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Why is polystyrene brittle and polycarbonate tough and what can we do about it?

R.J.M. Smit, W.A.M. Brekelmans, H.E.H. Meijer

Eindhoven University of Technology,
Department of Mechanical Engineering,
P.O. Box 513, NL 5600 MB Eindhoven

Introduction

On a macroscale, polystyrene (PS) is brittle and polycarbonate (PC) is tough. On a microscale, however, craze craze fibrils (length scale nm) break after 300% strain in PS and 100% in PC. This contradictory behaviour is elucidated and the toughening by the addition of cavitating rubbery particles is explained.

Intrinsic material behaviour

Uniaxial compression experiments and model fits (true stress versus compressive strain, $\lambda = \text{draw ratio}$):

- strain softening: decreasing stress results in increasing strain $\rightarrow$ unstable deformation
- strain hardening: increase in stress needed for increase in strain $\rightarrow$ stable deformation
- PS: more strain softening, less strain hardening
  $\rightarrow$ Polystyrene shows intrinsically a less stable deformation behaviour than polycarbonate
- crazes initiate after yield, triaxial stress level during craze initiation in PS $\approx$ 40 MPa and PC $\approx$ 90 MPa
- model offers accurate description of yield- and post-yield behaviour in arbitrary 3D stress states

Consequence for toughness

Deformation of a notched bar of PS and PC with a minor defect to model realistic (imperfect) specimen:

Polystyrene: at a global strain of 0.22%, the defect triggers local yielding, resulting in a critical dilative stresses ($>40$ MPa) $\rightarrow$ PS crazes

Polycarbonate: at a global strain of 1.1%, the notch tip causes critical dilative stresses ($>90$ MPa) $\rightarrow$ PC crazes

- PS is brittle because of high defect sensitivity
- PC is tough because of low defect sensitivity

Improving toughness

Enhance toughness by minimizing defect sensitivity. Possible routes:

1. reduce yield stress: minimizes (unstable) strain softening and reduces triaxial stresses
2. improve (stabilizing) strain hardening
3. avoid high triaxial stress states by incorporation of voids or cavitating rubbery particles

Rubber toughening is successful because:
- cavitating rubbery particles reduce triaxial stresses
- heterogeneous microstructure eliminates softening
- rubbery particles improve strain hardening

Conclusion

Brittleness of glassy polymers depends on unstable post-yield behaviour and triaxial crazing stress. Reducing softening, improving hardening and avoiding high triaxialities are the keys to enhanced toughness.

References