National Physical Laboratory

# Project SM06
# Design with Plastics for Long-term Performance

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# Project objective

- Develop a capability to design with polymers under long-term load
  - Develop a model for deformation of polymers under a simple load history – *constant stress*
    - Include non-linear behaviour
    - Generalise to multiaxial stress states
  - Develop methodology for using creep data to predict performance under varying stress
  - Prepare code to implement the model in a finite element system
  - Evaluate code

# Summary of progress

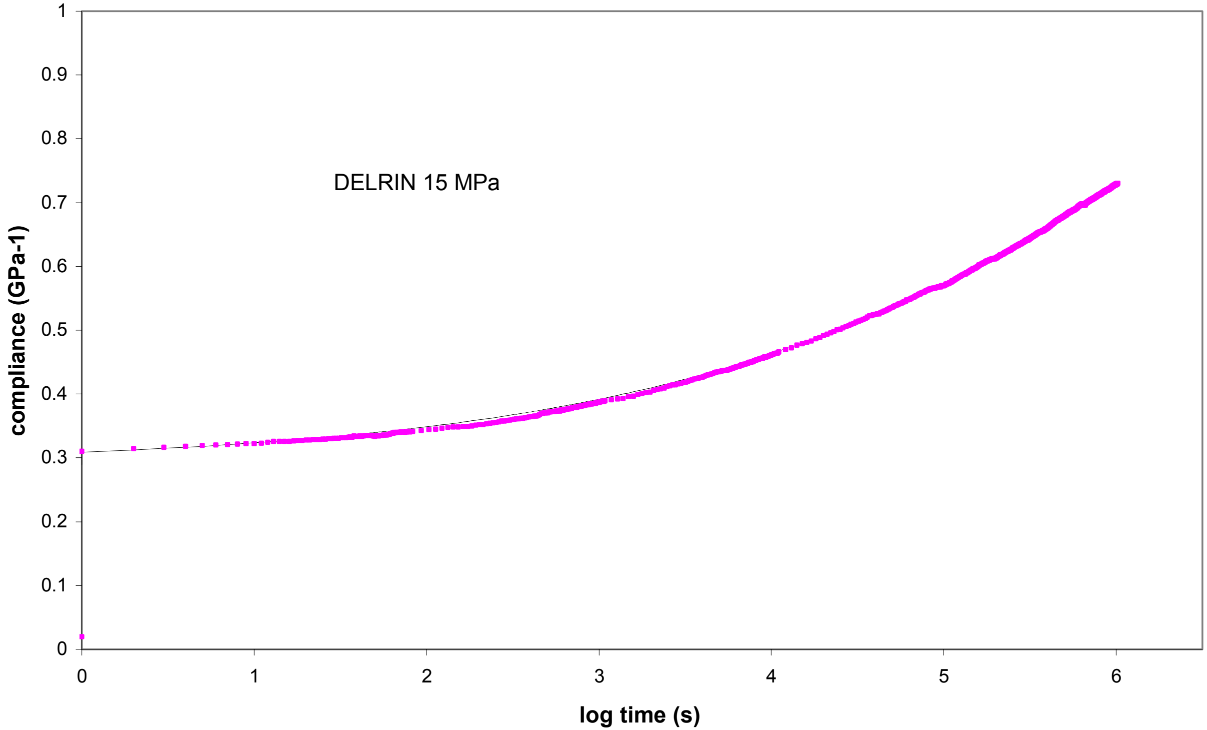
- Materials
  - Poly(oxymethylene) Du Pont DELRIN compression moulded
  - POM Du Pont DELRIN injection moulded – tested along flow
  - POM Ticona HOSTAFORM injection moulded – tested along and transverse to flow
  - Poly(butyleneterephthalate) Ticona CELANEX injection moulded
- Creep model development
  - Application of model to above test data
- Preparation of FE code
  - Necessary to establish how creep data should be used in situations where the stress is not constant
  - Explore using step loading tests

# Modelling creep under tension

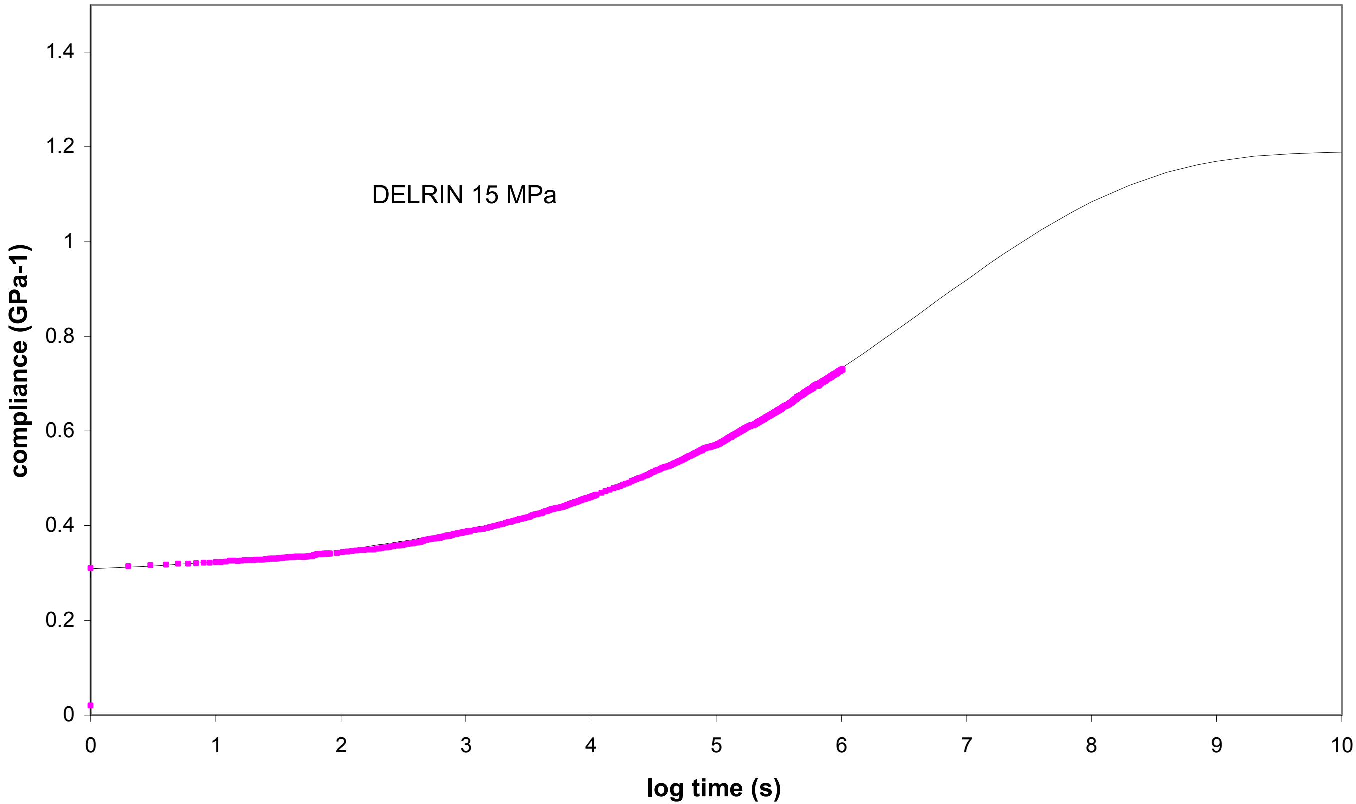
- A creep compliance function

$$D(t) = \frac{\varepsilon(t)}{\sigma_0} = D_0 + \Delta D\left(1 - \exp-\left(\frac{t}{t_0}\right)^m\right)$$

