

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

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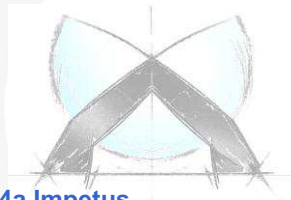
Abstract

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_PIECEWISE_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



4a Impetus
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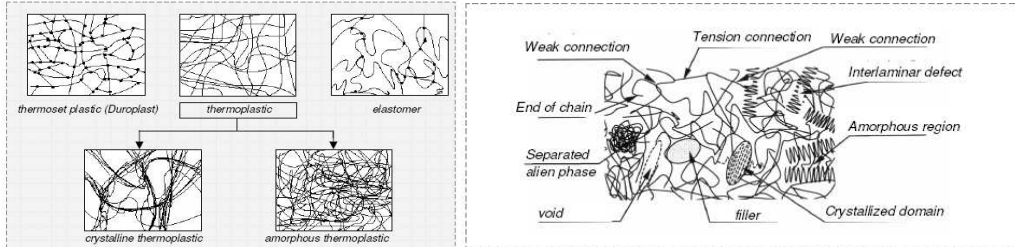
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Polymer materials general behavior [2]



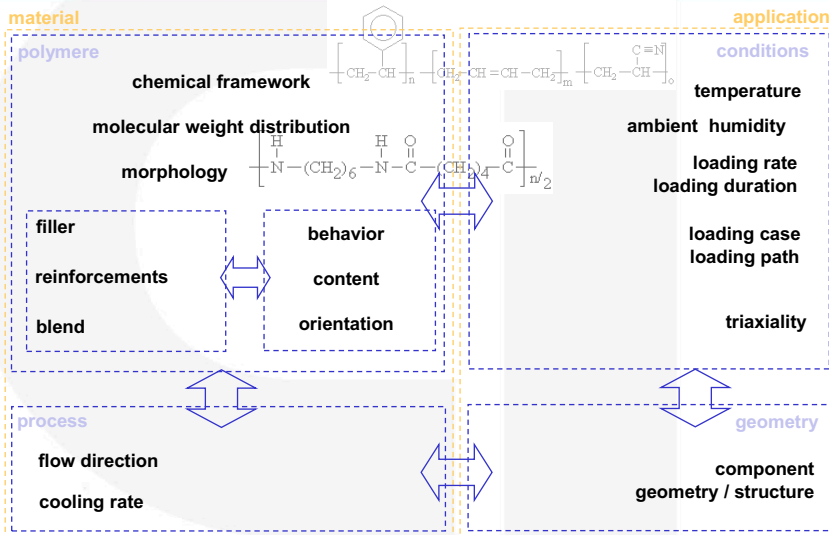
- The morphology and build up cross linking allows the distinction of three different types of polymer materials, with different mechanical characteristics.



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



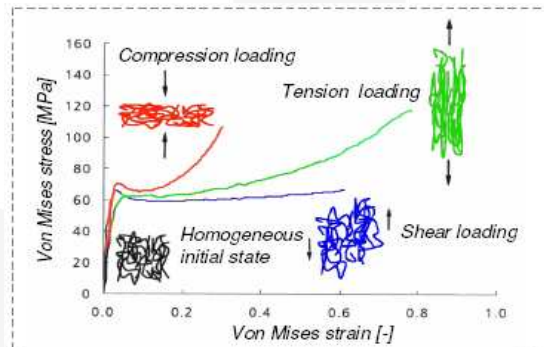
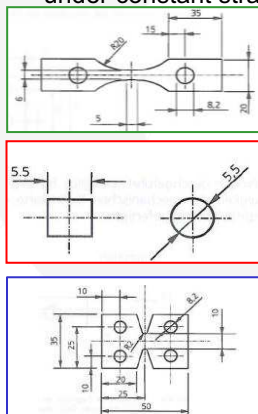
Polymer materials influences



