Validation of a SAMP-1 Material Card for Polypropylene-based Materials

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Scheme of the Presentation

• LyondellBasell is…

• SAMP1- is… (brief history from literature)

• Basic SAMP-1 inputs.

• Advanced modeling with SAMP-1: damage

• Validation on a prototypal part
World-Class Scale With Leading Market Positions

<table>
<thead>
<tr>
<th>Products</th>
<th>Global Position</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chemicals</strong></td>
<td></td>
</tr>
<tr>
<td>Ethylene</td>
<td>#5</td>
</tr>
<tr>
<td>Propylene</td>
<td>#5</td>
</tr>
<tr>
<td>Propylene Oxide</td>
<td>#2</td>
</tr>
<tr>
<td><strong>Polymers</strong></td>
<td></td>
</tr>
<tr>
<td>Polyolefins (PE + PP)</td>
<td>#1</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>#1</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>#4</td>
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<tr>
<td>Polypropylene Compounds</td>
<td>#1</td>
</tr>
<tr>
<td><strong>Fuel</strong></td>
<td></td>
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<tr>
<td>Oxyfuels</td>
<td>#1</td>
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<tr>
<td><strong>Technology and R&amp;D</strong></td>
<td></td>
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<tr>
<td>Polyolefins Licensing</td>
<td>#2</td>
</tr>
</tbody>
</table>

Note: Positions based on LyondellBasell wholly owned capacity and pro rata share of JV capacities as of December 31, 2012.
LyondellBasell Fast Facts

- One of the world’s largest plastics, chemicals and refining companies with revenues of $45 billion (2012)
- Global reach that addresses worldwide customer needs
- 58 manufacturing sites in 18 countries on five continents
- Sales in more than 100 countries
- Vertically integrated facilities enable conversion of crude hydrocarbons to materials for advanced applications
- Participation in 16 significant manufacturing joint ventures, 11 of which are outside of Western Europe and the United States, primarily in regions that have cost-advantaged raw materials or high growth rates

Tarragona, Spain
Global Reach

58 plants in 18 countries

More than 13,000 employees worldwide

Sales in more than 100 countries

Owned and operated by LyondellBasell, its subsidiaries and/or joint ventures.
Before SAMP-1: Needs for a SAMP-1 like material

• N. Temini, N. Billon, “Plasticité et incompressibilité des polymers solides – Etude expérimentale à moyennes et hautes vitesses”, 16ème Congrès Français de Mècanique, Nice, Septembre 2003


New experimental techniques allowed detailed measurement of volume variation in polymers subjected to tensile tests, not compatible with Von Mises plasticity
SAMP-1 is...

SAMP-1 Users: Initial Concerns


LyondellBasell Contribution

• M. Nutini, M. Vitali, “Characterization of polyolefins for design under impact: from true stress/local strain measurement to the F.E. simulation with Ls-dyna Mat. SAMP-1”, 7th Ls-dyna German forum, Bamberg 2008
SAMP-1 Users: Initial Concerns

How to characterize the materials for providing input data to SAMP-1?

Which tests?
- Tension, compression, shear
- Testing speeds?
- Material orientation?

Which testing methodologies?
- Engineering data?
- True stress/Strain?
- Local measurement?
- Optical methods, e.g. Digital Image Correlation (DIC)?

Data elaboration?
- Optimization techniques (based on what outputs)?
- Data filtering?
SAMP-1 Users: Initial Concerns

How to validate a SAMP-1 material card?

- First studies based on simple tensile / bending tests (reverse engineering)
- Additional studies on selected benchmark tests

Source: M. Nutini, M. Vitali, “Characterization of polyolefins for design under impact: from true stress/local strain measurement to the F.E. simulation with Ls-dyna Mat. SAMP-1”, 7th Ls-dyna German forum, Bamberg 2008
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SAMP-1 Advanced Input: Damage

Damage function implemented according to Chaboche-Lemaitre model: Continuum Damage Mechanics (CDM) approach


\[
D = \frac{A_{VOID}}{A_{TOT}} \quad \text{Damage function}
\]

\[
\sigma_{EFF} = \frac{F}{A_{EFF}} \quad \text{Effective stress}
\]
Damage Parameters Identification

LyondellBasell Contribution
Proposal for a method based on Local Strain Measurement

• M. Nutini, M. Vitali, “Characterization of polyolefins for design under impact: from true stress/local strain measurement to the F.E. simulation with Ls-dyna Mat. SAMP-1”, 7th Ls-dyna German forum, Bamberg 2008