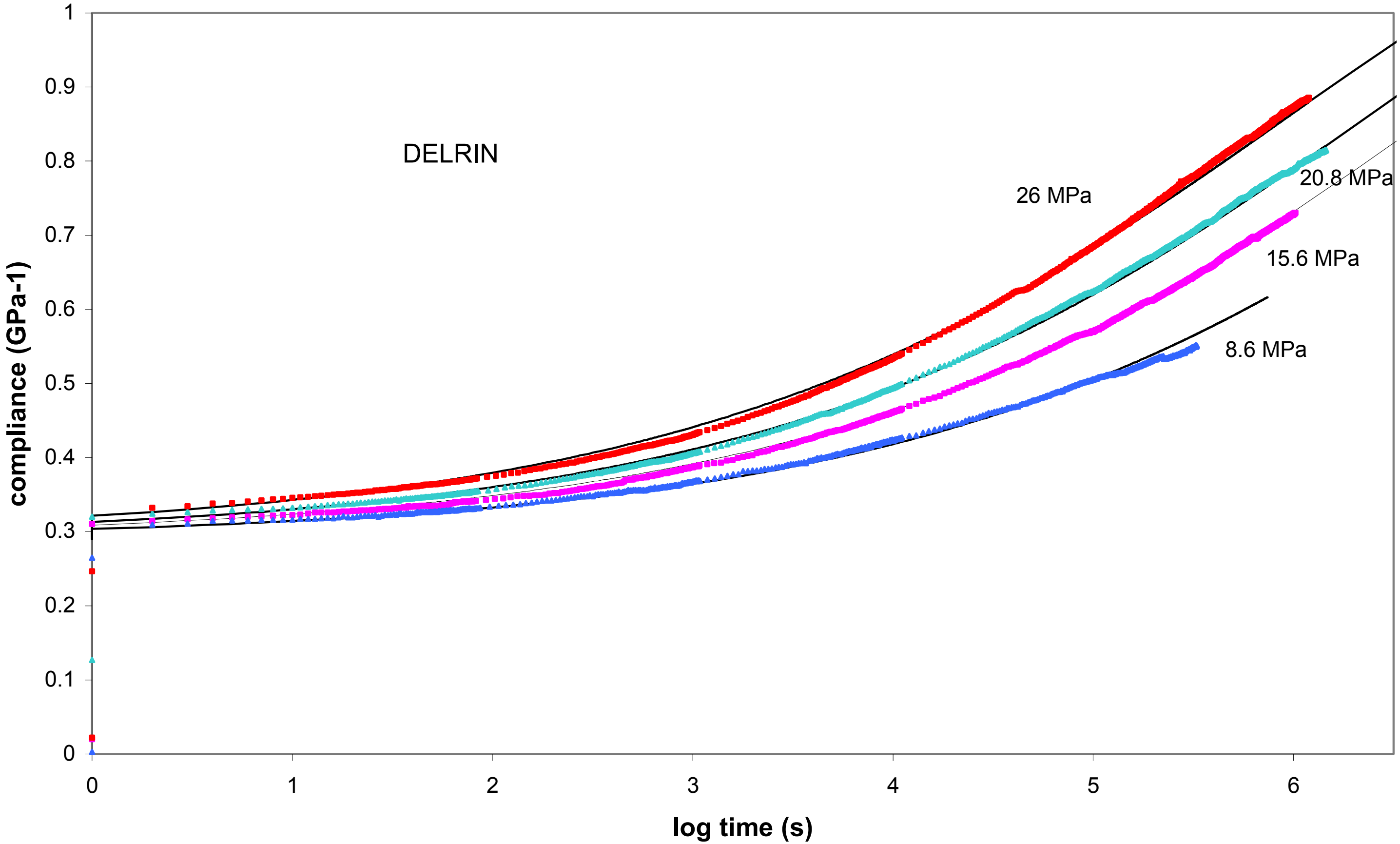
- $t_0$ is a mean retardation time



# Extrapolation to long times



# Modelling non-linear creep
## DELRIN compression moulded




- The retardation time parameter $t_0$ decreases with increasing stress

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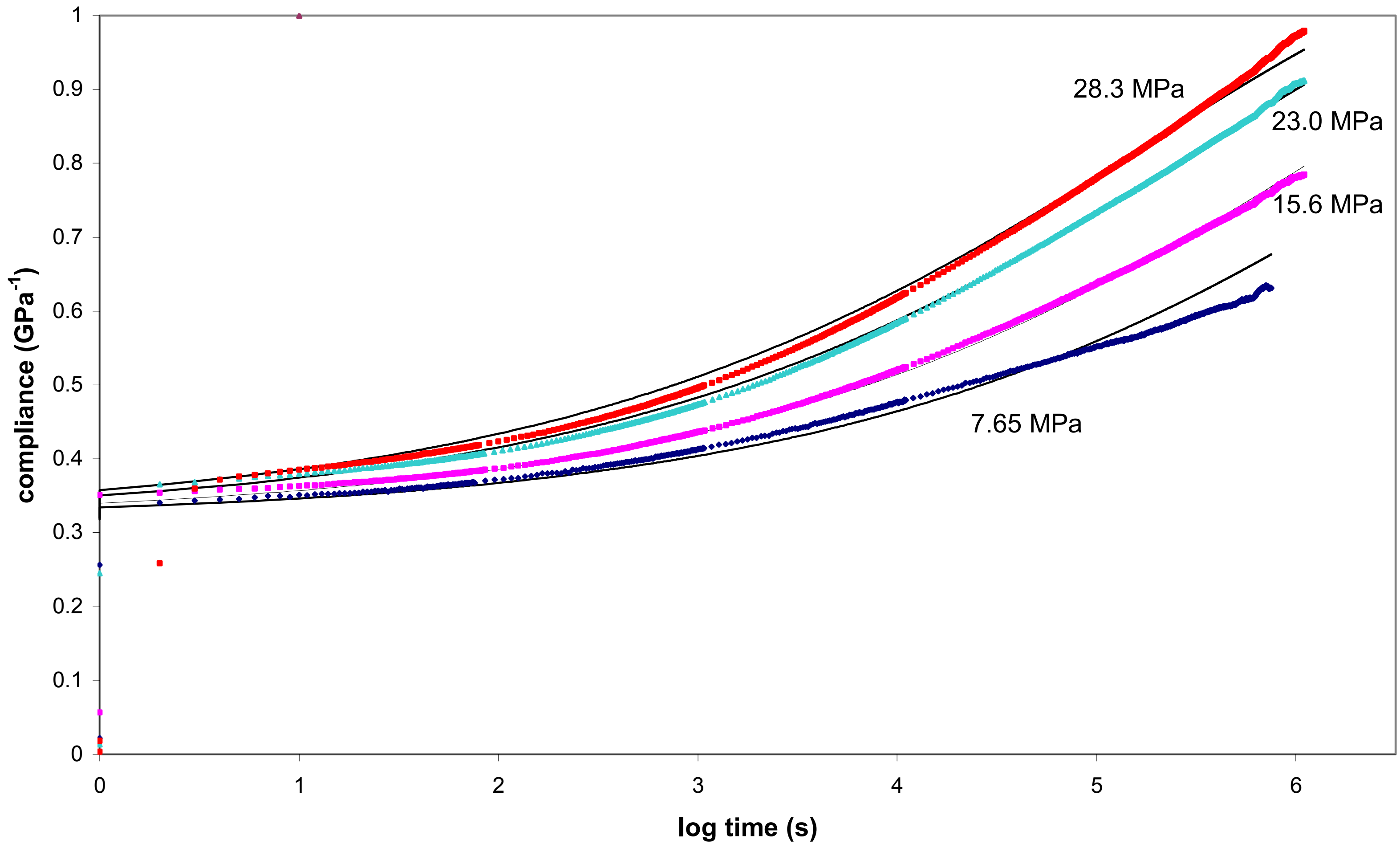
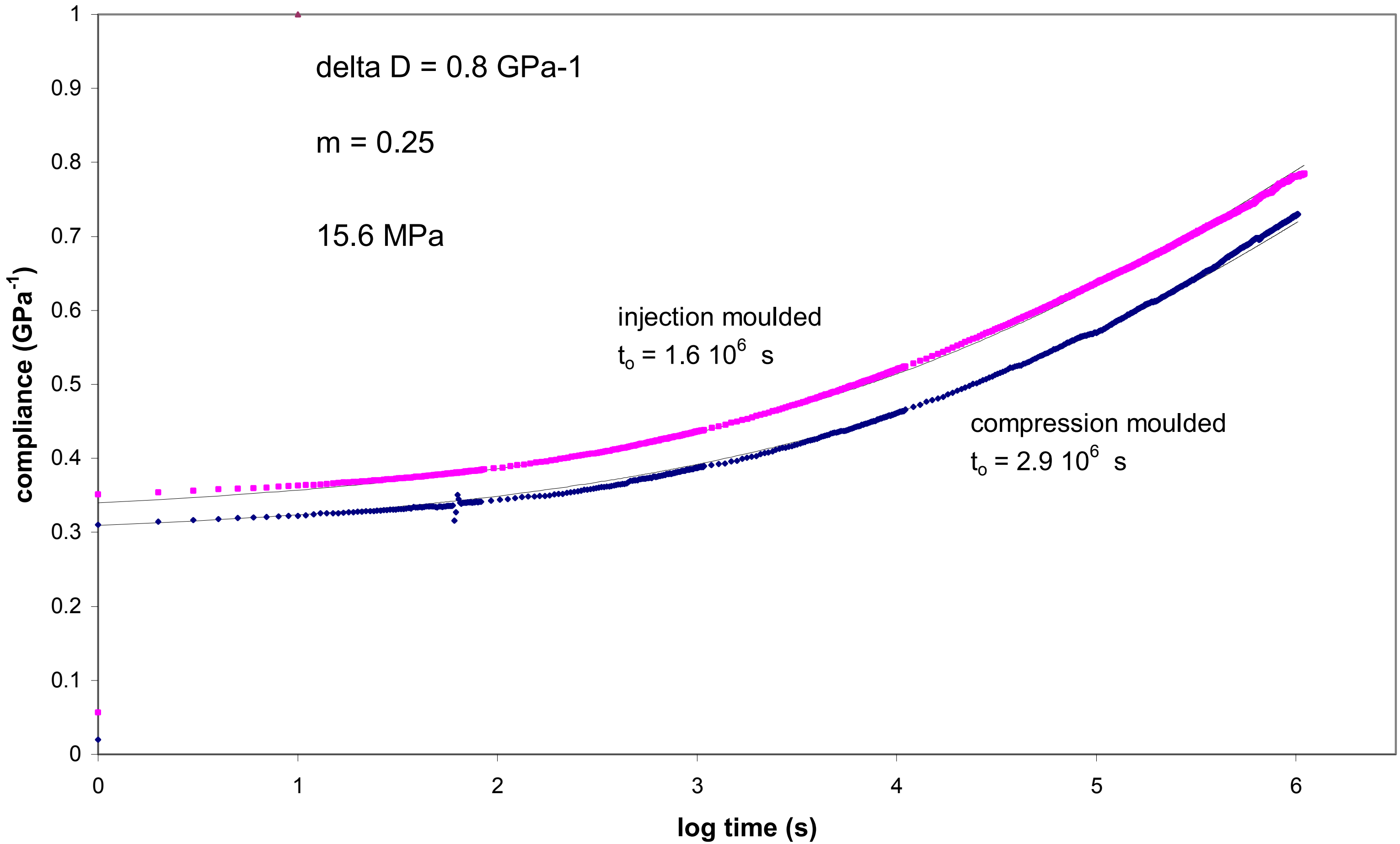
# OM injection moulded DELRIN

