Praktikum 2012 : Temperature dependence of viscosity of non-Newtonian materials

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Rotational viscometer

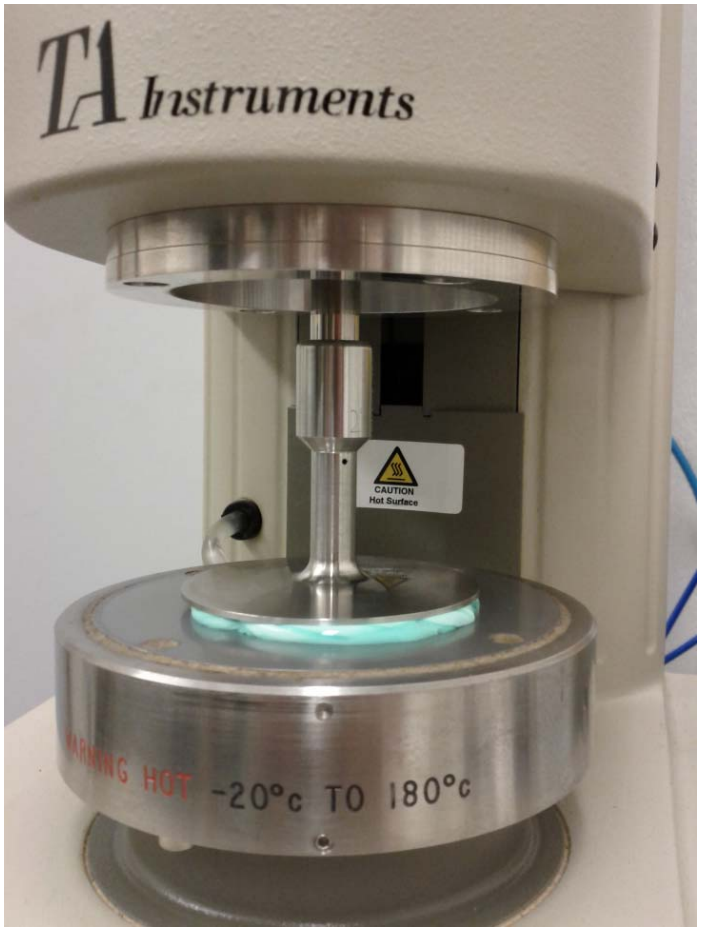
- Viscosity measurement on non-Newtonian materials : toothpaste, skin cream, adhesives…

- Upper plate is turning

- Bottom plate can be heated from -20°C to 180°C and cooled by water ⇒temperature dependence

