Failure models for plastics - material characterization for *MAT_ADD_EROSION (DIEM)

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Content

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- Failure models
- Measurement possibilities using 4a impetus
- Material modeling
- Validation
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Introduction

- Plastics in automotive pedestrian protection show different deformation and fracture behavior \(\rightarrow\) **Energy absorption**
- Failure is a function of load type, time, temperature, processing, …

Failure Models in LS-Dyna

Constant plastic strain

- Standard – simple

Plastic strain as function of strain rate

Constant plastic strain + damage evolution

- None standard - simple

Failure as function of triaxiality and strain rate

Many well known failure criteria for ductile materials [3]

- Tresca or maximum shear stress criterion
- von Mises yield criterion
- Gurson yield criterion for pressure-dependent metals
- Hosford yield criterion
- Hill yield criteria
- various criteria based on the invariants of the Cauchy stress tensor

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Failure Models for Plastics
DIEM-Model

- Failure surface in dependence of triaxiality and strain rate

Reverse engineering

4a impetus

Highspeed measurement
Parameterized material card
FE-Model of the tests
Solver
Setup
8 parameters
Finish
Verification
1 design
Domain reduction (SRSR)
Termination criteria
10 iterations
Optimization
1 objective
6 constraints
Composites
4 definitions
Build Metamodels
Sampling case_3PBEP
2 vars, 5 opt. designs
case_3PBEP_453g_1m
7 vars, 10 histo, 2 reps

(Failure) Measurement Possibilities using 4a impetus

Test specimens, test setup

3-point bending 0.1 mm/s - 4.5 m/s

Clamped bending - 4.5 m/s

T-specimen (rib) 0.1 mm/s - 4.5 m/s

Puncture test 0.1 mm/s - 4.5 m/s
Simulation Possibilities using 4a impetus
Test specimens, test setup

3-point bending 0.1 mm/s - 4.5 m/s
T-specimen (rib) 0.1 mm/s - 4.5 m/s

Clamped bending - 4.5 m/s
Puncture test 0.1 mm/s - 4.5 m/s
Measurement Possibilities using 4a impetus
High-speed camera

- **Visualization of dynamic failure behavior** of the material during test (crack initiation and propagation)
- Easy view, different angles possible
- Trigger signal from 4a impetus → **synchronizing**
<table>
<thead>
<tr>
<th>Load cases</th>
<th>Plasticity</th>
<th>Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Complex yield surface</strong></td>
<td><strong>Classical approach</strong></td>
</tr>
<tr>
<td>static, dynamic (2x)</td>
<td></td>
<td><img src="image" alt="Graph" /></td>
</tr>
<tr>
<td>static</td>
<td></td>
<td>Should be done with DIC (difficult at high strains !)</td>
</tr>
<tr>
<td>static</td>
<td></td>
<td>Typical no failure for plastics</td>
</tr>
<tr>
<td>static</td>
<td></td>
<td>Typical failure under tension</td>
</tr>
<tr>
<td>static (2x), dynamic (3x)</td>
<td></td>
<td>Only brittle materials, no failure for ductile materials</td>
</tr>
<tr>
<td>dynamic</td>
<td></td>
<td>4a impetus approach</td>
</tr>
<tr>
<td>static, dynamic</td>
<td></td>
<td>reverse engineering</td>
</tr>
<tr>
<td>static, dynamic</td>
<td></td>
<td>reverse engineering</td>
</tr>
</tbody>
</table>
Reverse engineering process with 4a impetus [7]

- **3-point-bending**

  - Static behavior - yield
  - Dynamic behavior - strain rate

- **Fit compression/tension behavior**

- **Check compression/tension behavior**

- **Clamped bending**

- **3-point-bending clamped**
Material Modeling – Validation

Validation for *MAT_SAMP-1

Validation on further tests (*MAT_SAMP-1) [7]

- Tensile test static
- T-specimen 2 m/s
- Clamped bending 4 m/s

(normalized displacement vs. normalized force)

- Simulation
- Mean value test curves
Failure Models for Plastics

DIEM-Model

- DIEM: Damage Initiation and Evolution Model [6]
- Base: Standard material model (e.g. *MAT_SAMP-1)
- 3 individual criteria can be used:
  - Ductile criterion: \( \varepsilon^p_D = \varepsilon^p_D (\eta, \dot{\varepsilon}^p) \)
  - Shear criterion: \( \varepsilon^p_D = \varepsilon^p_D (\theta, \dot{\varepsilon}^p) \)
  - Instability criterion: \( \varepsilon^p_D = \varepsilon^p_D (\alpha, \dot{\varepsilon}^p) \) \( \alpha = \frac{\dot{\varepsilon}^{\text{min}_\text{or}}}{\dot{\varepsilon}^{\text{maj}_\text{or}}} \)
  - After initiation the damage evolution occurs:
    \[ \sigma = (1 - D)C^{ep} : \varepsilon \]
Evaluation of the failure strains