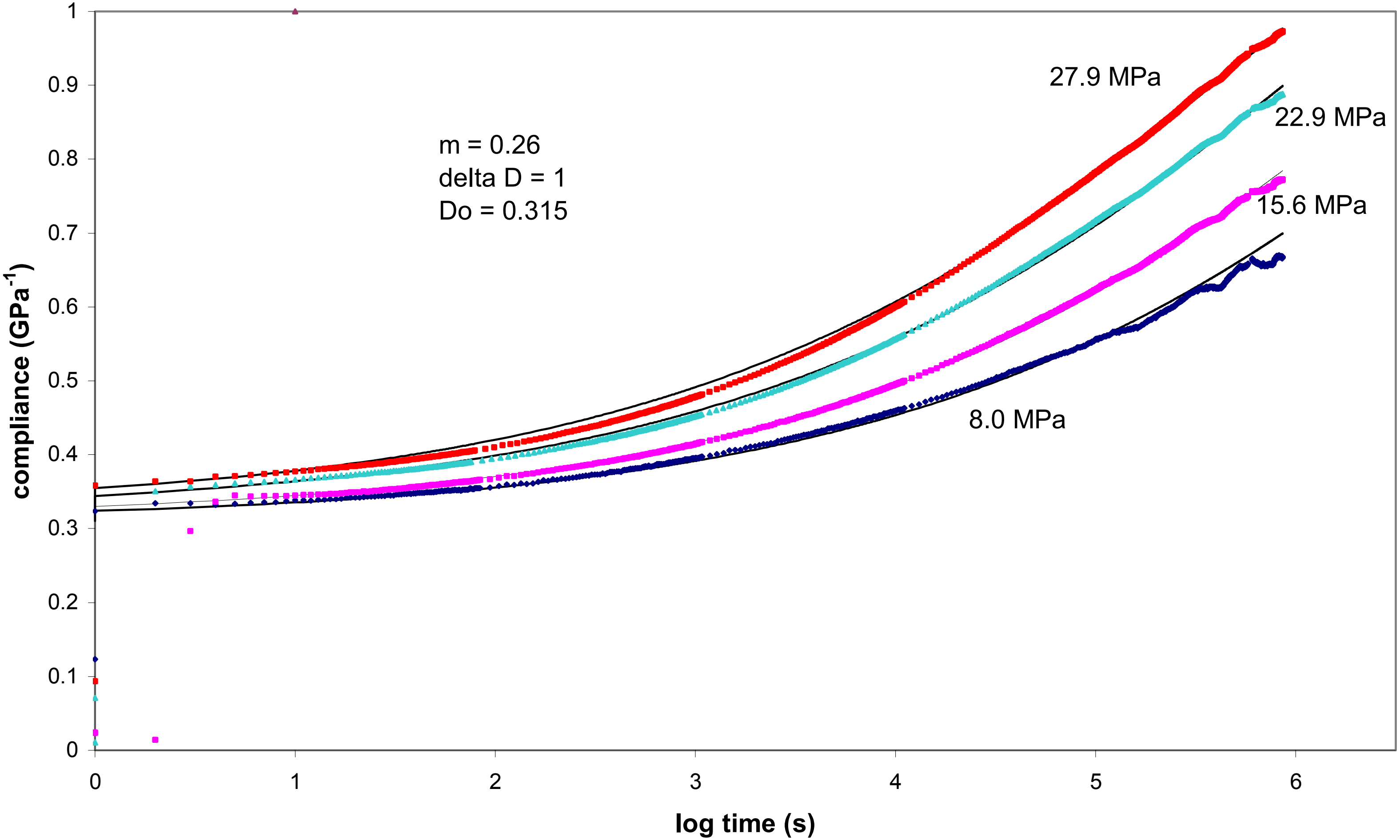
- Poor fit with constant m and ΔD



# Comparison of compression and injection moulded data - DELRIN

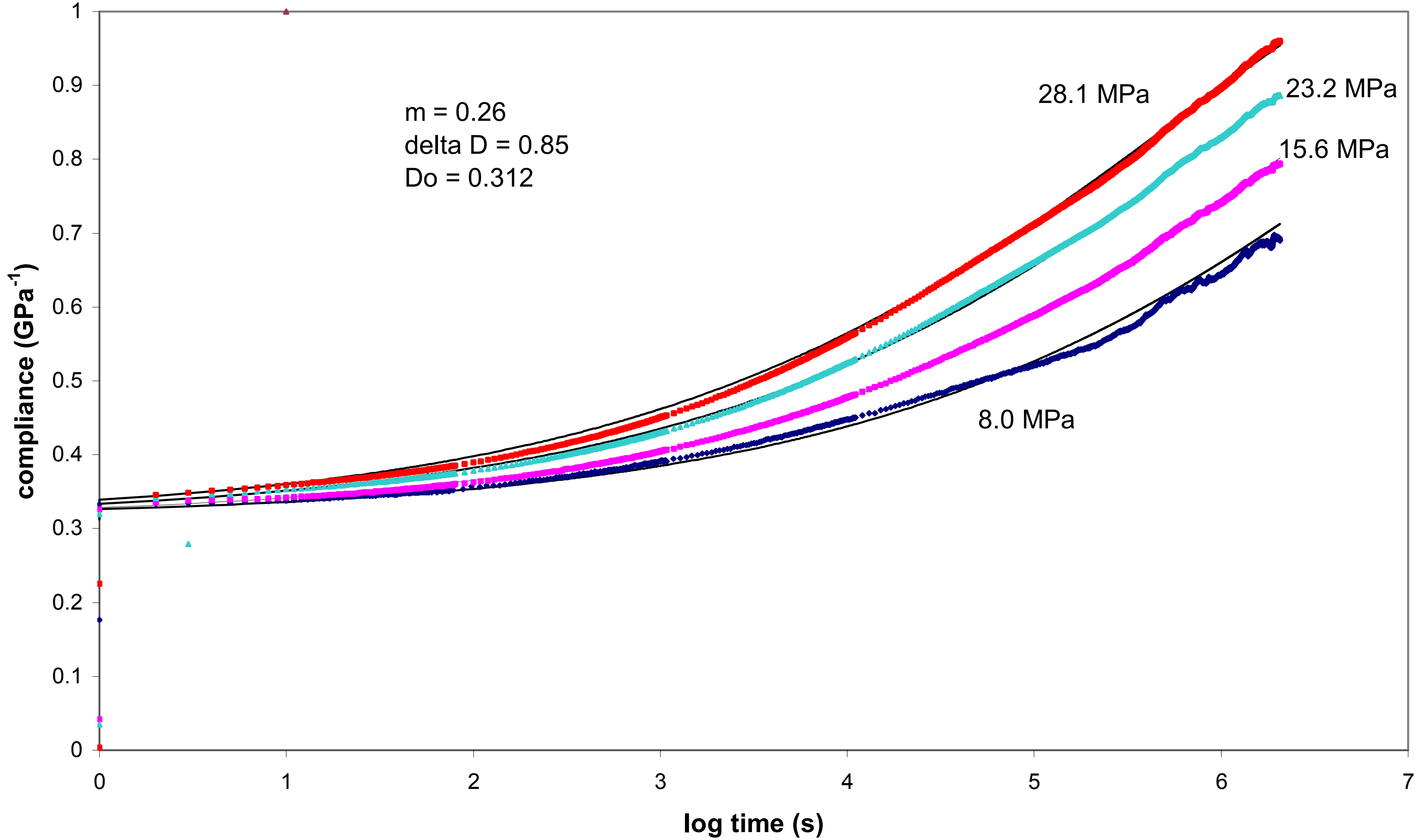


# OM injection moulded HOSTAFORM tested along flow



# IOSTAFORM injection moulded tested