- Shear stress vs. shear rate

Rotational viscometer



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Modeling

- Definition of viscosity for Newtonian materials: $\sigma_{ij} = \mu d_{ij}$

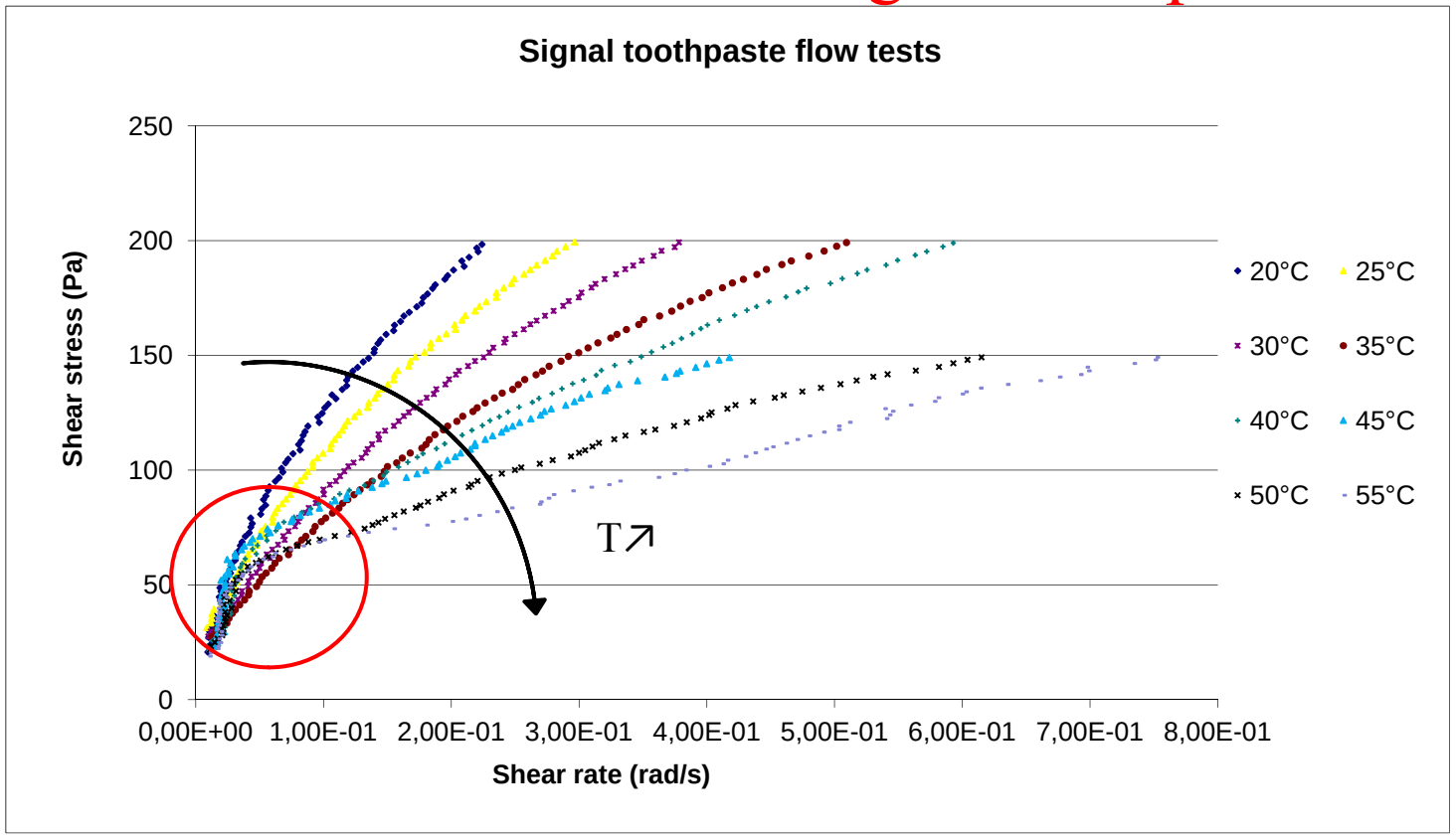
- Apparent viscosity for non linear viscoelatic materials:

  - Herschel-Bulkley model: $\sigma_{12} = \mu (d_{12})^n + \tau$

  - Ziegler Arctan model: $\sigma_{12} = \mu' d_{12} + \frac{2\tau'}{\pi} \arctan(\frac{d_{12}}{n'})$

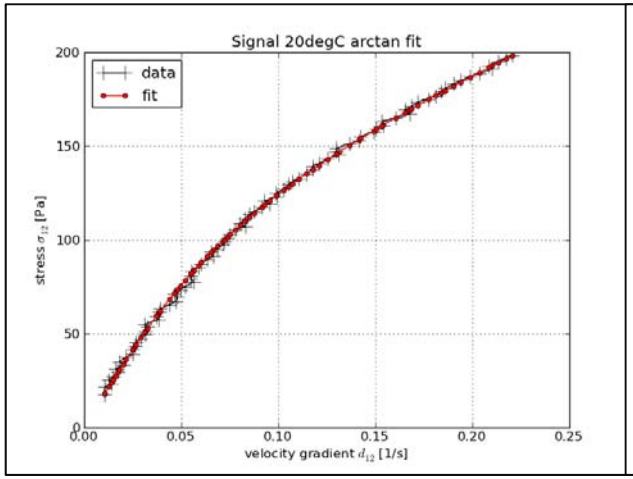
- Inverse analysis: Finding μ, n and tau with the stress/strain rate curve by minimizing the mean squared error (code in SciPy)