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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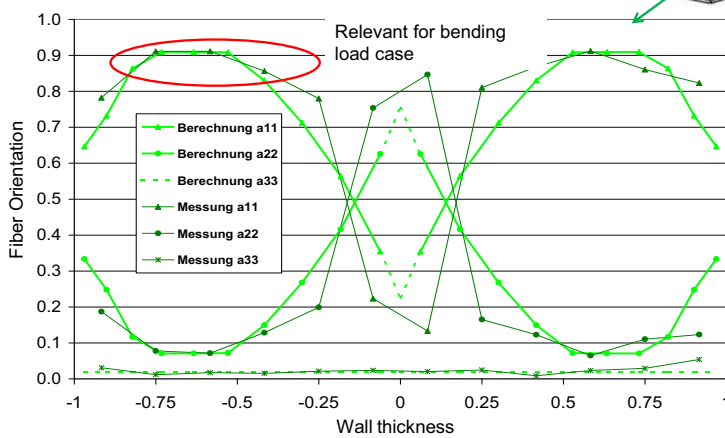
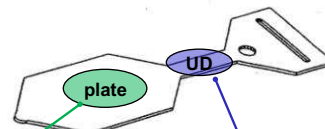
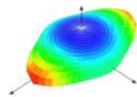
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Polymer materials influences caused by fiber reinforcement

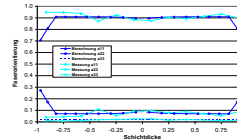


Average fiber orientation

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

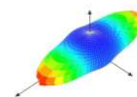


Profile over Wall thickness



Average fiber orientation

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

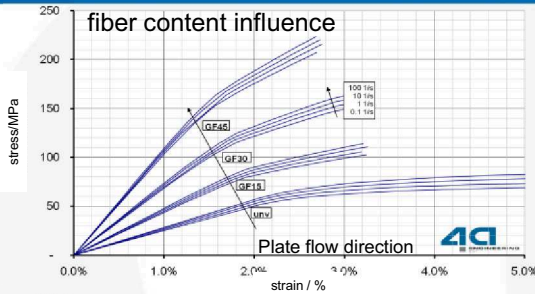


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Polymer materials influences caused by fiber reinforcement

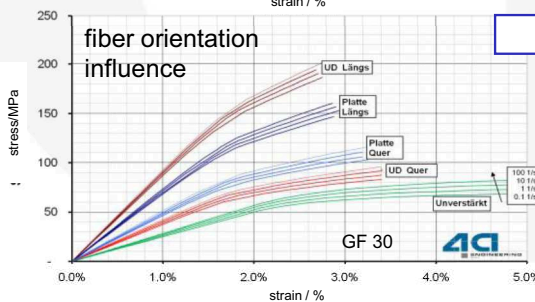


material behavior is

- 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.

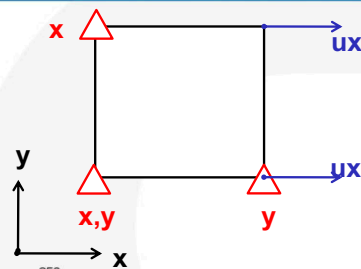


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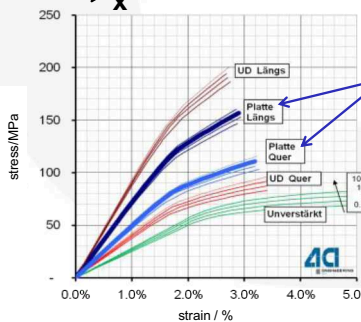
Polymer materials fiber reinforcement – standard LS DYNA materials