transverse to flow

- Small reduction in ΔD

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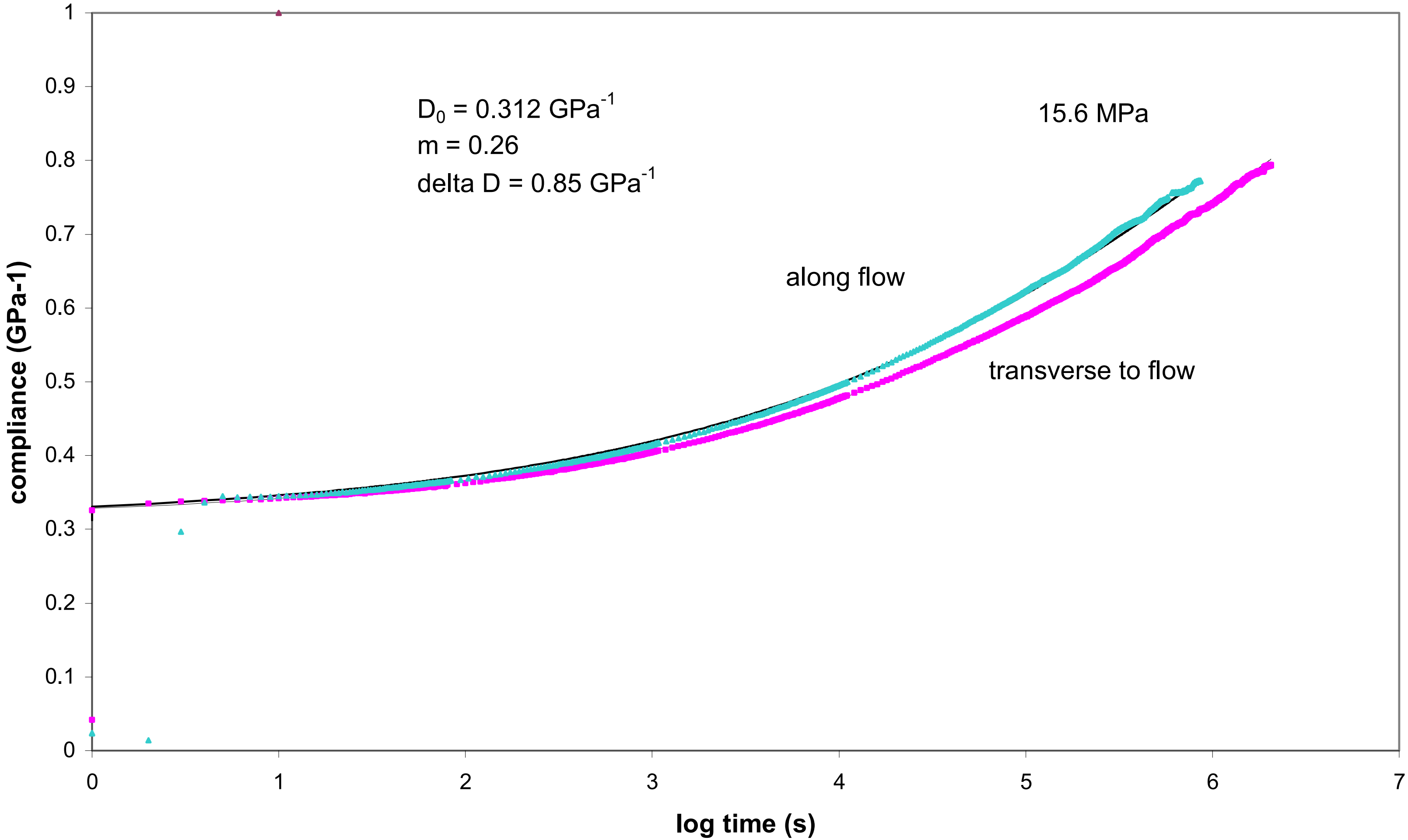
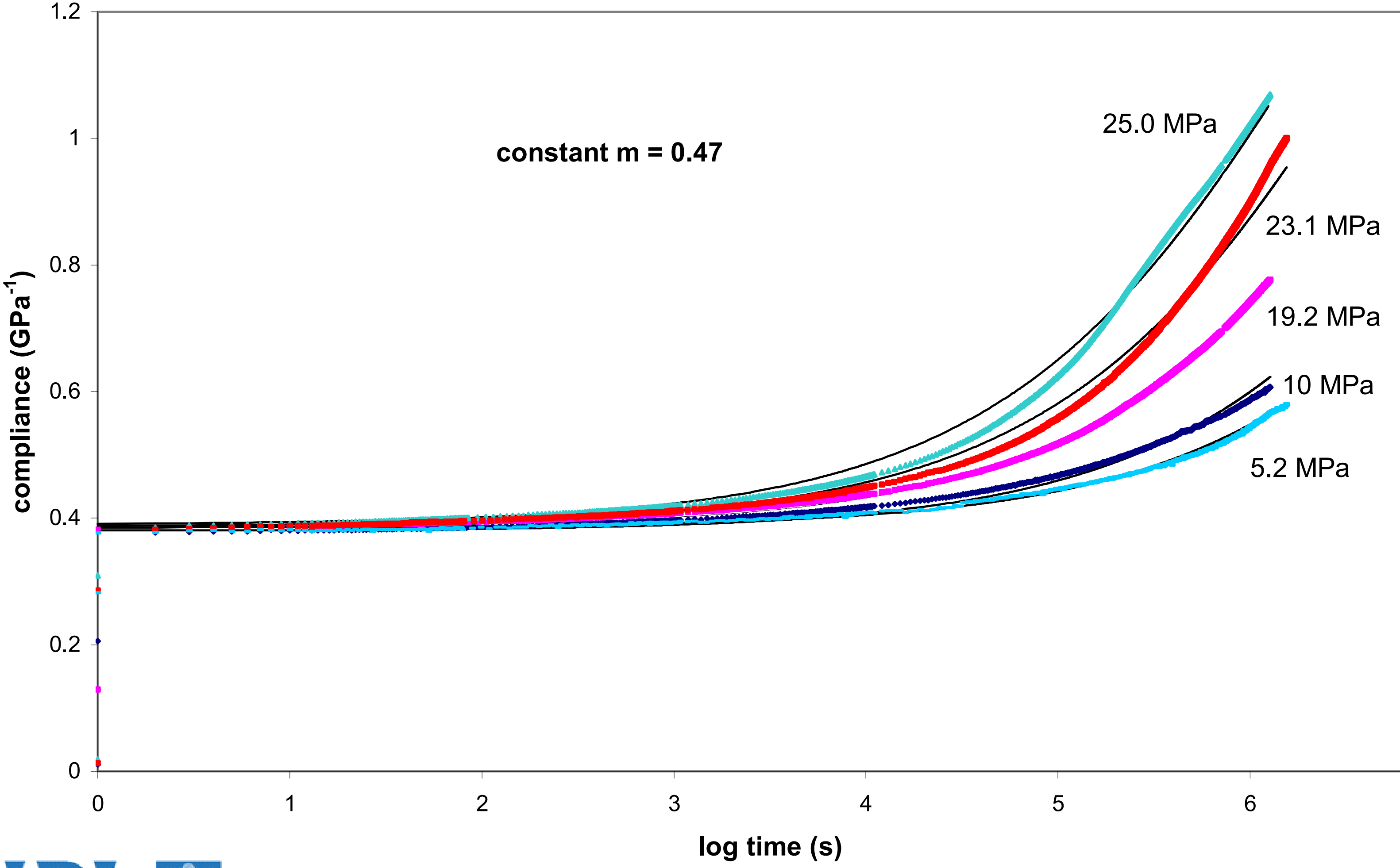
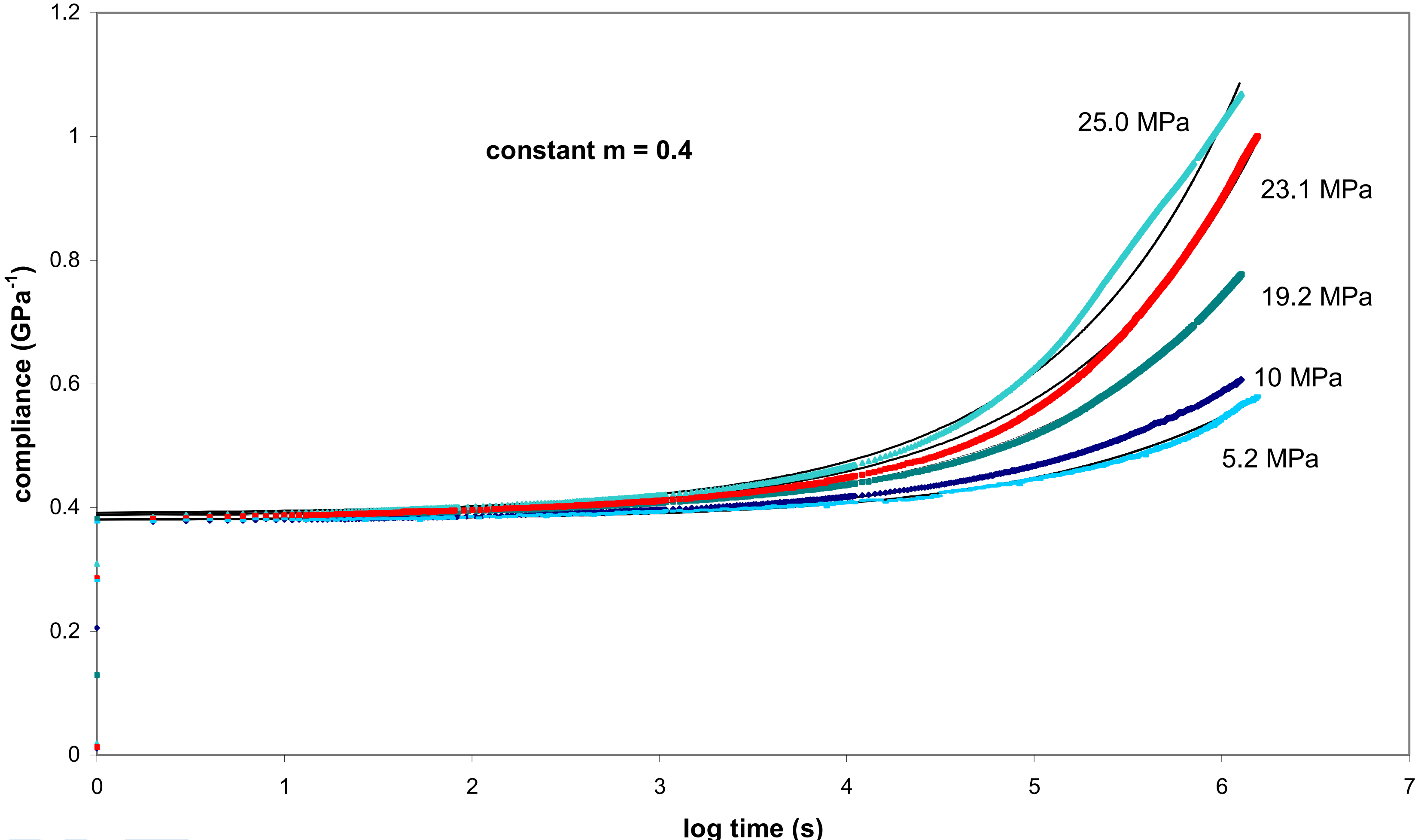
# Comparison along and transverse to flow - HOSTAFORM



