Multiscale Properties IAG Meeting

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Project SM06

Knowledge Based Design with Plastics

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Project Outline

- Objective - to develop a capability to design with polymers under long-term load

- Model long-term deformation behaviour

- Develop non-linear viscoelasticity theory to produce solutions for arbitrary stress states and stress histories

- Prepare code, based on this theory, for ABAQUS to obtain solutions using finite element methods

- Evaluate the code

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Design for linear elastic behaviour

- Analysis of measurements under tension

$$\sigma_T = E\varepsilon_T$$
$$\varepsilon_T = D\sigma_T$$

- Theory – linear elastic
  - Isotropic materials

$$\varepsilon_{ij} = \frac{J}{2}\left(\sigma_{ij} - \sigma_m\delta_{ij}\right) + \frac{B}{3}\sigma_m\delta_{ij}$$

- Material properties
  - J and B
  - or E and ν from tensile tests

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Design for non-linear, elastic behaviour

- Analysis of measurements under simple stress states

$$\varepsilon_{ij} = \varepsilon_{ij}{}^{e} + \varepsilon_{ij}{}^{p} \qquad \sigma_T = f(\varepsilon_T^p) = \sigma_{yT}(\varepsilon_T^p)$$

$$\sqrt{3}\sigma_{yS} = \frac{(3+\lambda)}{3}\sigma_{yT} = \frac{(3-\lambda)}{3}\sigma_{yC}$$

- Theory – elastic-plastic
  - $\sigma_0(\varepsilon^p) = f(q, \sigma_m)$ Yield criterion
  - $\varepsilon_{ij}{}^{p} = c\dfrac{\partial F}{\partial \sigma_{ij}}$ Plastic flow law
- Material properties
  - $\sigma_T(\varepsilon_T{}^p)$ and $\sigma_S(\varepsilon_S{}^p)$ hardening curves in tension and shear
  - $\nu^p(\varepsilon_T{}^p)$ Poisson’s ratio with plastic strain

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Design for non-linear, viscoelasticity

- Analysis of measurements on polymers under simple stress state and stress history (creep)

$$D(t) = D_0 + \Delta D\left(1 - \exp - \left(\frac{t}{t_0}\right)^n\right)$$

$$t_0 = A \exp - \alpha\overline{\sigma}$$

- Theory – non-linear viscoelastic
  - Not available in FE packages
  - Closest models are for time-dependent plasticity
  - These do not describe
    - Creep results
    - Response to step loading