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

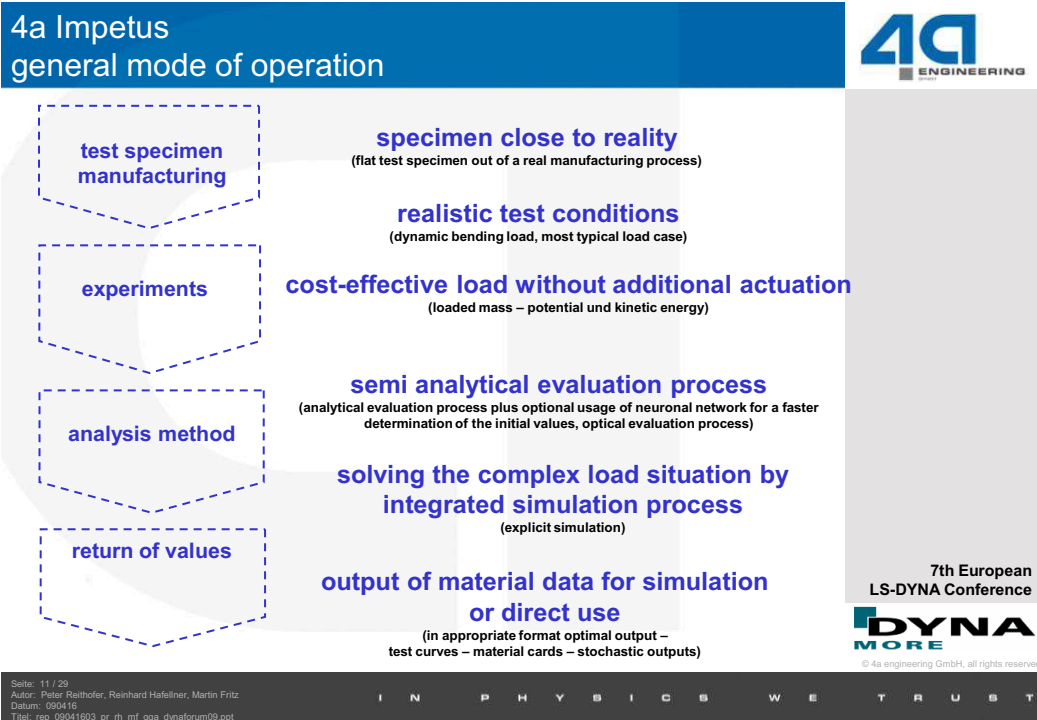
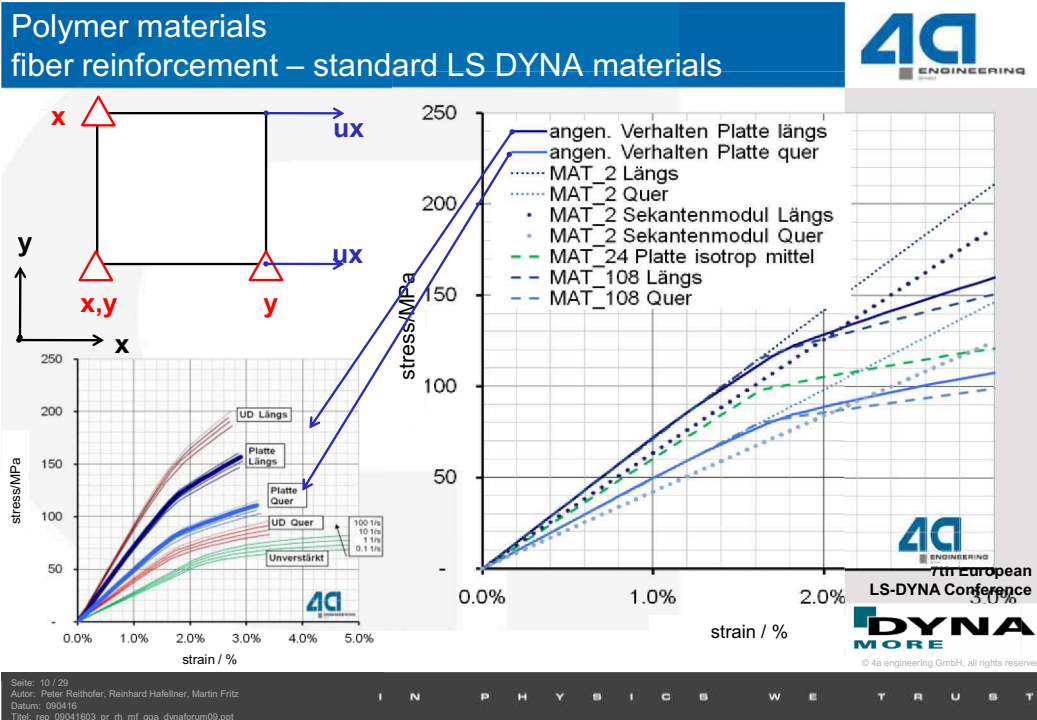
- **MAT_ORTHOTROPIC_ELASTIC (2)*
orthotropic, elastic, no damage
- **MAT_PIECEWISE_LINEAR_PLASTICITY (24)*
isotropic, elastic- visco plastic
- **MAT_NONLINEAR_ORTHOTROPIC*
orthotropic, non linear
- **MAT_ORTHOTROPIC_VISCOELASTIC*
orthotropic, visco elastic
- **MAT_ANISOTROPIC_VISCOPLASTIC*
isotropic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



