Short and long fiber reinforced thermoplastics material models in LS-DYNA

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  - fiber orientation and content – strain rate - temperature
- *MAT_24 – typical approach
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Introduction

Characteristic Structure of reinforced Plastics

Fiber size and geometry have significant influence on the part performance. Orthotropic properties increase with increasing fiber content while at the same time the effect of strain rate diminishes due to the less content of matrix material.

Experimental tool

- Plate
- UD
- Fiber

Dependence on fiber orientation

- UD longitudinal
- Slab longitudinal
- Slab perpendicular
- UD perpendicular
- Unreinforced

Dependence on fiber content

- GF45
- GF30
- GF15
- Unreinforced
fiber reinforced thermoplastics
exemplary material behavior

- Celanese has tested three reinforced materials PP GF30, PP GF40 and PP GF50
  - at 3 temperatures
  - at 3 different orientations
  by using a quasi static device and 4a impetus device.

- The material behavior of polymers and reinforced polymers depend on many factors such as
  - Temperature
  - Fiber orientation
  - Fiber content
  - Strain rate.

The following slides show exemplary the influence of these factors onto the measurement results of the 3-point-bending test.
fiber reinforced thermoplastics
influence of fiber orientation

This diagram shows the influence of the fiber orientation of the test specimens. The stiffness for the longitudinal direction is much higher compared to the perpendicular direction and therefore higher forces are needed in the test. The failure displacement increases with the orientation. At 0° orientation failure derives from the fibers while at 90° orientation the failure is dominated by the matrix material (plastics).
This force-displacement-diagram shows the influence of the fiber content of the test specimens. The more fiber content the higher is the stiffness and the forces in the test. The failure displacement decreases with the fiber content. The reason is the same as for the fiber orientation. Having low fiber content the matrix material dominates failure while at higher amounts of fibers the failure of the fibers leads to failure of the test specimens.

Raw material data provided by Celanese

3-point-bending at 1 m/s
+23°C
longitudinal

PP GF50
PP GF40
PP GF30
fiber reinforced thermoplastics
influence of strain rate

PP GF40
3-point-bending at 1 m/s
support distance 50 mm
+23°C

This force-displacement-diagram shows the strain rate dependency of the material. With increasing strain rate the force also increases. For this test setup the dynamic tests at 1m/s have a strain rate that is 1000 times higher than the quasi-static tests at 1 mm/s. Such a strain rate dependency is typical for plastics.
This diagram shows the influence of the temperature of the test specimens. The stiffness decreases with increasing temperature resulting in much higher forces at low temperatures in comparison to higher temperatures. Also the failure displacement decreases with lower temperatures, the test specimens become more brittle.
This diagram shows the calculated material models for PP GF40 using *MAT_24. The different Young’s Moduli and stress levels for the orientations are clearly visible. The high fiber content leads to quick failure in the tests with just a small amount of plastic strain, especially for the longitudinal direction.
# Material models in LSDYNA

## Overview

<table>
<thead>
<tr>
<th>No.</th>
<th>Elastic</th>
<th>Plastic</th>
<th>Damage</th>
<th>Strain rate</th>
<th>Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Orthotropic / Anisotropic</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>*MAT_ADD_EROSION</td>
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<tr>
<td>22</td>
<td>Orthotropic</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Orientation dependent</td>
</tr>
<tr>
<td>54</td>
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<td>None</td>
<td>Elastic Orthotropic</td>
<td>Strength</td>
<td>Orientation dependent</td>
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<tr>
<td>58</td>
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<td>Strength, Stiffness</td>
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<tr>
<td>103</td>
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<td>Plasticity</td>
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<td>None</td>
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<td>Hill</td>
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<td>Plasticity</td>
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<tr>
<td>158</td>
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<td>Viscoelasticity</td>
<td>Orientation dependent</td>
</tr>
</tbody>
</table>
Material models in LSDYNA
new features MAT_002

Anisotropic elastic solution with MAT_002_ANIS

Hyperelastic (total) formulation using Green-Lagrange strain \( E \)

\[
\sigma = J^{-1} F \cdot S \cdot F^T = J^{-1} F \cdot C \cdot E \cdot F^T
\]

Elastic-anisotropic behavior, stiffness matrix with 21 independent coefficients:

\[
C = \begin{bmatrix}
C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\
C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\
C_{33} & C_{34} & C_{35} & C_{36} \\
C_{44} & C_{45} & C_{46} \\
C_{55} & C_{56} \\
C_{66}
\end{bmatrix}
\]

Several possibilities to define material directions, e.g. AOPT, ELEMENT_SOLID_ORTHO, ...

