Characterisation of Binder Sheets Used in Polymer Bonded Explosives

Adam Halford, Dan Lewis

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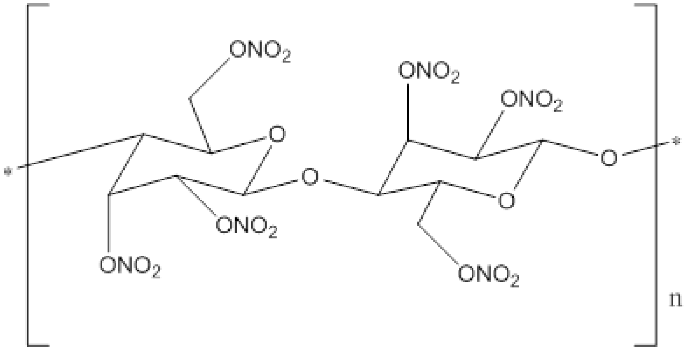
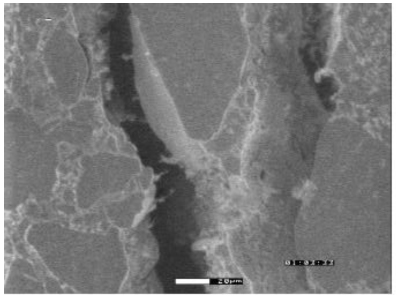
Introduction

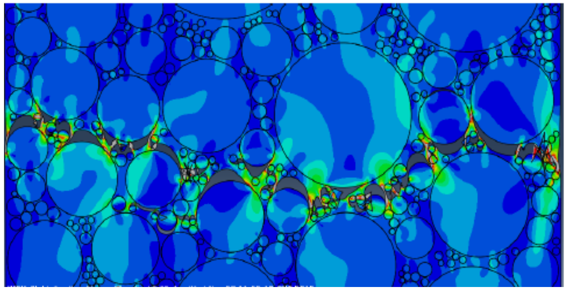
- Nitrocellulose is used as a common ingredient in energetic materials including propellants and polymer bonded explosives (PBX).
- The polymer is often used as a binding agent and in such materials is usually found plasticised to improve the physical properties of the resultant material.
- Plasticised nitrocellulose compositions often exhibit complex non-linear mechanical properties which need to be characterised as a function of temperature, strain rate etc.
- Additionally, nitrocellulose is known to be thermally unstable when compared to other similar binding materials. This results in a potential change to the physical properties of the NC and of the parent formulation as the polymer degrades.
- This leads to the characterisation of physical properties of the parent formulation and binder material as it ages.



Justification of Testing of binder sheets

- Treat the particulate fill as a ridged body due to it’s stiffness being orders of magnitude higher than that of the binder.
- Hence, mechanical properties of the parent PBXs and propellants are essentially derived from the properties of the binder and it’s interface with the hard inclusions within the formulation.
- Adhesion between binders and hard particulate inclusions within various PBXs and propellants is known to be a function of the binder material properties and their thermodynamic work of adhesion.
- Therefore, the mechanical properties of a PBX or propellant can be approximated to the binder material, even in cases where this binder is less than five percent by mass of the parent PBX.
- Using this formalisation, differences in properties of PBXs and propellants due to formulation material changes and ageing to name but two, can be investigated by physical testing of the binder material only.
    - Advantageous in instances where the binder material is non explosive, i.e. fluoropolymers or plasticised NC