# BT injection moulded CELANEX along flow



# njection moulded CELANEX with
# lastic flow

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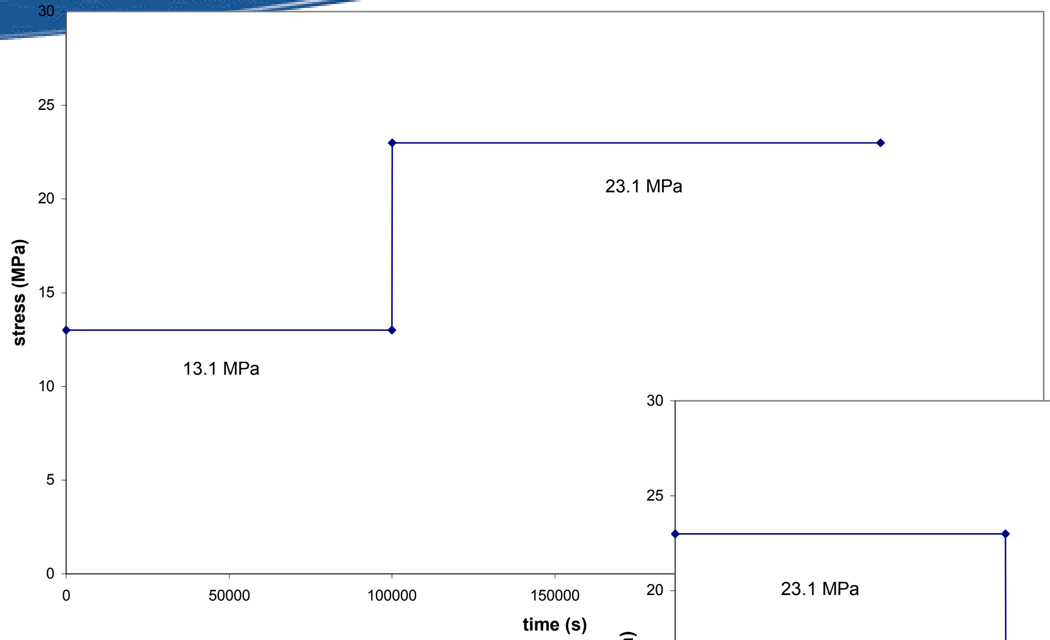
# pplication of the creep model in an E analysis

