Multiscale modeling of failure in ABS materials

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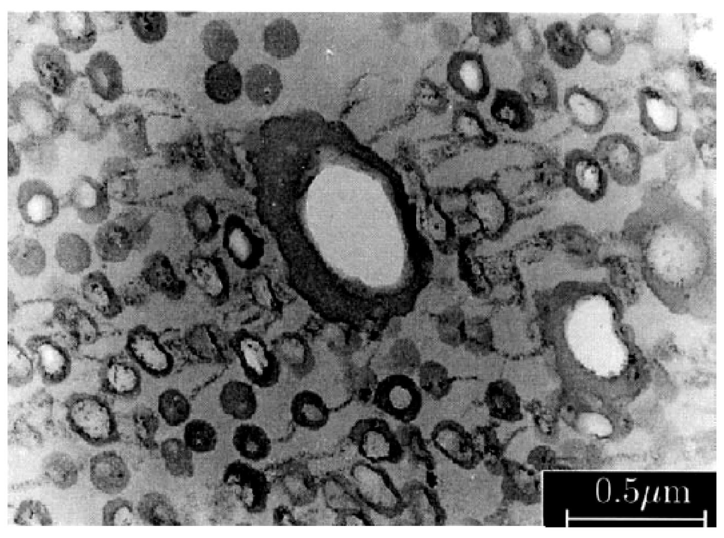
Motivation

- 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)



[Steenbrink,1998]

→ **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

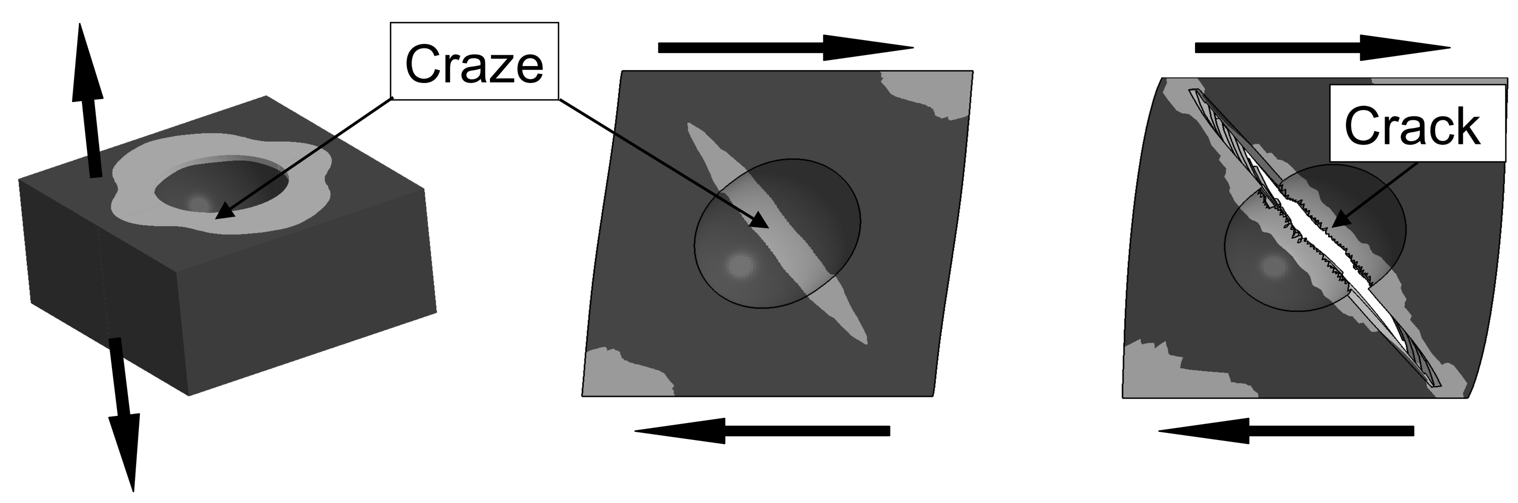
kinematics of inelastic deformation of continuum model

$D^c = \dot{\varepsilon}^c n \otimes n$ flow rule with direction n of max. principal stress

$\dot{\varepsilon}^c = \dot{\varepsilon}_0 \exp\left(\frac{A}{T}\left(\sigma_n - \sigma_c\right)\right)$ equivalent visco-plastic strain rate

