4a impetus (PART 1): Dynamic material characterization of plastics – development in the past 10 years

A. Fertschej, P. Reithofer, M. Rollant

4a engineering GmbH

1 Introduction

In recent years plastics have been used more and more in automotive industry primarily
- for cost reasons in complex design,
- for safety reasons in the area of occupant and pedestrian safety application and
- for CO_2 reduction reasons in lightweight applications with regard to structural performance needs.

Therefore simulation of the application load cases is an indispensable must have in the product development. Based on the successful usage of simulation tools in the metallic section, the standard simulation methods and material models can't represent the plastic material behavior. Many developments and improvements in the crashcode LS-DYNA especially for plastics and composites have been seen in the past 10 years, with the necessity to consider the deformation (viscoelasticity, viscoplasticity, anisotropy) as well as damage and failure behavior in the material model.

2 Retrospect

New developments in the testing and material characterization have been going along with requirements of these new models [1]. The classic testing methods ideally with mechanical understanding (tension, compression and shear) with local strain measurements (for example by DIC) are one approach to deal with this topic.

Another approach is to use the bending load case and its many advantages:
- this is the most frequently occurring load case in reality,
- the geometry of the test specimens can be very simple and
- tests can be performed very quickly and accurate using 4a impetus (see fig. 1).

Fig.1: Prototype of 4a impetus (2004 [2]), first commercial version (2006 [3]) and the current version (2015 [4])

In the presentation we will give an exemplary overview of the development in the field of plastic materials testing in the past 10 years
- starting with simple **`*MAT_02`**4 and high-speed tensile tests compared to the easy 4a impetus bending approach,
- showing the reverse engineering process with LS-OPT and the normal and clamped bending as alternative to high speed tensile tests,
- considering different loading situations (e.g. **`*MAT_187`**), needed test specimens and methods to characterize the material,
- including temperature and moisture dependencies for thermoplastics and
- concluding with current developments in considering the process influence and in failure prediction.

3 State of the art

In the field of old school material characterization static and dynamic tensile tests are the base for a **`*MAT_024`** material card generation. For plastics and composites there is no high-speed tensile testing standard method available. Considering complex yield surfaces (tension, shear, compression, ...) or anisotropy is often a known issue and well researched in several public founded projects, but cannot be seen as standard in automotive simulation applications.
4a impetus stands for the new solution, starting from measurement data handling up to an automatic material parameter identification process (MPIP) based on reverse engineering. The hardware and software products are used by automotive OEMs and their suppliers, material suppliers, research institutes and engineering service providers. Meanwhile 4a offers standards to generate simple material cards like **`*MAT_024`**, considering anisotropy **`*MAT_054/058/157`**, compression/tension behavior **`*MAT_124/187`**.

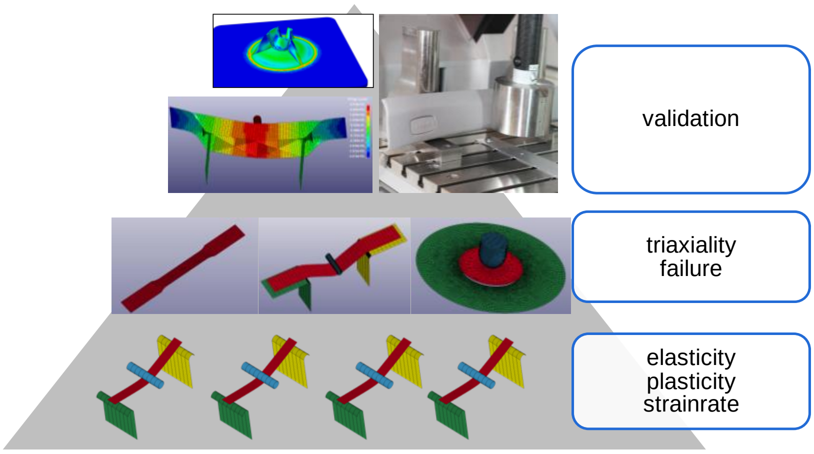


Fig.2: 4a impetus material characterization pyramid for plastics [5], [6],[7]

4 Summary & Outlook

Driven by the increasing requirements of the industry to predict not only the "average" deformation behavior, the simulation methods and the therefore needed material models as well as the testing methods have to be improved continuously. 4a impetus is the first approach, closing the gap between the simulation and testing fractions.
Due to lightweight applications and the mechanical structural relevance of plastic and composite materials especially damage and failure prediction as well as considering process induced inhomogeneity (e.g. short and long fiber reinforced materials, foamed plastics, ...) will be R&D topics in the next years.

5 Literature

[1] Kolling, St. et.al.: *SAMP-1: A Semi-Analytical Model for the Simulation of Polymers*, 4. LS-DYNA Anwenderforum, Bamberg 2005
[2] Hafellner, R. et. al: *Neue flexible Methoden der Materialdatenermittelung für die dynamische Simulation*, 3. LS-DYNA Anwenderforum, Bamberg 2004
[3] Fritz, M. et. al: *Kunststoffcharaktersierung mit Impetus II - Der effiziente Weg zu validierten dynamischen Materialdaten*, LS-DYNA Forum, Frankenthal 2007
[4] http://impetus.4a.co.at
[5] Reithofer, P. et. al: *Dynamic Material Characterization Using 4a impetus*, 29th Regional Conference of the Polymer Processing Society, Graz 2015
[6] Fertschej, A. et. al: *Failure models for thermoplastics in LS-DYNA*, 29th Regional Conference of the Polymer Processing Society, Graz 2015
[7] Reithofer, P. et. al: *Zeitabhängiges Materialverhalten von Kunststoffen*, 4a. Technologietag, Schladming 2016

4a impetus (PART 1):
Dynamic material characterization of plastics development in the past 10 years

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

14th German LS-DYNA Conference
10th – 12th October 2016, Bamberg, Germany

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

4a technology group

4a technology-group: founded in 2002

Location: Traboch, Austria

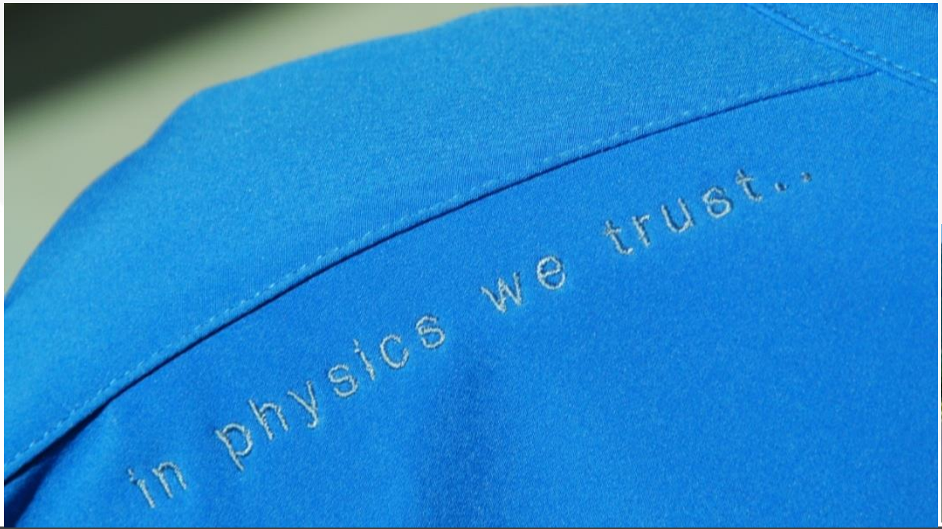
Number of employees > 80

Field of operation: global

Certificates: ISO 9001

more than 2000 projects

more than 400 customers

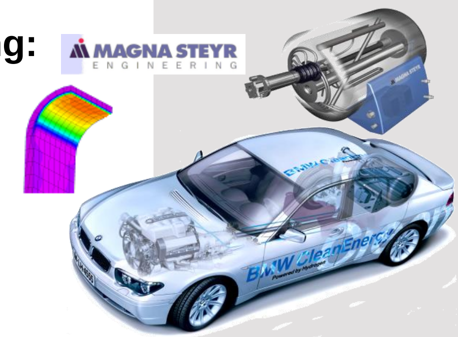


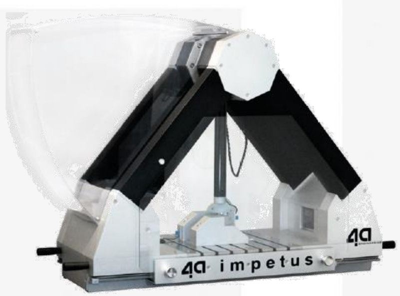
4a engineering GmbH

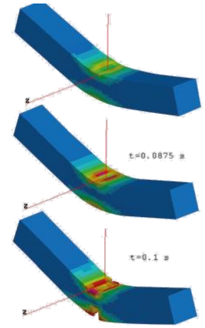
- polymer and materials science
- numerical simulation methods
- fiber reinforced plastics and composites
- product development
- method and software development
- material characterization

strut bar:

LH_2 – tank mounting:

