4a impetus – efficient evaluation of material cards for non-reinforced and reinforced thermoplastics

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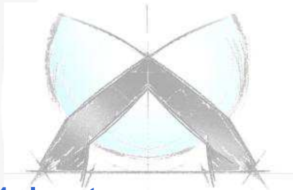
Abstract

LS-DYNA© has included plenty of material cards, each of them offering different scalability and complexity to describe the behavior of non- reinforced thermoplastics. The consideration of the strain rate behavior is included in many material cards, e.g. in the well known MAT_PICEWISE_LINEAR_PLASTICITY. More complex material models can also handle varying compression and tension behavior as well as unloading by using damage functions. One of the recent development results is MAT-SAMP-1 by Du Bois, Kolling, Feucht and Haufe. This specially developed material model for polymers includes a yield surface out of different loading cases and a damage function for better description of unloading.

For better use of the above mentioned models a huge amount of tests have to be carried out, to determine the material parameters and to represent the thermoplastic characteristics in crashworthiness simulations. 4a impetus builds up an efficient and reliable process, starting with realistic tests and finally ending up with a validated material card. Recent developments of new test methods for 4a Impetus are presented, that satisfy the needs of complex material models as well as the expectations with regard to easy and favorable testing.

Limits and opportunities of different test methods and material card implementations are shown and compared to each other especially focused on typical polymer behavior. Finally the influence of fiber reinforcement is discussed and solutions to determine material parameters by using micro mechanic models (4a MicroMec) are shown.

4a impetus – efficient evaluation of material cards for non-reinforced and reinforced thermoplastics



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content

- polymer materials
  - general behavior
  - influences
  - classical approach for the measurement of thermoplastics
  - influences caused by fiber reinforcement
- 4a Impetus
  - general mode of operation
  - dynamic bending test
  - static bending
  - optimization
  - graphical user interface
  - stress/strain rules
  - strain rate rules
  - LS DYNA Material Cards
  - different test assemblies
- outlook and conclusions

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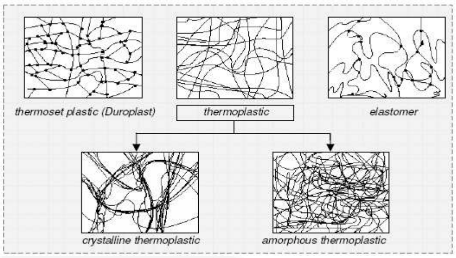
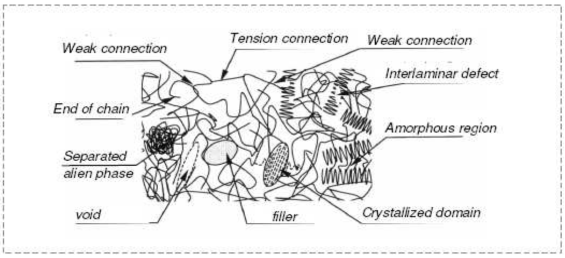
Polymer materials general behavior [2]

- The morphology and build up cross linking allows the distinction of three different types of polymer materials, with different mechanical characteristics.





- Due to the thermoplastic morphology different reasons can be identified as a trigger for break.

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Polymer materials influences

material

polymere
- chemical framework
- molecular weight distribution
- morphology

- filler
- reinforcements
- blend

- behavior
- content
- orientation

process
- flow direction
- cooling rate

application

conditions
- temperature
- ambient humidity
- loading rate
- loading duration
- loading case
- loading path
- triaxiality

geometry
- component geometry / structure

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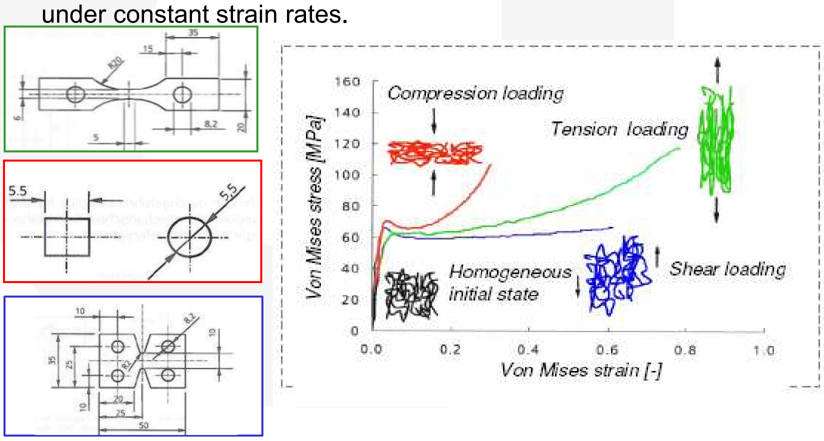
Polymer materials
classical approach for measurement of thermoplastics

