Workshop „Dynamic Plastic Material Characterization using the 4a impetus Pendulum“, Würzburg
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R&D and engineering services

Core competence
- Polymer and materials science
- Numerical simulation methods
- Lightweight applications
- Fiber reinforced plastics and composites
- Method development for virtual engineering

15 to 20 key customers

More than 500 projects
- 45% automotive
- 15% aerospace
- 15% mechanical engineering
- 10% medical engineering
- 15% consumer goods
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://gm-volt.com/

source: Dynamore GmbH
Motivation
Motivation
4a impetus

- **Motivation:** material card for simulation of plastic materials
  - Under dynamic loading
  - Realistic loading, near to reality
  - Reproducible (database structure)
  - Reduction of development time and costs
  - Evaluation and validation in one system

- Typical applications / simulation topics
  - Automotive industries → occupant and pedestrian safety
  - Drop test → consumer goods

Drop test
Occupant simulation

Crash
Bending test on 4a impetus

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Motivation

Industrial needs

Customer wishes:

- Cost reduction → specimen quantity and cost
- Time reduction
- Less testing
- Replacement of tests through simulation

Results in:

- High reliability of simulation models
- Reliable material cards → more testing
- Smarter test equipment
Motivation

Bending load case (loading near to reality)

- Original test curve tension
- Scaling 1.25

Many plastics show a strong load type dependency. [1] [2]
Motivation
Material variety (reproducible → database structure)
4a impetus

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4a impetus

History of 4a impetus

2015
4a impetus
Software solution from the test to the material card

4a impetus Hardware

External Testing

4a impetus Software

directly linked

ASCII DATA
Complete system from the test to the validated material card
Applications
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)
Applications
Quality control - comparison of supplier

- Fast and easy comparison by instrumented impact test
- Accurate evaluation of force-displacement curve
- Bending test
  simple sample generation even out of a component
- Same evaluation

Averaging, filter, ....
Applications
Material cards by compression tests

Foams (EPP, PUR, …)
*MAT_LOW_DENSITY_FOAM
*MAT_FU_CHANG_FOAM
*MAT_SIMPLIFIED_RUBBER_FOAM
Applications
Material cards by 3-point-bending tests

Unreinforced plastics
(PA6, PBT, PE, PP, PC, ABS ...)
*MAT_SAMP-1

Reinforced plastics
(PP GF, PA6 GF, PBT GF ...)
*MAT_24 for exposed directions

Metals
(DC04, ALU 6000, ...)
*MAT_PIECEWISE_LINEAR_PLASTICITY

σ = σ₀ + E ⋅ εₚ ⋅ \frac{1}{\left[1 - \frac{E}{H} \cdot εₚ\right]}

σ = A + Bεₚ^n
Applications
Material cards composites – front hood

Honeycomb (Nomex, …)
*MAT_LOW_DENSITY_FOAM
Applications

Component testing

- Weather strip
- Wire harness
- Water hose
- Brake tube
- Air bag module
- Sun shield
- Foamed parts
- Swirl body
- Multi layer composites
Hardware

4a impetus

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4a impetus
Single and double pendulum

- Single pendulum **0.5 - 4.5 m/s**
  - maximum energy ~20J (changing introduced energy by adding mass)
  - maximum energy ~50J in work
  - maximum acceptable acceleration 2000 g

- Double pendulum **unique selling point 0.5 - 8 m/s**
Test methods

- Compression test (foam materials)
- Bending test (solid materials)
- Clamped bending test (dominating part: tension)
- Puncture test (biaxial loading, failure)
- Quasi-static tests are made in addition by default
- Double pendulum:

dynamic 3-point-bending

dynamic compression
Measurement technique
The deceleration of the pendulum arm and the rotation angle of the shaft are measured. This allows a very exact determination of dynamic force/replacement-characteristics.
Measurement technique
Analog/digital converter

- Using 16 bit and up to 2 MS/s total sampling rate for analog channels. For a velocity of 5 m/s you have a resolution of **400 samples/mm**. So also brittle materials can be tested and natural frequencies of test specimens can be measured.

- A separate digital 32-bit counter at the data measurement device allows the use of digital rotary transmitter and facilitates the analog sampling.
Measurement technique
Incremental rotary transmitter

- Very exact sensor resolution **320,000 points / turn**
  → theoretical resolution **0.01 mm** in the circular path of the pendulum
- Sensor doesn’t have a dead range
- 0-pulse of the rotary transmitter can be used as trigger for the measurement
- Possibility of evaluation: displacement out of the angle → calibration of the system
Measurement technique
Incremental rotary transmitter

Calculation of the displacement
Evaluation out of the angle signal vs. acceleration signal
Calibration of the system using the angle signal vs. acceleration signal is possible

3-point-bending test 1mps

Compression test for foam 3.5mps
Measurement technique

Acceleration sensors

Concept using plug-in sensors

- Piezo resistive sensors (50g - 1000g)
- Capacitive acceleration sensors
  - 5g – 400g
  - Temperature compensated
  - Low noise option available
- accuracy of 1% in the measurement range of 10% - 100%.