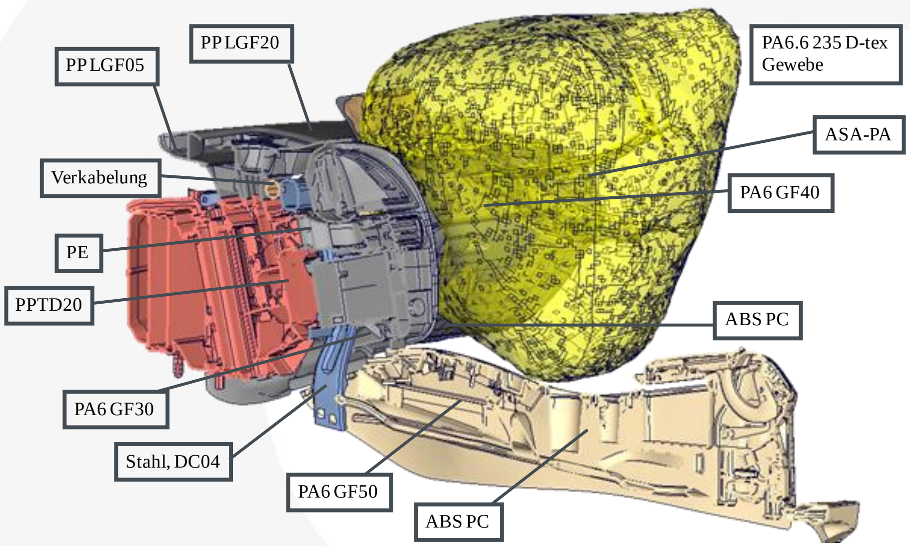






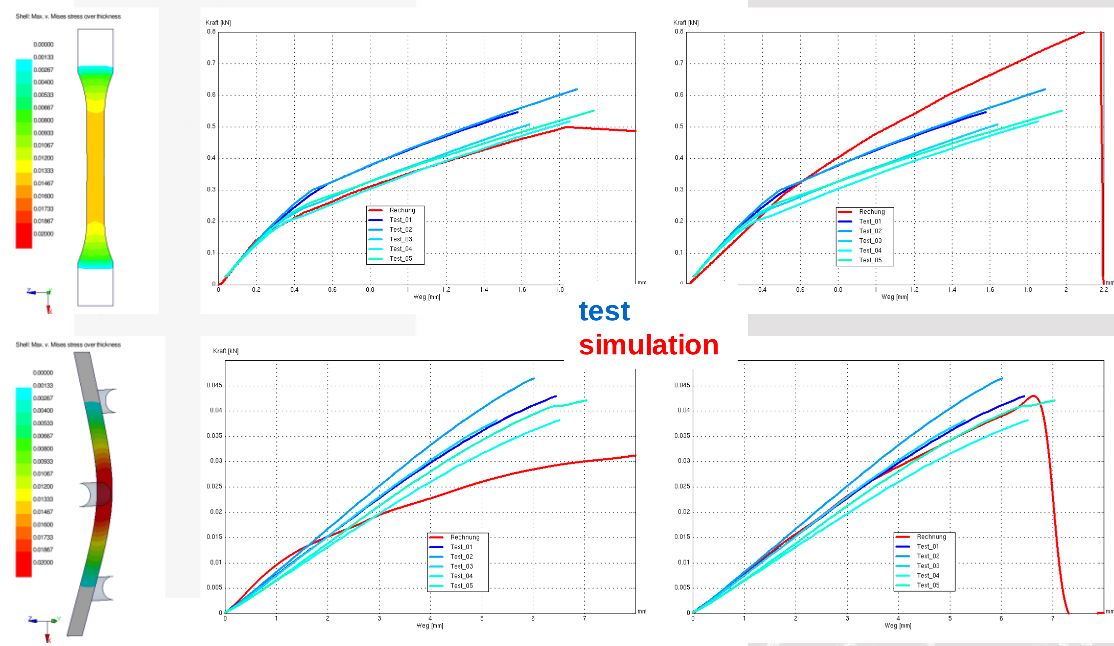
validated material cards for plastics, composites, metals, foams, ….

material variety



bending load case

original test curve tension **scaling 1.25**



R. Luijkx - *Kunststoffmaterialien in der Interieur Funktionsauslegung bei Audi AG,* 4a Technologietag 2010

Dynamic material characterization of plastics first steps ….