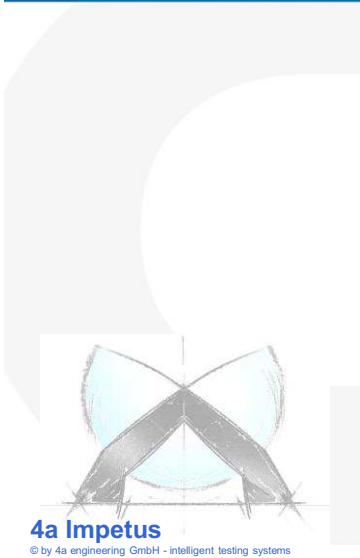
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4a Impetus dynamic tests up to a velocity of 10 m/s are possible



bending test on 4a Impetus

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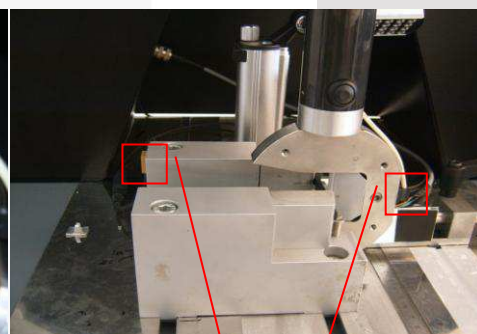


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4a Impetus dynamic bending test



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

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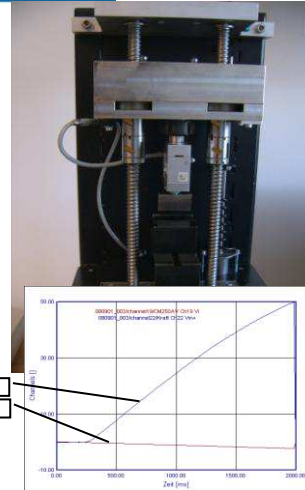
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I N P H Y S I C S W E T R U S T

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.



