Mechanical testing for generating input to numerical simulation of impact response of injection-moulded components

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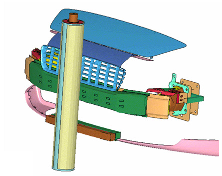
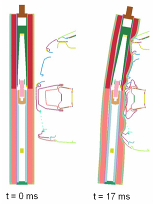
Introduction

- Numerical simulation of impact loading of polymers is of industrial interest, as polymers are increasingly being used in critical applications, such as automotive components

Objective, challenges and approach

- Objective: Improve material models and material data (input to the models)
- We address experimental challenges, such as non-uniform strain fields and force oscillations
  - Full-field strain measurements and inverse modelling techniques are employed to deal with non-uniform strain fields
- Low-speed impact cases in our study:
  - Unloading response of parts in a pedestrian safety system – typical impact speed 10 m/s
  - Impact fracture of exterior parts in cold weather – typical impact speed for relevant cases: 4 m/s
- Our focus is on the polymer materials, mechanical testing (polymer-related challenges), and the moulding process (process-induced effects)
  - Polypropylene materials containing talc and elastomers

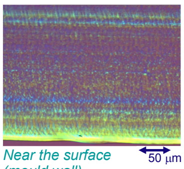




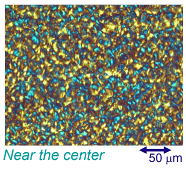
Simulated impact between pedestrian (leg) and car front. Note the energy absorber behind the bumper.

Process-induced effects (injection moulding process)

- Inhomogeneity, anisotropy and residual stresses of injection-moulded parts are challenges when trying to model and simulate the mechanical response
- Processing conditions, e.g. the injection speed, affect the mechanical properties
- Geometry parameters, such as part thickness and surface roughness, affect the mechanical properties, in interaction with the moulding process

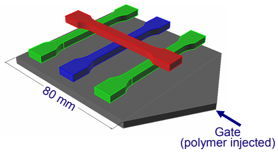


Near the surface (mould wall)



Near the center

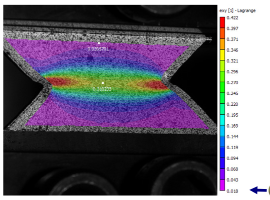
Typical variation of microstructure through the thickness of a 4 mm thick injection-moulded part. This is due to the thermo-mechanical history during processing. Photos: Polarised optical microscopy of microtomed sections.

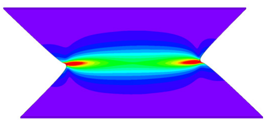


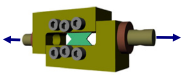
Test specimens for tensile, compressive and shear testing machined from a moulded part (grey), in order to study effects of anisotropy, variation along flow path etc. A gating system with two gates can also be used, creating a weld line.

Shear tests

- Challenges: Non-uniform strain field and non-shear strain components



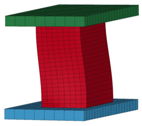




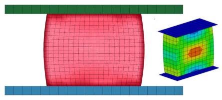
Experimental (left) and simulated (right) shear strains in a *V-notched rail shear* test (ASTM D 7078)

Compressive tests

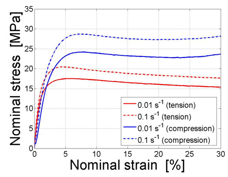
- Challenges: Buckling (limiting the max. strain) and barrelling (non-uniform strain)
- Experimental work in progress: Effects of specimen height/width ratio, and friction between specimen and fixture



Buckling of a test specimen

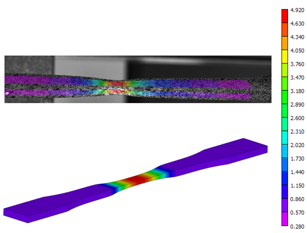


Barrelling of test specimen and effective plastic strains

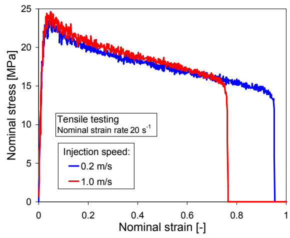


Tensile tests (≤ 10 m/s)

- Challenges: Strain localisation (necking) and force oscillations



Axial Lagrange strain of necking specimen. Full-field measurements (upper image) and simulation (lower).

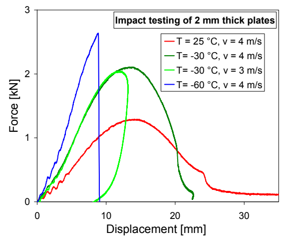


Effect of processing conditions (injection speed) on the tensile response at a rather high strain rate

Impact tests

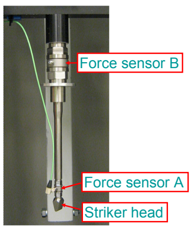
- Low-temperature low-speed impact – centrally loaded plates
  - Effects of impact speed, temperature, plate thickness, surface roughness, processing etc

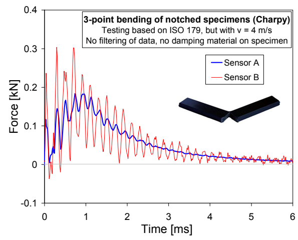
Punctured specimen (T = -30 °C, v = 4 m/s)



Testing of 2 mm thick plates (hemispherical ø20 mm striker and ø40 mm clamping ring)

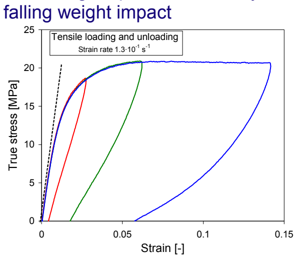
- Improved titanium striker with force sensor close to striker head
  - Reduced dynamic effects (force oscillations) for low-force impact



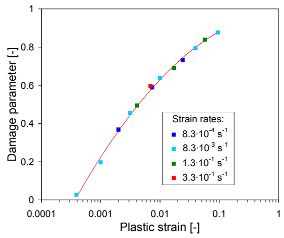


Unloading response (rebound)

- Unloading response studied by tensile loading/unloading and by instrumented falling weight impact



Tensile loading to different strains, followed by unloading at the same rate



A damage parameter *d* from tensile loading/unloading tests, defined by $E_{eff} = E(1 - d)$, where E_{eff} is the effective unloading modulus

Conclusion

- There are several challenges involved in obtaining true stress-strain data of ductile polymers for different stress states and large strains
- Mechanical properties of injection-moulded parts may vary from point to point, hence, effects of processing (injection moulding) must be assessed
- Full-field strain measurements and inverse modelling can provide more reliable true stress-strain data for large strains

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