Multiscale modeling of failure in ABS materials

Martin Helbig*, A.H. Clausen**, Thomas Seelig*
*Institute of Mechanics (KIT), **SIMLab (NTNU Trondheim)

Motivation

• enhanced fracture toughness and ductility of ABS (acrylonitrile-butadiene-styrene) relies on microscopic deformation and damage mechanisms: void growth, shear yielding, crazing

• many details of these mechanisms are still not well understood:
  - their individual contribution to the overall toughness
  - their dependence on micro-structural parameter (e.g. rubber particle size and volume fraction)

→ aim of present study: constitutive modelling of the effect of crazing at different length scales

Continuum modelling of crazing

earlier work:
- discrete cohesive zones [Tijssens et al. 2000]
- special continuum finite elements [Socrate et al. 2001]

present model:
- accounts for the essential features of crazing
- crazing considered the only source of inelasticity
- orientation of craze not constrained by FE mesh

kinematics of inelastic deformation of continuum model

$$D^e = \varepsilon^e n \otimes n$$

flow rule with direction n of max. principal stress

$$\dot{\varepsilon} = \dot{\varepsilon}_0 \exp \left( \frac{A}{T} (\sigma_n - \sigma_c) \right)$$

equivalent visco-plastic strain rate

$$\sigma_n = n \cdot \sigma \cdot n$$

resolved normal stress on craze

Test example: single craze around void

- crazes can freely form in arbitrary directions
- crack formation by element elimination at critical value of inelastic strain

Calibration of the homogenized model

• uniaxial tensile tests on ABS with unknown composition
• estimation of rubber content to \( f \approx 0.2 \)
• yield strength relation \( \sigma_y(\Delta \varepsilon / \Delta \varepsilon_{crit}) \) fitted to agree with experimental stress-strain curve

experiment vs. model response

effect of rubber content

<table>
<thead>
<tr>
<th>( \sigma ) (MPa)</th>
<th>5%</th>
<th>10%</th>
<th>20%</th>
<th>40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \varepsilon )</td>
<td>0</td>
<td>0.4</td>
<td>0.8</td>
<td>1.2</td>
</tr>
<tr>
<td>experimental</td>
<td>40</td>
<td>30</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>model simulation</td>
<td>40</td>
<td>30</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

effect of strain rate

<table>
<thead>
<tr>
<th>( \sigma ) (MPa)</th>
<th>10^{-5} s^{-1}</th>
<th>10^{-7} s^{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \varepsilon )</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>experimental</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>model simulation</td>
<td>10</td>
<td>50</td>
</tr>
</tbody>
</table>

cyclic tests

• decrease of unloading slope with increasing inelastic deformation
• damage evolution

Plastic zone in notched specimen

• stress whitened zone at crack tip for ABS material
• model for distributed crazing led to more realistic shape of plastic zone than pure void growth [Pijnenburg et al. 2005]

Acknowledgment: Financial support of this work by the German Science Foundation (DFG) under grant no. SE 872/5-2 is gratefully acknowledged. We would also like to thank the DAAD for funding a research stay of M.H. at SIMLab.