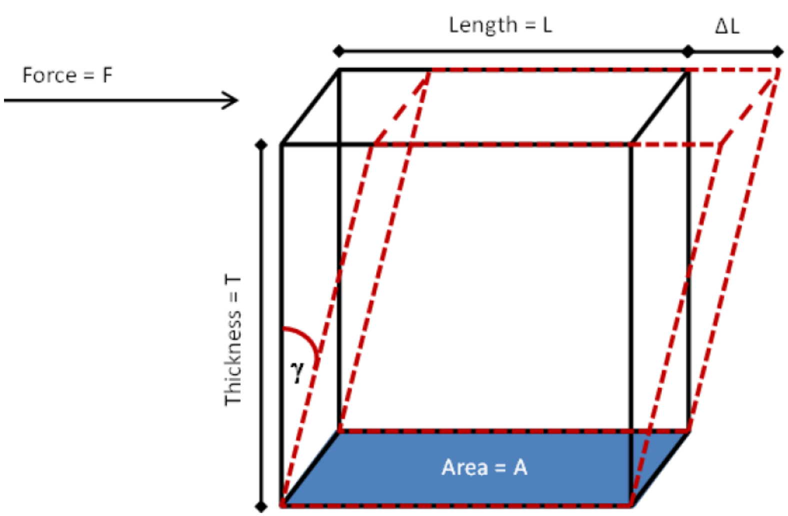


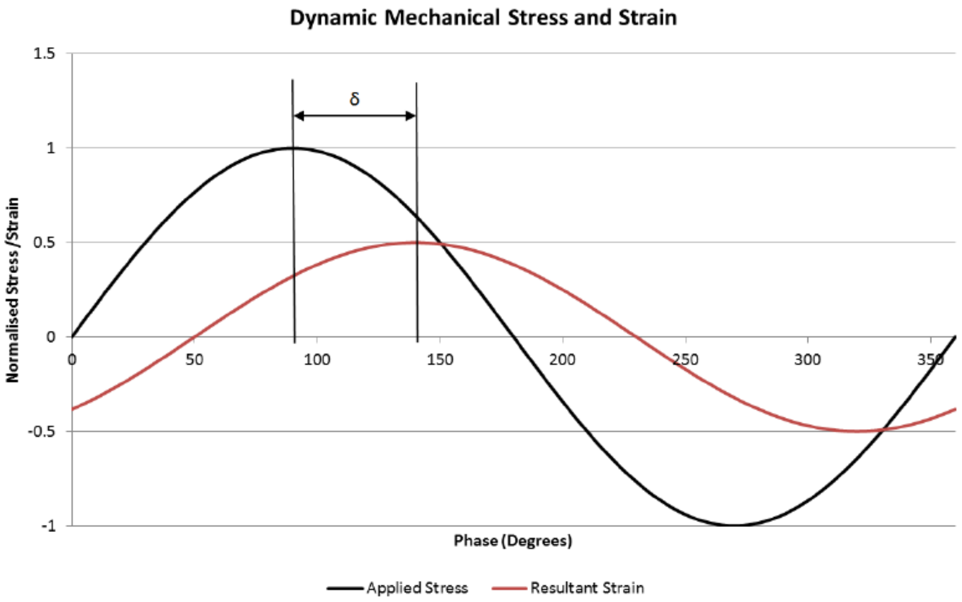
Oscillatory rheology

- Characterises the binders' mechanical properties by application of a dynamic stimulus – similar to DMA
- A rotational shearing force is applied to the material in a controlled manner (Stress or strain) to obtain various parameters dependant on the test.

$$G'(t) = \cos\delta\left(\frac{\sigma(t)}{\varepsilon(t)}\right)$$

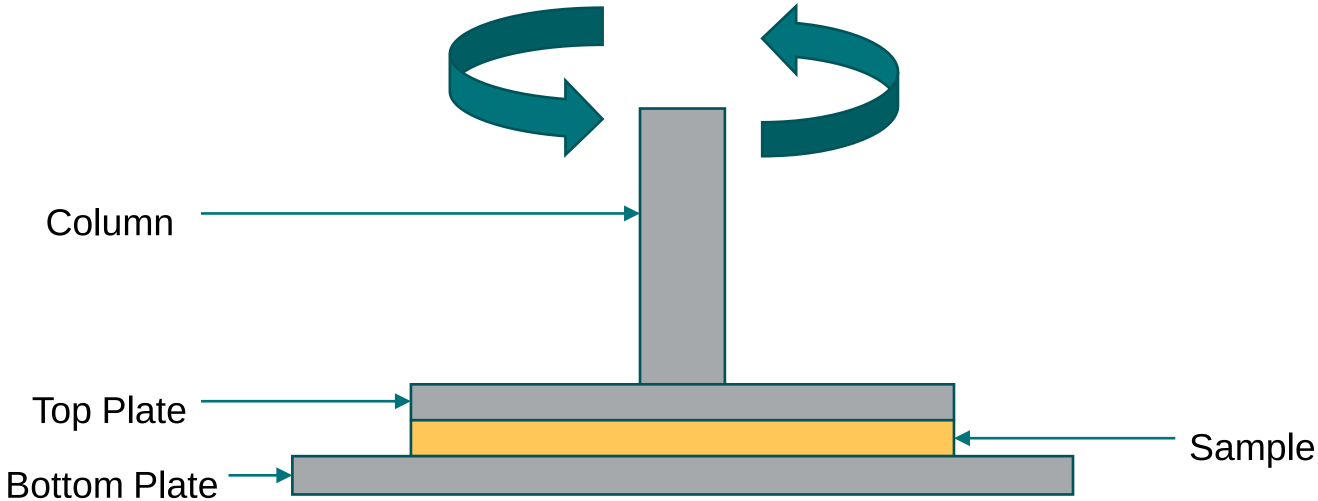
$$G''(t) = \sin\delta\left(\frac{\sigma(t)}{\varepsilon(t)}\right)$$





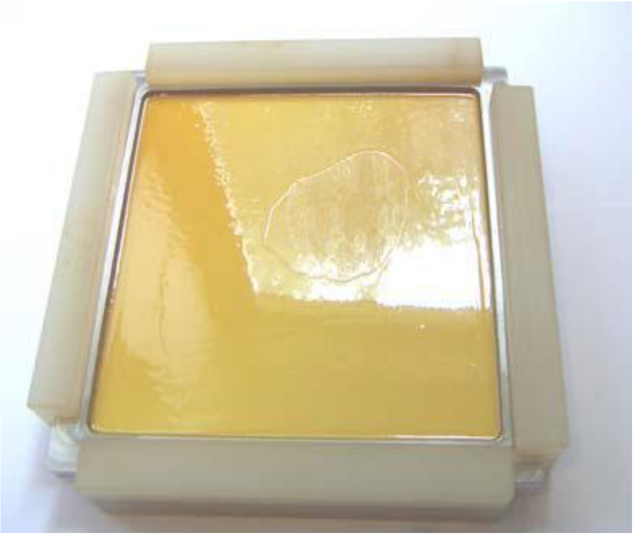
Oscillatory rheology

- Samples are cut from bulk material as circular disks and placed between a temperature controlled base plate and plate attached to a moveable column.
- The testing fixture, in this case a 25mm circle, is then lowered into contact which is maintained at a pre-set normal force
- This normal force must be large enough to ensure ‘perfect’ contact but also small enough as not to induce additional energy into the material
- Suitable values were obtained through experimentation and monitoring of normal force relaxation times and resultant properties