For the measurement of the mechanical behavior of thermoplastics at high velocities and different loading cases specially prepared specimens [3] and optical measurement equipment [3] [5] are needed. The classical highly complex approach and the huge amount of measurement data have to be handled to get good true stress / strain curves under constant strain rates.



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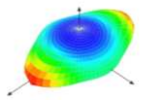
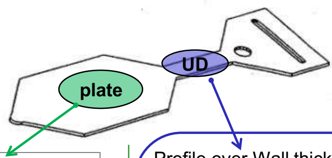
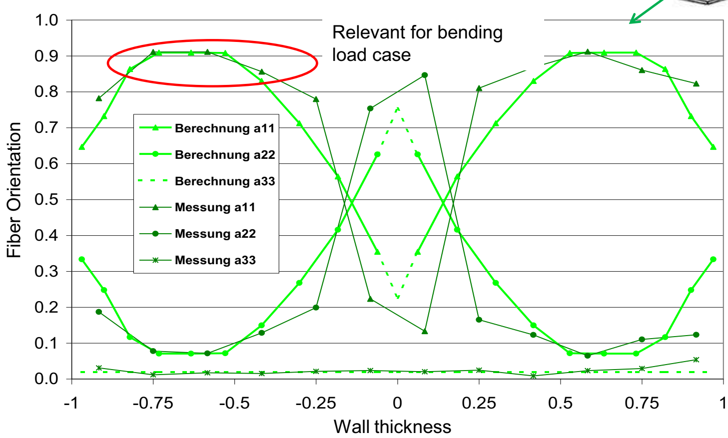
Polymer materials
influences caused by fiber reinforcement

Average fiber orientation

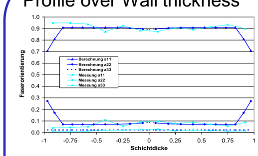
$$a_{ij} = \begin{bmatrix} 0{,}66 & 0 & 0 \\ 0 & 0{,}32 & 0 \\ 0 & 0 & 0{,}02 \end{bmatrix}$$





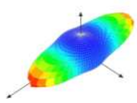


Profile over Wall thickness

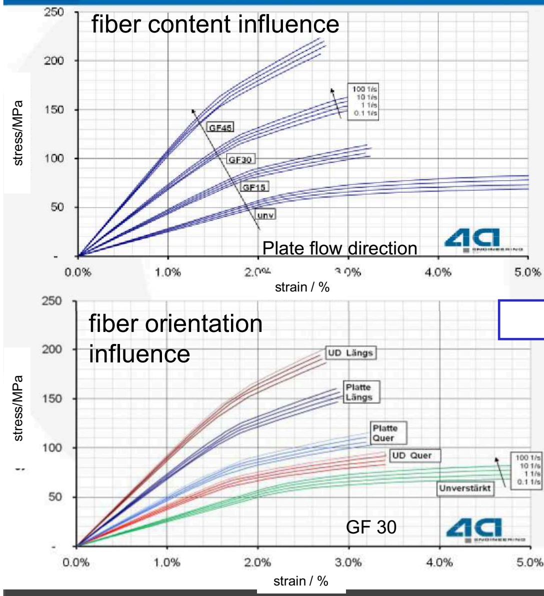


Average fiber orientation

$$a_{ij} = \begin{bmatrix} 0{,}87 & 0 & 0 \\ 0 & 0{,}11 & 0 \\ 0 & 0 & 0{,}02 \end{bmatrix}$$



Polymer materials
influences caused by fiber reinforcement



material behavior is

- orthotropic
- visco elastic
- visco plastic

Identification of the dominant parameter:
By increasing fiber content the influence of the fiber orientation induced orthotropic grows and the influence of the matrix dominate strain rate may decrease.

