

## Network density : a key factor in macroscopic toughness?

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**/Introduction**

Although amorphous polymers like Polystyrene (PS, cd-boxes) and Polycarbonate (PC, cd's) are similar materials, their macroscopic deformation behaviour in tension is quite different (**fig.1a**).

- PS: crazing → brittle, small macroscopic strains
- PC: necking → ductile, large macroscopic strains



fig.1a Brittle and tough

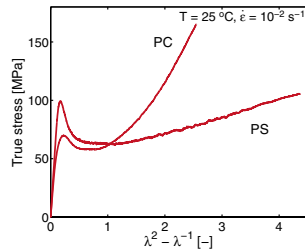


fig.1b Compression tests

PS suffers from extreme localisation due to (**fig.1b**):

- much strain softening. Elimination of strain softening inhibits localisation and brittle fracture [1, 2].
- weak strain hardening. Strain hardening: entropic contribution of entangled polymer network [3]

**/Objective**

Determine relation between molecular structure and post-yield behaviour. Alter molecular structure of PS:

- blending with Polyphenylene oxide (PS/PPO)
- cross-linking with DEGDMA (x-PS)

**/Results and conclusions**

Materials are characterised by DMTA.

- Dynamic modulus in rubbery region → molecular weight between entanglements → network density
- With increasing %PPO in PS/PPO and cross-linker in x-PS, the rubber modulus ( $G_{N^0}$ ) and thus the network density ( $\nu_e$ ) increase (**fig.2**).

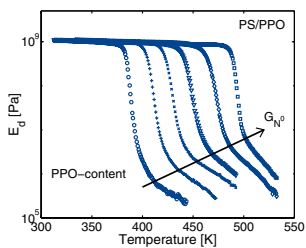
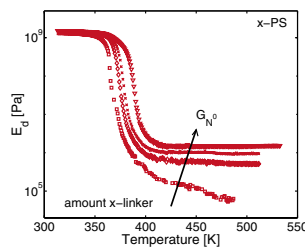


fig.2 DMTA PS/PPO (left) and x-PS



**/References:**

[1] TERVOORT, T.A. *Constitutive modelling of polymer glasses: finite nonlinear viscoelastic behaviour of polycarbonate*, PhD thesis, Eindhoven University of Technology, Eindhoven, The Netherlands, 1996

[2] SMIT, R.J.M *Toughness of heterogeneous polymeric systems: a modelling approach*, PhD thesis, Eindhoven University of Technology, Eindhoven, The Netherlands, 1998

[3] HAWARD, R.N.: *Strain hardening of thermoplastics*, *Macromolecules*, v26, n22, p5860-5869, 1993

Compression tests are performed to determine the intrinsic properties (strain softening and hardening).

- In Gaussian theory → true stress proportional to  $\lambda^2 - \lambda^{-1}$  → strain hardening modulus ( $G_p$ )

With increasing network density in PS/PPO and x-PS the strain hardening modulus increases (**fig.3**).

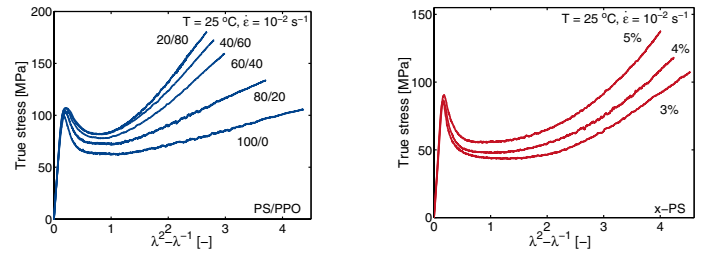


fig.3 Compression tests PS/PPO (left) and x-PS

Strain hardening modulus vs. network density gives a linear relationship for PS/PPO and x-PS (**fig.4a**).

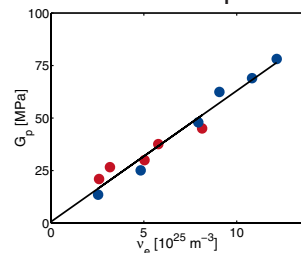


fig.4a  $G_p$  vs.  $\nu_e$

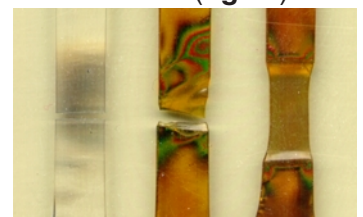


fig.4b PS/PPO 100/0 to 20/80: crazing to shear yielding

For high PPO content in the PS/PPO blends ductile macroscopic deformation behaviour is observed in tension (**fig.4b**), whereas x-PS remains brittle. The amount of softening (yield-drop) of PS/PPO in compression reduces strongly with increasing %PPO and temperature (**fig.3 & 5a**, encircled: ductile in tension).

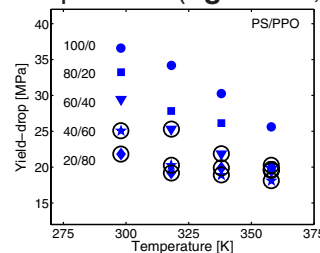


fig.5a Yield-drop in PS/PPO



fig.5b Embrittled PC

As under a certain threshold of yield-drop ductile behaviour is observed, strain softening appears to be the key factor in macroscopic toughness. This is confirmed by embrittlement of strongly annealed PC in which yield-drop has increased considerably (**fig. 5b**).