National Physical Laboratory

SM06: Knowledge based design of plastics

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Polymer: Multiscale Properties IAG Meeting

September 2006

Aims

- Develop and code a validated model for predicting the long term performance of plastics used in load bearing applications
- Provide guidance / measurement protocols on the use of the model

  - Predictive modelling is an underpinning technology for materials design
  - Significant technical improvement to industry – current models are inaccurate for polymers
  - Enables users to shorten design cycles, reduce over-engineered products and increase reliability

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Deliverables

- D1: Develop a model for long term deformation behaviour of plastics under multi-axial stress states, coded into an FE package to be described in an NPL open report

- D2: Evaluation of the model and coding for arbitrary stress/strain histories and a case study demonstrating the model in use, to be presented as a scientific paper submitted to a journal

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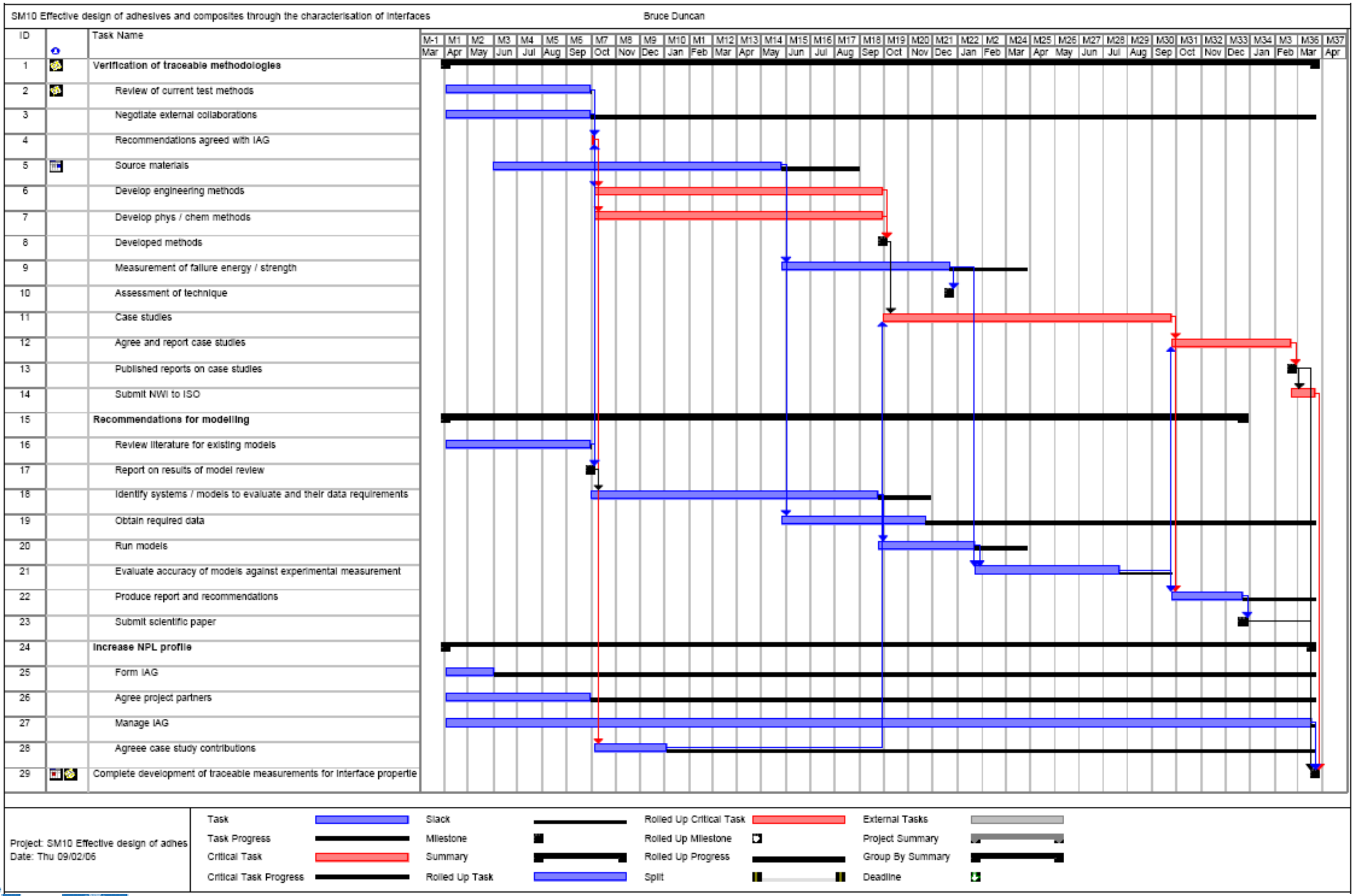
Gantt Chart – Project Plan