$\sigma_n = n \cdot \sigma \cdot n$ resolved normal stress on craze

Test example: single craze around void

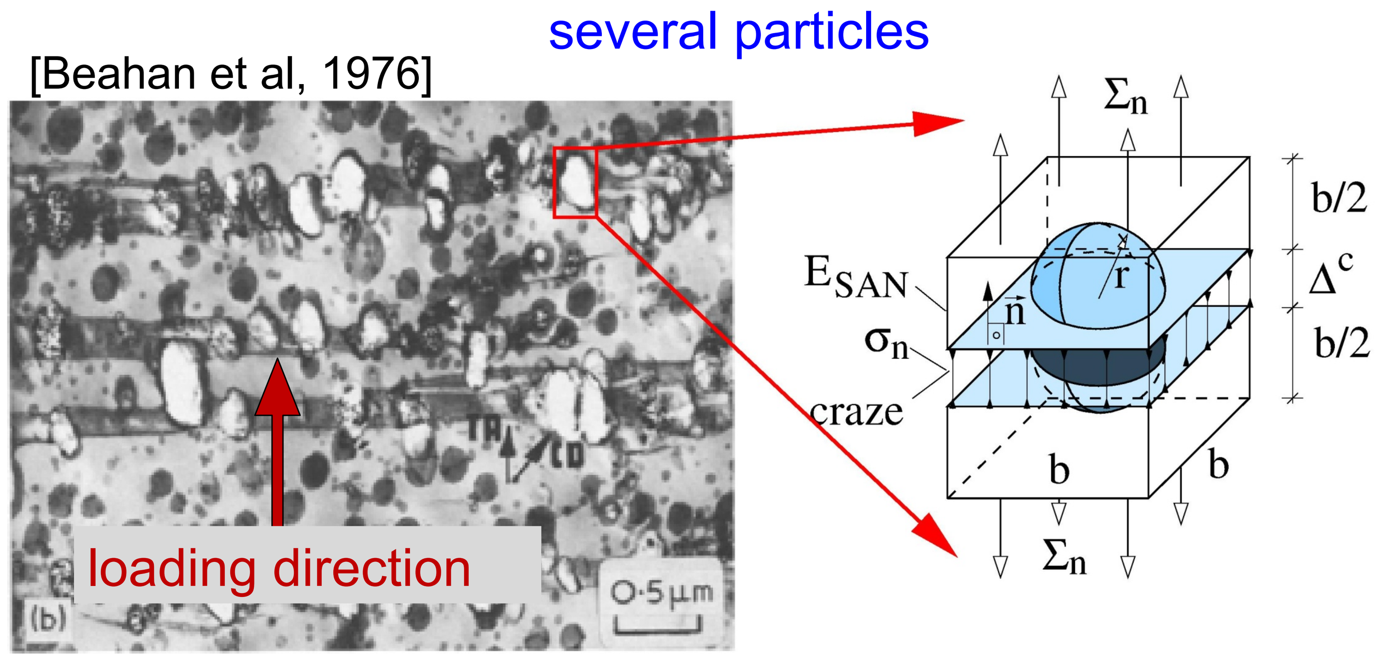


- crazes can freely form in arbitrary directions
- crack formation by element elimination at critical value of inelastic strain

Homogenized model for distributed crazing in rubber-toughened materials

on larger length scale: band-like damage zones comprising several particles

[Beahan et al, 1976]



overall inelastic strain rate due to distributed crazing

$$\dot{\varepsilon}^c = \frac{\dot{\Delta}^c}{b + \Delta^c} = \frac{\dot{\Delta}^c}{\Delta^c_{crit}} \left(\frac{r}{\Delta^c_{crit}} \left(\frac{4\pi}{3f}\right)^{1/3} + \frac{\Delta^c}{\Delta^c_{crit}} \right)^{-1}$$

driving stress for craze growth

$$\sigma_n = n \cdot \Sigma \cdot n \left(1 - \pi \left(\frac{3f}{4\pi}\right)^{2/3} \right)^{-1}$$