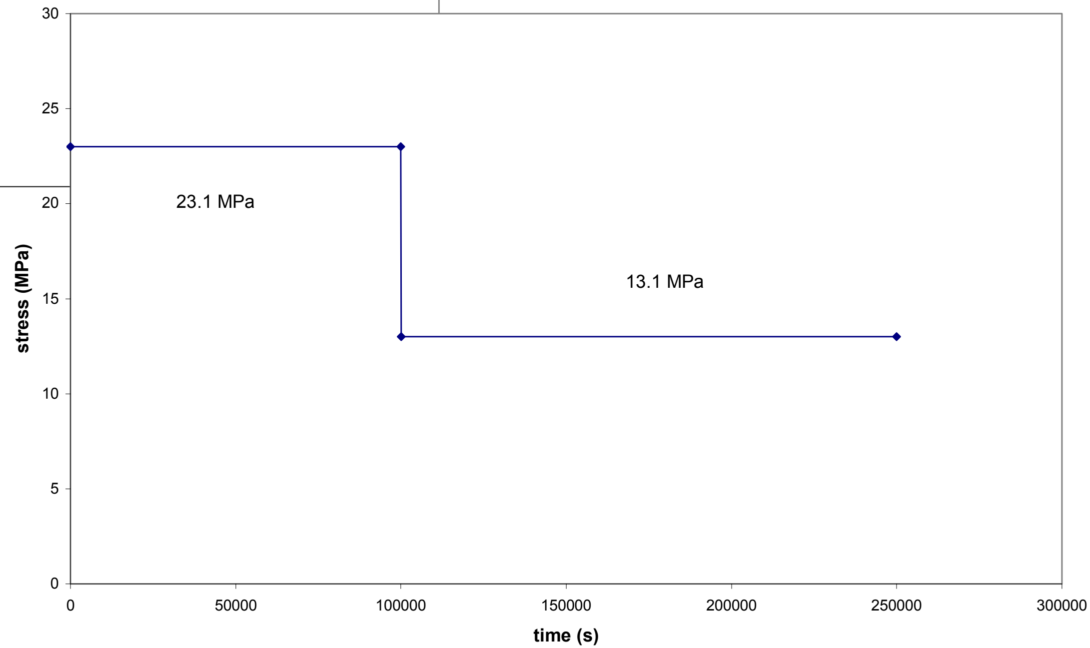
- How are creep functions to be used in situations where the stress is changing with time

- Explore using step loading tests with ABAQUS
  - Use creep functions in ABAQUS to model polymer creep

