Modeling the interaction of crazing and matrix plasticity in rubber-toughened polymers

Thomas Seelig\(^1\) and Erik Van der Giessen\(^2\)

\(^1\)Fraunhofer-Institute for Mechanics of Materials, Freiburg, Germany, see@iwm.fhg.de
\(^2\)University of Groningen, The Netherlands, E.van.der.Giessen@rug.nl

1. Introduction

The superior fracture toughness of ABS materials macroscopically corresponds to a large plastic ("stress whitened") zone ahead of notches or crack tips and results from dissipative micromechanisms initiated at small rubber particles which are finely dispersed in the glassy matrix. These micromechanisms are well known to be shear yielding and crazing, typically in conjunction with rubber particle cavitation. Less clear, however, is the predominance of shear yielding or crazing as the major source of inelasticity and energy dissipation.

The objective of this study is to gain basic understanding of the interaction and competition of matrix plasticity (shear yielding) and crazing on the microscale of ABS by means of micromechanical finite element models taking both mechanisms into account.

2. Modeling

Since the rubber particles are much smaller than a typical notch radius (see figure above) we consider a representative sample of the material subjected to uniform overall loading (strain \(\varepsilon\)). The rubber particles typically cavitate early in the course of loading, so they are here treated as voids. Yielding of the surrounding matrix is described by a constitutive model that accounts for characteristic features of glassy polymers such as rate-dependence, intrinsic softening and rehardening due to molecular alignment.

Within the 2D (plane strain) finite element model cohesive surfaces are introduced along preferred directions between the voids to describe the formation of crazes.

3. Results

Results presented here for uniaxial overall strain \((\varepsilon_1=\varepsilon_2=0, \text{ high stress triaxiality})\) focus on the effect of the rubber content (i.e. particle distance at fixed particle size) on the local interaction of matrix plasticity and crazing as well as on the macroscopic response in terms of overall stress \(\Sigma\) vs strain. The contour plots below show patterns of plastic strain in periodic microstructures with 5\% (left) and 20\% (right) porosity.

In the material with low porosity (5\%) the interaction between adjacent voids is so small that crazes start to break down prior to yielding (in form of shear bands). In contrast, at a high porosity crazing is accompanied by the formation of a network of shear bands between the voids. The cohesive surface model for crazing consists of an initiation criterion, a rate-dependent relation between the craze stress \(T\) and the separation \(\Delta u\) of the craze-bulk interfaces (craze-widening) and a criterion for craze-breakdown at a critical craze width. Different variations of the craze-widening law are considered.

\(\Sigma\) [MPa] vs \(\varepsilon\) [0.01, 0.2] (without crazing)