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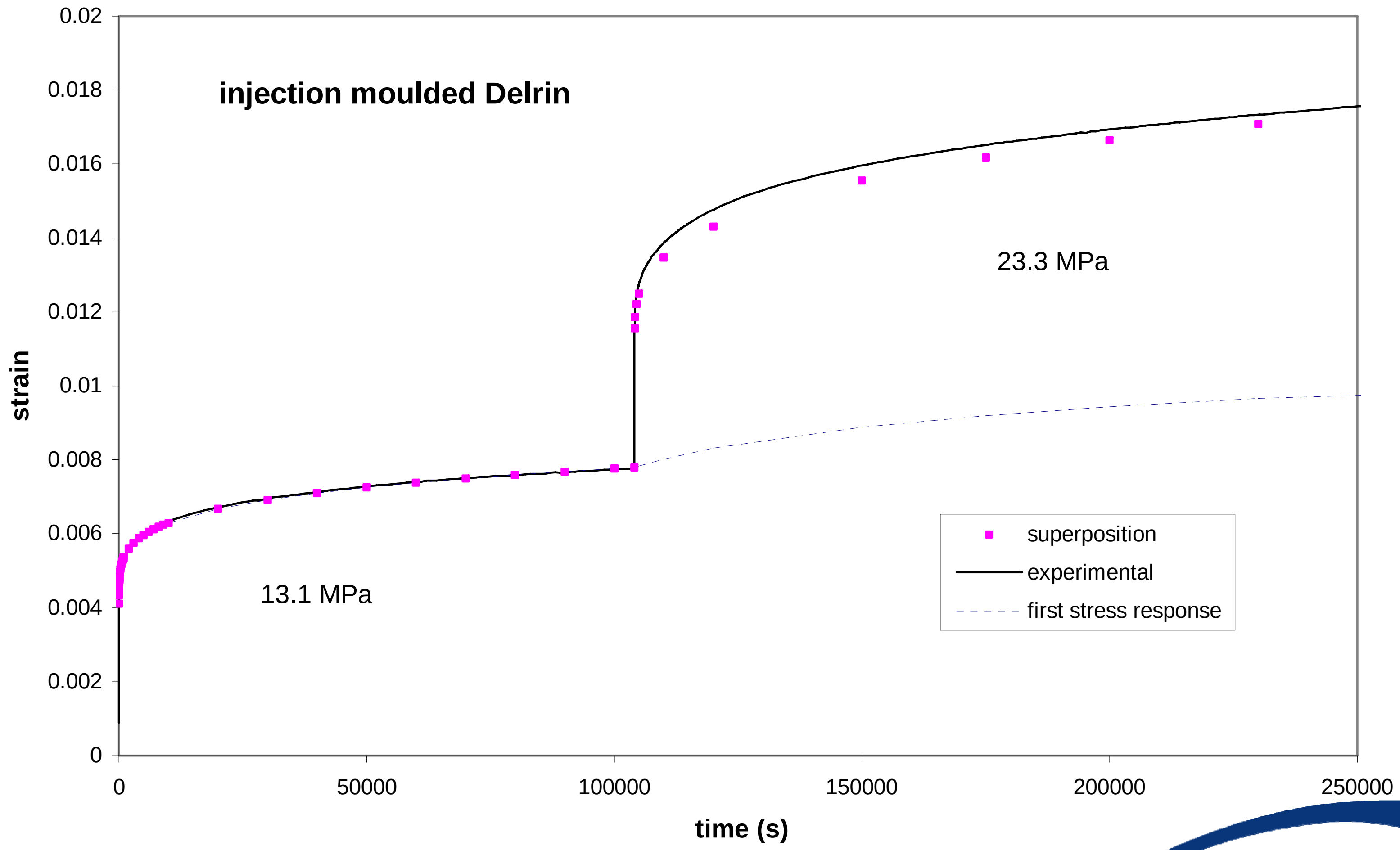
2-step loading – measurement and prediction



Non-linear viscoelasticity in SM06

- Stress/strain equations for multiaxial and time-dependent stresses

$$\varepsilon_{ij}(t) = \varepsilon_{ij}{}^{d}(t) + \frac{1}{3}\varepsilon_{m}(t)\delta_{ij}$$

$$\varepsilon_{ij}{}^{d}(t) = \frac{1}{2}\int_0^t \dot{\sigma}_{ij}{}^{d}(\tau)J(t-\tau)d\tau$$

$$J(t-\tau) = J_0 + \Delta J\left[1-\exp\left[-\left(\int_\tau^t \frac{du}{t_0(\overline{\sigma}(u))}\right)^n\right]\right]$$

$$\varepsilon_{m}(t) = \int_0^t \dot{\sigma}_{m}(\tau)B(t-\tau)d\tau$$

$$B(t-\tau) = B_0 + \Delta B\left[1-\exp\left[-\left(\int_\tau^t \frac{du}{t_0(\overline{\sigma}(u))}\right)^n\right]\right]$$

- Material properties
  - $J(t) = 2(1+\nu)D(t)$
  - $B(t) = 3(1-2\nu)D(t)$ assuming constant Poisson's ratio

Next steps

- Evaluation of FE code
  - Compare FE predictions with measurements of creep under step loading and unloading
  - Compare predictions and measurements of creep under flexural loading
  - Compare predictions and measurements under a constant strain (stress relaxation)

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New project proposal

- SM06 is a small project

- New project proposal for 2008+
  - Accelerated methods for determining long-term properties of plastics

  - Excluded from submission to the MAC for 2nd year running

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