2004

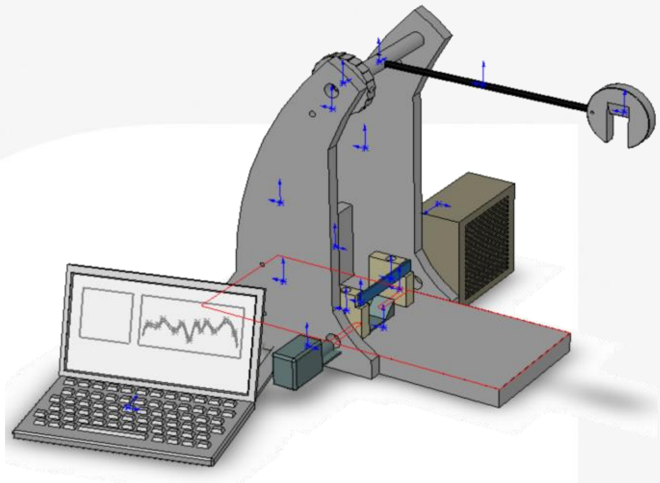
2005

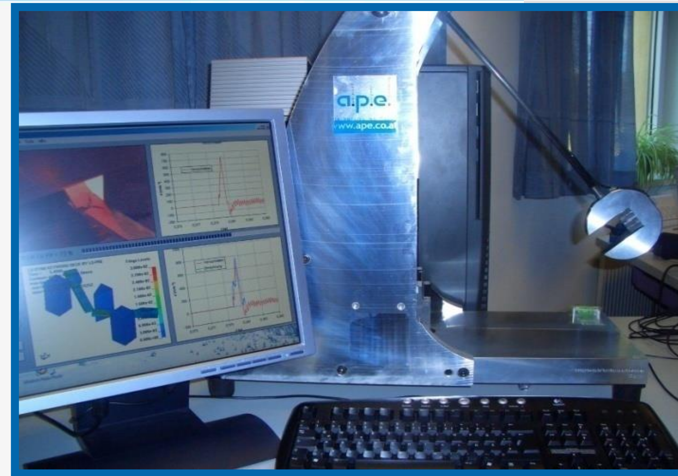
2006

2007

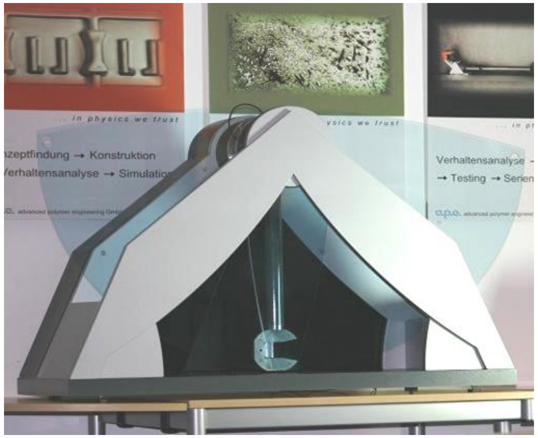
2008

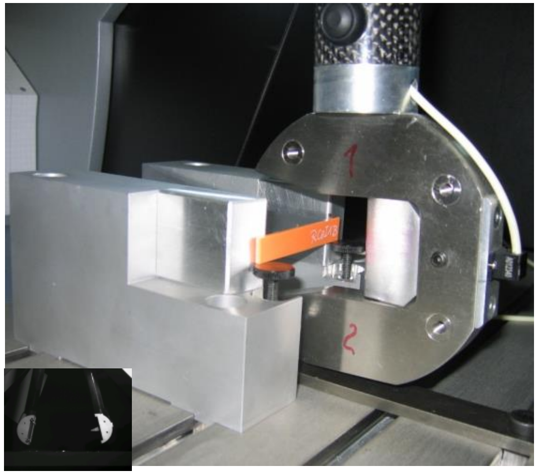
2009



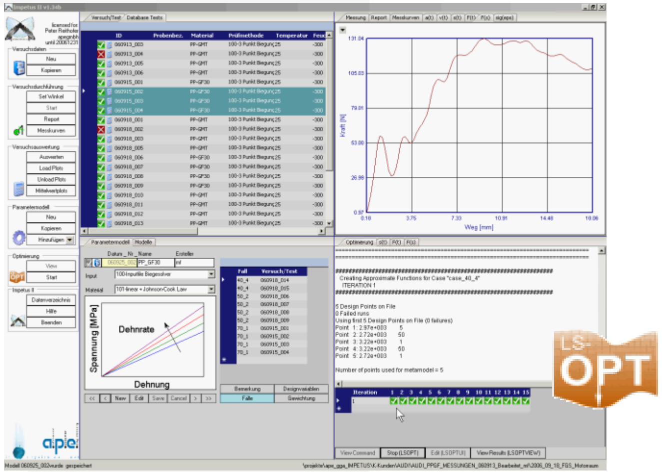


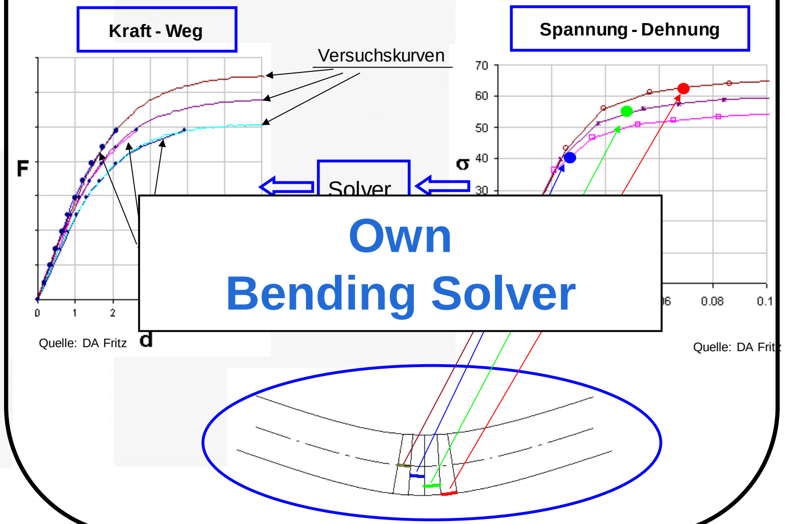
4a impetus Hardware





4a impetus Software

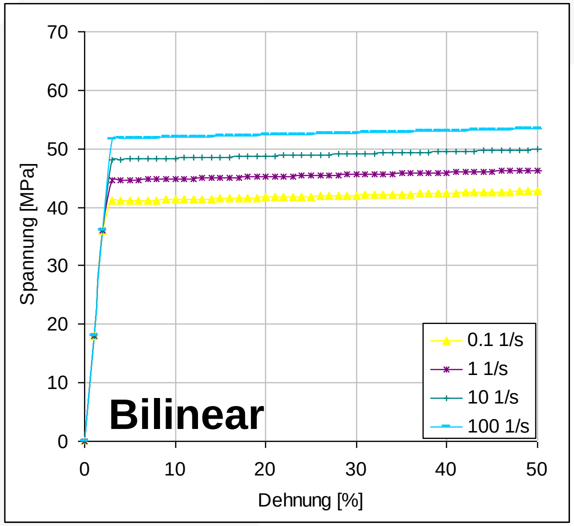


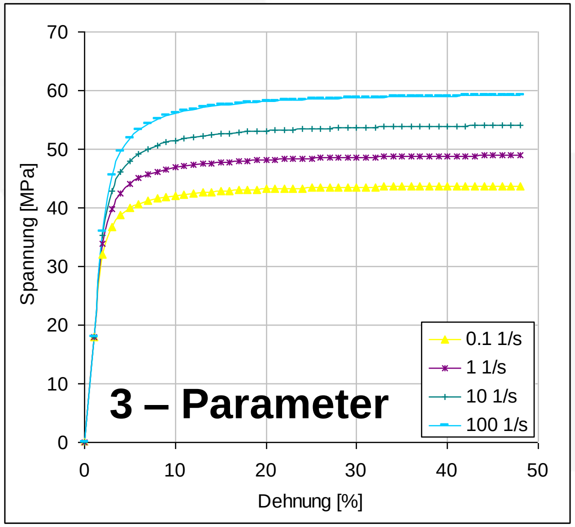


Dynamic material characterization of plastics
6. LS-DYNA Forum 2007

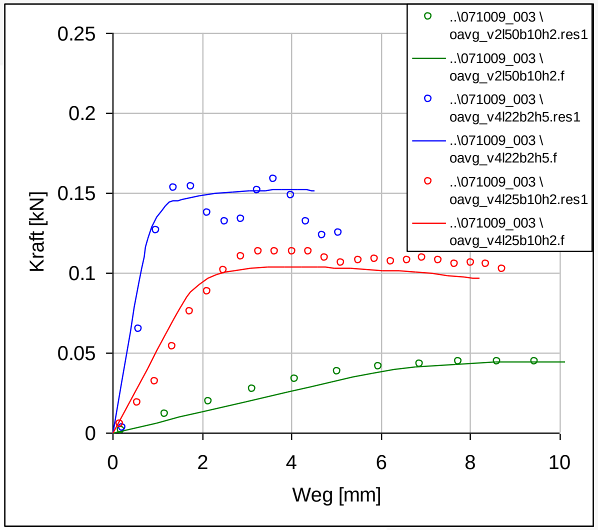
ENGINEERING GmbH

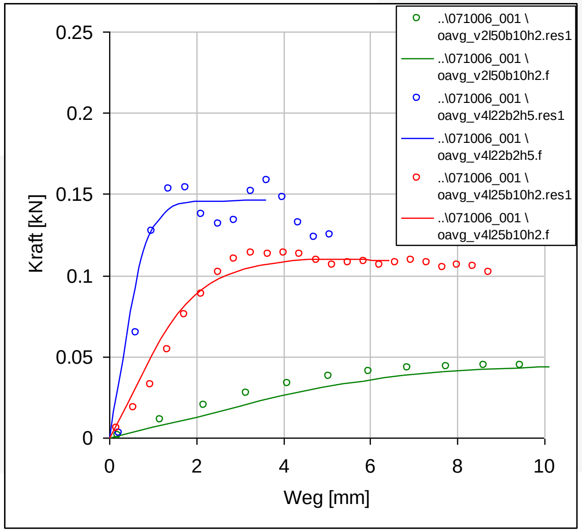
Hardening function

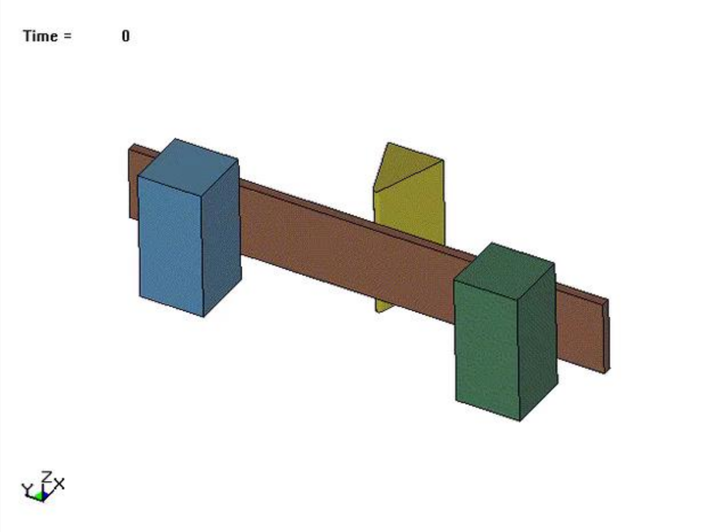




Bending test







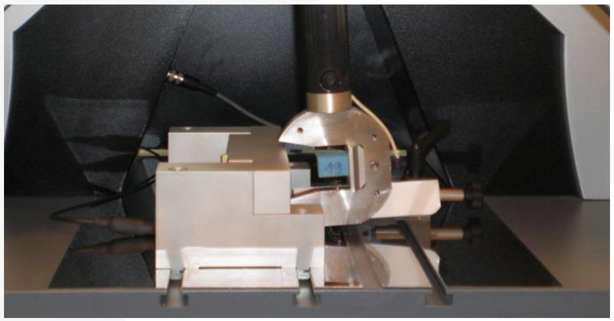
Typical material card
***MAT_024**

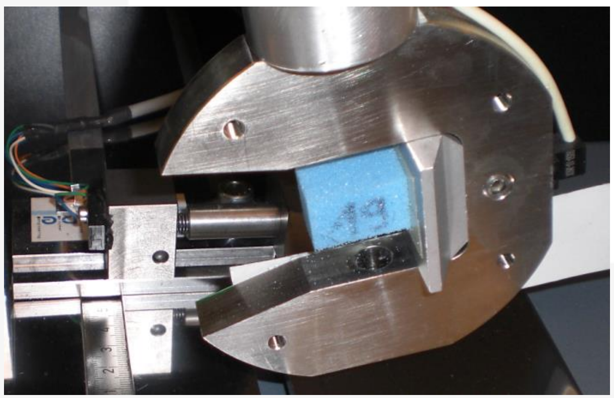
applicable
1-100 1/s

Interior / Exterior drop tests

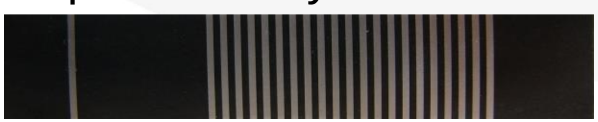
4a ENGINEERING GmbH

4a impetus Hardware

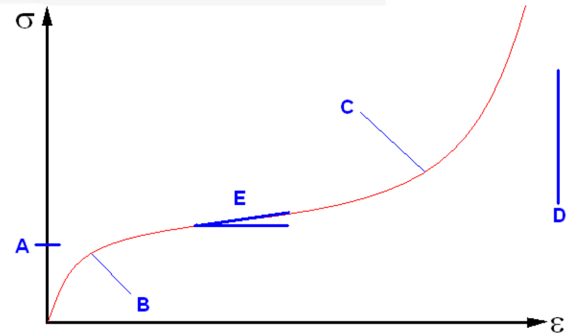




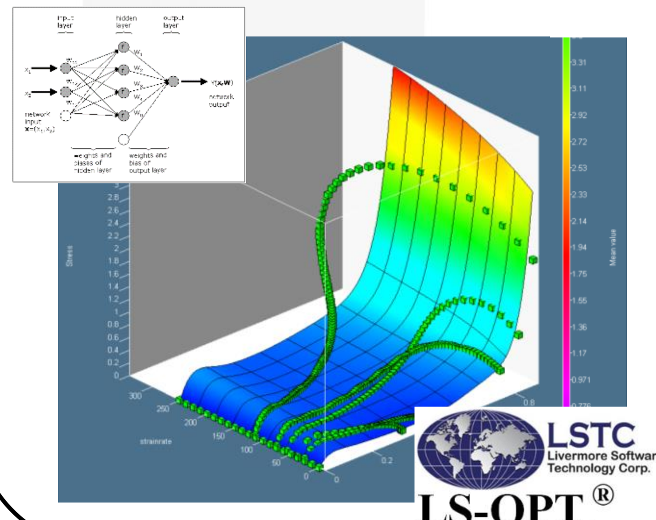
Optical Sensor
impact velocity & detection

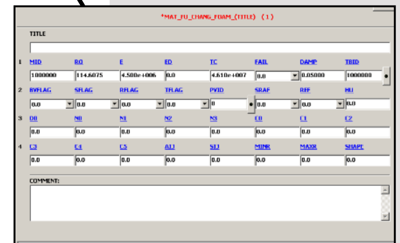


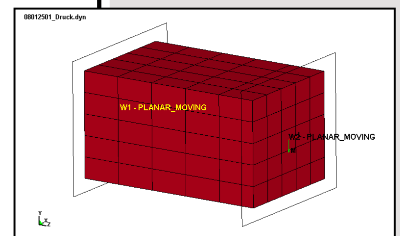
4a impetus Software

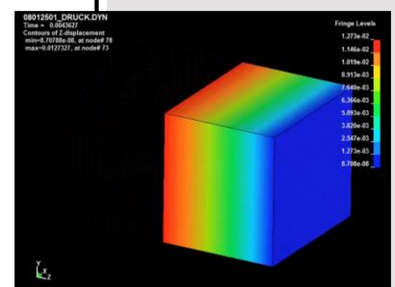


Parameter Identification
vs. Neuronal Net









4a impetus Hardware

v m/s		
4		
2.5	40	510
1	60	1300
0.001	50	

applicable 0.001-100 1/s

bending setup

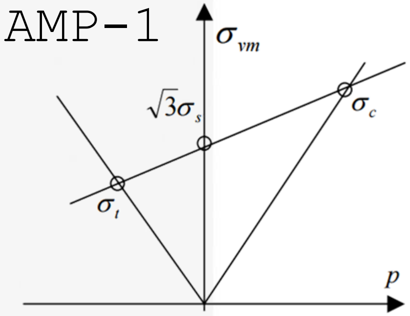
Tension loadcase

Fixed bending

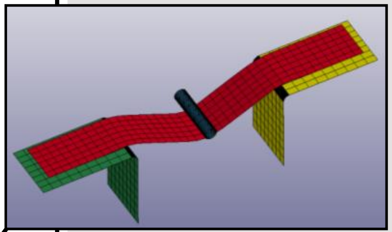
4a impetus Software

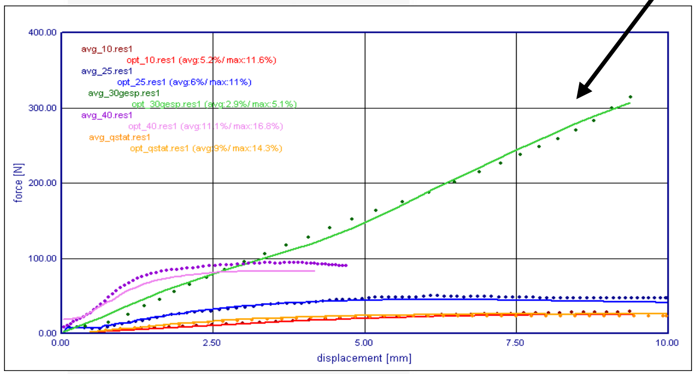
`*MAT_PLASTICITY_COMPRESSION_TENSION`

`*MAT_SAMP-1`



Drucker-Prager [Kolling2005]