Use invariant node numbering is recommended \( \rightarrow *\text{CONTROL\_ACCURACY: INN=4} \)

No plasticity, no damage, no failure (but: brittle failure possible via *MAT_ADD_EROSION)
Material models in LSDYNA
new features MAT_002

<table>
<thead>
<tr>
<th>CARD #</th>
<th>mid</th>
<th>ro</th>
<th>c11</th>
<th>c12</th>
<th>c22</th>
<th>c13</th>
<th>c23</th>
<th>c33</th>
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<td>CARD #2</td>
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<td>c24</td>
<td>c34</td>
<td>c44</td>
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<td>c25</td>
<td>c35</td>
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<td>c16</td>
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<td>yp</td>
<td>zp</td>
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<td>a2</td>
<td>a3</td>
<td>macf</td>
<td>ihis</td>
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<td>v2</td>
<td>v3</td>
<td>d1</td>
<td>d2</td>
<td>d3</td>
<td>beta</td>
<td>ref</td>
</tr>
</tbody>
</table>

- $C_{ij}$: constants in the 6x6 anisotropic constitutive matrix $\sigma_{ij} = C_{ijkl}\varepsilon_{kl}$
- AOPT: usual options to define the material's coordinate system
- ihis: flag for element-wise definition of the stiffness tensor with *INITIAL_STRESS_SOLID. This allows mapping of locally anisotropic data.

Old approach: each element one material card

New approach: one property *INITIAL_STRESS_SHELL (SOLID)
Material models in LSDYNA
combination of material models

Approaches in literature

- **MAT54 + MAT108**
  - Spritzgussbauteile aus kurzfaserverstärkten Kunststoffen: Methoden der Charakterisierung und Modellierung zur nichtlinearen Simulation von statischen und crashrelevanten Lastfällen, Julian Schöpfer, Institut für Verbundwerkstoffe GmbH, Dissertation 2011
    [http://www.dynamore.de/de/download/papers/forum10/papers/F-IV-03.pdf](http://www.dynamore.de/de/download/papers/forum10/papers/F-IV-03.pdf)

- **MAT_157 = MAT_002 + MAT_103**
  - R. Jennrich: Experimentelle und numerische Untersuchung eines kurzglasfaserverstärkten Kunststoffes, Dynaforum 2014, Bamberg
Material models in LSDYNA
new features MAT_157

IP-wise Initialization

*MAT_157: Selective mapping IHIS

\[ IHIS = a_0 + 2a_1 + 4a_2 + 8a_3 \]

<table>
<thead>
<tr>
<th>FLAG</th>
<th>Description</th>
<th>Variables</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_0$</td>
<td>Material directions</td>
<td>$q_{11}, q_{12}, q_{13}, q_{31}, q_{32}, q_{33}$</td>
<td>6</td>
</tr>
<tr>
<td>$a_1$</td>
<td>Anisotropic stiffness</td>
<td>$C_{ij}$</td>
<td>21</td>
</tr>
<tr>
<td>$a_2$</td>
<td>Anisotropic constants</td>
<td>$F, G, H, L, M, N$</td>
<td>6</td>
</tr>
<tr>
<td>$a_3$</td>
<td>Stress-strain curve</td>
<td>$LCSS$</td>
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</tr>
</tbody>
</table>

*INITIAL_STRESS_SOLID: NHISV

- In addition to 6 stress values and eps NHISV history variables can be initialized
- NHISV must correspond to the $a_i$ that define IHIS in *MAT_157

\[ NHISV = 6a_0 + 21a_1 + 6a_2 + 1a_3 \]
Material models in LSDYNA simulation process chain

Available simulation process chain for injection molded parts

- **Injection molding** (Moldflow, Moldex, ...)
- **Micromechanic modeling** (4a micromec, ...)
  