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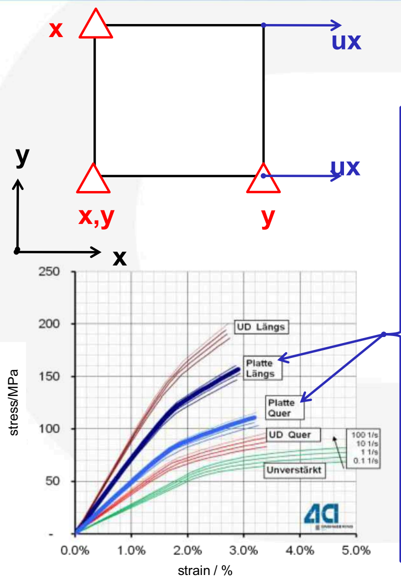
Polymer materials
fiber reinforcement – standard LS DYNA materials



For thermoplastic parts the plate area is typical. Several standard materials laws are presented, that can more or less represent the real material behavior.

Available LS-Dyna Material Laws

- *MAT_ORTHOTROPIC_ELASTIC (2)*
  orthotropic, elastic , no damage
- **MAT_PIECEWISE_LINEAR_PLASTICITY (24)*
  isotropic, elastic- visco plastic
- *MAT_NONLINEAR_ORTHOTROPIC
  orthotropic, non linear
- *MAT_ORTHOTROPIC_VISCOELASTIC
  orthotropic, visco elastic
- *MAT_ANISTROPIC_VISCOPLASTIC
  isotropic elastic, anisotropic visco plastic
- **MAT_ORTHO_ELASTIC_PLASTIC (108)*
  orthotropic, elastic – *plastic*
- ……

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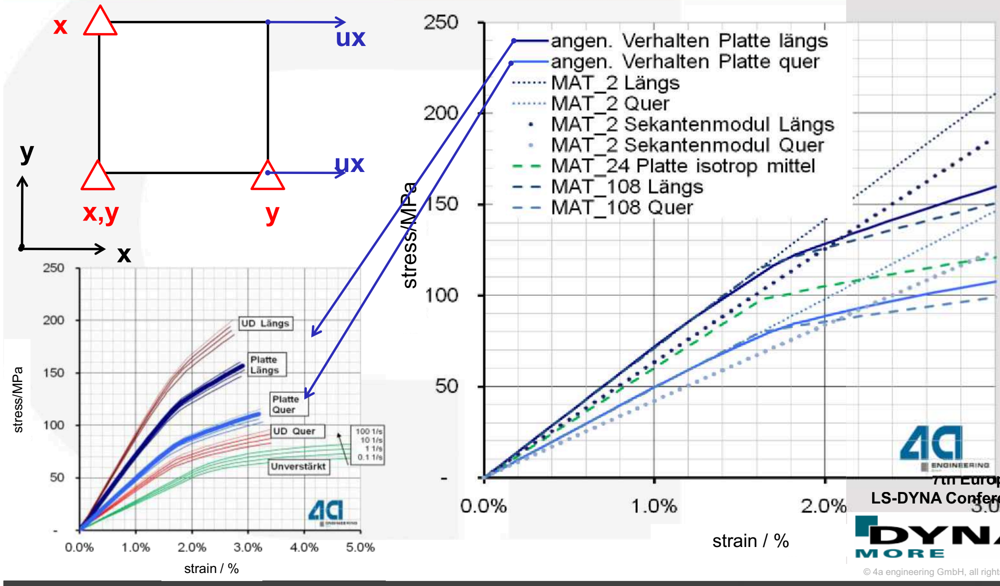
Polymer materials
fiber reinforcement – standard LS DYNA materials



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4a Impetus
general mode of operation

test specimen manufacturing

specimen close to reality
(flat test specimen out of a real manufacturing process)

realistic test conditions
(dynamic bending load, most typical load case)

experiments

cost-effective load without additional actuation
(loaded mass – potential und kinetic energy)

analysis method

semi analytical evaluation process
(analytical evaluation process plus optional usage of neuronal network for a faster determination of the initial values, optical evaluation process)

solving the complex load situation by integrated simulation process
(explicit simulation)

return of values

output of material data for simulation or direct use
(in appropriate format optimal output – test curves – material cards – stochastic outputs)