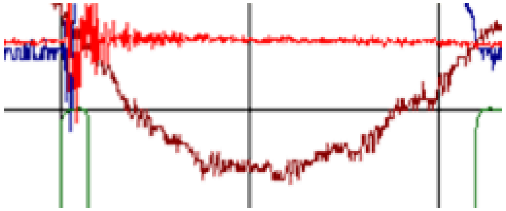


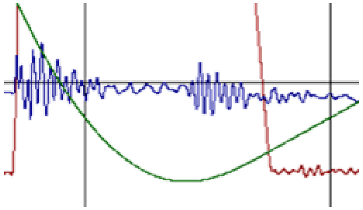
···· averaged test curves
— result of simulation

Dynamic material characterization of plastics Measurement update, 2009

4a impetus Hardware

4a impetus Software

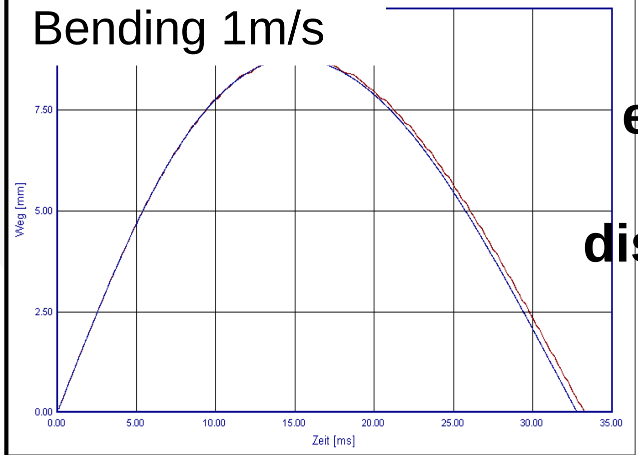




0,01 mm

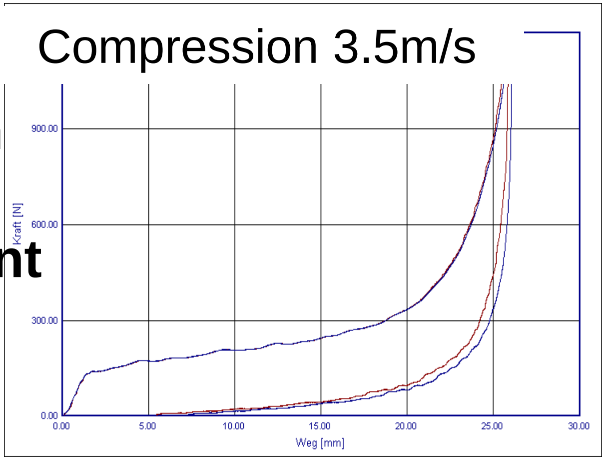
100.000 → 1.000.000 samples/s

Bending 1m/s

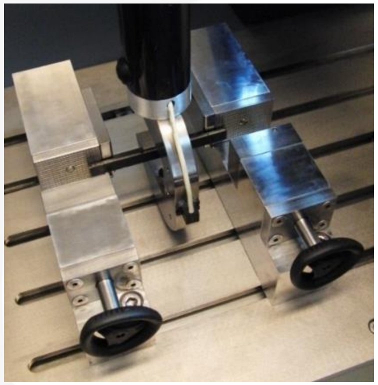


New evaluation velocity, displacement

Compression 3.5m/s



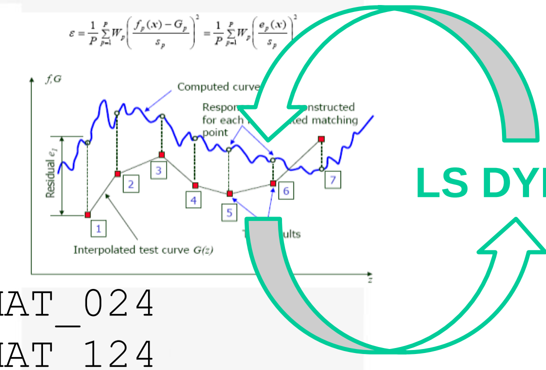
4a impetus Hardware



Fixed bending

Component testing

4a impetus Software



LS-OPT®

*MAT_024
*MAT_124
*MAT_SAMP-1

Hardening Laws

Bilinear

$$\sigma = \sigma_0 + E_T \cdot \varepsilon_p$$

G'sell Jonas

$$\sigma = \sigma_0 + K \cdot (1 - e^{-w \cdot \varepsilon_p}) \cdot e^{h \cdot \varepsilon_p^n}$$

4a three parameter law

$$\sigma = \sigma_0 + E \cdot \varepsilon_p \cdot \frac{1}{\left[1 - \frac{E}{H} \cdot \varepsilon_p\right]}$$

Strain rate Laws

Cowper Symonds

$$\sigma = \sigma_0(\varepsilon)\left[1 + \left(\frac{\dot{\varepsilon}}{D}\right)^{\frac{1}{p}}\right]$$

Johnson Cook

$$\sigma = \sigma_0(\varepsilon)\left[1 + C \ln \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right]$$

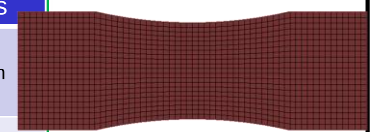
4a impetus Hardware

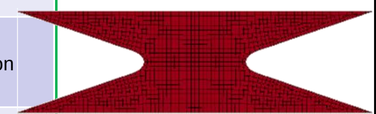
4a impetus Software

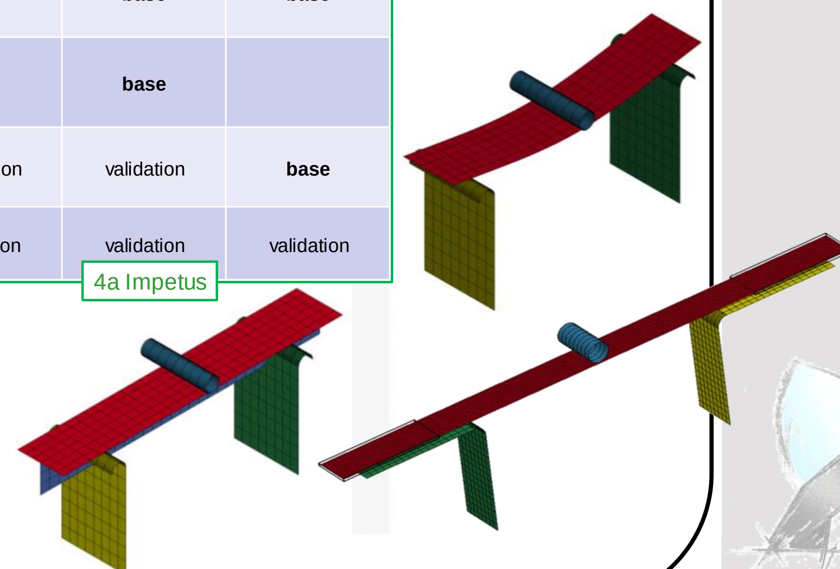
	*MAT_24 Dynamat	*MAT_187 Dynamat	*MAT_24 Impetus	*MAT_124 Impetus	*MAT_124 Impetus
	base	**base**	validation	validation	validation
		base			
	validation	**base**	validation	validation	validation
	validation	validation	**base**	**base**	**base**
				base	
	validation	validation	Validation	validation	**base**
	validation	validation	validation	validation	validation