Plan

- Stage 1: Agree Materials and Case Studies
- Stage 2: Multi-axial creep data
- Stage 3: Multi-axial model
- Stage 4: Software coded and tested
- Stage 5: Validation via case study

- Stage 1: planned at start of project, and reviewed in following slides
- Stage 1 review will be held this month
- Stage 2 will be planned this month

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Objectives of Stage 1 (April – August 2006)

- Define and agree modelling approach to be developed
  - Greg to discuss next
  - Discussion note is available on request

- Agree materials to be used in the remainder of the project
  - POM and PBT
    - Currently testing Dupont materials Delrin and Crastin
    - Initial tests on Delrin will be discussed by Greg
    - Planning to test Ticona materials as well

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Objectives of Stage 1 (April – August 2006)

- Agree format of the case study
  - Evaluation of modelling and implementation
    - Step loading
    - Constant deformation rate (putting strain on in small steps)
    - Tensile stress relaxation
      - For all above tests we can obtain accurate data from uniaxial tensile creep tests
  - Case study
    - Predict creep of a bend specimen
      - Stresses vary with position
      - Stresses and strains redistribute with time
      - We can measure specimen deformation and compare to predictions

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Objectives of Stage 1
(April – August 2006)

- Agree data acquisition requirements
  - Model has to handle non-linear behaviour and multiaxial stress states
  - Minimum data requirements are
    - Tensile creep tests at different stresses
    - Compressive creep tests at one stress
      - Test procedure is being written
    - Shear creep tests will be used to evaluate the model

- Stage 1 has been completed

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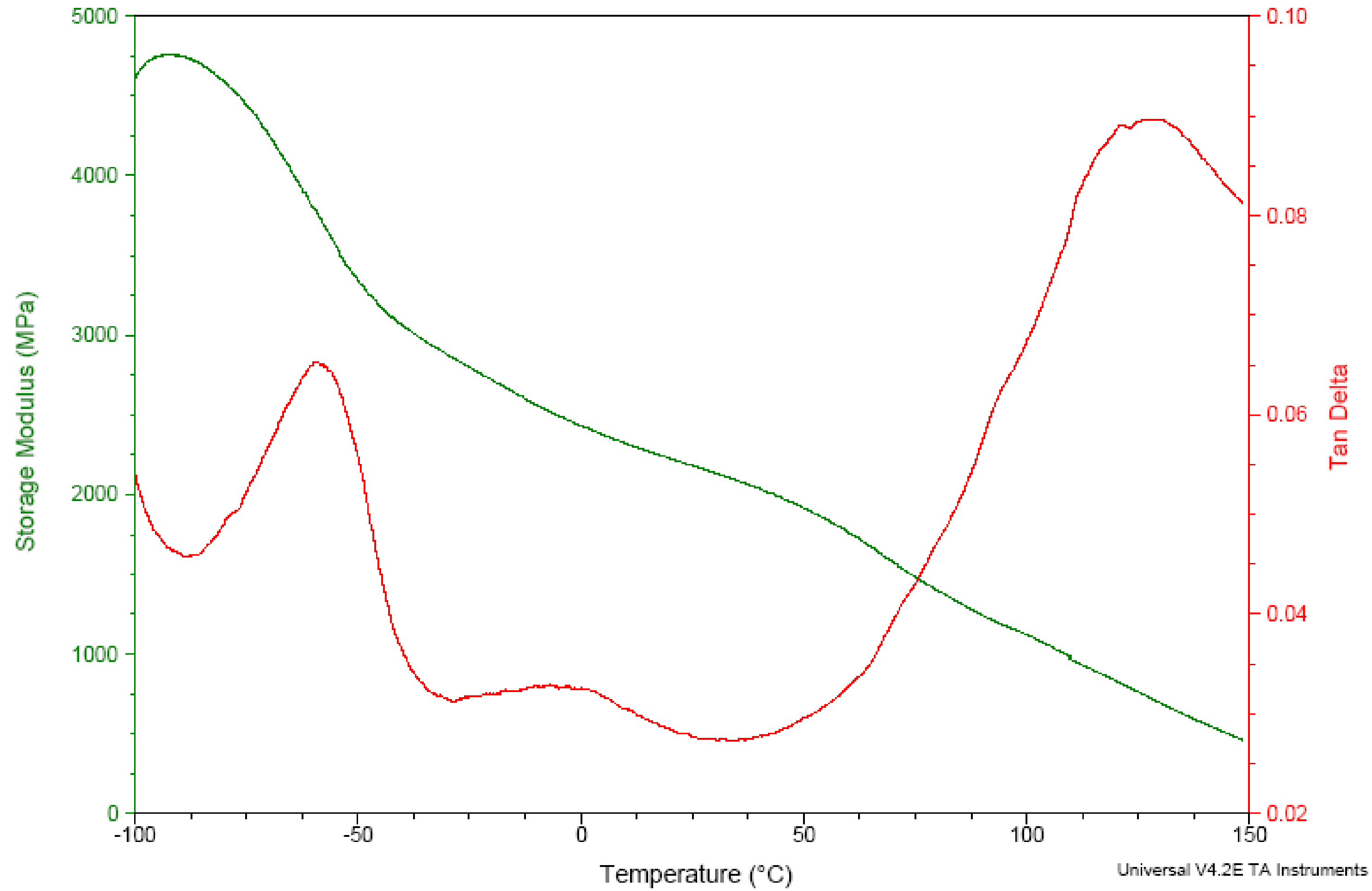
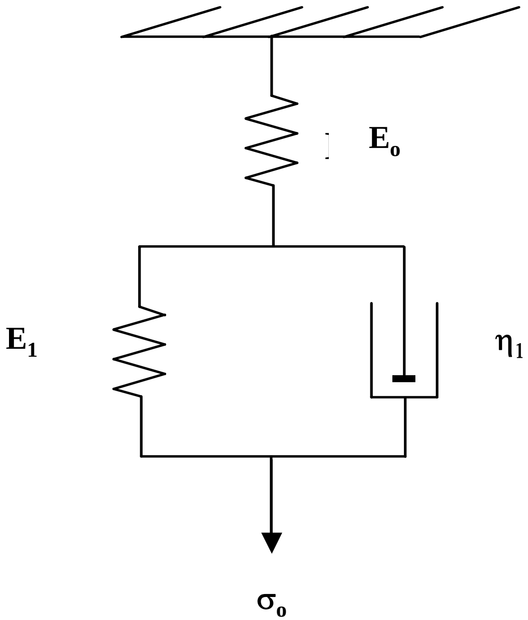
Modelling time-dependent behaviour