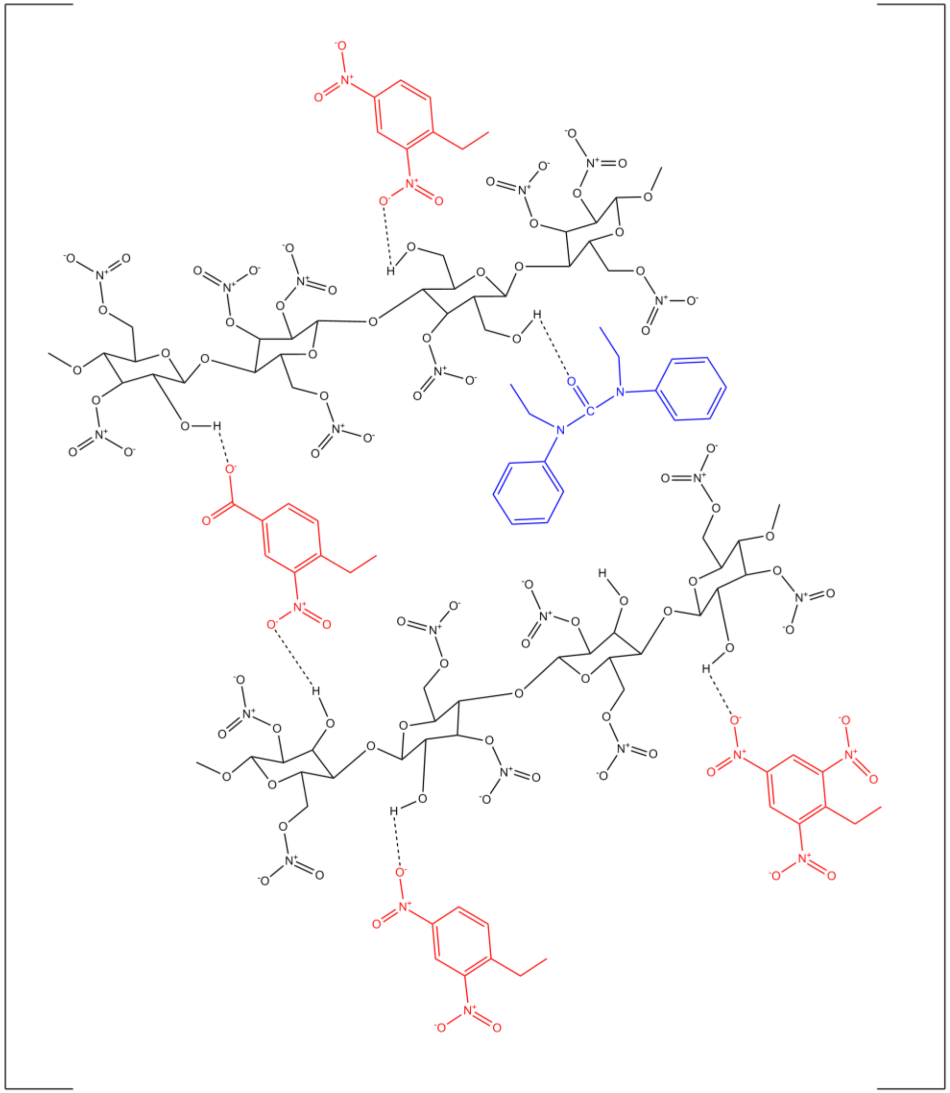


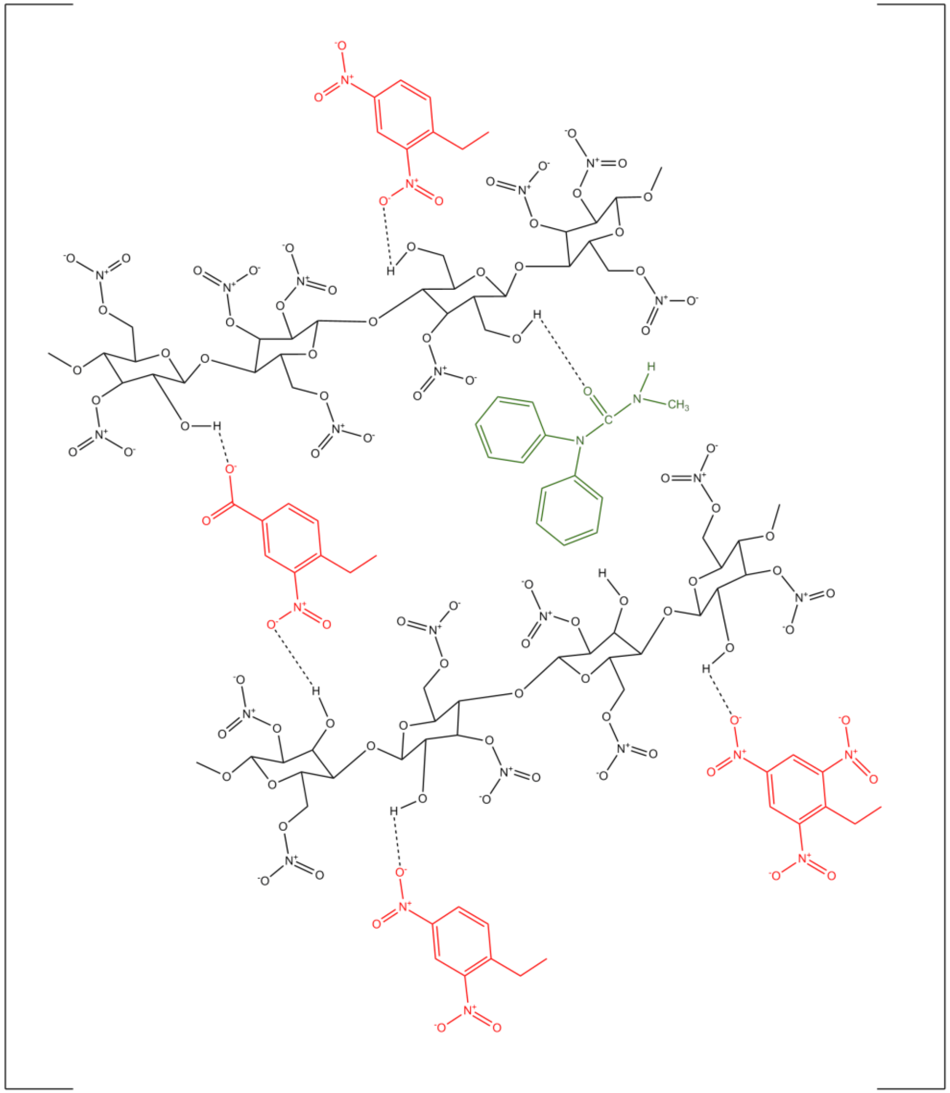
Case Study

- Compare the differences between various binder formulations that utilise different stabilisers.
- Some stabilisers act as processing agents or plasticisers themselves.
- The study considers differences in baseline material properties as well as a short accelerated ageing trial to investigate material behaviour as a function of NC degradation.