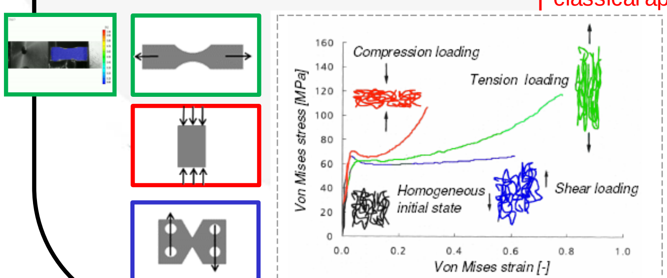
classical approach

4a Impetus

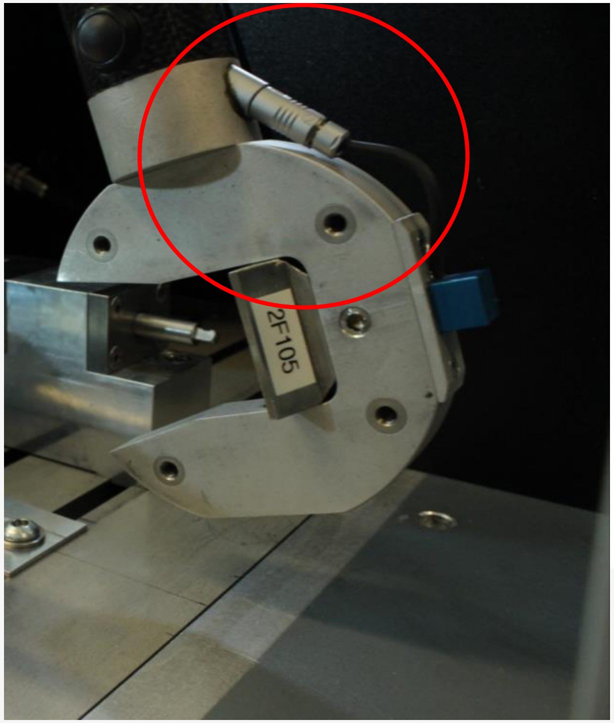






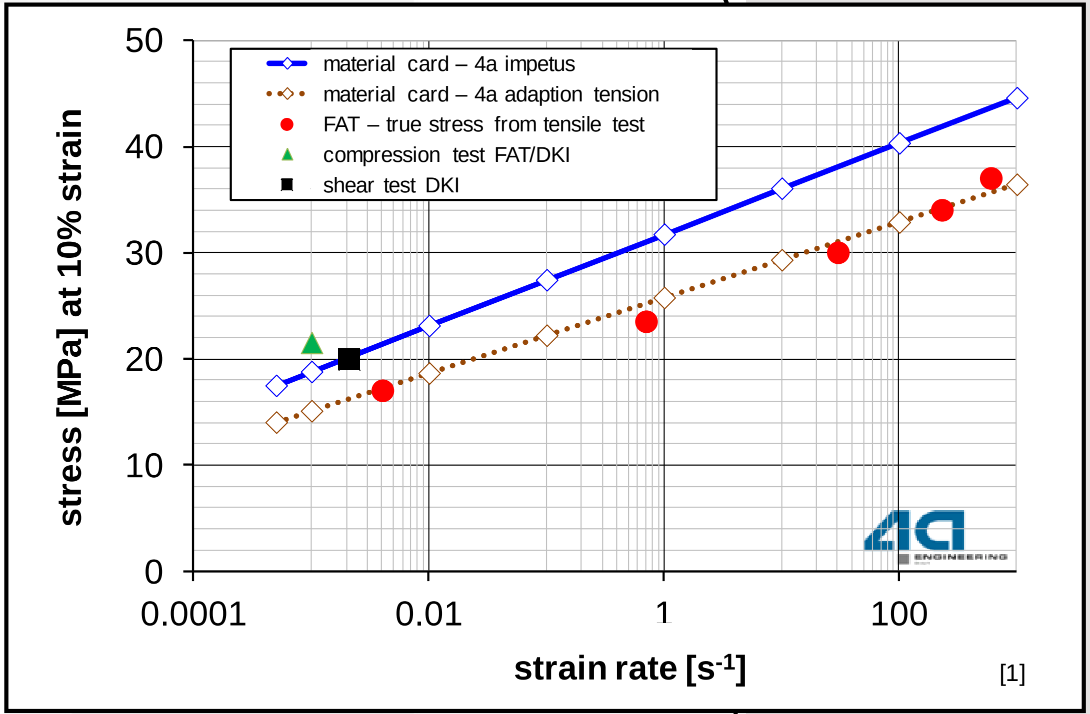


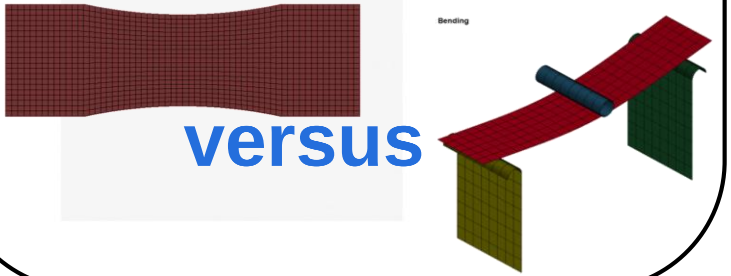
4a impetus Hardware



plugable acceleration sensor for pendulum

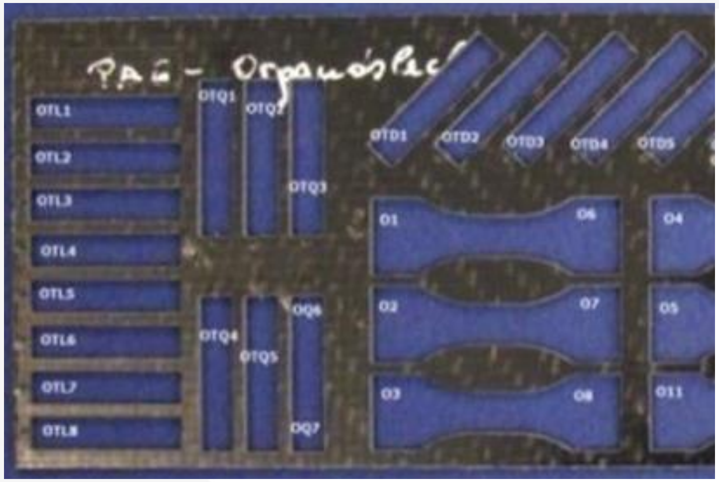
4a impetus Software

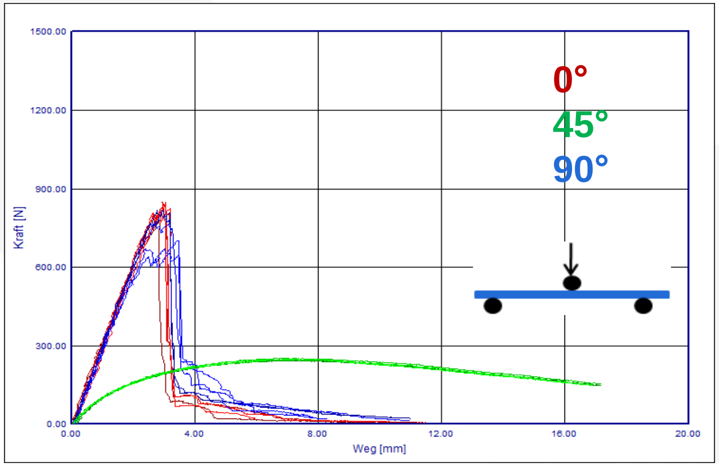




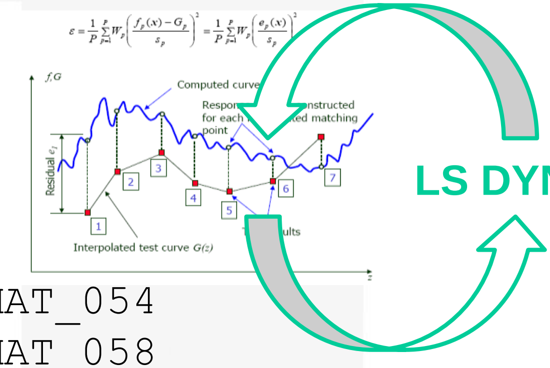
versus

4a impetus Hardware





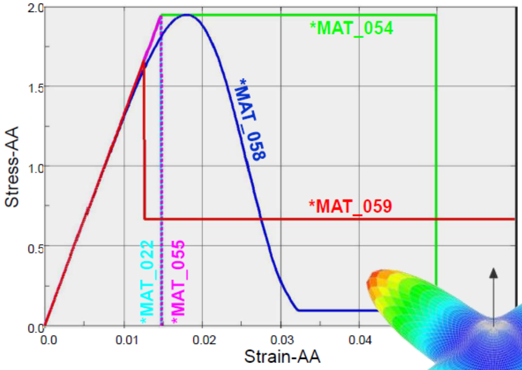
4a impetus Software



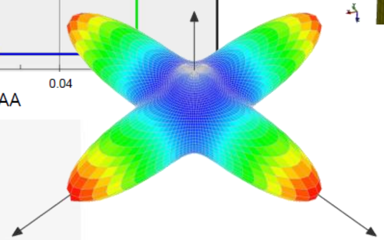
LSTC Livermore Software Technology Corp.
LS-OPT®

