Material Models For Thermoplastics In LS-DYNA®
From Deformation To Failure

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Detroit 12.6.2018
AGENDA

- introduction 4a
- motivation
- material models
- material characterization
- ...
- Summary & Outlook
4a engineering

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

- efficient high-dynamic testing
- dynamic material behaviour
- plastics, foams, composites, …
- validated material cards ready to use for your crash-simulation
intelligent reliable solutions for plastics, composites, metals, foams, ...

**Valimat**
- Triaxiality $\sigma_{vm}$
- Damage/Failure $\varepsilon_p$
- Anisotropic $\Phi_p$
- Hardening $\eta$

**Fibermap**
- Individual mapping process information

**Micromec**
- 3D anisotropic material cards

**Impetus**
- Efficient dynamic testing

from test to validated material cards
Commonly Used Material Models For Plastics

- **MAT_024 - The workhorse** (*MAT_081,*MAT_089,*MAT_123, …)
- **MAT_124 - The hidden**
- **MAT_187 - The plastic expert**

<table>
<thead>
<tr>
<th>Material model</th>
<th>Yield surface</th>
<th>Visco-elasticity</th>
<th>Visco-plasticity</th>
<th>comp./tension symmetry</th>
<th>plastic Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAT_024</strong></td>
<td>von Mises</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>MAT_124</strong></td>
<td>2x von Mises</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>MAT_187</strong></td>
<td>General over triaxiality</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Ph.D-thesis of F. Kunkel

- Injection molded PP T16 (Hostacom XBR 169G)
- specimen milled out in W0 and W90
- classical static and dynamic tests with DIC

The Old School - material characterization as described in the material model

- Tensile
- Shear
- Compression

comparison IMPETUS™ bending
Characterizing mechanical deformation behavior of plastics

**The Old School** - material characterization as described in the material model

→ no constant loading (triaxiality) and strain rate

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P. Reithofer, pres_18061101_pr_eng_INTLSDYNA+P224+PLASTIC
efficient dynamic testing
2004 - motivation

material variety

bending load case

Source: R. Luijikx - Kunststoffmaterialien in der Interieur Funktionsauslegung bei Audi AG, 4a Technologietag 2010
efficient dynamic testing

- desktop testing device
- instrumented high speed testing
  - acceleration → force / displacement
- impact velocity 0.5 – 4.5 m/s
- maximum energy 50 J
efficient dynamic testing

Universal static testing

<table>
<thead>
<tr>
<th>Force [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>15</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>35</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>45</td>
</tr>
<tr>
<td>50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Displacement [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>15</td>
</tr>
<tr>
<td>20</td>
</tr>
</tbody>
</table>

W0, 23°C

0.1 mm/s  
1 mm/s  
1 m/s  
4 m/s

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P. Reithofer, pres_18061101_pr_eng_INTL0DYNAR+P224+PLASTIC
reverse engineering

Mean Squared Error

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

Source: Dynamic Material Characterization Using 4a impetus – PPS Conference 2015, Graz
reverse engineering

Source: Dynamic Material Characterization Using 4a impetus – PPS Conference 2015, Graz
from test to material card

*MAT_024

static
dynamic

\[ \sigma_{vm} \]

\[ \varepsilon_p \]

Hardening
from bending → \textit{MAT}_024

···· averaged test curves
— result of simulation

Component

Asymmetry

Strainrate

Yield

Young’s Modulus

Starting parameter

force [N]
displacement [mm]

\[
v_0 \quad [\text{m/s}]
\]

\begin{align*}
0.0001 & \quad 0.001 \\
1 & \quad 4
\end{align*}

\[
\text{Young’s Modulus}
\]

\[
\text{Yield}
\]

\[
\text{Starting parameter}
\]

\[
\text{Asymmetry}
\]

\[
\text{Component}
\]
from bending → *MAT_024

<table>
<thead>
<tr>
<th>( v ) [m/s]</th>
<th>span [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0001</td>
<td>40</td>
</tr>
<tr>
<td>0.001</td>
<td>40</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
</tr>
</tbody>
</table>

- averaged test curves
- result of simulation

resulting yield curves

<table>
<thead>
<tr>
<th>( \dot{\varepsilon} )</th>
<th>( \varepsilon )</th>
<th>( \sigma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \varepsilon_1 )</td>
<td>( \sigma_1 )</td>
<td>( \varepsilon_2 )</td>
</tr>
</tbody>
</table>

---

Component

Asymmetry

Strainrate

Starting parameter

Young’s Modulus

Yield

---

IN PHYSICS WE TRUST
from test to material card
from tension bending $\rightarrow$ *MAT_124/187

- averaged test curves
- result of simulation

<table>
<thead>
<tr>
<th>Component</th>
<th>Asymmetry</th>
<th>Strainrate</th>
<th>Yield</th>
<th>Young’s Modulus</th>
<th>Starting parameter</th>
</tr>
</thead>
</table>

$V_0 = \begin{cases} 
4 & 
\text{Dynamic tension bending (clamped bending)} \\
0.001 & 
\text{static tensile} 
\end{cases}$
MPIP - comparison of results

![Graphs showing force vs. displacement for different materials and conditions.](image-url)
from test to material card
efficient dynamic testing

- Different load cases
  - Bending
  - Tension Bending
  - Compression
  - Puncture
  - Component
  - ...

- High speed camera
  - Sync. recording

- Maximum energy 50 J

- Material Card
  Deformation $\rightarrow$ Failure
Injection mold for material characterization

- DOM & Wall thickness
- Melt- & Weldlines
- Plate 120 x 80 x 2 mm
- Multi-Specimen & Rib & Component
MPIP – from failure → *MAT_ADD_EROSION

- Component
- Strainrate
- Yield
- Young’s Modulus
- Starting parameter
- FAILURE

<table>
<thead>
<tr>
<th>Strainrate</th>
<th>Failure</th>
<th>Trend</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 mm/s</td>
<td>1.0 mm/s</td>
<td>4.0 mm/s</td>
<td>9.0 mm/s</td>
</tr>
<tr>
<td>0.3 mm/s</td>
<td>1.2 mm/s</td>
<td>4.2 mm/s</td>
<td>9.2 mm/s</td>
</tr>
</tbody>
</table>

- Force [N]
- Stress [MPa]
- Strain [%]
- Displacement [mm]
from failure → Validation on component
from test to material card

**Triaxiality**

**Deformation → Failure**

**Creep → Static → Crash**

**ISOTROPIC → ANISOTROPIC**

**Hardening**

**Anisotropic**

**Damage/Failure**
Summary & Outlook

- advantages micro mechanical approach
  - model understands \textit{fiber orientation, aspect ratio}
  - simulation process chain considering local anisotropy \textit{process \rightarrow structural}

- Validation results (coupon and component level)
  - Good correlation in deformation behavior
  - promising results in capturing failure \textit{\rightarrow improvement post failure especially shells}

- Outlook
  - failure/damage \rightarrow further research
  - DIC measurement – biaxial behavior
  - Usage for endless fiber reinforced materials
Outlook - Dynamic tensile testing