- Design for long-term performance
- Develop a model for deformation under a simple load history – *constant stress*
  - Non-linear behaviour
  - Multiaxial stress states
- Use a finite element analysis to calculate stresses and strains under an arbitrary load history

Dynamic mechanical properties of Du Pont Acetal copolymer - DELRIN



Linear viscoelastic behaviour



- Time-varying strain under constant stress

$$\varepsilon(t) = \frac{\sigma_0}{E_0} + \frac{\sigma_0}{E_1}\left(1 - \exp - \frac{t}{\tau_1}\right) + \frac{\sigma_0}{E_2}\left(1 - \exp - \frac{t}{\tau_2}\right) + \ldots\ldots$$

$$\tau_i = \frac{\eta_i}{E_i}$$

  – τ_i is the retardation time for the ith process

- Definition of a creep compliance function

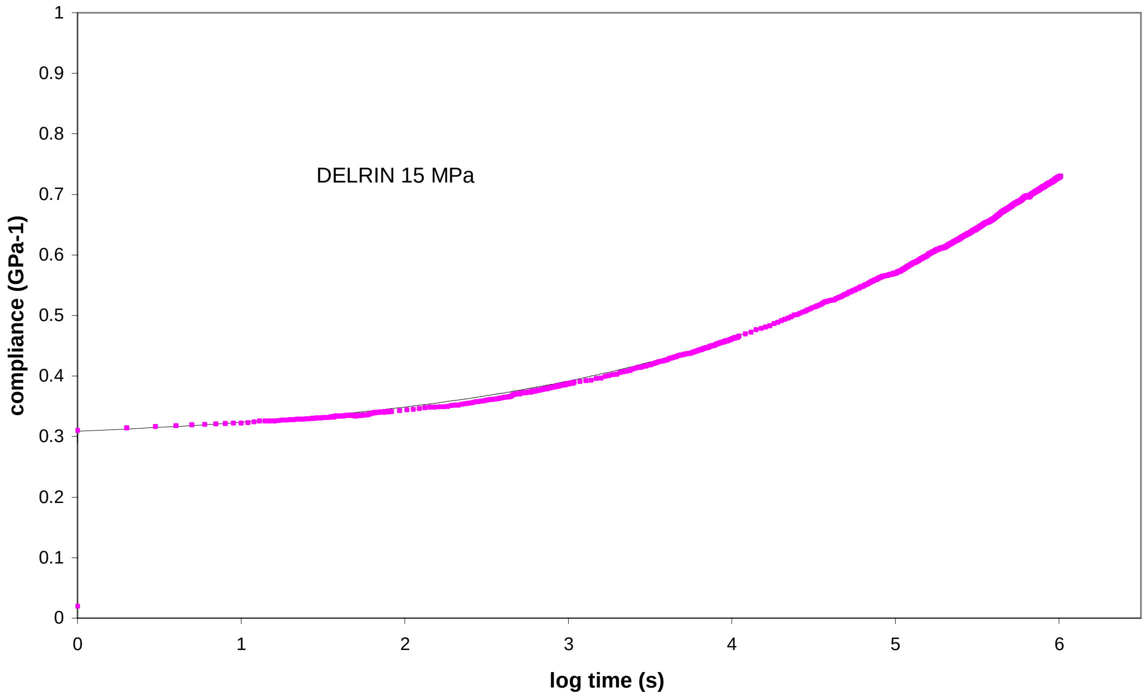
$$D(t) = \frac{\varepsilon(t)}{\sigma_0} = D_0 + D_1\left(1 - \exp - \frac{t}{\tau_1}\right) + \ldots.$$

Modelling creep under tension in plastics

- A creep compliance function

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

- τ is a mean retardation time



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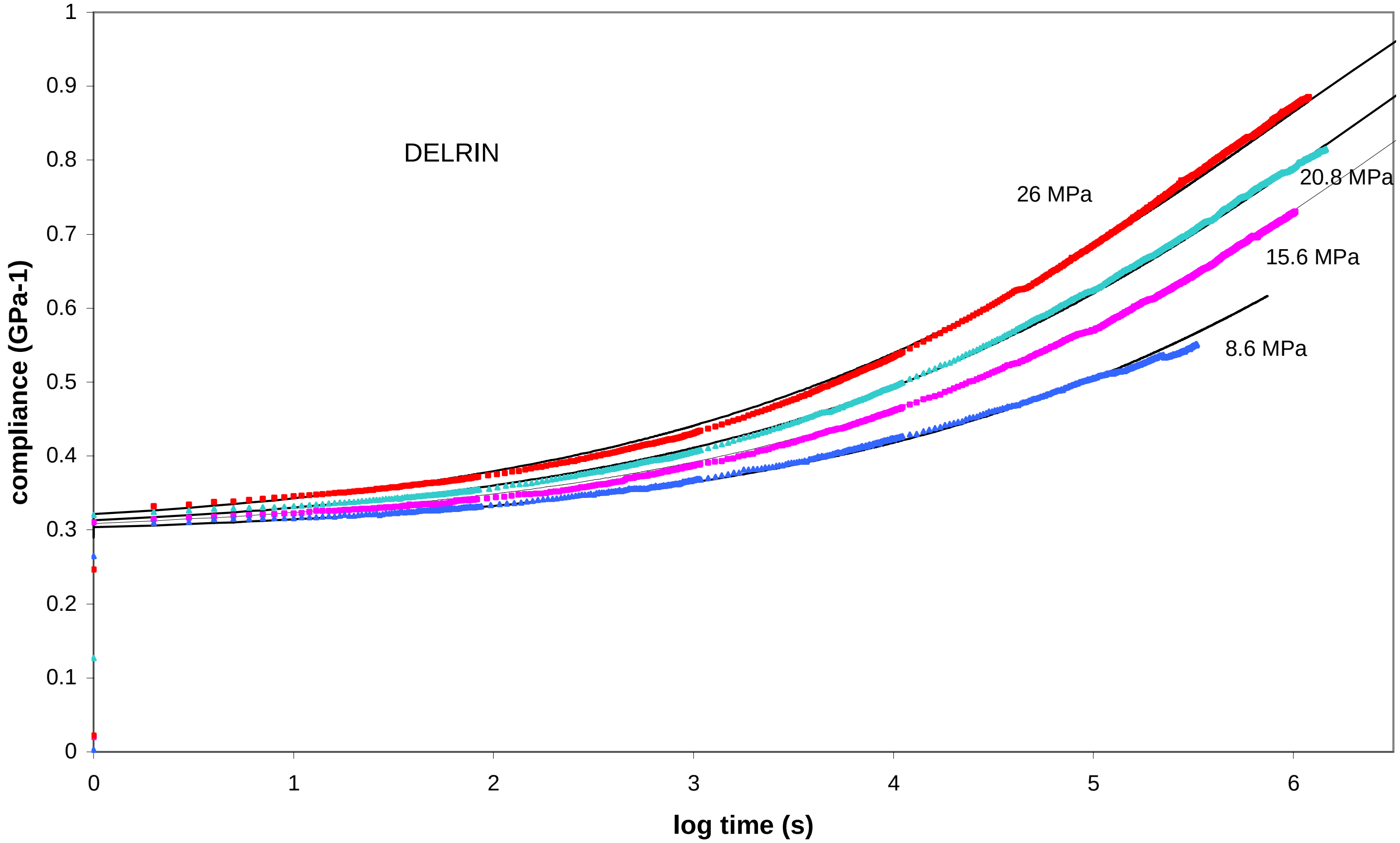
Modelling non-linear creep in tension



