Mechanical response of injection-moulded parts at high strain rates

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BACKGROUND

Impact response of polymer parts is critical for applications such as automotive components and subsea installations for oil and gas exploitation. In order to cut development costs it is an increasing demand to simulate reliably the mechanical response of polymer parts subjected to impact loading. Hence, there is a focus on developing better material models, and improving the material data for these models. This poster presents some results from an ongoing project.

MECHANICAL TESTING

WHY?

As input for the simulations we need true stress-strain curves in tension at different strain rates, and true stress-strain in compression

MECHANICAL TESTING

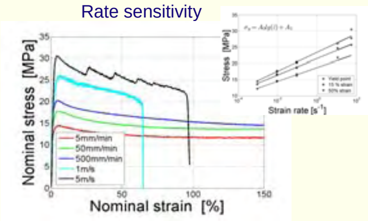
Material

- Mineral and elastomer modified polypropylene (PP) (from Borealis)
- Density 940 kg/m^3
- MFI (230 °C/2.16 kg) 17 g/10 min

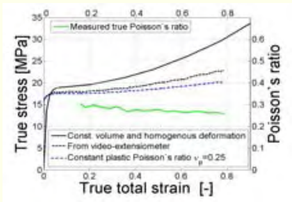
Uniaxial tension

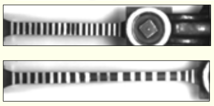
- Injection-moulded test specimens with cross-section 4 mm × 10 mm
- Video extensiometer used for obtaining true stress-strain
- The plastic Poisson's ratio $\nu_p = -\varepsilon_p^T / \varepsilon_p^L$ decreases with strain (Drucker-Prager model assumes constant Poisson's ratio)
- Rate sensitivity of yield stress and post-yield stress at a given nominal strain can be represented by an Eyring equation $\sigma = A_0 \ln \dot{\varepsilon} + A_1$

Rate sensitivity



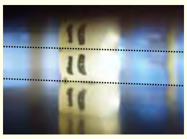
True stress-strain

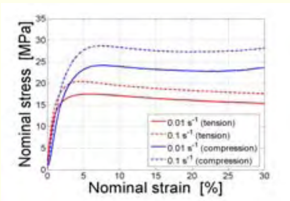




Uniaxial compression

- Specimens (10 mm long and cross-section 4 mm × 10 mm) were milled from injection-moulded multipurpose specimens (same as for tension)
- Compression and tension stress-strain curves show similar initial strain hardening
- Yield point in compression is at higher nominal stress and strain than in tension
- Pressure sensitivity parameter $\lambda = \sigma_C / \sigma_T = 1.35$ (obtained from ratio of maximum nominal stresses)





CONCLUSION

- Traditional linear-elastic–viscoplastic models, with pressure-sensitive yield and plastic dilatation, predict monotonic loading reasonably well
- Unloading is not well predicted, and a more advanced model for the recoverable strain is needed

FURTHER WORK

- Non-linear elasticity
- Viscoelastic model to predict unloading
- Models for damage and fracture
- Fracture models with special cohesive elements to distinguish between contributions from bulk plasticity and fracture
- Process-induced morphology

SIMULATION AND VALIDATION

WHY?

Predict the energy absorption and the possibility for failure in impact loading of components

NUMERICAL SIMULATIONS (WITH LS-DYNA)

Material model

- Linear-elastic–viscoplastic with pressure sensitivity and plastic dilatation
- Elastic rate effects are neglected
- 'Viscoplastic' means rate dependent yield stress and plastic flow
- Yield sensitive to hydrostatic stress (Raghava yield criterion):

$$(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2+2(\sigma_C-\sigma_T)(\sigma_1+\sigma_2+\sigma_3)=2\sigma_C\sigma_T$$

A modification of the von Mises criterion: Yielding is sensitive to the hydrostatic stress (pressure), giving different yield stresses in tension and compression. Molecular basis: Chains are disentangled in tension, but not in compression

- Flow rule (plastic strain vs stress) obtained from a Drucker-Prager flow potential

This flow rule accounts for volume change (dilatation) during plastic flow. The plastic dilatation is due to cavitation/crazing (for shear yielding the volume is constant).

Validation

- Tensile testing at strain rates up to 5 m/s

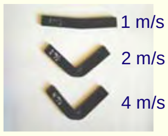
Good agreement between simulation and experiments

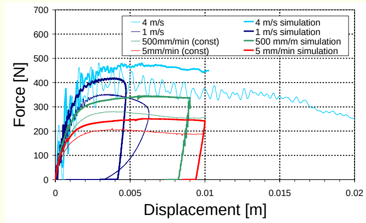
- Compression testing (quasi-static)

Only initial behaviour was well predicted. Above the yield point the simulations (based on flow curves in tension) overpredicted the strain hardening

- Three-point bending (instrumented 'falling weight' used for rates ≥ 1 m/s)

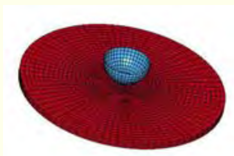
Standard von Mises yield criterion ($\sigma_C = \sigma_T$) gave better prediction than Raghava (the latter overestimated the compressive stresses)

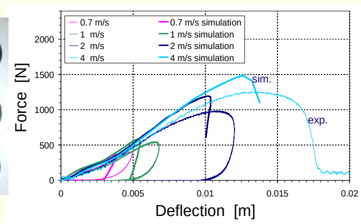




- Centrally loaded plates (using instrumented 'falling weight')

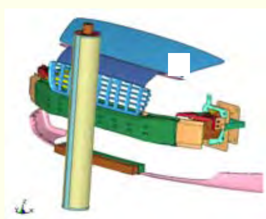
Raghava model gave better prediction than von Mises. At low rates the force curves are overpredicted and the unloading occurs to early. At high rates the predictions are OK up to half maximum force.

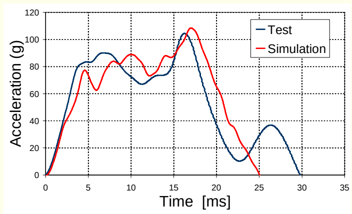




Application

- Simulation of crash test with an artificial leg (NCAP test)
- Good agreement between experiment and simulation





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