# btain solutions for 2-step reep tests

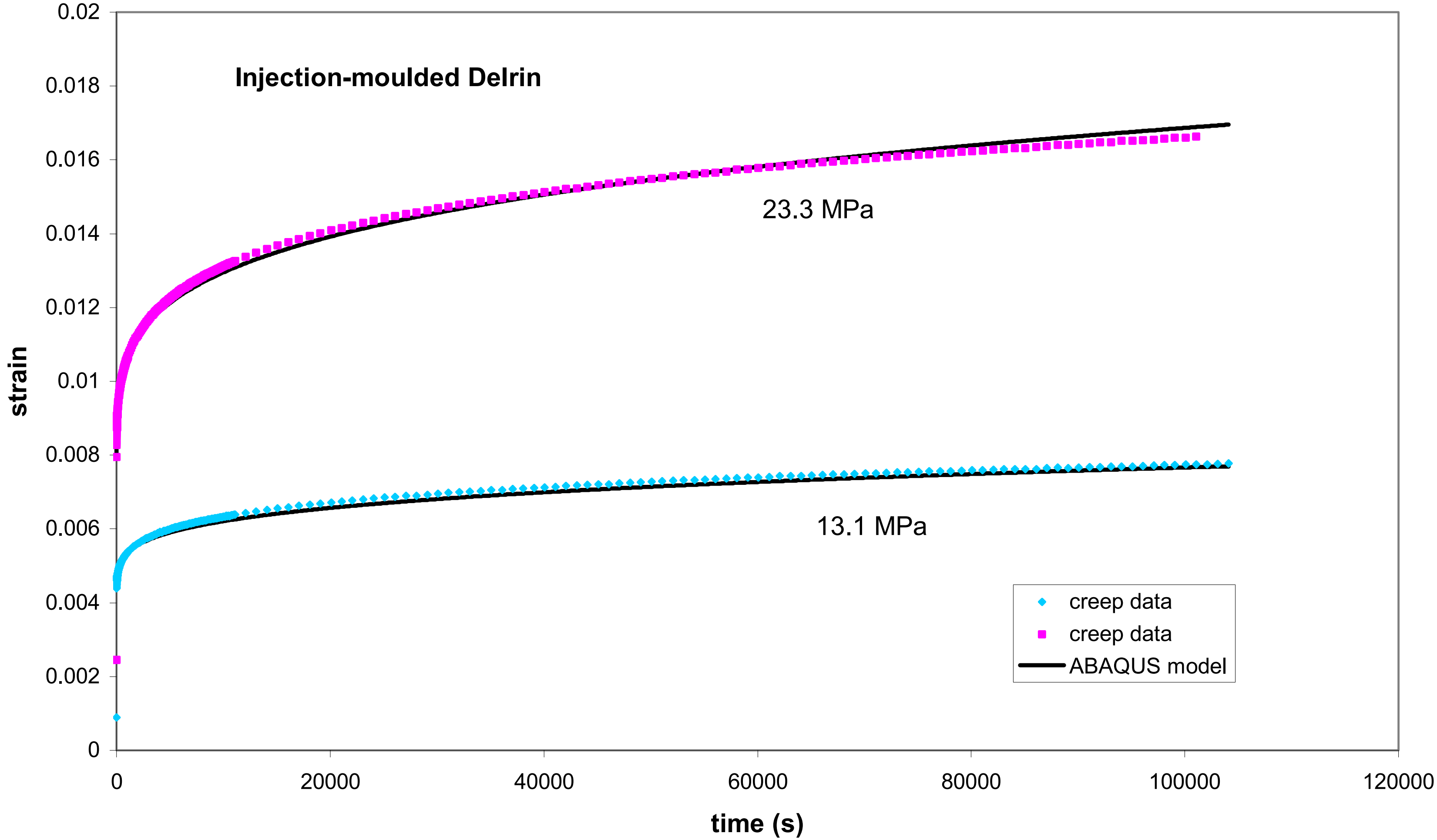
## Stress histories



# DELRIN – application of ABAQUS creep model

$$\varepsilon(t) = \sigma D_0 + A\sigma^n t^m$$

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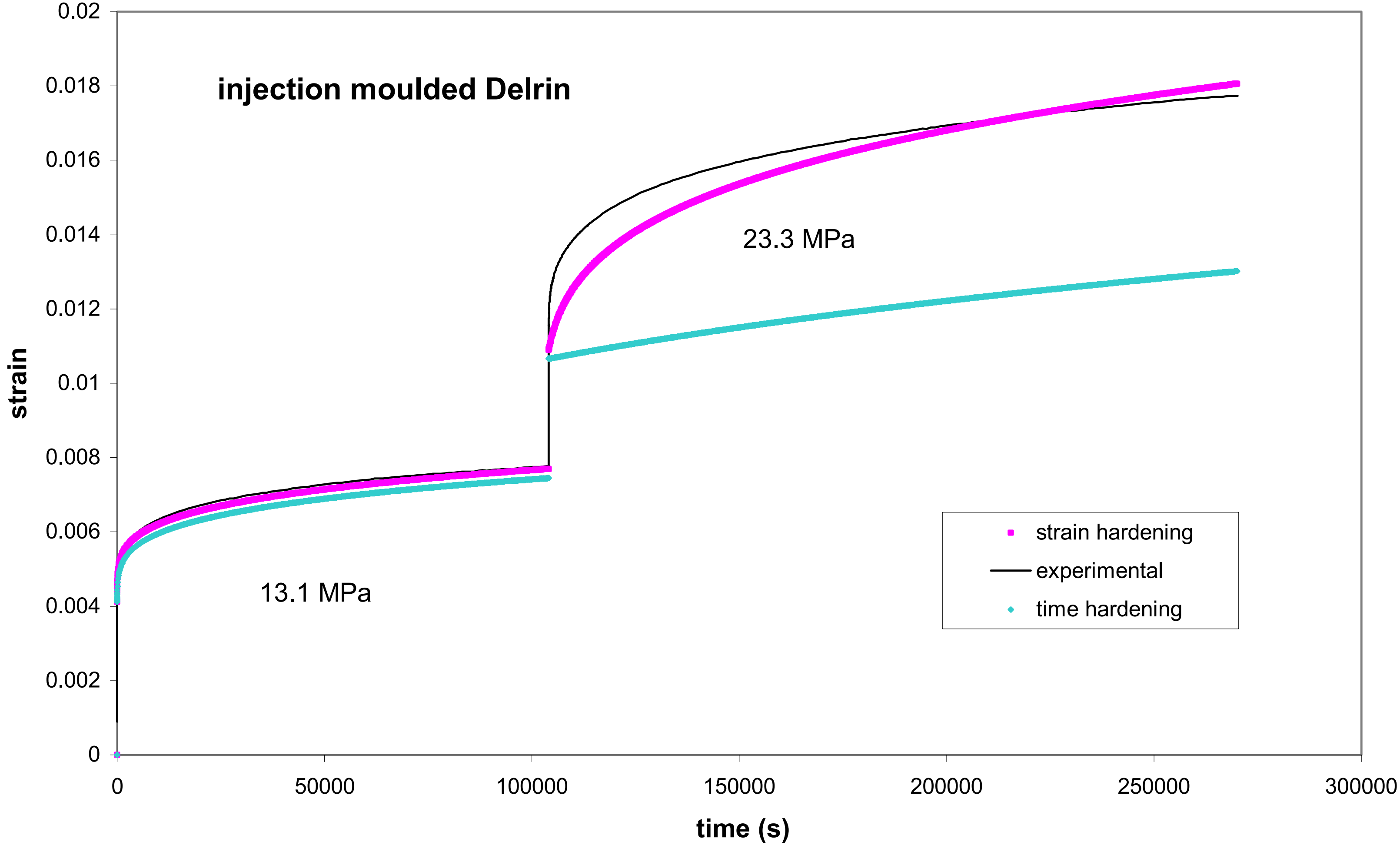
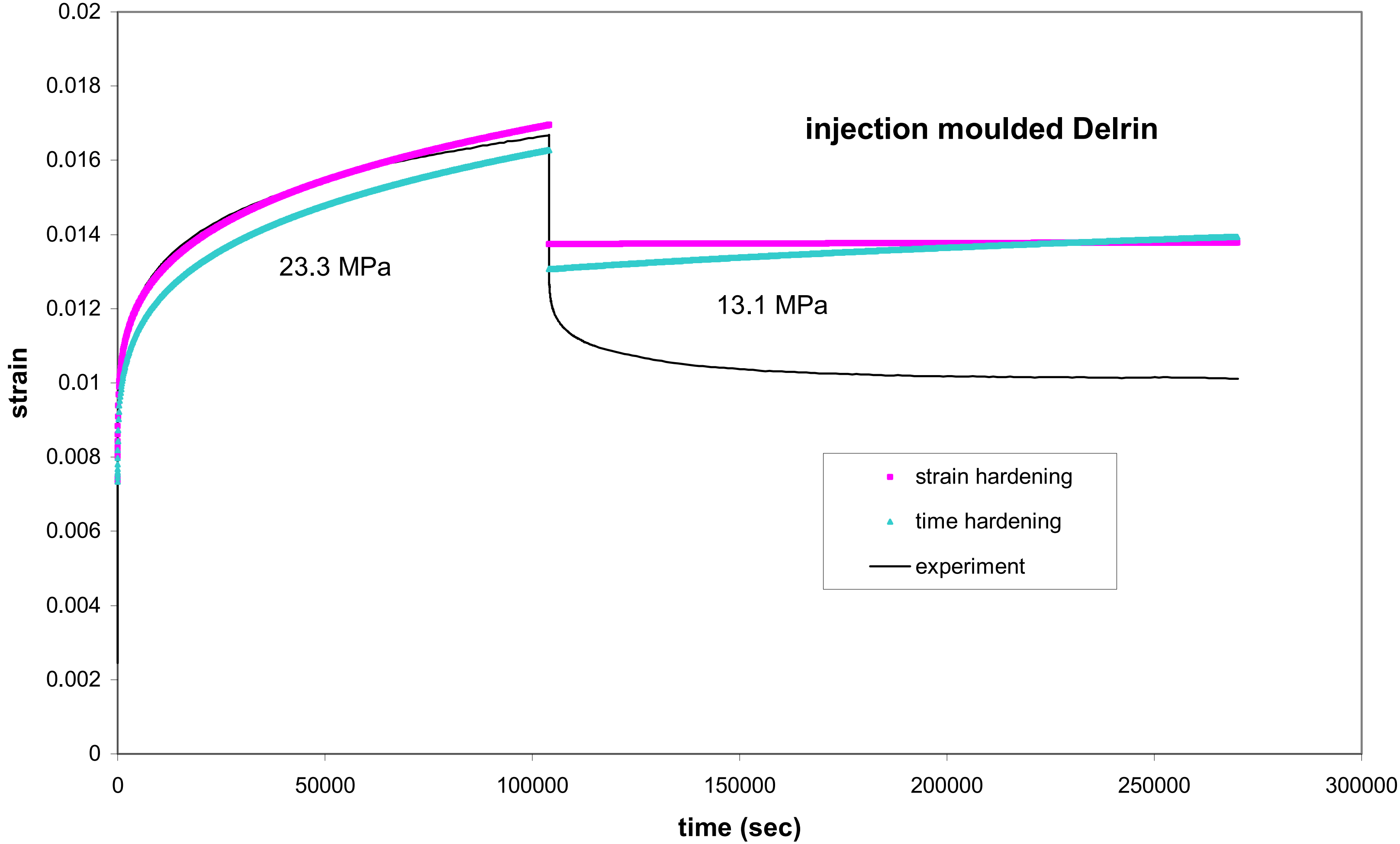
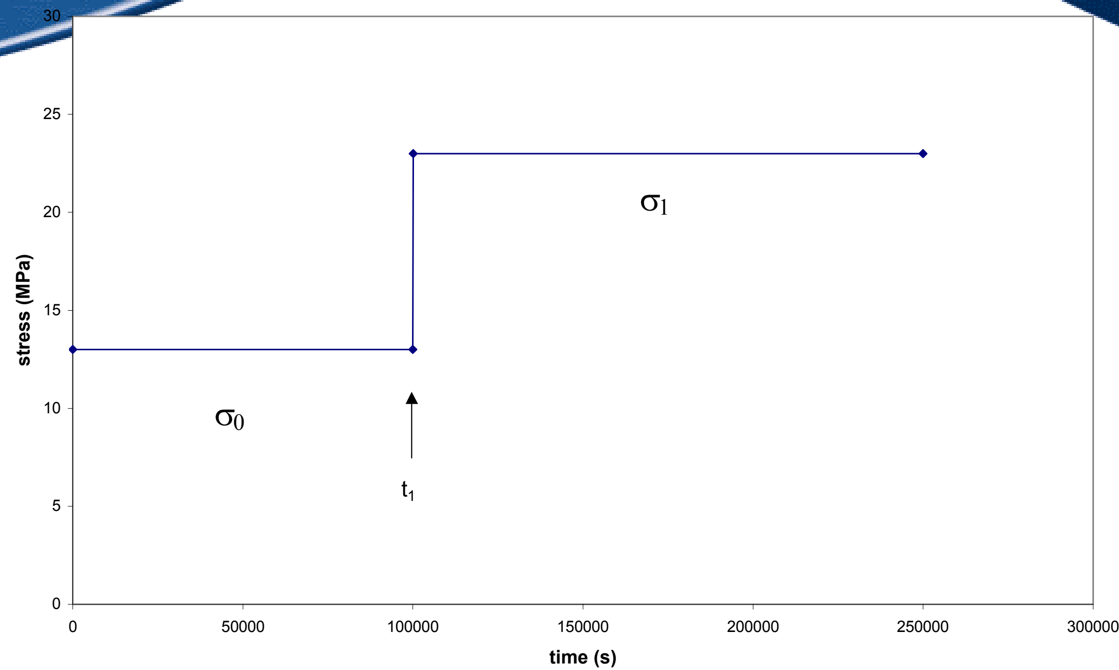
# tep loading predictions using
# BAQUS



