Damage in Rubber-Toughened Polymers – Modeling and Experiments

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1 Introduction

The enhanced ductility and fracture toughness of rubber-toughened polymers such as Acrylonitrile-Butadiene-Styrene (ABS) relies on microscopic deformation and damage mechanisms, which are void growth, shear yielding and crazing, e.g. [1,2].

In the present work a constitutive model is suggested which explicitly accounts for microstructural parameters and assumes distributed crazing to be the only inelastic deformation mechanism. The model was implemented in LS-Dyna as user-material.

The deformation and fracture behavior of a commercial ABS was determined by tensile tests under different conditions. Digital image correlation (DIC) was used to analyze the strain from the optical displacement measurement.

2 Homogenized model for distributed crazing in rubber-toughened materials

Crazes are localized zones of fibrillated polymer material, which form in the direction normal to the maximum principal stress and are able to transfer stress. Under continued loading their growth proceeds until a critical craze thickness is reached. Then rupture of the fibrils takes place and the craze turns into a micro-crack.

Crazing is found uniformly distributed over large regions of the material allowing for macroscopic description in a homogenized manner. The rubber particles typically cavitate prior to the occurrence of crazing and are considered simply as voids in the present study.

The kinematics of inelastic deformation is described by the overall separation vector δ, the craze orientation (unit normal vector) $\boldsymbol{n}$ and the average spacing b between the craze zones.
Key microstructural parameters in rubber-toughened polymers are the size r and the volume fraction f of the rubber particles. In addition, since inelastic deformation and failure take place by crazing, the ultimate craze opening δ_{crit} at craze breakdown plays a pivotal role and introduces a characteristic length which has to be related to the initial craze spacing b_0 being a function of r and f. We establish the connection between theses microstructural characteristics by means of simple micromechanical considerations based on the unit cell model sketched in Fig. 1. Simple scaling relations are used to determine the initial spacing b_0 between crazes and the effective normal and shear stress $\tilde{\sigma}_n, \tilde{\sigma}_\tau$ acting on the craze area [4].
The overall elastic stiffness is considered by a two-step homogenization. According to the Mori-Tanaka model the void volume fraction f of the rubber particles is considered e.g. [3]. Additionally the evolution of damage D due to distributed crazing is considered at effective the 4th order effective elasticity tensor $\boldsymbol{E}^*(f,D)$.

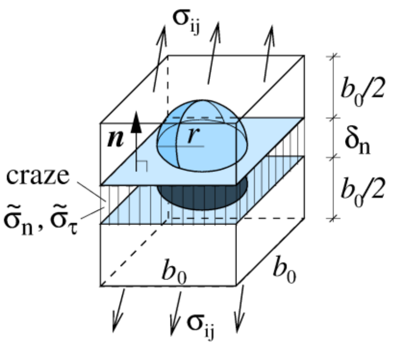

Fig.1: Unit cell of microstructure with single craze in equator region of rubber particle

3 Model calibration of evaluation

In order to analyze in how far the model is capable to capture the deformation behavior of some real ABS material, tensile tests have been performed on a commercial, off-the-shelf ABS grade without any information of its microstructure. The tensile experiments were carried out on a servo-hydraulic testing machine at room temperature and at different constant values of the nominal strain rate. The in-plane strain field was analyzed using 2D digital image correlation (DIC). Fig. 2a shows stress-strain curves to compare the adjusted model and experiments under uniaxial tensile loading. Uniaxial cyclic tensile tests show hysteresis and a decreasing unloading-reloading slope with increasing inelastic deformation (Fig. 2b). The model response under repeated unloading and reloading is depicted by the solid curve in Fig. 2b.

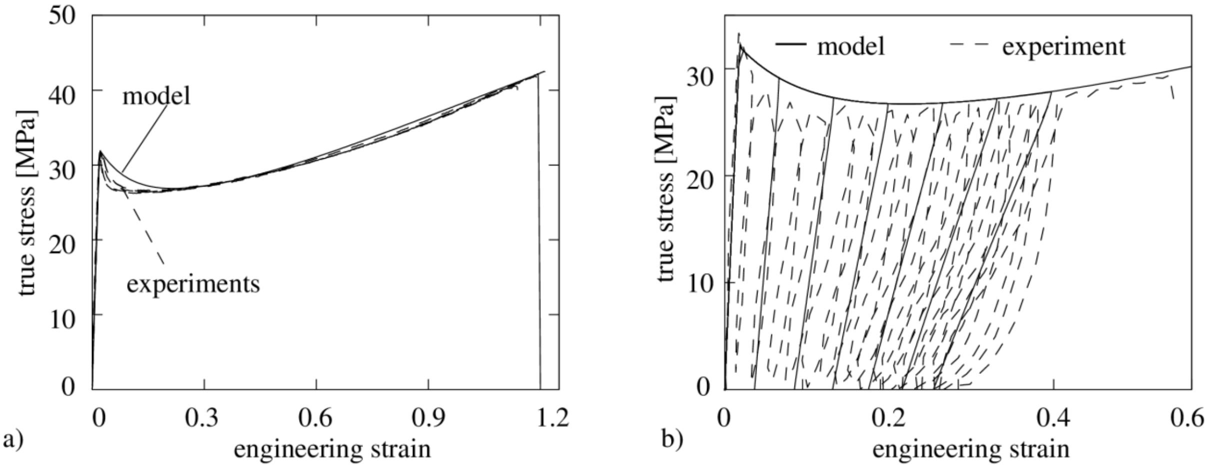

Fig. 2: a) uniaxial true stress vs. engineering strain response of commercial ABS and calibrated model, b) effect of unloading after different levels of straining

4 Summary

A micromechanical material model for distributed crazing in rubber toughened amorphous thermoplastics is introduced, which takes the most important microstructural parameters into account. The model was adjusted to experiments on a commercial ABS.

5 Literature

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