- strain rate = 0.01 s⁻¹
- strain rate = 1 s⁻¹
- strain rate = 100 s⁻¹
### Failure models

- **GUI – different possibilities to setup failure models**

#### Material behaviour

<table>
<thead>
<tr>
<th>Material source</th>
<th>Implemented</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elasticity</td>
<td>Linear isotropic elastic</td>
</tr>
<tr>
<td>Plasticity</td>
<td>Yes</td>
</tr>
<tr>
<td>Failure/Damage</td>
<td>Yes</td>
</tr>
<tr>
<td>Material card</td>
<td>*MAT_SAMP-1 (*MAT_107)</td>
</tr>
</tbody>
</table>

**Material properties**

- **Damage/Failure case**
  - Add Erosion DEEM

- **Material card id**
  - None
  - Plastic strain
  - Add Erosion

- **Function (Hardening, Elastic curve form)**
  - Curve 1
  - Curve 2
  - Scale curve 1

- **Strain rate dependency**
  - Table

- **Strain rate dependency**
  - Table

- **Fracture**
  - Johnson-Cook

- **Ductile Damage Settings**
  - lower triax value: -0.99
  - upper triax value: 0.99
  - step size triax: 0.33

- **Shear Damage Settings**
  - None

- **FLC Damage Settings**
  - None

- **Plasticity**
  - Add Erosion

- **Strainrate Settings**
  - Johnson-Cook

- **Postfailure**
  - Johnson-Cook
  - Mohr-Coulomb

- **Load cases**
  - Fracture Energy (TSAX)

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#### Postfailure

- **GroupName: 51_failure**
  - xf_NUM...
  - fd_BC
  - fd_C
  - fd_SHC
  - fd_SHT
  - fd_T
  - fd_BT

- **GroupName: 52_failure**
  - fv_scale
  - fv_epspkt
  - fv_epsp_

- **GroupName: 53_postfailure**
  - pf_QBC
  - pf_QC
  - pf_QSHC
  - pf_QSH
  - pf_QT
  - pf_QBT

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#### Triaxiality

- **Triaxiality**

#### Strain rate dependency

- **Strain rate dependency**

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#### Post failure

- **Post failure**

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**4a impetus**
GUI – different possibilities to setup failure models

- Density
- Plasticity
- Function (Hardening, Elastic curve form)
- traumatic
- Strain rate dependency
- Triaxiality

Loadcases
- Case name
- Test
- Optimization
- Weighting case

Ductile Damage Settings
- lower triax value
- upper triax value
- step size triax
- Shear Damage Settings
- FLC Damage Settings
- Strainrate Settings
- Postfracture
- Fracture energy (TSHAX)

Equation:
\[ f_d^{JC D_1} + f_d^{JC D_2} \cdot e^{-f_d^{JC D_3} \cdot \eta} \]
Failure Modeling - Validation
*MAT_SAMP-1 with *MAT_ADD_EROSION

- 3-point-bending, 4 m/s, unfiltered curves
- The test curves are matched very well [7]
Dynamic puncture test, 6.3 m/s
The test curves are matched very well [7]
Failure Modeling - Validation
*MAT_SAMP-1 with *MAT_ADD_EROSION

- Dynamic puncture test with the part, 4.3 m/s
- The test curves are matched very well [7]

Example: 30 measurements for both materials (30 users)
Failure probability: 20% and 80%
Material behavior of plastics depends on load type, time, temperature, processing, …

Easy evaluation of failure at high strain rates → Clamped 3-point-bending tests and puncture tests on 4a impetus

*MAT_SAMP-1 + *MAT_ADD_EROSION → material can be reproduced best possible and close to reality

The reverse engineering process to determine the material parameters using 4a impetus works properly

The latest software release of 4a impetus includes up to date failure modeling → accurate material modeling
Thank you for your attention!

Wednesday, 8:30: Workshop: MPIP – Material Parameter Identification Process with 4a impetus

Thursday, 8:55: *MAT_4A_MICROMEC – Theory and Application Notes

Thursday, 11:30: Biotex BigBag Simulation – LS-Dyna Airbag Tool – Unusual Application

15th TECHNOLOGIETAG

28th February – 1st March 2018
in Schladming, Austria

„Plastics – Testing and Simulation”
further information: http://technologietag.4a.co.at/