Deutsche Simulia Konferenz 2014, Dresden

[9] Materialcharakterisierung von Kunststoffen mit 4a Impetus

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

Deutsche SIMULIA-Konferenz 2012 , Hamburg



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