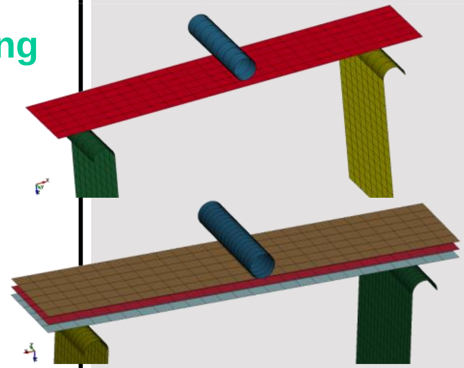
*MAT_054
*MAT_058

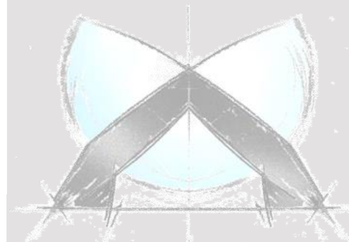
Reverse Engineering



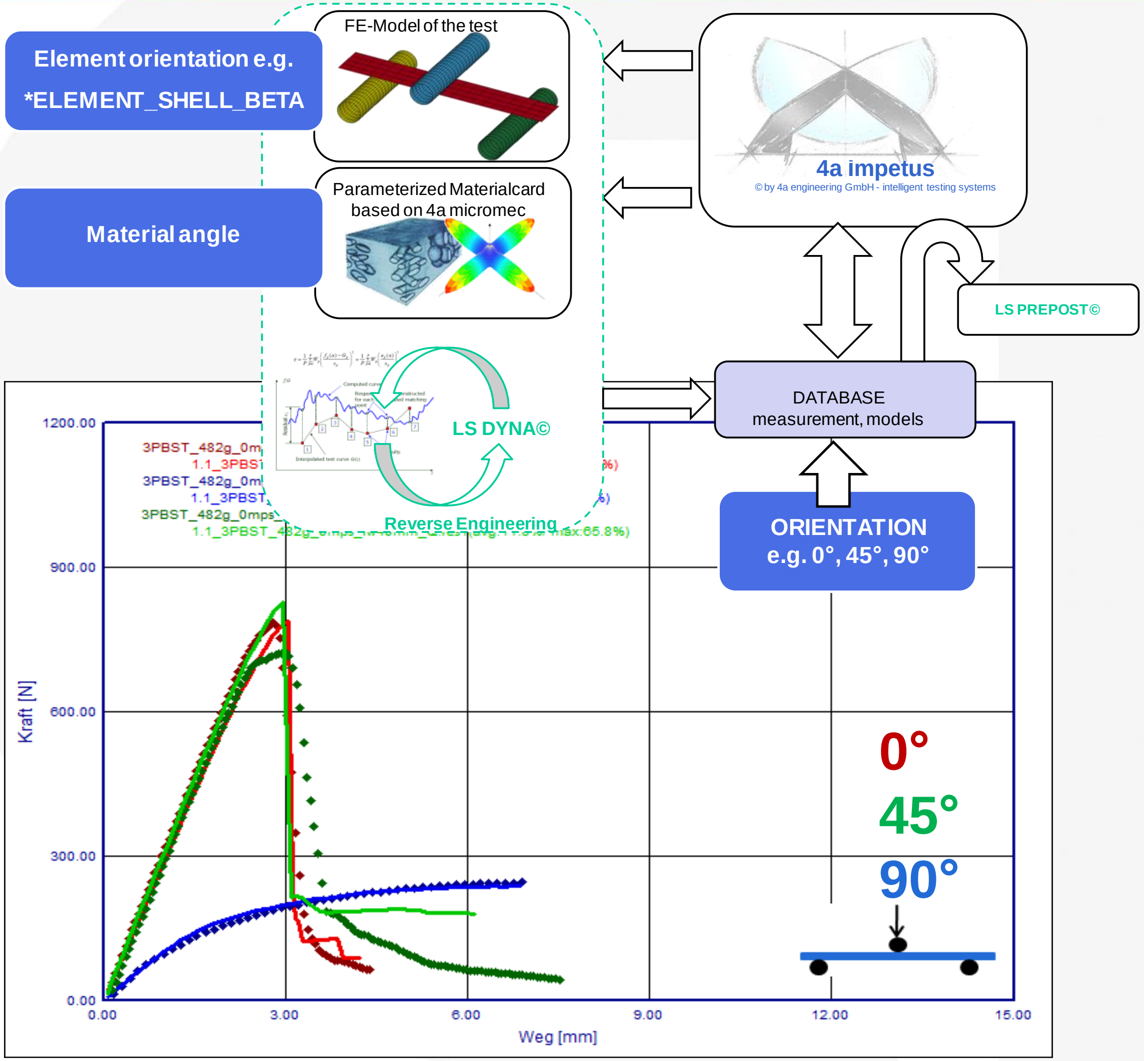
[DYNAmore]

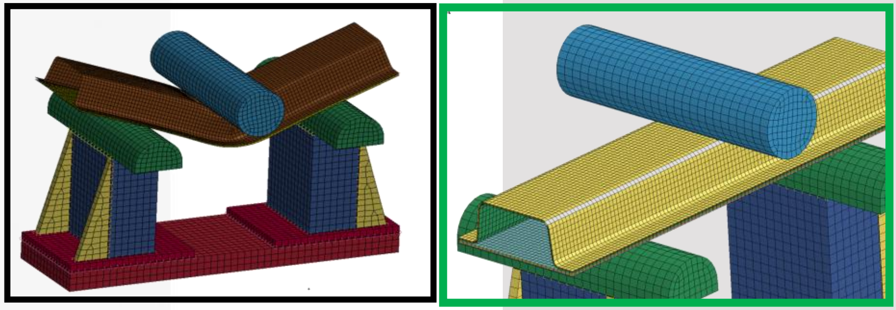


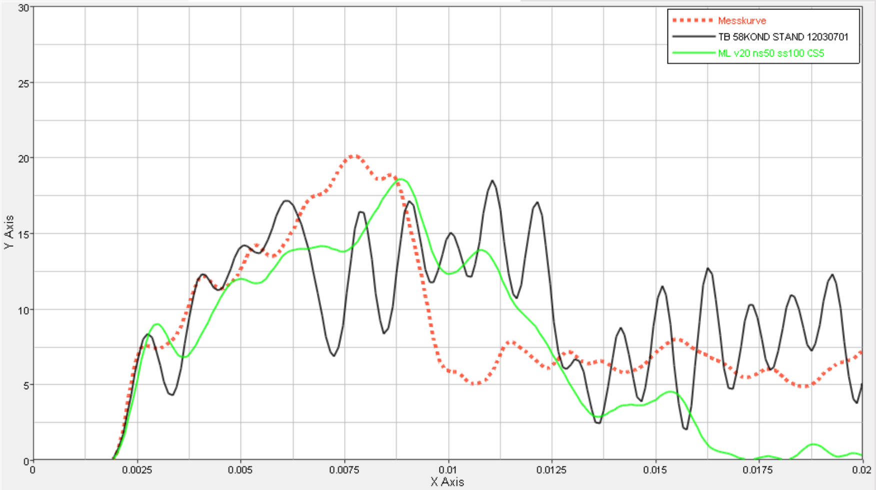




Dynamic material characterization of plastics
11th LS-DYNA Forum, 2012





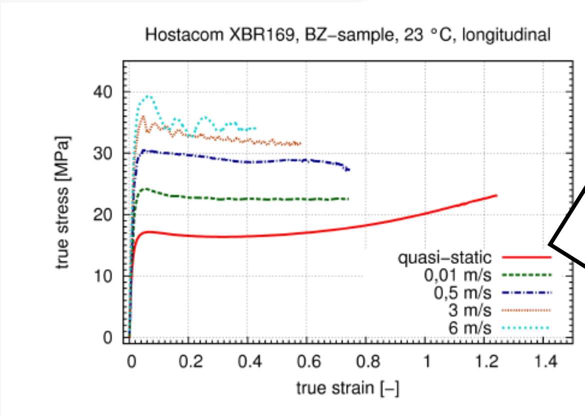


By courtesy of Magna Steyr Engineering Austria

P. Reithofer - *Dynamische Materialcharakterisierung von Composites mit 4a impetus*, 11. LS-DYNA FORUM, ULM

ENGINEERING GmbH

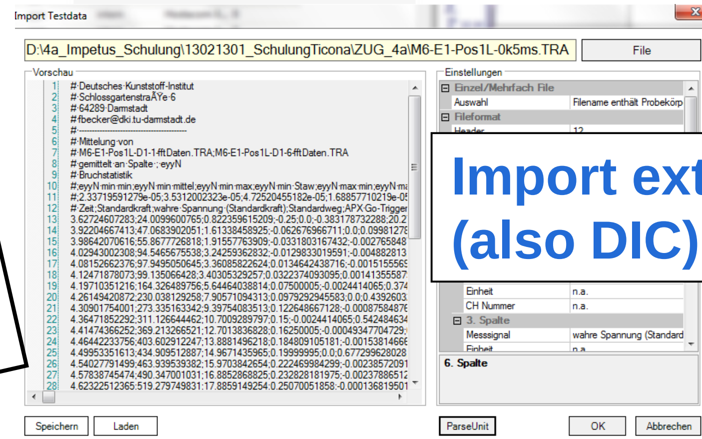
4a impetus Measurement



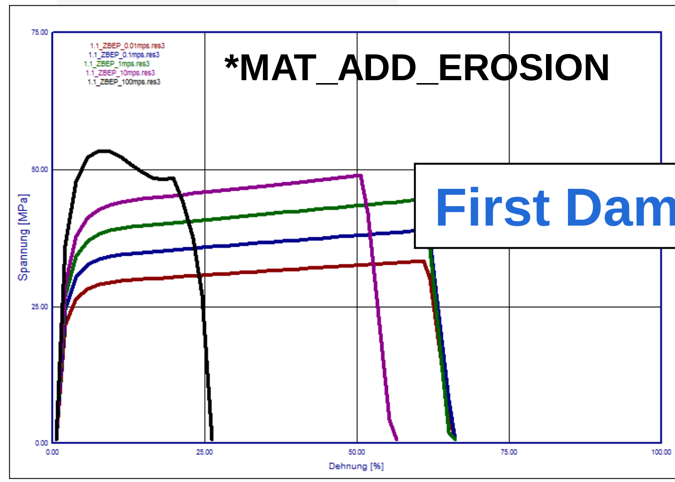
Supported data:

- Zwick ASCII format
- Shimadzu ASCII format
- Plain text
- CSV
- Excel

4a impetus Software



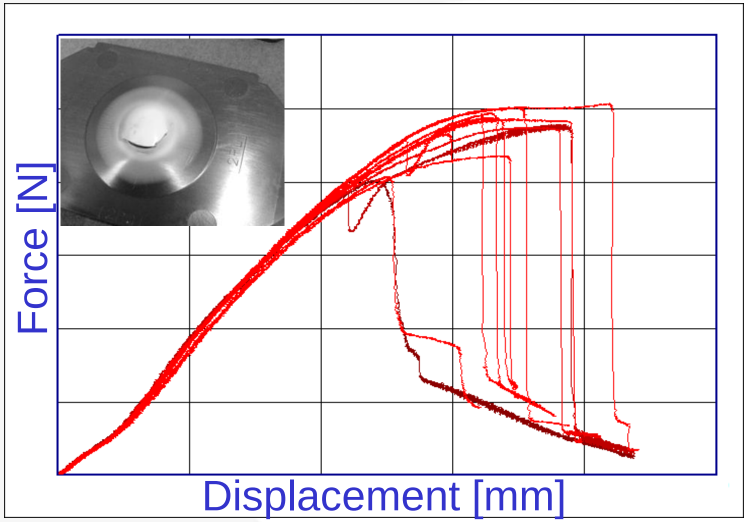
Import external Data (also DIC)