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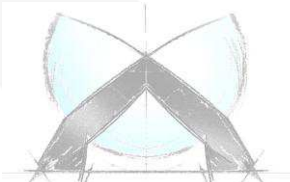
dynamic tests up to a velocity of 10 m/s are possible



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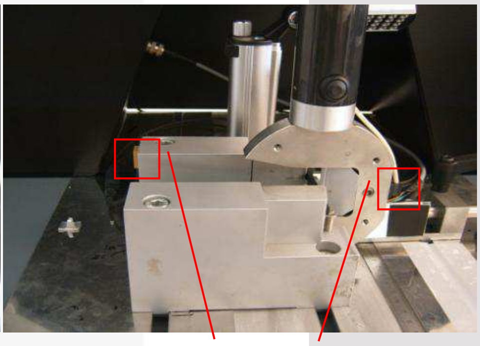
bending test on 4a Impetus

4a Impetus
dynamic bending test



dynamic 3-point-bending

testing mass: 510g and 1311g

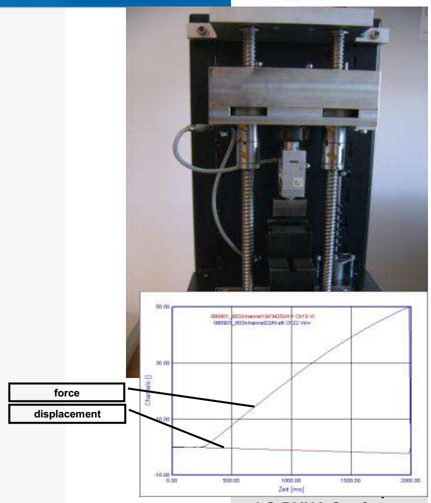
test velocity: 0.7 – 4 m/s

radius of fin and counter bearing: 2 mm

50 g acceleration sensors on pendulum and counter bearing

4a Impetus
quasi static test

- 4a Impetus is available with a in-house developed quasi static test equipment.
- The typical test velocity is about 1 mm/s.
- Alternatively an interface to standard test results recorded and evaluated with Zwick testXpert is integrated.
- So the goal is reached, to take into account the influence of strain rates less than 1 1/s for the building of the material model.



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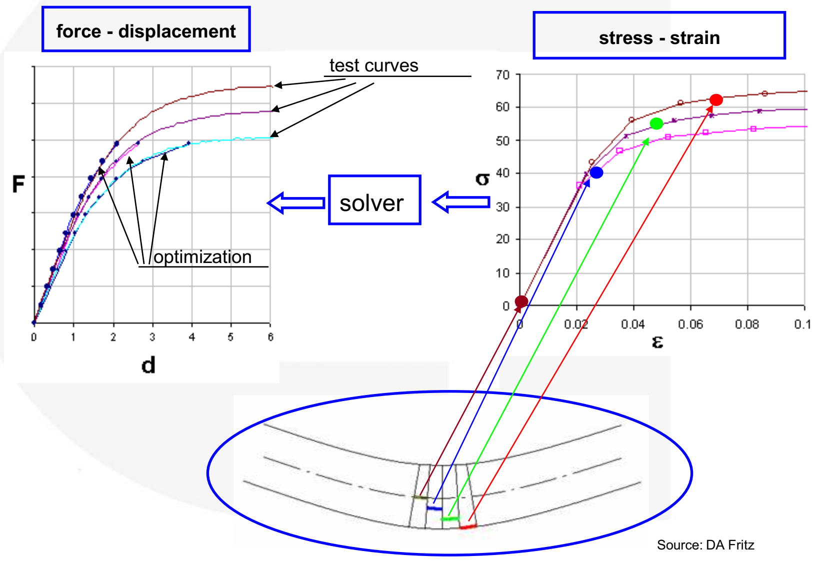
4a Impetus
optimization – reverse engineering