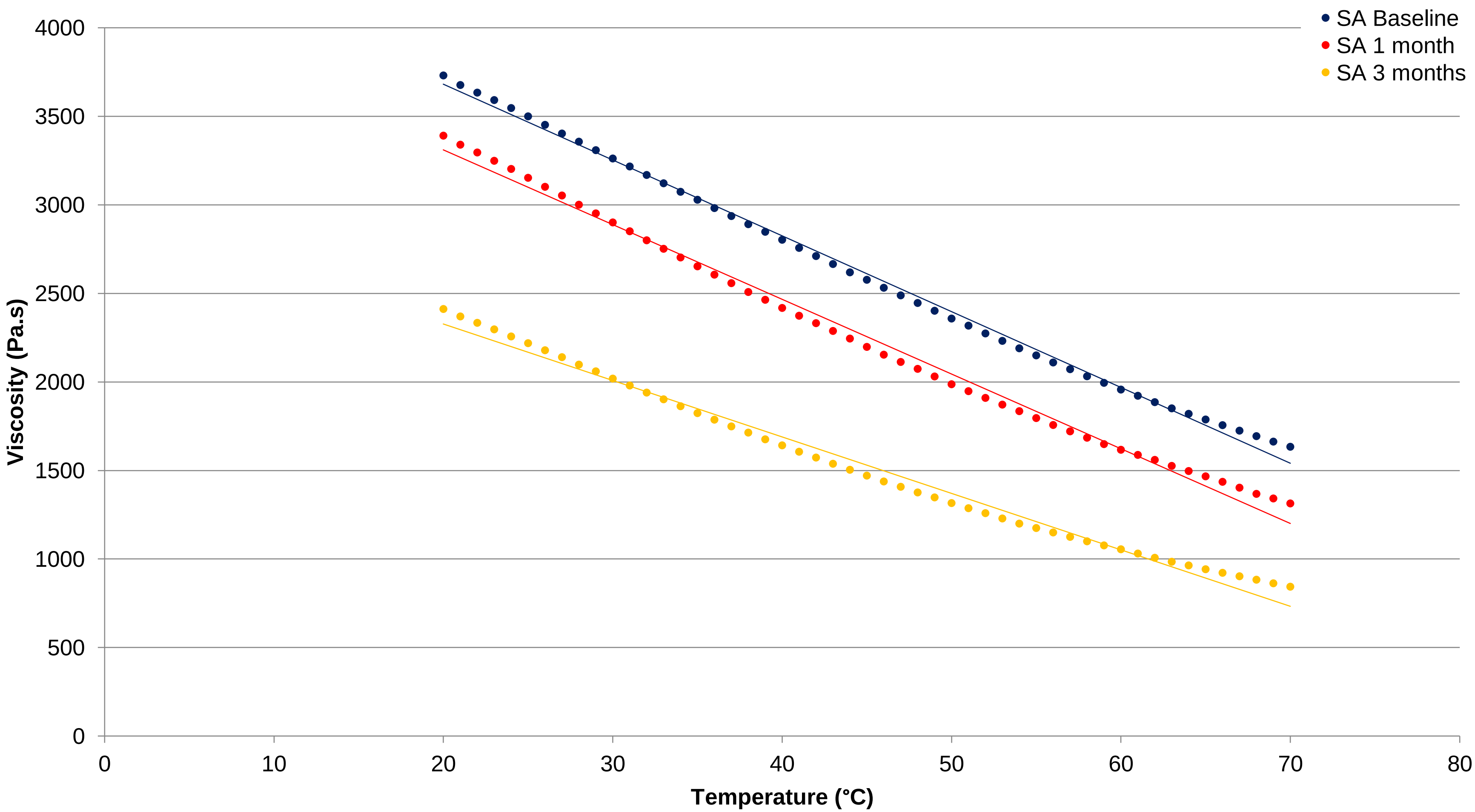


Gel Structure of NC/K10/Stabiliser

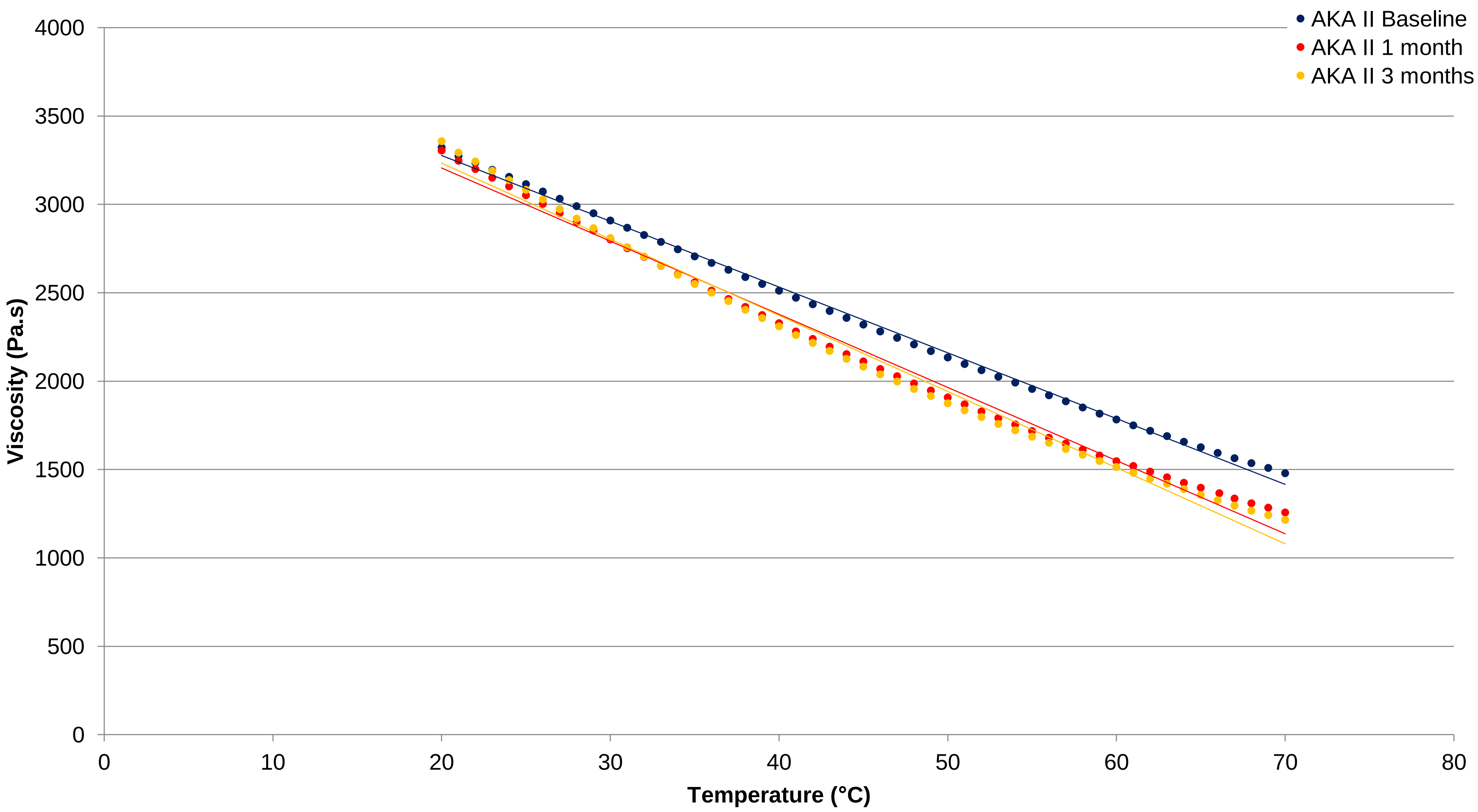




Temperature Sweep



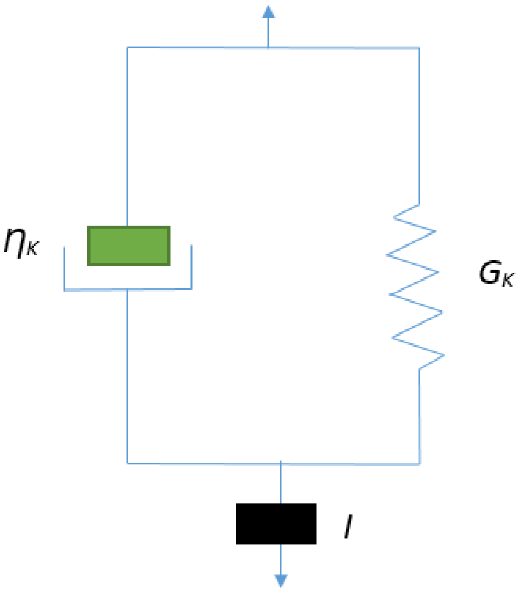
Temperature Sweep