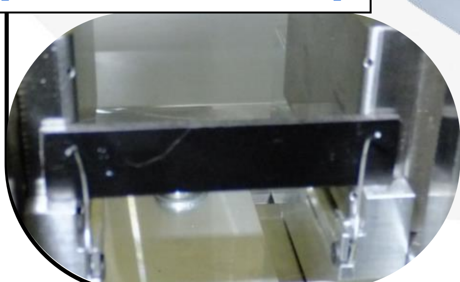
First Damage models

Dynamic material characterization of plastics 2014

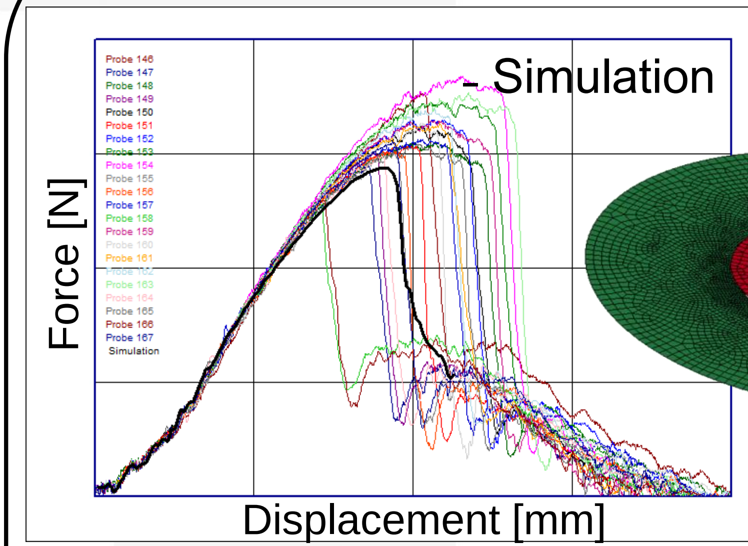
4a impetus Hardware

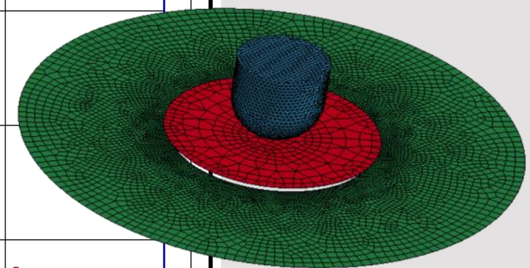


Temperature (-30°C & 80°C)



4a impetus Software

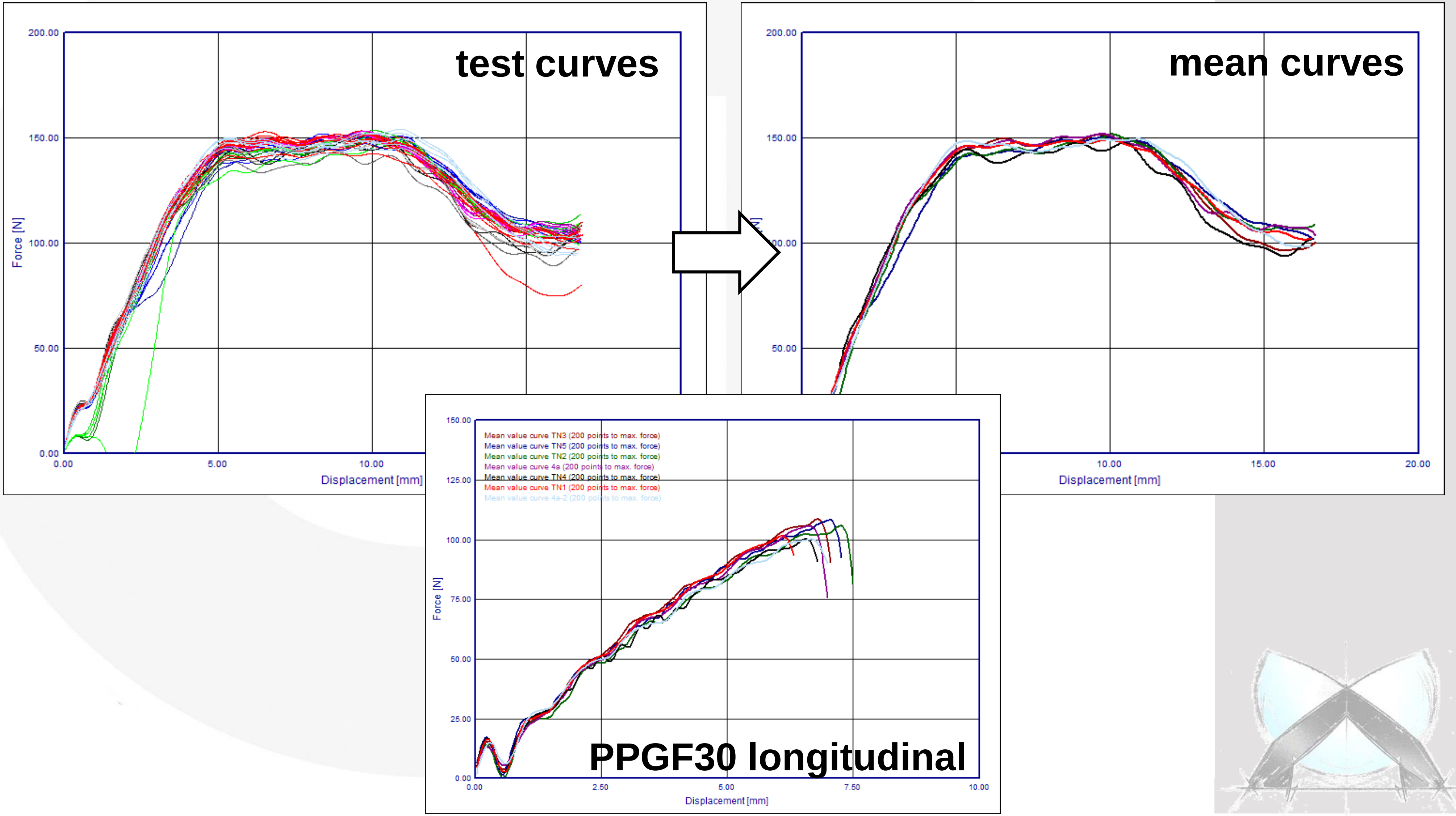




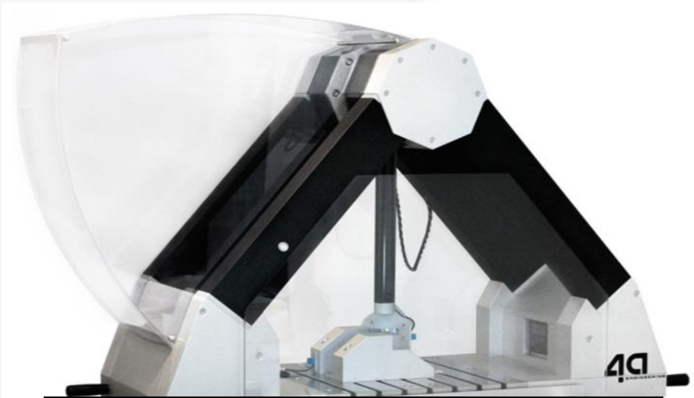
Puncture Test

Statistical methods → failure

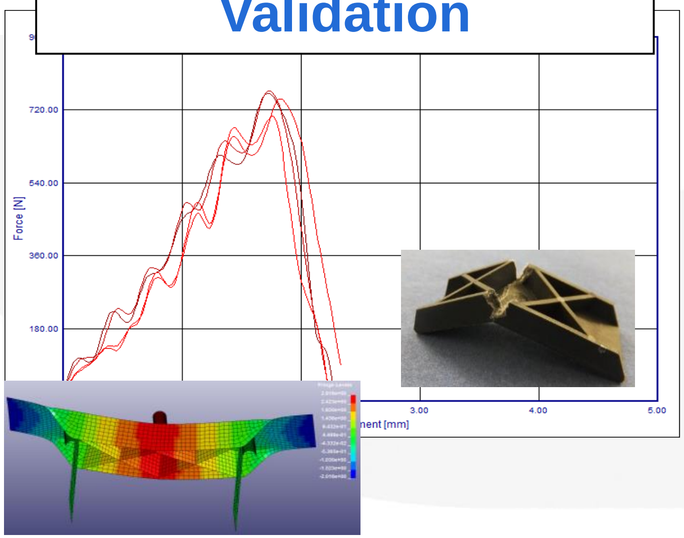
Dynamic material characterization of plastics
Round Robin Test 2014