- The retardation time parameter τ decreases with increasing stress

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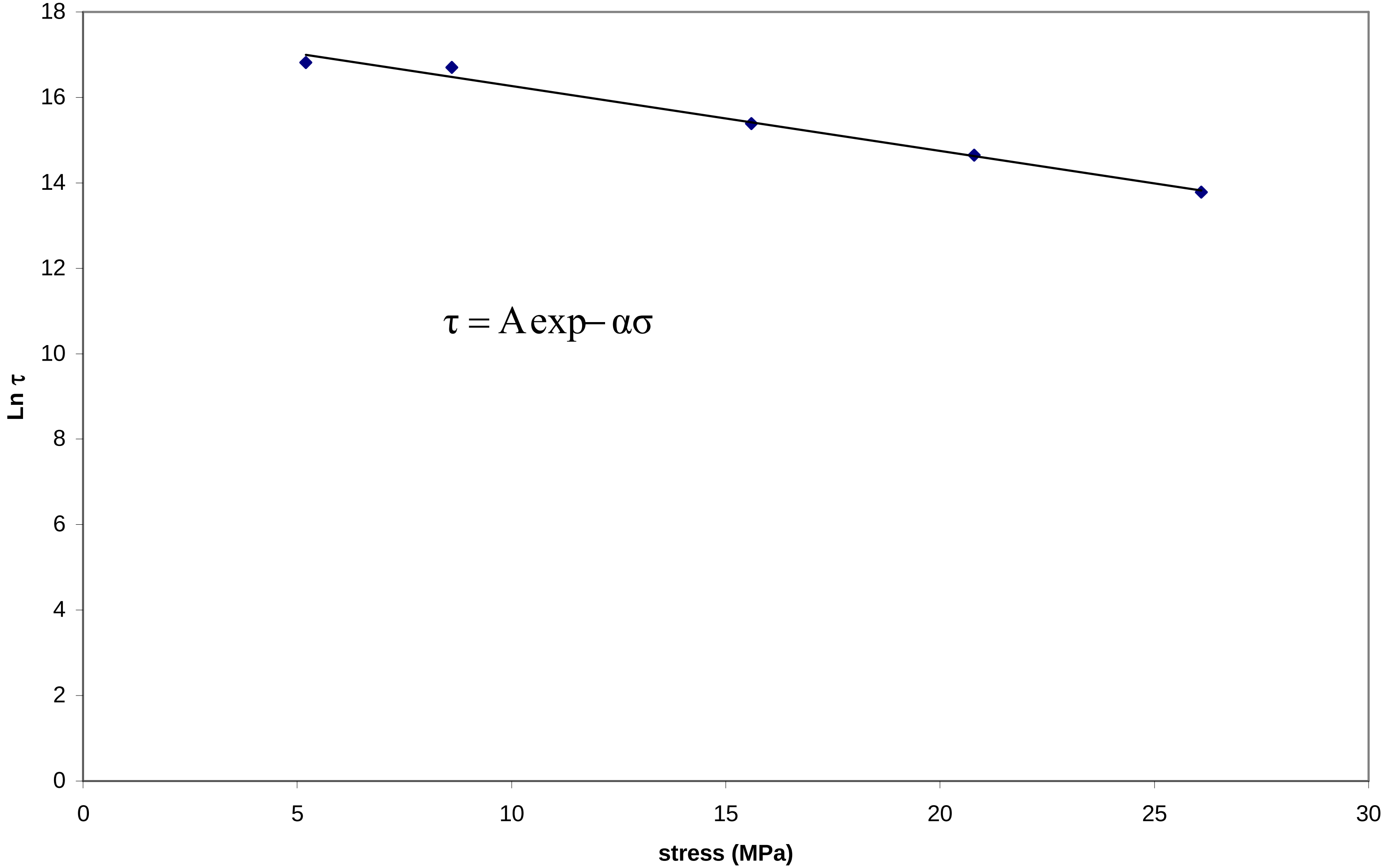
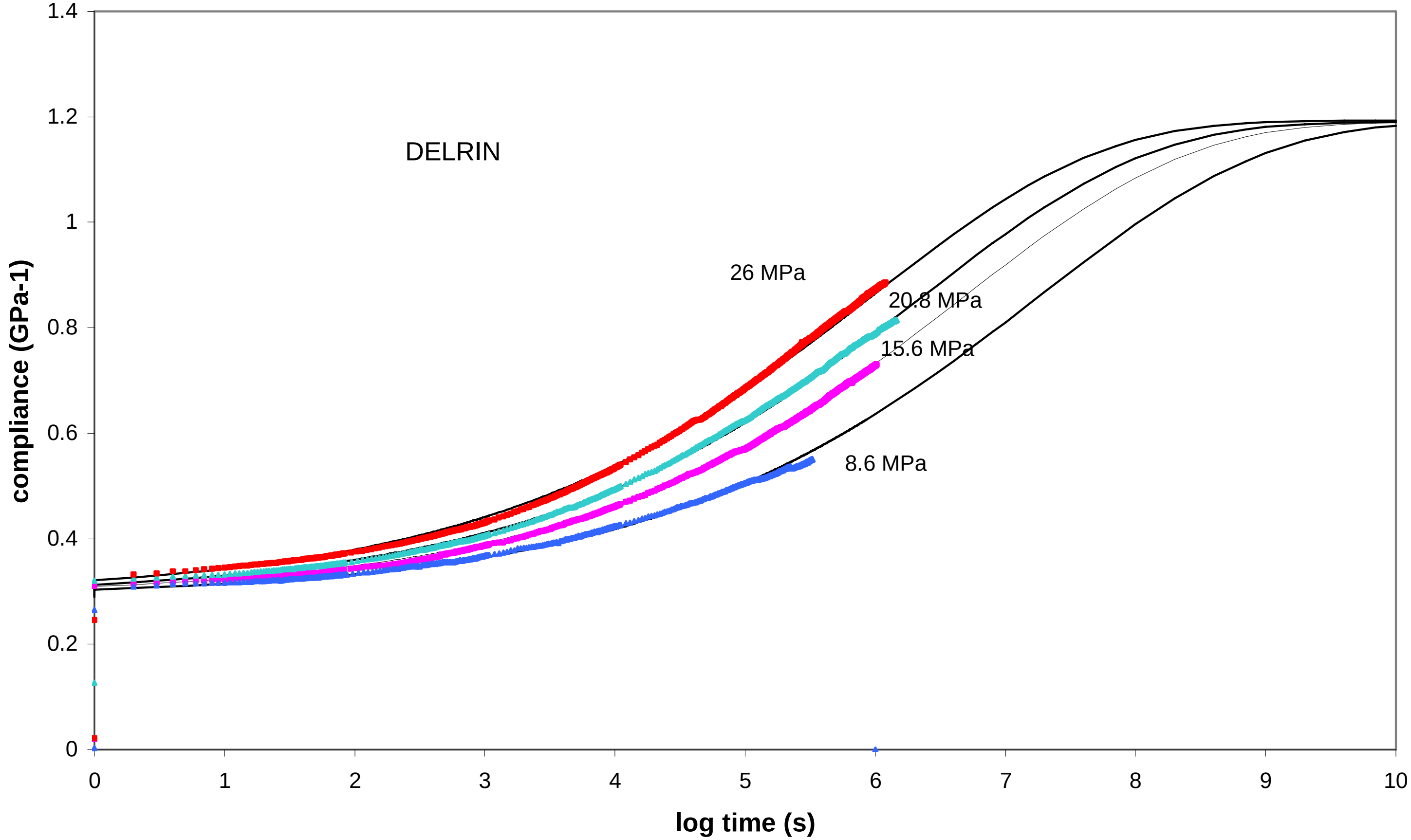
Variation of retardation time with stress