Creep Ringing

Kelvin-Voigt

Viscoelastic Solid

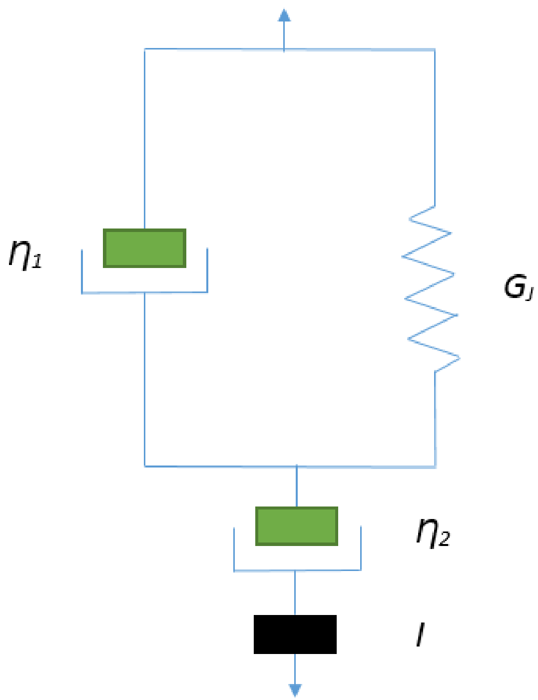


$$\gamma(t) = \gamma_K \left[1 - e^{-A_K t}\left(\cos(\omega_K t) + \frac{A_K}{\omega_K} sin(\omega_K t)\right)\right]$$