Advantages:

- Exchangeable sensors → individual measurement range
- Quick change of the acceleration sensor („plug and test“) – 2 screws
- Simple distribution for calibration

Temperature and moisture sensor is also included.
Software
Complete system from the test to the validated material card
4a impetus software
Process / functional range

- Test plan setting
- Performing measurements (only 4a impetus hardware)
- Evaluation of the measurements
- Measurement results
- Import of external measurement results
- Model build up
- Material models
- Optimization
4a impetus is a pendulum test device to characterize materials by (clamped) 3-point-bending, compression and puncture tests.

- Capturing different strain rates and the strain rate dependency
  - changing the pendulum speed and/or changing the support distance
- Capturing compression/tension behavior
  - import quasi-static tensile (and shear and compression) test
  - clamped bending test
- Capturing loading / unloading → damage
  - 3-point-bending test
  - Multiple loading clamped bending test
- Capturing failure
  - Clamped bending test → uniaxial; puncture test → biaxial
- Capturing component test → T-specimen
Using the 4a impetus software the user can

- **Import** additionally any other tests (e.g. quasi-static bending, tensile or compression test, any supplier) **into the test data base** (e.g. force/displacement curves),

- **Evaluate** all the tests (also the imported ones) and use these data **only** or **additional** for generating the material card or calculate the test curves using the material card (validation).
Can be used local or in network

Supports LS-Dyna, Abaqus, PAM-Crash, Radioss

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
### Available test methods - Interfaces in 4a impetus V3.2

<table>
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<tr>
<th></th>
<th>ABAQUS</th>
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<th>PAMCRASH</th>
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**in progress**

**implemented**

**tested**
## 4a impetus
Generating material cards – different approaches

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<th>Classic Approach</th>
<th>4a Impetus</th>
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<td>static and dynamic tests</td>
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<td>Shear</td>
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<td>static tests</td>
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<tr>
<td>Biaxial tension puncture test</td>
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<td>static tests</td>
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<tr>
<td>3-point-bending</td>
<td>static and dynamic tests</td>
<td>static and dynamic tests</td>
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<tr>
<td>Clamped 3-point-bending</td>
<td>dynamic tests</td>
<td>dynamic tests</td>
</tr>
<tr>
<td>Bending using T-specimen</td>
<td>Also possible with 4a impetus software</td>
<td></td>
</tr>
</tbody>
</table>
4a impetus
Generating material cards – influence of triaxiality

4a impetus

Classic approach
Generating material cards - LS-Dyna material models

- MAT_19: *MAT_STRAIN_RATE_DEPENDENT_PLASTICITY* (von Mises)
- MAT_24: *MAT PIECEWISE_LINEAR_PLASTICITY* (von Mises)
- MAT_124: *MAT_PLASTICITY_COMPRESSION_TENSION* (Drucker Prager)
- MAT_187: *MAT_SAMP-1* (general yield surface)

All LS-DYNA material cards are available using user defined interfaces!

Same possibilities for the other solvers (e.g. Abaqus, PamCrash, …)
Generating material cards

1\textsuperscript{st} step: performing static and dynamic bending tests

2\textsuperscript{nd} step: evaluation of the data

3\textsuperscript{rd} step: material characterization – identification of the parameters using LS-OPT

Young’s Modulus

\begin{itemize}
  \item plastic characteristics
  \item strain rate dependency
  \item validation
\end{itemize}
Reverse Engineering

**FE-Model of the test**

**Parameterized Materialcard**

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

**Spannung (MPa)**

**Dehnung**

**Reverse Engineering**

**LS DYNA©**

**LS PREPOST©**

**DATABASE**

measurement, models
Sequential Response Surface Method

Mean Squared Error

\[
MSE(x) = \frac{1}{P} \sum_{i=1}^{P} W_i \left( \frac{F_i(x)}{S_i} - G_i \right)^2
\]

[4]
3rd step: material characterization - plastic characteristics

Final Result

Design Variable 1

Design Variable 2

Region of Interest

starting design

optimum

Displacement [mm]

Force [N]