Extrapolation to long times



- D_0, ΔD and n are assumed to be independent of stress

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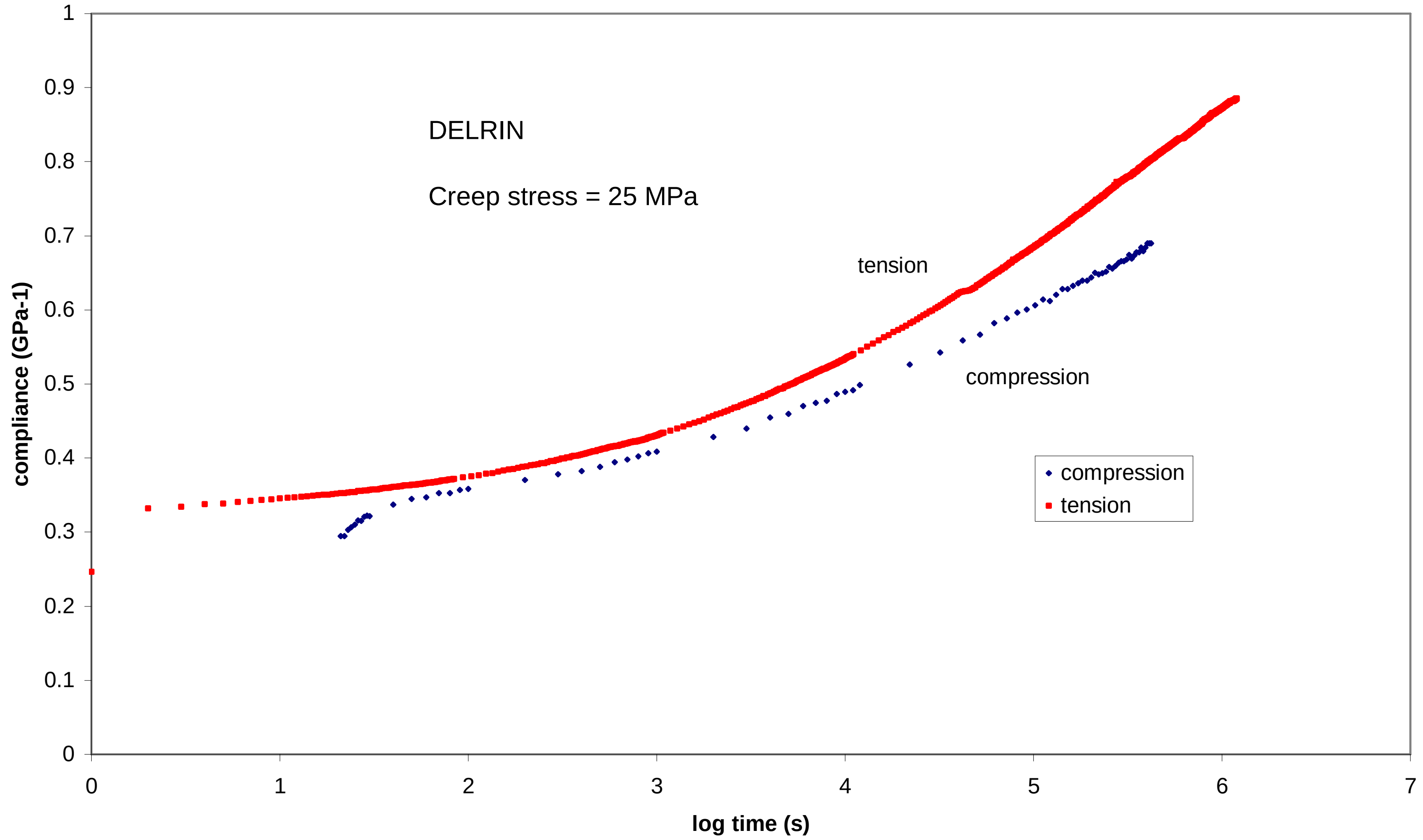
Creep under other stress states - compression