$$G' = G_K \quad G'' = \eta_K \omega$$

Jeffreys

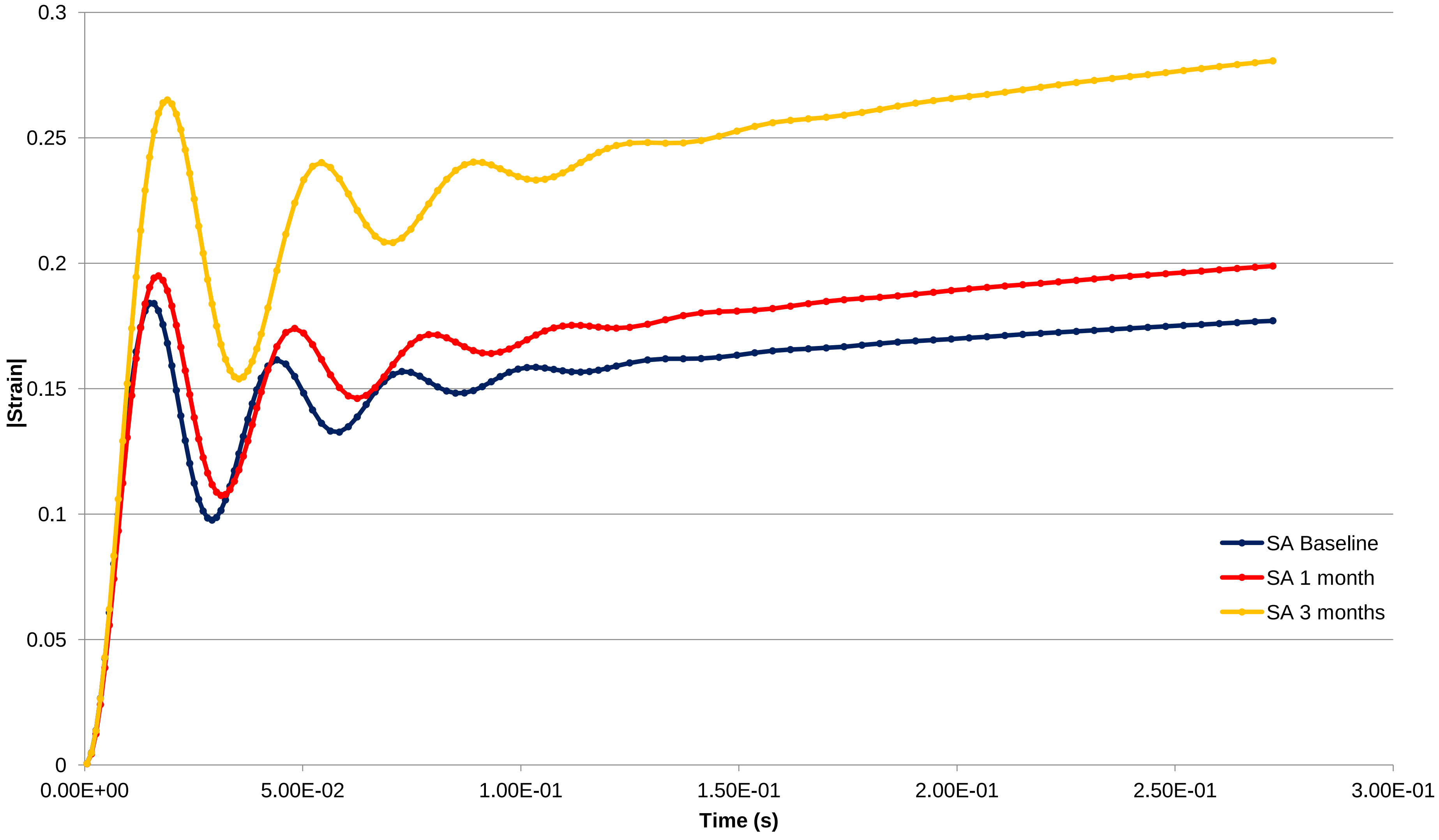
Viscoelastic Fluid



$$\gamma(t) = \dot{\gamma}_J t - B_J - e^{-A_J t}\left[B_J \cos(\omega_J t) + \frac{A_J}{\omega_K}\left(B_J - \frac{\dot{\gamma}_J}{A_J}\right) sin(\omega_J t)\right]$$

$$G' = G_J \frac{(\lambda_2 \omega)^2}{1+(\lambda_1 \omega)^2} \quad G'' = G_J \frac{(\lambda_2 \omega)\left[1+(\lambda_1^2 - \lambda_1 \lambda_2)\omega^2\right]}{1+(\lambda_1 \omega)^2}$$