Source: DA Fritz

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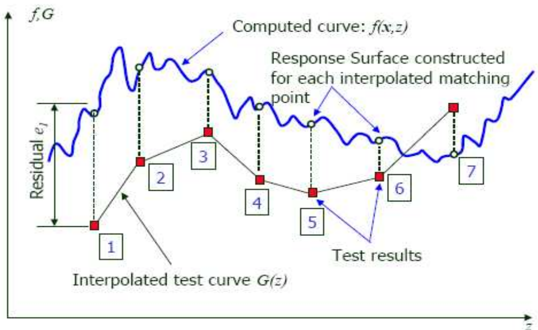
4a Impetus
optimization – reverse engineering

- minimization of the average deviation between simulation and test curves

$$\varepsilon = \frac{1}{P}\sum_{p=1}^{P} W_p\left(\frac{f_p(x)-G_p}{s_p}\right)^2 = \frac{1}{P}\sum_{p=1}^{P} W_p\left(\frac{e_p(x)}{s_p}\right)^2$$



LS-OPT® User's Manual v3.3 Mär 2008 - page 69

- essential to control the optimization process is a parameterized material card.

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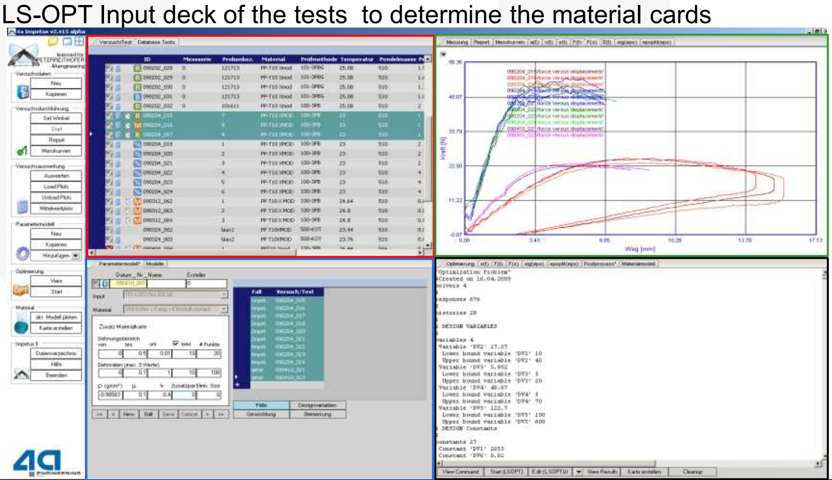
4a Impetus
graphical user interface

The whole process to determine validated material cards is included in one software solution, starting with testing up to a speed of 10 m/s and ending with automatic set up of a LS-OPT Input deck of the tests to determine the material cards



Database Tests
Evaluation Test
Database Material
Optimization

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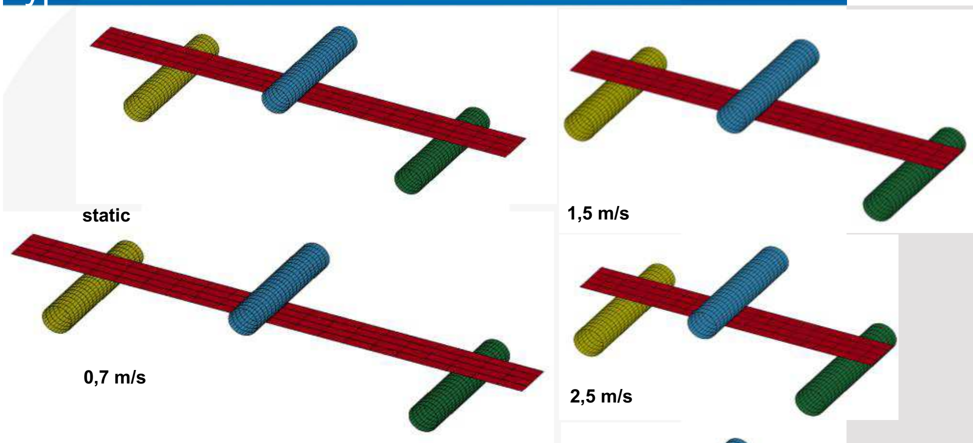
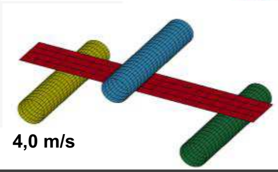
4a Impetus
typical simulation models



The models are controlled by the underlying database of the conducted tests.