4a impetus Measurement

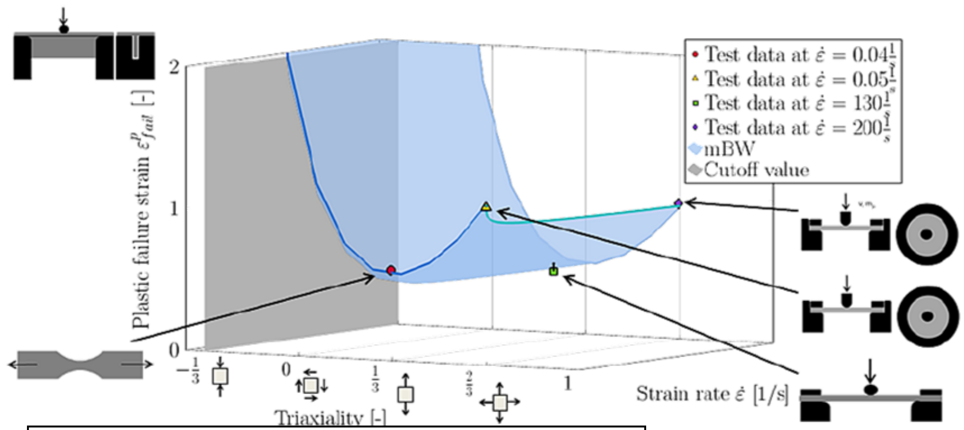


Validation

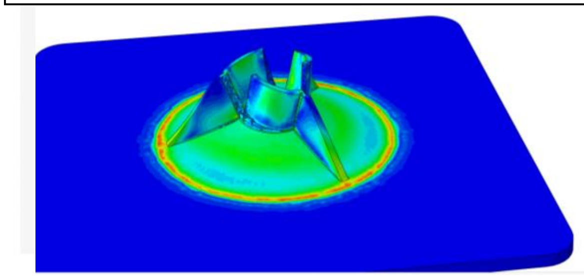


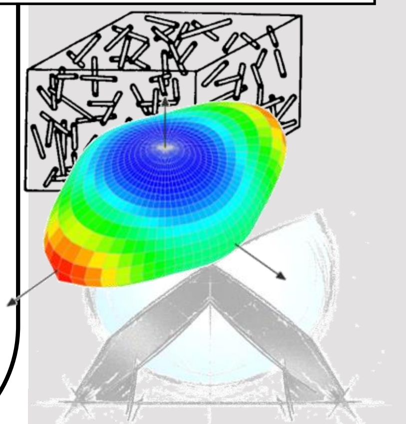
4a impetus Software

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



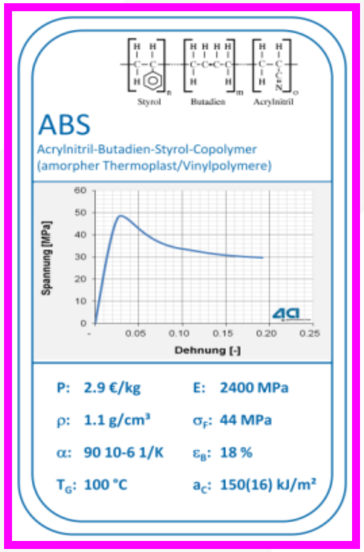
Failure
Anisotropy

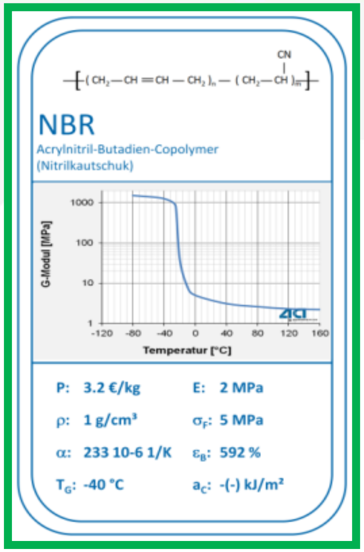


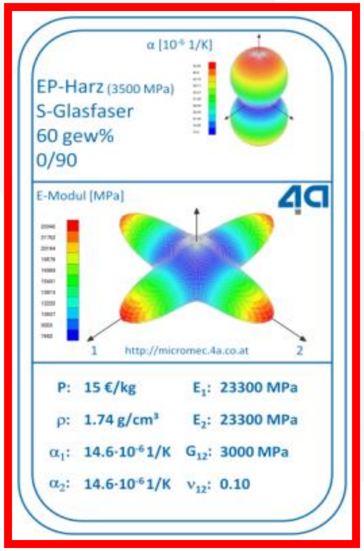


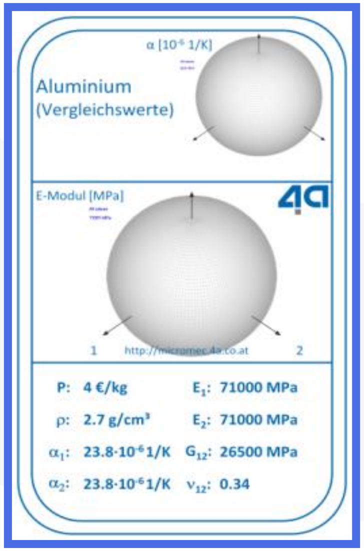
I N P H Y S I C S W E T R U S T

Dynamic material characterization of plastics
Summary





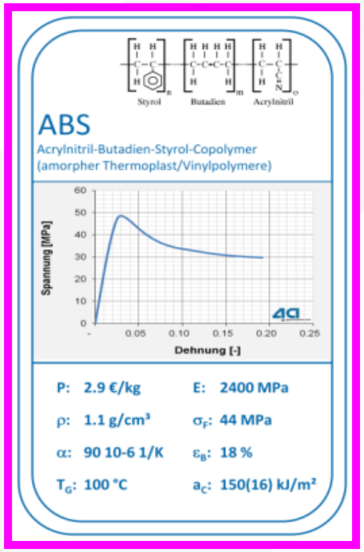


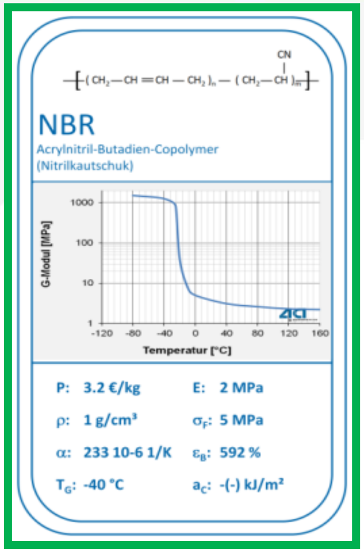


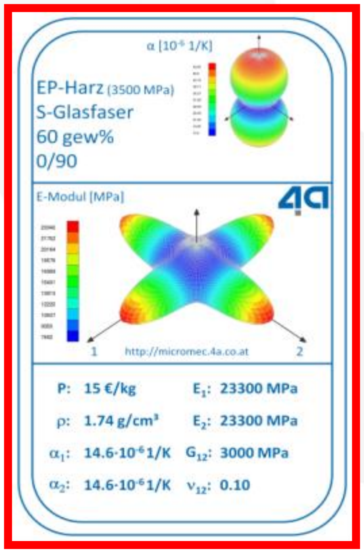
We have already tested a wide range of

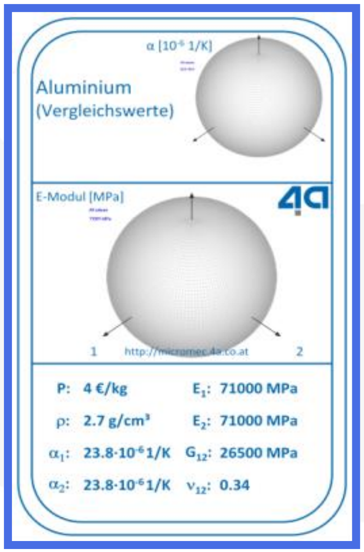
- **thermoplastics** (ASA, ABS+PA; ABS+PC; PA6; PA6(6) GF30..50; PA66+P6; PBT GF30; PC; PE; PP; PP+ varnish; PP rubber modified; PP GF20..40; PP Impact modified; PP MX10; PP MX20; PP MX40; PP CF; PP+EPDM; MuCell-materials, …)
- foams (EPP30..80; PU RG 55, PU RG 65)
- **rubbers** (EPDM, silicone, TPS, …)
- **thermoset materials** (CFK, GFK with epoxy resin, …)
- **metals** (aluminum, DC04, …)
- others
  - fabric (interior, …)
  - glue (front hood, …)
  - wood (beech, multiplex, chipboards, MDF)

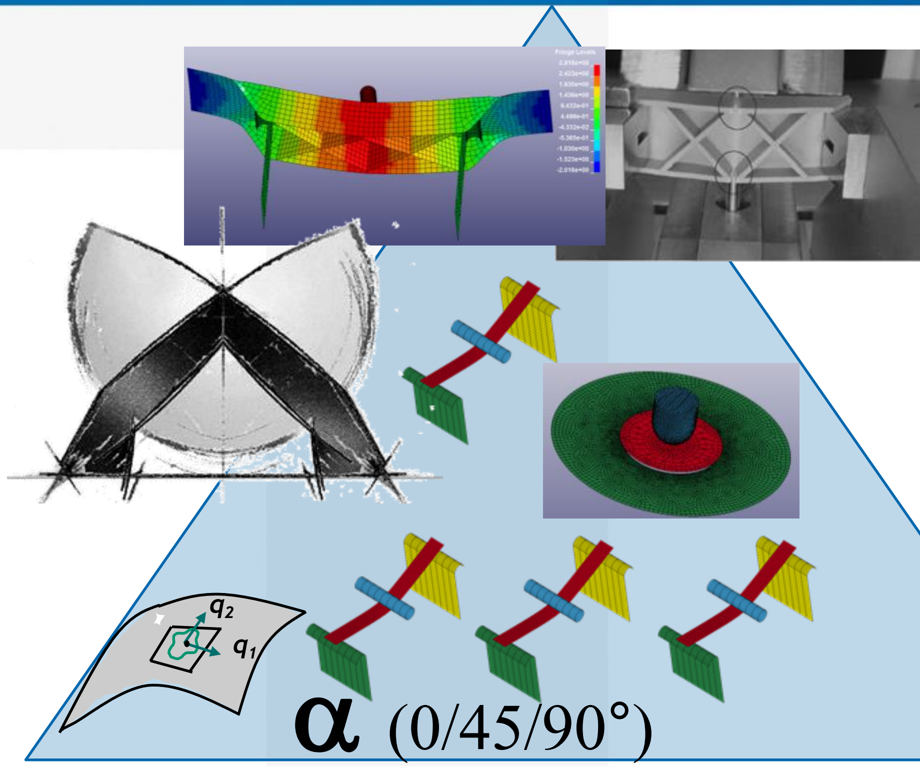
Dynamic material characterization of plastics
Summary



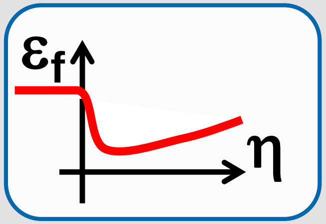


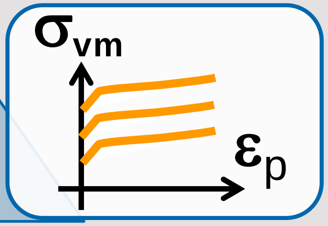






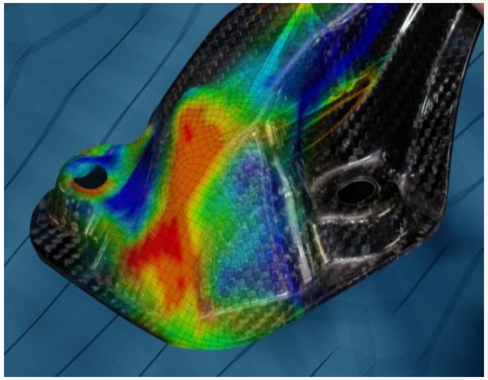
component validation





Workflows
validated material card

Thank you for your attention!



14th TECHNOLOGIETAG

23.- 24. March 2017
in Schladming, Austria

„Light weight applications & Composites"
More information: *http://technologietag.4a.co.at/*