Δ^c craze width
Δ^c_{crit} max. craze width
r rubber particle size

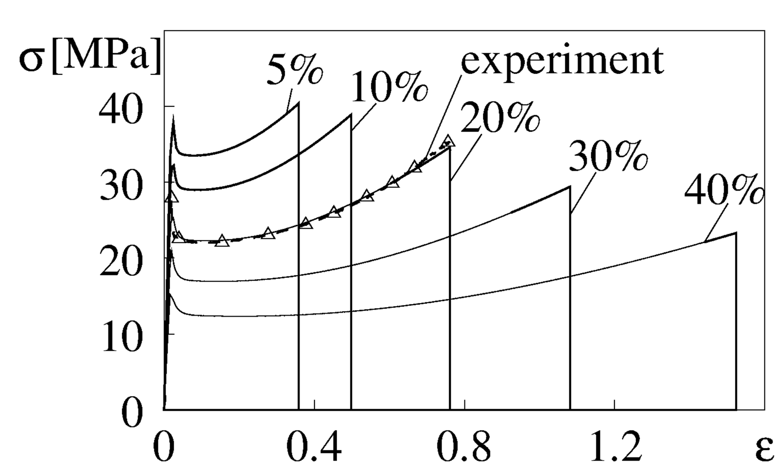
$b(r,f) = r(4\pi/3f)^{1/3}$ average spacing of crazes, f rubber content

Calibration of the homogenized model

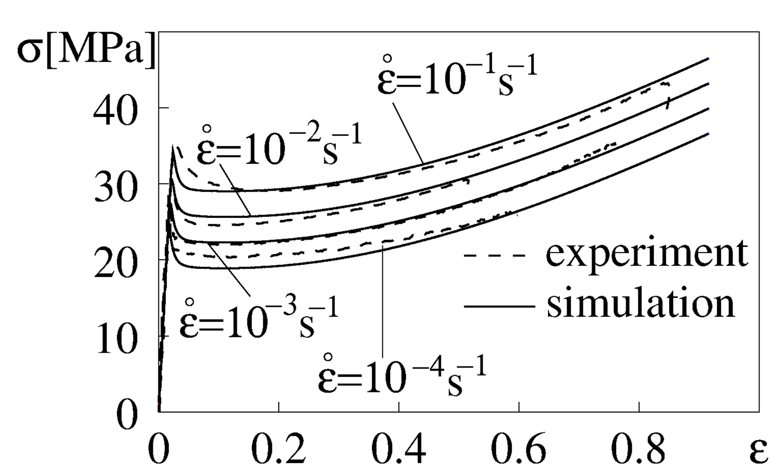
- uniaxial tensile tests on ABS with unknown composition
- estimation of rubber content to $f \approx 0.2$
- yield strength relation $\sigma_c(\Delta^c/\Delta^c_{crit})$ fitted to agree with experimental stress-strain curve

experiment vs. model response

effect of rubber content

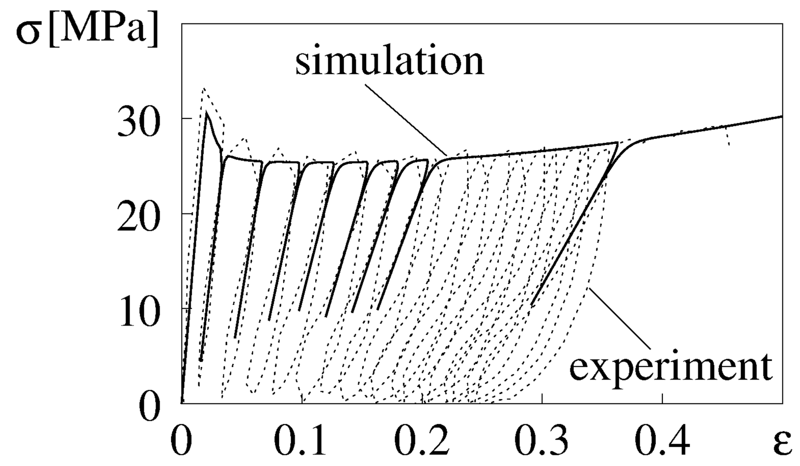


effect of strain rate



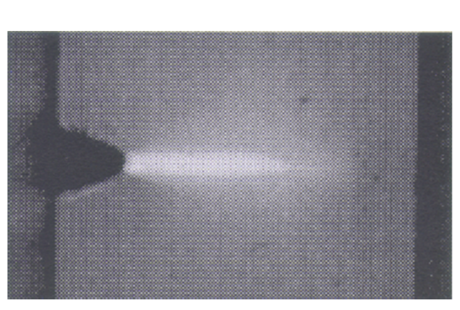
cyclic tests

- 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]



experiment

simulation

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