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Autor: Peter Reithofer, Reinhard Hafellner, Martin Fritz
Datum: 090416
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IN PHYSICS WE TRUST

4a Impetus
implemented stress strain rules

To reproduce the measured mechanical behavior different material laws can be used, to describe the stress strain dependency.

- Bilinear - often implemented in LSDYNA material cards as two parameter law

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

- Ludwik

$$\sigma = A + B\varepsilon_p^n$$

- Bergström

$$\sigma = A + k\sqrt{1 - \exp(-0.5\,\varepsilon_p)}$$

- G'sell Jonas - well known for description of polymers with hardening [7]

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

- 4a three parameter law (modified Schmachtenberg) [7]

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

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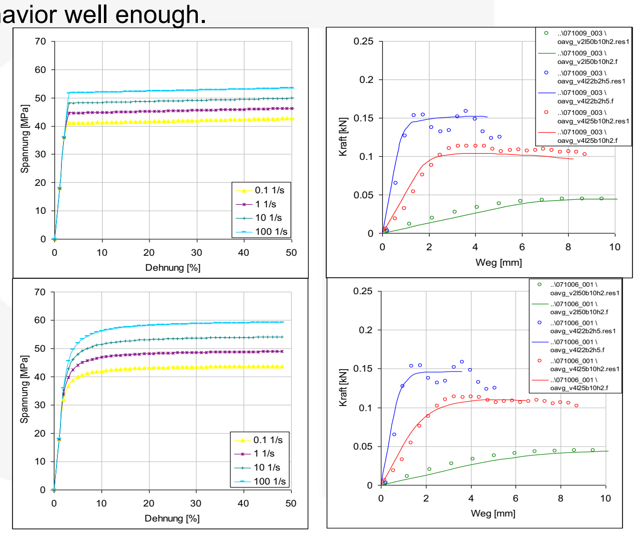
4a Impetus
implemented stress strain rules

Depending on the examined material also simple stress strain rules can reflect the material behavior well enough.

bilinear visco plastic

three parameter visco plastic



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4a Impetus
implemented strain rate rules

Different well known strain rate rules are available in 4a Impetus

- Power law – simplest law

$$\sigma = \sigma_0(\varepsilon)\,\dot{\varepsilon}^n$$

- Cowper Symonds – often implemented in LS DYNA

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

- Johnson Cook – especially for high strain rates

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

- Kang – can also rebuild low strain rates

$$\sigma = \sigma_0(\varepsilon)\left[1 + C_1\,\ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} + C_2\,\left(\ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)^2\right]$$

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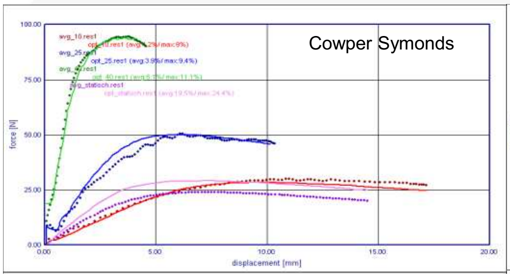
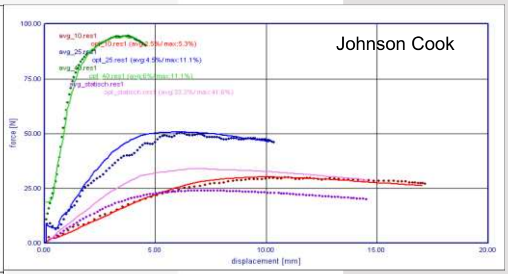
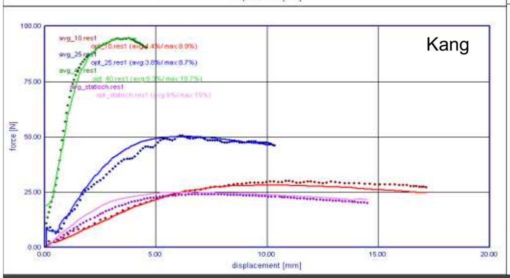
4a Impetus
implemented strain rate rules

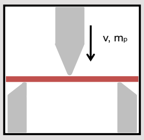
Best representation of velocity dependent measurement through Kang model







v m/s	l_w mm	m pendulum g
4	25	510
2.5	40	510
1	60	1300
0.001	50	



···· averaged test curves
— result of simulation

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DYNAmore

4a Impetus
implemented LS DYNA Material Cards

Currently the following LS DYNA material cards are implemented in the 4a Impetus system. Further material cards can be easily integrated in the material card build up process.