Example Creep Ringing Data



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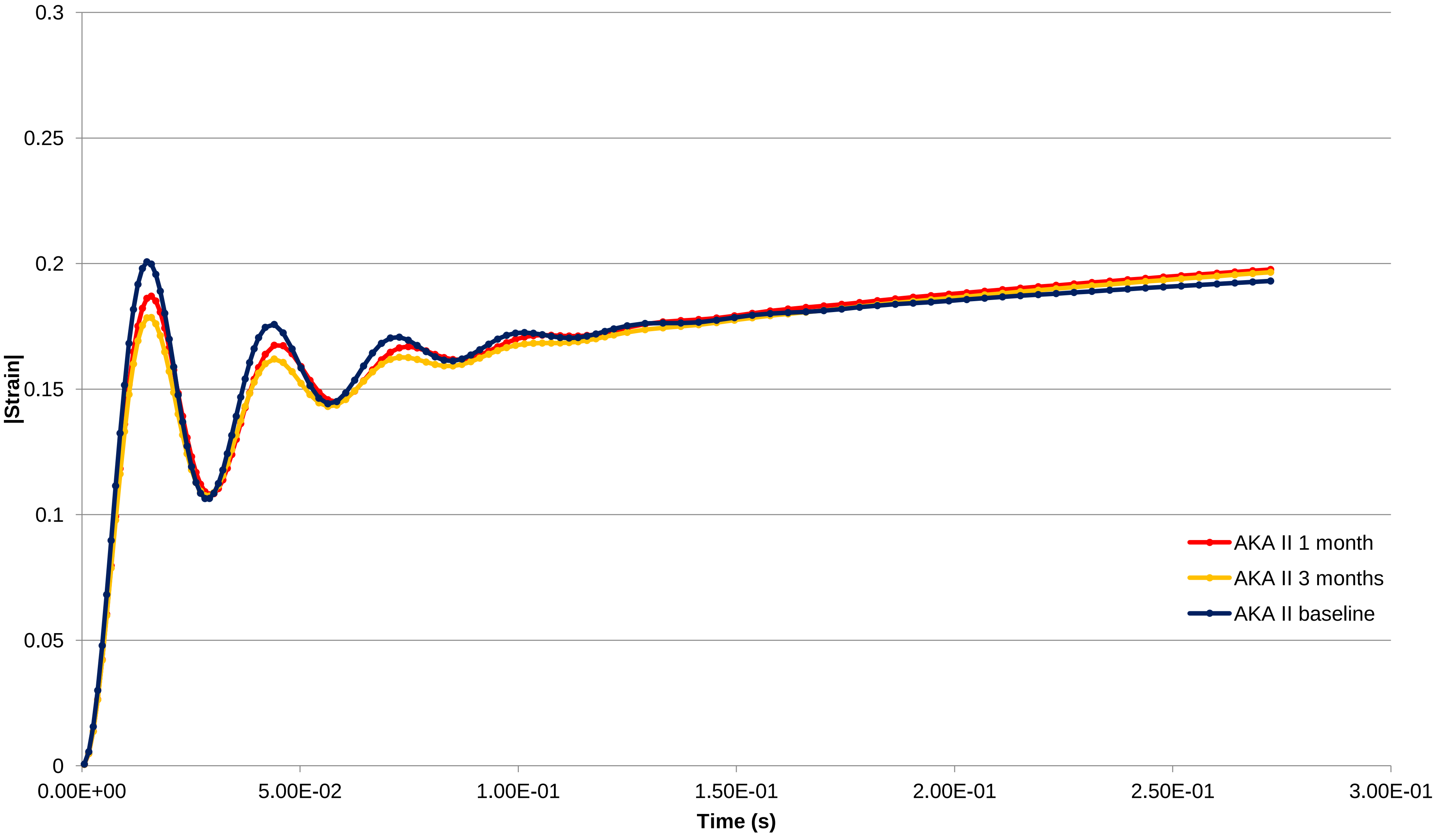
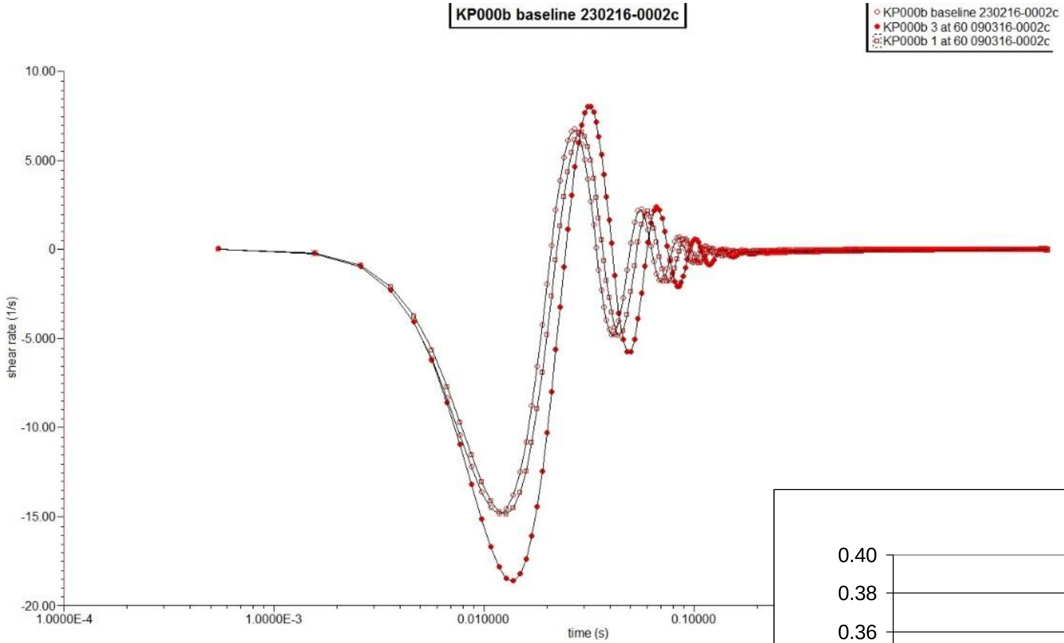
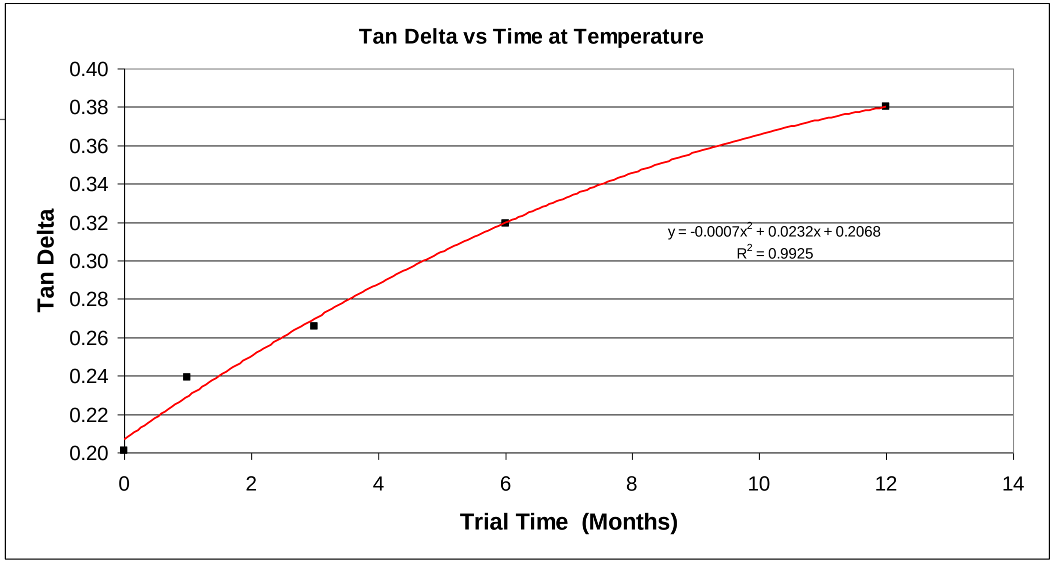


Creep Ringing Fitted data – Jeffries Overdamped Model





Future Work

- Continuation of thermal ageing to increases the volume of available data, improving the confidence in the fitted model

- Correlation of fitted parameters of constitutive models to the age of the material.
  - Empirical relationship (model) between degradation and physical properties

- Further correlation of fitted parameters (as well as more traditional parameters) to actual molecular weight as determined by MALS-GPC

- Molecular weight determination from rheological properties – requires derivation of supporting constants

Questions?