force
displacement

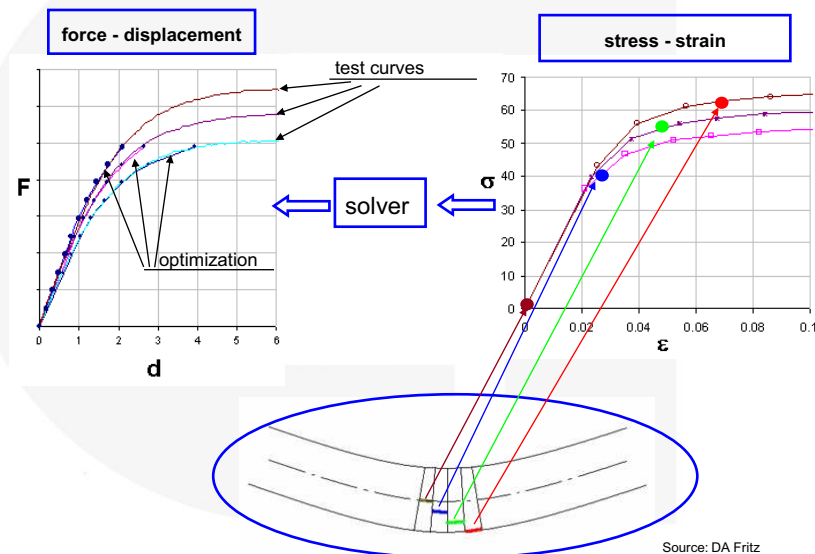


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4a Impetus optimization – reverse engineering



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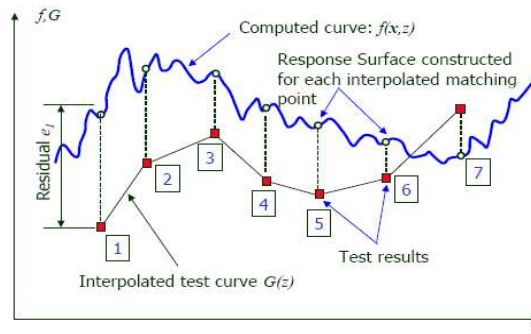
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4a Impetus optimization – reverse engineering



- 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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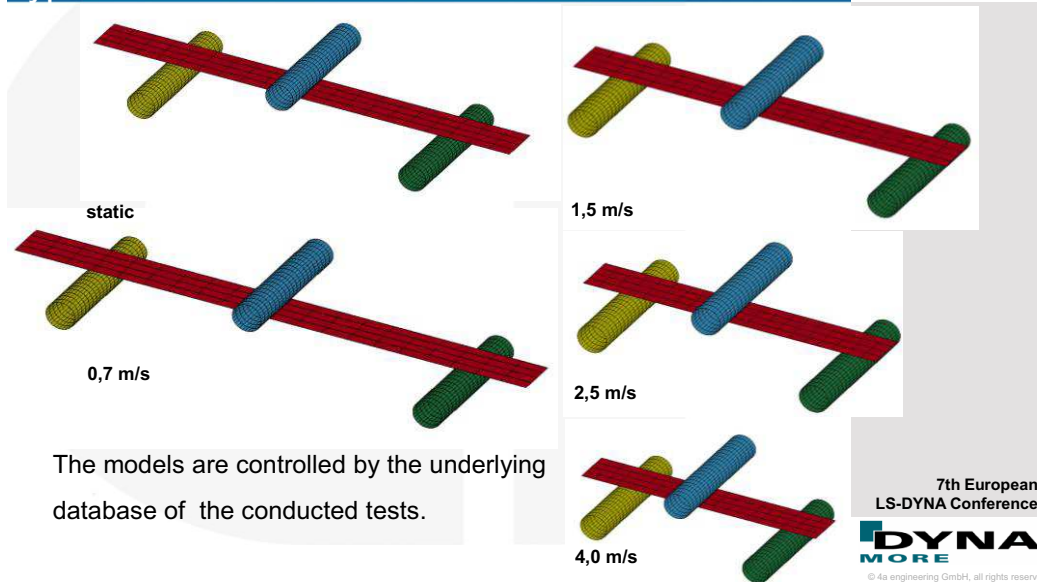


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I N P H Y S I C S W E T R U S T

4a Impetus typical simulation models



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



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]

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

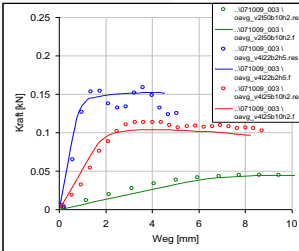
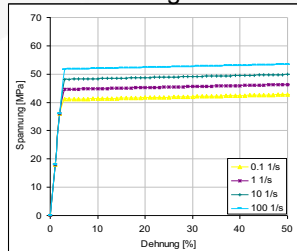