- Mat 24 (MAT_PIECEWISE_LINEAR_PLASTICITY)
  very fast material card. Combined with dynamic bending test this material card is a possibility to take into account an average tension/ compression behavior.
  Can be also used with LS DYNA implicit.
- Mat 81 (MAT_PLASTICITY_WITH_DAMAGE)
  like Mat 24 with the enhancement of damage model
- Mat 124 (MAT_PLASTICITY_COMPRESSION_TENSION)
  possibility to consider different Tension and Compression loading
  Only available for LS-DYNA explicit.
- Mat 187 (MAT_SAMP-1) [2][4][6]
  recent development especially for polymers,
  treat different loading cases, multi axiality and damage.
  Only available for LS-DYNA explicit. At the moment not all features are implemented in 4a Impetus.

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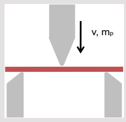
4a Impetus
different test assemblies

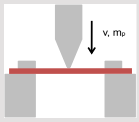
3 Point Bending test

static and dynamic (0.001 – 10 m/s)
considers tension and compression → mixed mode material cards
realistic unloading and loading → damage function can be obtained
used together with MAT 24 → fast determination and good general prediction



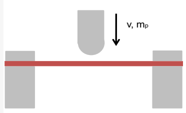
fixed 3 Point Bending test

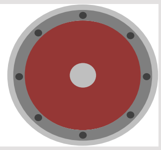
static and dynamic (0.001 – 10 m/s)
the loading case starts with bending and rapidly changes to tension dominated load case. Combined with normal 3 Point bending test
the tension and compression difference of materials can be shown.
Material Cards like MAT_PLASTICITY_COMPRESSION_TENSION can be determined.

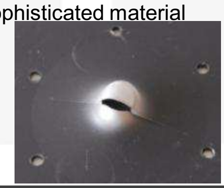


puncture test (biaxial)

static and dynamic (0.001 – 10 m/s)
ongoing work to fulfill the needs of sophisticated material models MAT_SAMP-1







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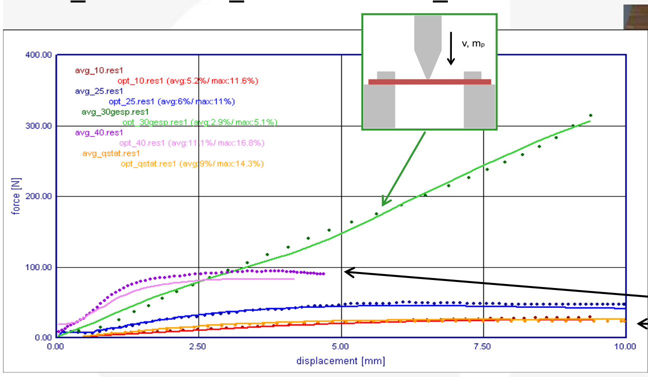
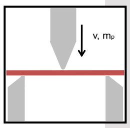
4a Impetus
different test assemblies

Showcase for the use of material cards considering different tension and compression behavior like
MAT_PLASTICITY_COMPRESSION_TENSION or MAT_SAMP-1