Extension of the model to multiaxial stresses

- Retardation times are related to an effective stress

$$\tau = A \exp - \alpha \bar{\sigma}$$

- and

$$\bar{\sigma} = \mu \sigma_e + (1 - \mu) \sigma_k$$

- where

σ_e is the effective shear component of stress

σ_k is the hydrostatic component of stress

μ is a material parameter

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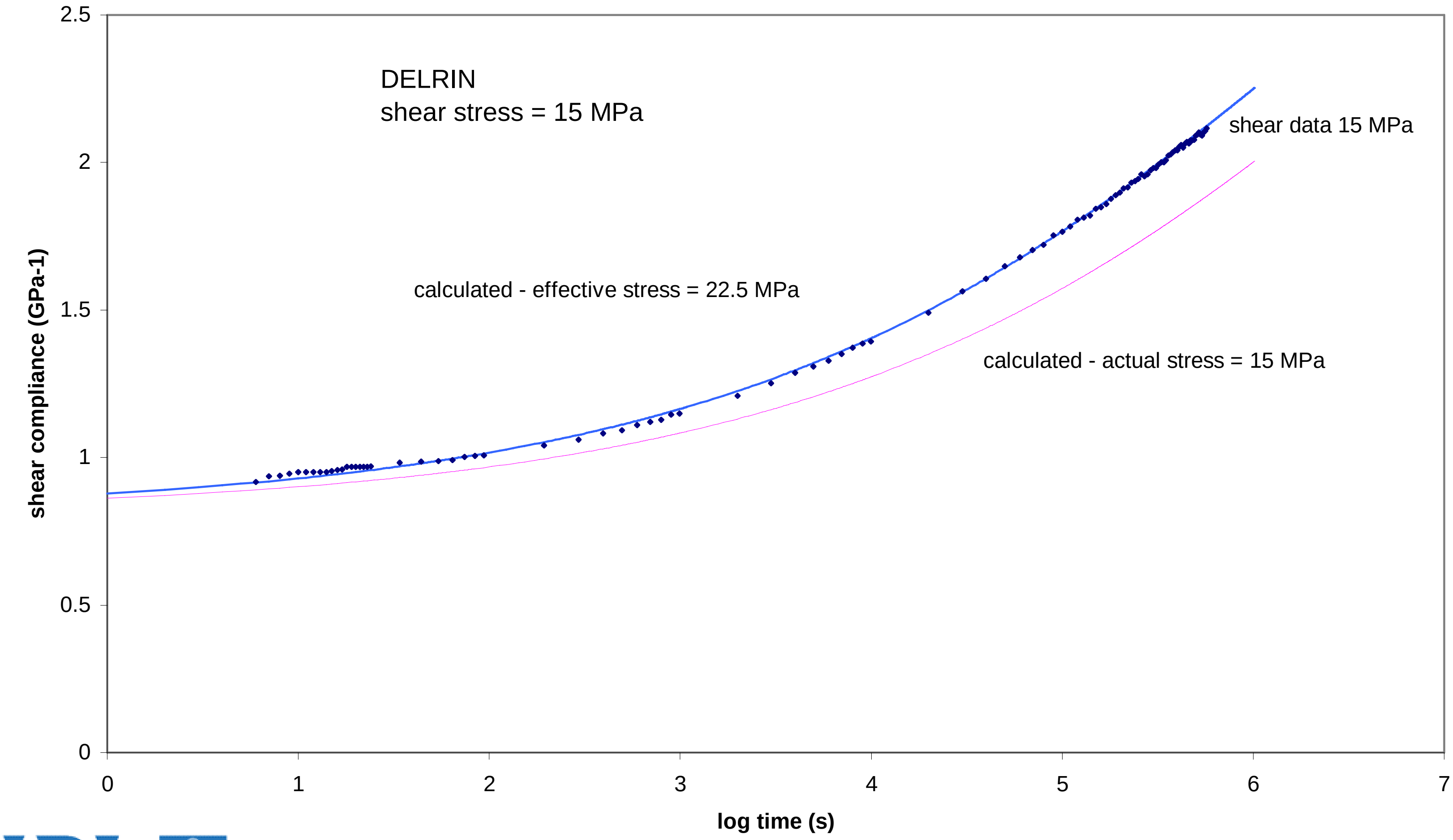
Comparison of measured and calculated creep under shear

- From compression and tension data, $\mu = 0.87$



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Next steps

- Further tests on POM to confirm model
- Creep tests on PBT
  - explore suitability of creep model
- Tensile creep tests on injection moulded POM
  - explore influence of processing method

- Establish how to implement model in a finite element system
  - solve problems where stress is changing with time