4a Impetus implemented stress strain rules

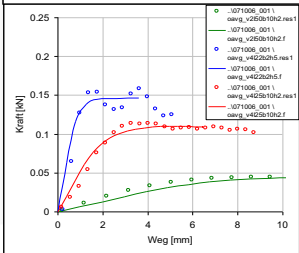
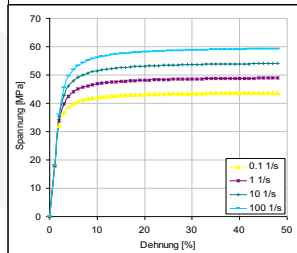


Depending on the examined material also simple stress strain rules can reflect the material behavior well enough.

**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

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

- Cowper Svmonds – often implemented in LS DYNA

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

- Johnson Cook – especially for high strain rates

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

- Kang – can also rebuild low strain rates

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

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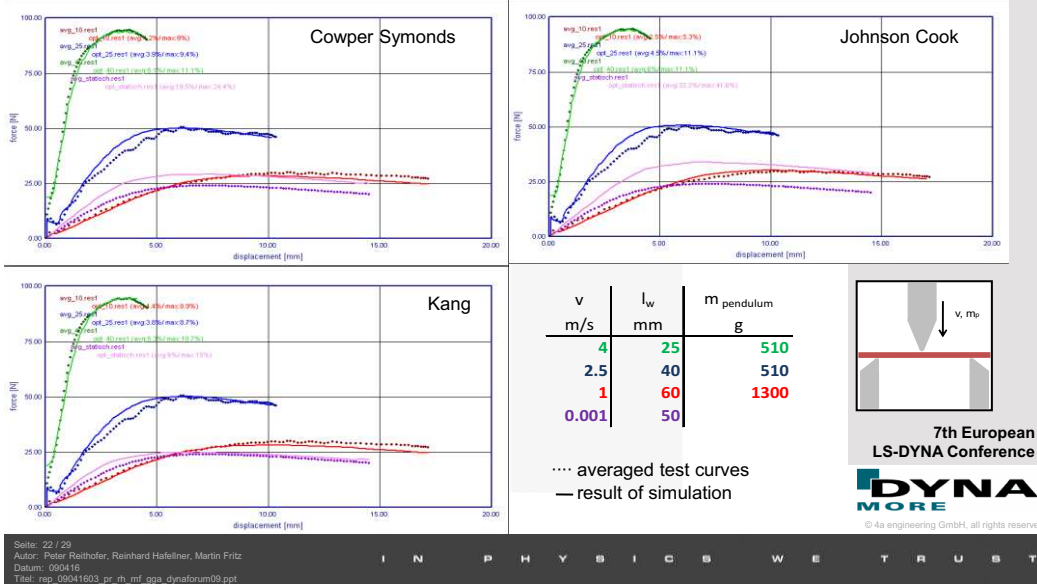
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4a Impetus implemented strain rate rules



Best representation of velocity dependent measurement through Kang model



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.



4a Impetus different test assemblies



3 Point Bending test

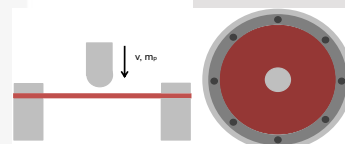
static and dynamic (0.001 – 10 m/s)
 considers tension and compression → mixed mode material cards
 realistic unloading and loading → damage function can be obtained
 used together with MAT 24 → fast determination and good general prediction