Iteration 1
Iteration 2
Iteration 3
Iteration 4
Iteration 5
Iteration 6
Final Result
Development of the design variable $\sigma_y$
4a impetus
Generating material cards

- 1\textsuperscript{st} step: performing static and dynamic bending tests
- 2\textsuperscript{nd} step: evaluation of the data
- 3\textsuperscript{rd} step: material characterization – identification of the parameters using LS-OPT

Young’s Modulus

\[ \text{Displacement [mm]} \]

\[ \text{Force N} \]

- lw 30 mm / 0.3 mm/s
- lw 50 mm / 1 m/s
- lw 40 mm / 2.5 m/s
LS-Dyna: *MAT24 (von Mises)

- No tension/compression asymmetry
  - good conformity for bending
  - poor conformity for tension
  or vice versa
**4a impetus**

**Generating material cards**

- **LS-Dyna**: *MAT187 (general yield surface)
- Tension/compression asymmetry → good conformity for all load cases

--- lw 50 mm / 1 m/s
--- lw 40 mm / 2.5 m/s
--- lw 30 mm / 4.0 m/s

![Graph showing load vs displacement for different conditions](image)
Reverse Engineering 4a impetus

**Static Behavior - Yield**

- lw 50 mm / 1 mm/s

Simulation vs. mean value curve of the tests

**Dynamic Behavior – Strain Rate**

- 3 point bending
  - 0.1 mm/s
  - 1 m/s
  - 2.5 m/s
  - 4 m/s

Simulation vs. mean value curve of the tests

- Clamped bending 4 m/s

Simulation vs. mean value curve of the tests

**Fit Compression/Tension Behavior**

- Reverse Engineering

**Check Compression/Tension Behavior**
Validation 4a impetus (*MAT_SAMP-1)

Dynamic puncture test with the part
The test curves are matched very well
Examples of measurement results
Within a round robin test many materials were tested using the 4a impetus test systems of some customers.

The results for the bending test of the material PCABS (thickness 3 mm) shows a good conformity for all 4a impetus test devices.
Examples of measurement results
PP GF30 longitudinal and perpendicular orientation

The mean value curves of PP GF30 in longitudinal and perpendicular orientation are also well reproducible and comparable for all 4a impetus test systems.
Examples of measurement results

The reinforced material PP T20 was tested on all 4a impetus test systems related to failure; the tests showed a well reproducibility.

The range of failure is shown in the right diagram by the two extreme curves.
Examples of measurement results

Aluminum

- Using aluminum test specimens high forces and accelerations should occur. All 4a impetus test systems had a comparable result.
- The range of failure is shown again in the right diagram by the two extreme curves.
Further helpful links

- Homepage of 4a impetus: http://impetus.4a.co.at/en/
- Homepage of 4a engineering GmbH: http://www.4a-engineering.at/en/
- Homepage of the 4a technology day with many interesting presentations from various companies: http://technologietag.4a.co.at/

- Some recent papers about 4a impetus:
  A. Fertschej, P. Reithofer, M. Rollant (4a engineering GmbH) - *Materialmodelle für Kunststoffe, Komplexe Fließflächen und Versagen*, 4a Technologietag 2014, Schladming (Link)
  R. Jennrich, M. Roth, Prof. S. Kolling (Technische Hochschule Mittelhessen)


Summary
Summary

- 4a impetus offers comprehensive and fast testing possibilities
- Using reverse engineering appropriate material models are generated in an efficient way for the simulation (LS DYNA, PAM CRASH, ABAQUS, Radioss)
- Quasi-static tests can be integrated without any problem and effort.
- 4a impetus is an outstanding system to generate material data bases for everyday simulations.
- Quality control of the generated material cards is assured as 4a impetus is a complete software solution (testing and simulation) independent of the place of location.
Summary

- Unique test system
  - Double pendulum
  - Flexible pendulum (carbon arm, mass add, changeable sensors)
  - Instrumented (unique force–displacement)

- Unique software solution
  - Material characterization → material cards

- Markets
  - Automotive, aerospace, rail
  - Consumer goods (mobile phones, power tools, …)
  - Packing industries
  - Material supplier (plastics, composites, …)
  - Plastics manufacturing industries
Literature

W. Retting, Hanser Verlag 1991

M. Junginger, Fraunhofer EMI Bericht 15/02

[3] Mechanical Characterization of Talc Particle Filled Thermoplastics  
Frank Kunkel, Florian Becker, Stefan Kolling, Europäisches Dynaforum 2011, Straßburg  

Anja Förderer, Dynamore Workshop Kunststoffe, Filderstadt, 2013

A. Fertschej, P. Reithofer, M. Rollant, Europäisches Dynaforum 2015, Würzburg