# tep unloading predictions using
# ABAQUS



# olution by superposition



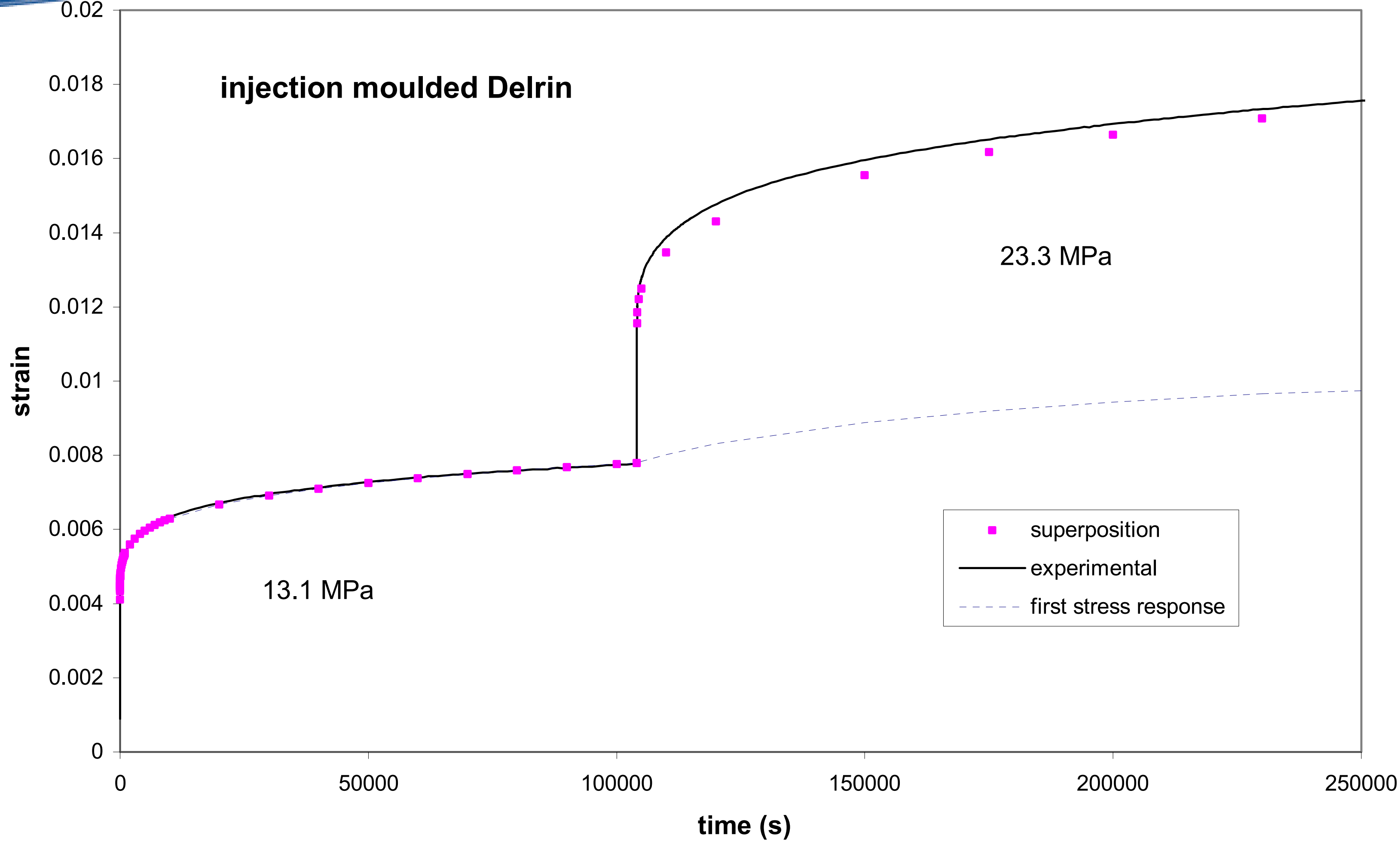

## Linear behaviour

$$\varepsilon(t) = \sigma_0 D(t) + (\sigma_1 - \sigma_0) D(t - t_1)$$

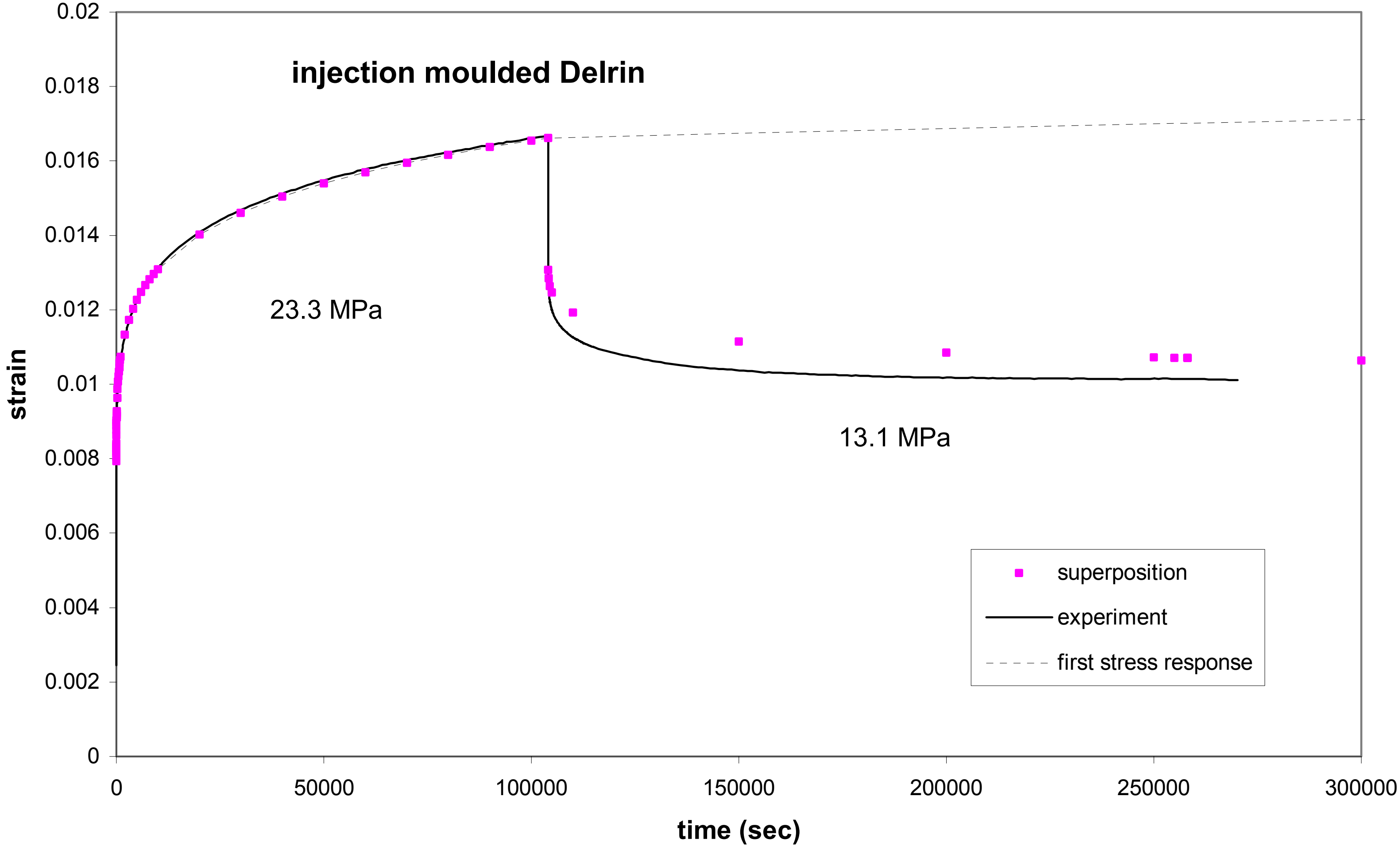
## Non-linear

$$\varepsilon(t) = \sigma_0 \left[ D_0 + \Delta D \left[ 1 - \exp - \left( \frac{t_1}{t_0} + \frac{t - t_1}{t_{01}} \right)^m \right] \right] + (\sigma_1 - \sigma_0) \left[ D_0 + \Delta D \left[ 1 - \exp - \left( \frac{t - t_1}{t_{01}} \right)^m \right] \right]$$

# Comparison of superposition solution with experiment



# Comparison of superposition solution with experiment - unloading



# urther work

- Generalise the superposition solution for continuous changes of stress with time.
- Use this formulation to code the model into an FE system
- Evaluate code by comparing predictions for different load histories with experiment
  - Step loading and unloading in tension
  - Creep under flexure
  - Stress relaxation
- Explore discrepancies with predictions of stress removal
- Explore modifications needed to model creep in PBT
  - Assess anisotropy in injection mouldings