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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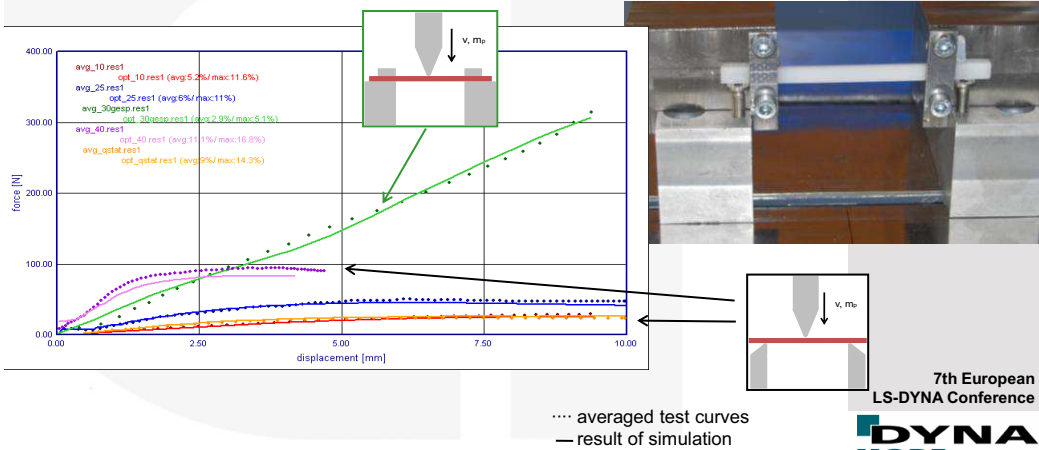


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4a Impetus different test assemblies



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



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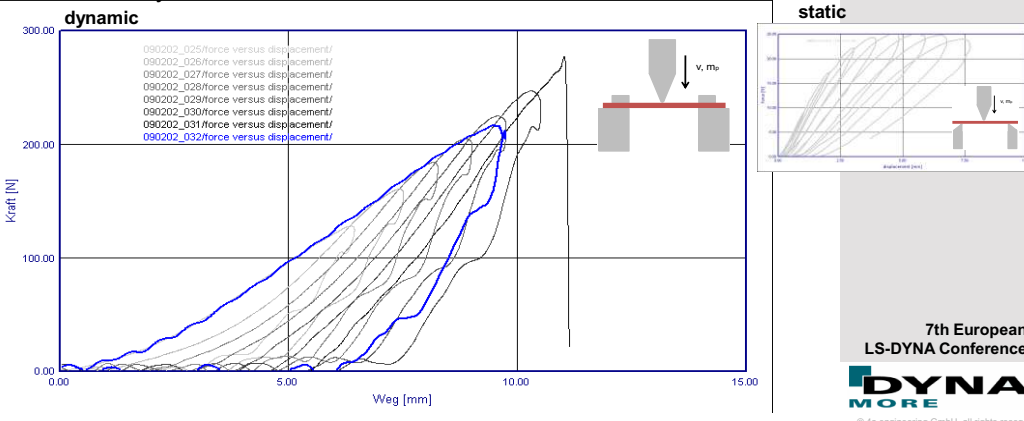


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outlook damage function



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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**DYNA
MORE**
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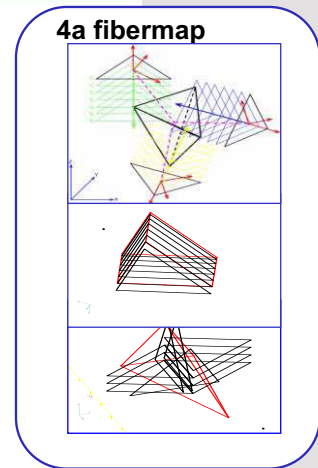
outlook short fiber reinforced thermoplastics



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



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

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MORE**
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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_PIECEWISE_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] **Charakterisierung und Modellierung unverstärkter thermoplastischer Kunststoffe zur numerischen Simulation von Crashvorgängen**
M. Junginger, Fraunhofer 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 Materialdatengenerierung am Beispiel von Polyamid**
P. Fuchs, Institut für Werkstoffkunde und Prüfung der Kunststoffe
an der Montanuniversität Leoben

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