Damage function associated to the volume strain, experimentally accessible

\[ \tilde{m} := \ln \frac{V}{V_0} = (\varepsilon_1 + \varepsilon_2 + \varepsilon_3) \]

\[ D = 1 - \frac{V_0}{V} = 1 - e^{-\tilde{m}} \]

Effective stress identified as the stress at constant volume

\[ \sigma_{\text{EFF}} = \sigma_{\text{CV}} \]
Damage Parameters Identification

Alternative approaches


- Gongyao Gu, Yong Xia, Chin-hsu Lin, Shaoting Lin, Yan Meng, Qing Zhou, “Experimental Study on characterizing damage behavior of thermoplastics”, Materials and Design 33 (2013), p. 199-207

Damage function through elastic modulus measurement from uniaxial tensile tests with repeated unloading
Damage Parameters Identification

LyondellBasell Method and Alternative approaches

Comparative assessments:


- Gongyao Gu, Yong Xia, Chin-hsu Lin, Shaoting Lin, Yan Meng, Qing Zhou, “Experimental Study on characterizing damage behavior of thermoplastics”, Materials and Design 33 (2013), p. 199-207

Comparison of the results from volume strain and Modulus variation: conflicting responses!

- Results overlapping (Balieu et al.)

- Results are different (Gu et al.): Damage underestimated when volume strain is used rather than elastic modulus (D=0.4 vs. D=0.9)
Damage: deeper investigations of the Damage Physics


Debonding of (talc) particles from the polymer matrix leads to micro cavities initiation and to the damage of the matrix
Damage: deeper investigations of the Damage Physics

LyondellBasell Contribution (study in progress)

Debonding of (talc) particles from the polymer matrix leads to micro cavities initiation and to the damage of the matrix

Source: LyondellBasell
Damage modeling

- Considering how damage originates and evolves in talc-filled materials, and also the uncertainties in the current debate as emerging from the references:
  
  - The Chaboche-Lemaitre model coupled with volume-strain based parameter identification is the preferred choice for this class of materials
  
  - A dedicated test will be used for its validation
Choice of a further validation test

Industrial prototypal part (energy absorber), made of talc-filled, impact-modified PP

Testing several SAMP-1 features as:

- Strain rate dependence
- Complex loading (Tension, Compression, Bending)
- Damage (portions of the part are subjected to unloading during the impact sequence)
Material card preparation

- Data from tensile test at different speeds, using DIC/Optical strain measurement, measured on specimens cut from injection molded plaques

- Compression / Shear data: through scaling tensile stress-strain curves. Scaling Coefficient: 1.3 to 1.5 for compression, 0.7 for shear

- Poisson ratio: function of the strain

- Average (Long/Transv) material properties are used
Result: Compression modeling

- Several scaling coefficients used.
- Comparison based on Force vs. displ. Curve (right)
- Definitely good agreement between experiment and simulation.
- Scaling coefficient for compression data from tensile data better around 1.4
Result: Compression modeling

- Several scaling coefficients used.
- Comparison based on displ. vs. time (right)
- Note: the slope after velocity is reversed \((t = 35 \text{ ms about})\) is the same for all the simulations (Same damage parameters!)

- Best result: scaling coefficient around 1.4
Result: Alternative modeling

- Simulations with SAMP-1 have provided force-displ-time curves in better agreement with the real test than MAT_024 and MAT_081.

- Taking into account the slight anisotropy in the material is believed to improved the prediction accuracy.
Result: Damage modeling

- For this class of materials the damage model combined with parameter identification through volume strain give good results (see the slope after motion reversal).

- Arbitrary scaling of damage curves to reach the value 0.9 at failure (to simulate Gu’s results) does not give reasonable predictions.

- Damage is better evaluated from 3-D strain measurement (curve DIC3D).
Result: Deformation

The deformation predicted using SAMP-1 is definitely closer to the real test than the one predicted by MAT_024.

Part deformation during the real test (left) and simulated with SAMP-1 (center) and MAT_024 (right); t= 15 ms (top) and t=25 ms (bottom)
Conclusions

The benchmark case here presented confirms that accurate local strain measurement using non contact optical-based methods are suitable to generate input data for impact analyses for advanced material laws, as SAMP-1, taking into account peculiar characteristics of polymeric materials, as viscoelasticity, viscoplasticity, pressure-dependent yield stress, plastic dilatation and damage. In particular, the validity of the approach to damage modeling based on the measurement of volume strain has been experimentally verified for mineral-filled Polypropylene-based compounds.
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