Application of different plasticity models to PC/ABS blends within micromechanical approaches

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Rubber-toughened thermoplastic polymers such as PC/ABS blends exhibit a non-monotonic dependence of fracture toughness on composition, e.g. [6]. The key parameters determining the mechanical response of PC/ABS are the PC vs. ABS ratio and the rubber content in ABS. In this contribution, two micromechanical modeling approaches (single particle unit cell models, random representative volume elements) are considered to investigate this behavior. Thereby, different visco-plasticity models are utilized to capture the specific deformation behavior of each phase. Computational studies of both micromechanical modeling approaches are compared to each other as well as to experimental data.

1 Introduction

PC/ABS blends are ternary polymer blends of the homogenous amorphous thermoplastic polycarbonate (PC) and the rubber-toughened thermoplastic acrylonitrile butadiene styrene (ABS). Commercial PC/ABS grades are characterized by the key microstructural parameters PC vs. ABS ratio and rubber content in ABS. Their composition is crucial for the deformation behavior and in particular the fracture toughness since experiments show a non-monotonic dependence of the fracture toughness of PC/ABS blends on their composition [6]. Through a variation of the key blend parameters this work aims to numerically investigate the relationship between composition and fracture toughness of PC/ABS blends.

2 Constituent behavior

The stress-strain responses of the two blend constituents, PC and ABS to uniaxial tensile tests is depicted in Figs. 1 and 2. After a small elastic domain, both exhibit softening upon yield as well as progressive rehardening for large plastic deformations. The strain rate dependence of ABS is more pronounced, as shown in Fig. 5 below. PC behaves plastically incompressible whereas ABS exhibits plastic dilation (Fig. 2). The latter is due to the underlying micro-mechanisms rubber particle cavitation, void growth and distributed crazing [9].

3 Constitutive modeling

The constitutive model for each constituent is chosen to capture the specific deformation behavior. In case of the plastically incompressible PC phase \( J_2 \)-plasticity is used. The isochoric plastic rate of deformation is given by

\[
\dot{D}^p = \dot{\varepsilon}^p \frac{1}{||\sigma'||} \sigma'
\]  

(1)

where \( \sigma' \) is the deviatoric part of Cauchy stress. An Eyring-ansatz for the inelastic strain rate reads

\[
\dot{\varepsilon}^p = \dot{\varepsilon}_0 \exp(A(\sigma_e - \sigma_y))
\]  

(2)

with \( \sigma_e \) the von Mises stress and \( \sigma_y \) representing the yield stress. The micromechanics based homogenized model for distributed crazing by [4] is chosen for the ABS phase. Therein the dilatant plastic part of the rate of deformation is given by

\[
\dot{D}^p = 1/b \left( \delta \otimes n \right)^{sv}
\]  

(3)

with the average craze spacing \( b \) and the craze normal vector \( n \). The overall craze opening rate \( \delta \) depends on the craze stress analogous to Eq. (2).

The calibration of the hardening behavior was carried out using experimental data from uniaxial tensile tests by [3] (PC) and [4] (ABS), respectively. Using experimental data for initial yield stresses measured over a large range of strain rates [1–3, 5, 7, 10–12] the viscous properties were calibrated by means of linear regression (Fig. 5).

4 Microstructure modeling

Micrographs for PC-rich blends show a matrix-particle morphology with dispersed ABS particles in a PC matrix [8]. To represent these microstructures two different micromechanical approaches are used: periodic unit cell models with a body-centered cubic (BCC) arrangement and representative volume elements (RVE) with a random arrangement of spherical particles.
5 Computational results

For each modeling approach finite element models of four PC-rich blends (PC/ABS = \{60/40, 70/30, 80/20, 90/10\}) are evaluated. Also, the material parameter determining the rubber content in ABS is varied in the range from 1\% to 50\% in each finite element model. To mimic conditions usually prevailing in fracture experiments an elevated stress triaxiality $\sigma_e/\sigma_m = 1$ and a strain rate of $\dot{\varepsilon} = 10^3\; \text{s}^{-1}$ are considered in the simulations. Local failure is modeled by element deletion. In the ABS phase failure was assumed to occur upon a critical overall craze opening. In the PC a hydrostatic stress based failure criterion was used. Examples of locally failed finite element models for both approaches are depicted in Figs. 3 and 4.

The computational results show a non-monotonic dependence of the specific work until failure on the composition for both modeling approaches (Figs. 6 and 7). In both cases a rubber content in ABS of 10\% and a PC vs. ABS ratio of 90/10 prove most beneficial i.e. maximize the specific (per area) work until fracture. High rubber contents larger than 40\% appear not suited for rubber toughening due to the relatively low fracture energy. In case of the BCC unit cell models the effect of a variation of the rubber content in ABS has an even stronger influence on the specific work of fracture than the PC vs. ABS ratio.

6 Conclusions

In accordance with experimental data, e.g. [6], the numerical results show a non-monotonic dependence of fracture toughness of PC/ABS blends on composition. The rubber content in ABS proves crucial for optimizing the fracture toughness of PC/ABS blends. For both modeling approaches an optimum rubber content is predicted, which is independent of the PC vs. ABS ratio.

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