  **Fiber orientation**
  
  \[
  \begin{bmatrix}
  0.66 & 0 & 0 \\
  0 & 0.32 & 0 \\
  0 & 0 & 0.02 
  \end{bmatrix}
  \]

- **Mapping** (4a fibermap, ...)
  
  **In plane mapping**

- **Crash Simulation** (LS-DYNA)
  
  **orientations**
  
  *ELEMENT_SHELL_BETA
  
  *ELEMENT_SHELL_COMPOSITE
  
  *INITIAL_STRESS_SHELL(SOLID)
  
  *ELEMENT_SOLIDORTHO

  **standard material models**
  
  *MAT_(ANISO)TROPIC_ELASTIC
  
  *MAT_ANISOTROPIC_ELASTIC_PLASTIC
Material models in LSDYNA simulation process chain

- Available simulation process chain for injection molded parts

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**Moldflow Results**

- 0 - All

1610 Fill time / [s] / NDDT
1760 Pressure at V/P switchover / [MPa] / NDDT
1770 Temperature at flow front / [°C] / NDDT
1600 Density / [g/cm³] / NDDT / Time
1900 Extension rate / [1/s] / NDDT / Time
4021 Fiber orientation tensor / [ ] / NDDT
1630 Freeze time / [s] / NDDT
1180 Pressure / [MPa] / NDDT / Time
1584 Shear rate / [1/s] / NDDT / Time
1537 Shear rate, maximum / [1/s] / NDDT / Time

**Export**

- Clear List
- Load List
- Save List

---

*ELEMENT_SHELL_BETA

**Prefix**

**Main**

<<ID;0D8S>><<1;0D8S>><<Nd1;0D8S>><<Nd2;0D8S>><<Nd3;0D8S>><<Nd4;0D8S>><<0.0;1D16S>><<0.0;1D16S>><<0.0;1D16S>><<theta;5D16S>>

**Main**
Material models in LSDYNA
4a impetus process

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

Element orientation e.g.
*ELEMENT_SHELL_BETA

Material angle

FE-Model of the test
Parameterized Materialcard
based on 4a micromec

LS DYNA©
Reverse Engineering

ORIENTATION
e.g. 0°, 45°, 90°

DATABASE
measurement, models

LS PREPOST©

© 4a engineering GmbH - intelligent testing systems
FE-Model of the test
Parameterized Materialcard
based on 4a micromec
Reverse Engineering

LS DYNA©
Material models in LSDYNA
Comparison on PPGF40 (MAT_002)

Orthotropic material models without plasticity or damage (MAT_002, MAT_022) can reproduce the longitudinal direction, but are too stiff in perpendicular direction.
Orthotropic material models with plasticity and rate dependence (MAT_157) can reproduce both directions.
Conclusion

- Orthotropic material models without plasticity or damage (MAT_002, MAT_022) can reproduce the longitudinal direction, but are too stiff in perpendicular direction.

- Orthotropic material models with plasticity (Mat_108) can reproduce both direction but since plastics are rate dependent there is a need to take an average strain rate for the material parameters.

- Orthotropic material models with plasticity and rate dependence (MAT_157) can reproduce both directions.

- Orthotropic material models with damage (MAT_054, MAT_058, MAT_158) can reproduce both directions. MAT_054 and MAT_058 can have rate dependent damage.

- Outlook: MAT_058 with new possibilities for strain rate dependent orthotropic elasticity
Veranstaltungshinweis


Das Thema heuer lautet „Leichtbau und Composites“.

Nähere Informationen sind demnächst auf der Homepage http://technologietag.4a.co.at/ verfügbar.
Vielen Dank für die Aufmerksamkeit
Literatur


