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

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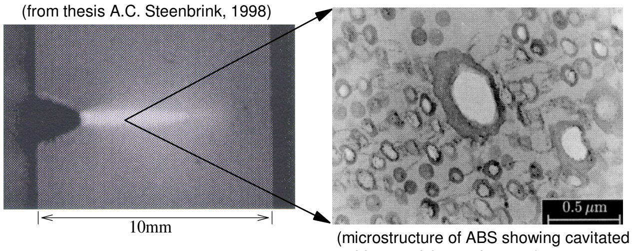
## 1. Introduction

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.

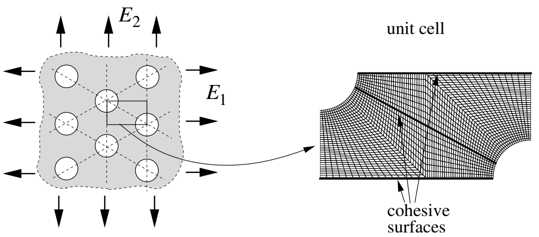
(from thesis A.C. Steenbrink, 1998)




(microstructure of ABS showing cavitated rubber particles and crazes)

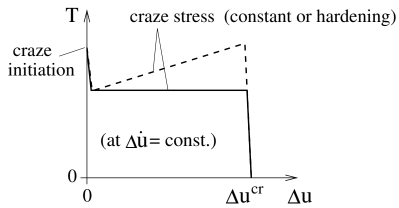
## 2. Modeling

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 ***E***). 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.



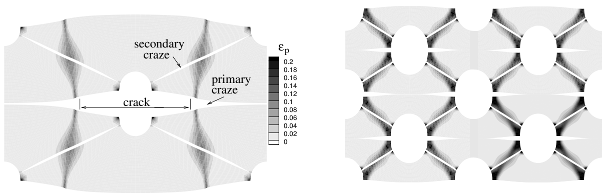

Within the 2D (plane strain) finite element model **cohesive surfaces** are introduced along preferred directions between the voids to describe the formation of crazes.

The cohesive surface model for crazing consists of an **initiation criterion**, a rate-dependent relation between the craze stress $\mathbf{T}$ and the separation $\Delta\mathbf{u}$ 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.

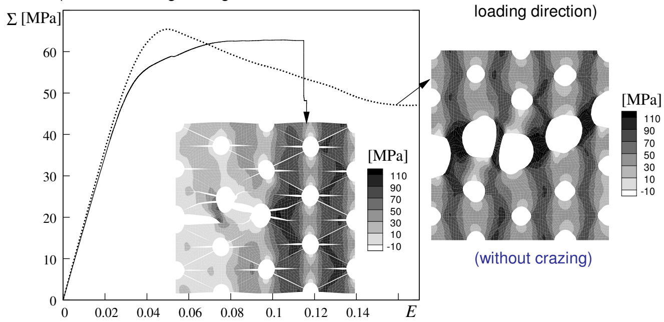


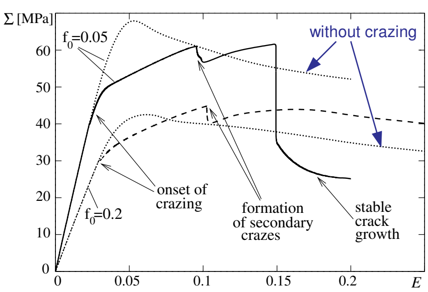

## 3. Results

Results presented here for uniaxial overall strain ($E_1$=0, 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 $\mathbf{\Sigma}$ vs strain. The contour plots below show patterns of plastic strain in *periodic* microstructures with 5% (left) and 20% (right) porosity.




(effect of crazing in irregular microstructure and distribution of local stress in loading direction)




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.
However, in both cases the occurrence of crazing gives rise to a **stable overall stress-strain response** over a significantly larger range of deformation than in the case when crazing is neglected (shown by the dotted curves for comparison). This effect is important with regard to the lateral (normal to a crack) extension of the plastic zone being much larger than the microstructure (see top figure), which would not be possible for an overall response displaying early softening. The analogous finding is obtained for a *non-periodic* void arrangement (above). Hence crazing, which accommodates overall dilation enforced by highly triaxial loading without implying overall softening, appears to play an important role in the build-up of the plastic zone at notches or cracks in ABS.