···· averaged test curves
— result of simulation

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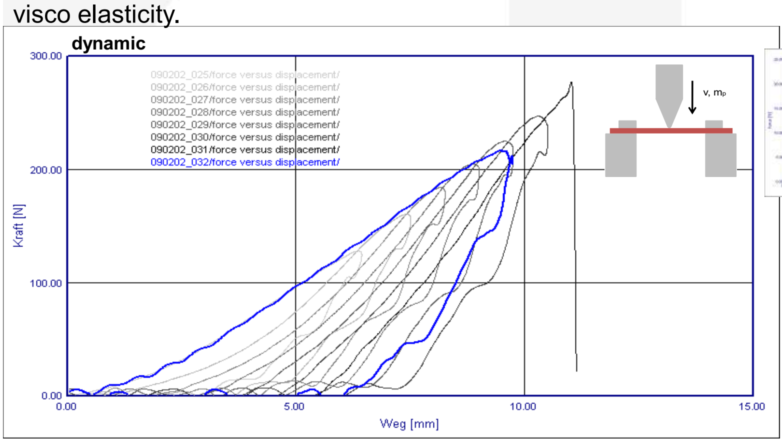
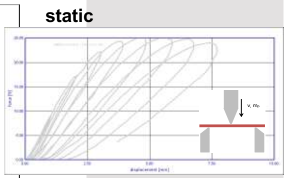
outlook
damage function

Current works engage with multiple loading and unloading in dynamic as well as in static load cases to determine an automated damage function of material models. The following picture shows multiple loading and unloading with 4a Impetus (1-2 m/s). Another important aim is to deal with visco elasticity.





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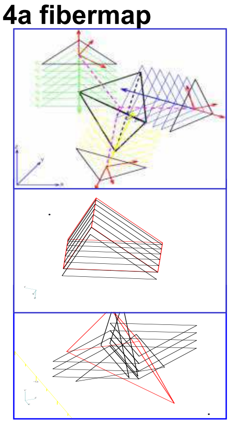
outlook
short fiber reinforced thermoplastics

It is planned to implement further standard material laws to determine orthotropic behavior

LS-Dyna Material Laws

- *MAT_ORTHOTROPIC_ELASTIC (2)
  orthotropic, elastic , no damage
- *MAT_ANISTROPIC_VISCOPLASTIC
  isotropic elastic, anisotropic visco plastic
- *MAT_ORTHO_ELASTIC_PLASTIC (108)
  orthotropic, elastic – *plastic*

4a fibermap



Combined with 4a fibermap and 4a MicroMec we see a huge leverage effect to tune up standard simulation processes.

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conclusion

LS-DYNA© has included plenty of material cards, each of them offering different scalability and complexity to describe the behavior of non-reinforced thermoplastics. The consideration of the strain rate behavior is included in many material cards, e.g. in the well known MAT_PICEWISE_LINEAR_PLASTICITY. More complex material models can also handle varying compression and tension behavior as well as unloading by using damage functions. One of the recent development results is MAT-SAMP-1 by Du Bois, Kolling, Feucht and Haufe.

For better use of the above mentioned models a huge amount of tests have to be carried out, to determine the material parameters and to represent the thermoplastic characteristics in crashworthiness simulations.

4a impetus builds up an efficient and reliable process, starting with realistic tests and finally ending up with a validated material card. Recent developments of new test methods for 4a Impetus have been presented, that satisfy the needs of complex material models as well as the expectations with regard to easy and favorable testing.

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

appendix literature

[1] **LS DYNA Keyword User Manual**
May 2007, Version 971

[2] **Mechanik der Kunststoffe**
W. Retting, Hanser Verlag 1991

[3] **Charaktersierung und Modellierung unverstärkter thermoplastischer Kunststoffe zur numerischen Simulation von Crashvorgängen**
M. Junginger, Frauenhofer EMI Bericht 15/02

[4] **Validation and Verification of Plastics under Multiaxial Loading**
A. Ratai, S. Kolling, A. Haufe, M. Feucht, P. Du Bois
7th GERMAN LS-DYNA Forum, Bamberg 2008

[5] **Characterization of Polyolefines for Design Under Impact: from True Stress / Local Strain Measurements to the F.E. simulation with LS-DYNA Mat. Samp-1**
M. Nutini, M. Vitali, 7th GERMAN LS-DYNA Forum, Bamberg 2008

[6] **A Constitutive Formulation for Polymers Subjected to High Strain Rates**
S. Kolling, A. Haufe, M. Feucht, P. Du Bois
9th International LS-DYNA User Conference

[7] **Anwendung von neuronalen Netzen für die Materialdatengener-ierung am Beispiel von Polyamid**
P. Fuchs, Institut für Werkstoffkunde und Prüfung der Kunststoffe an der Montanuniversität Leoben

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