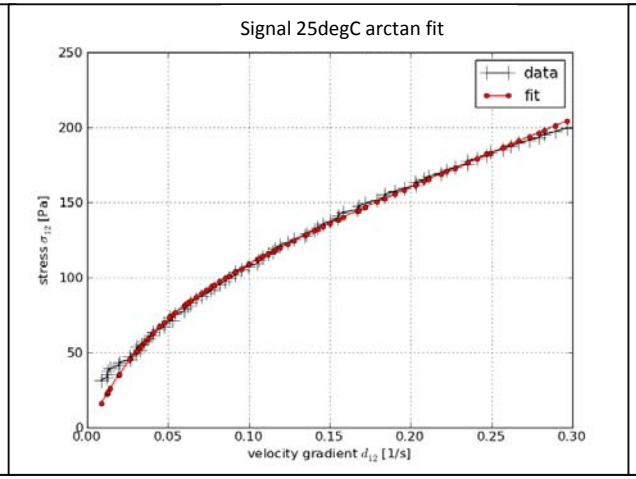
Measurements on signal toothpaste

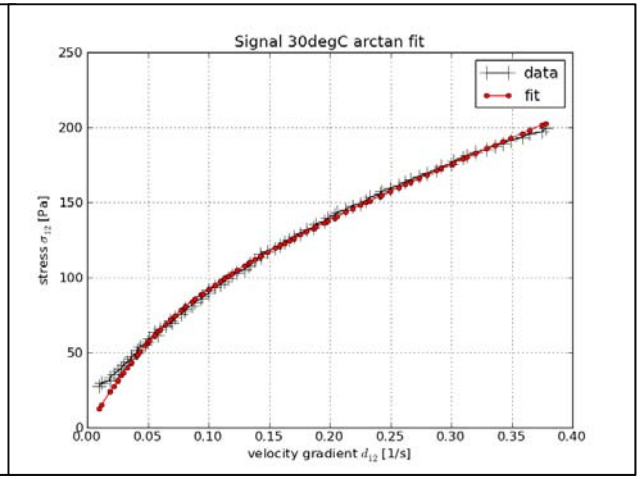


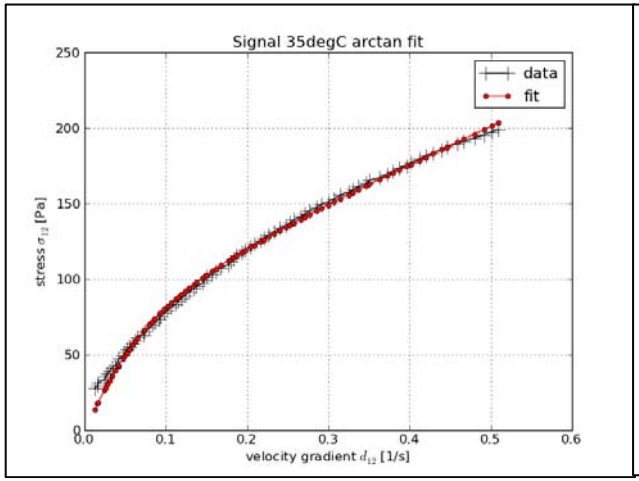
Composition: Calcium Carbonate, Aqua, Sorbitol, Hydrated Silica, Sodium Laury Sulfate, Sodium Silicate, Sodium Monofluorophosphate, Aroma, Cellulose Gum, Potassium Citrate, Benzyl Alcohol, Sodium Saccharin, Calcium Glycerophosphate, PEG-32, Limonene, CI 73360

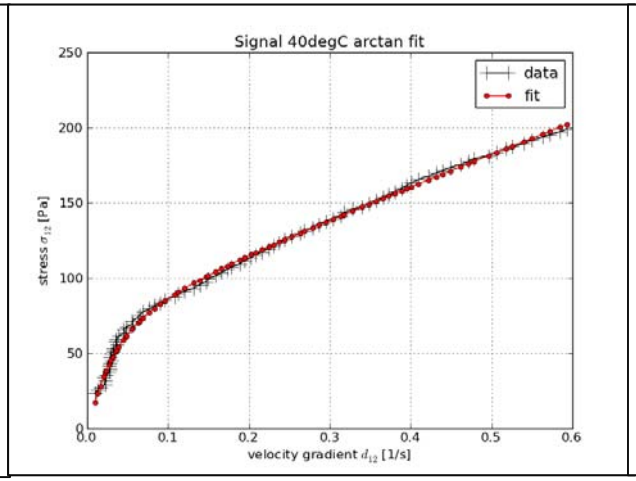
Signal toothpaste: Arctan Fit

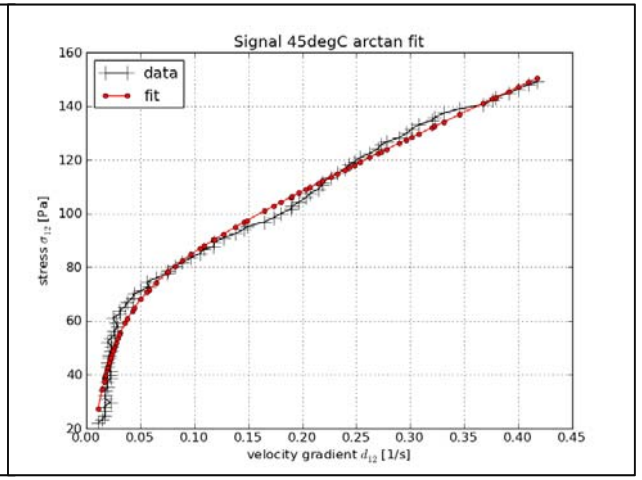




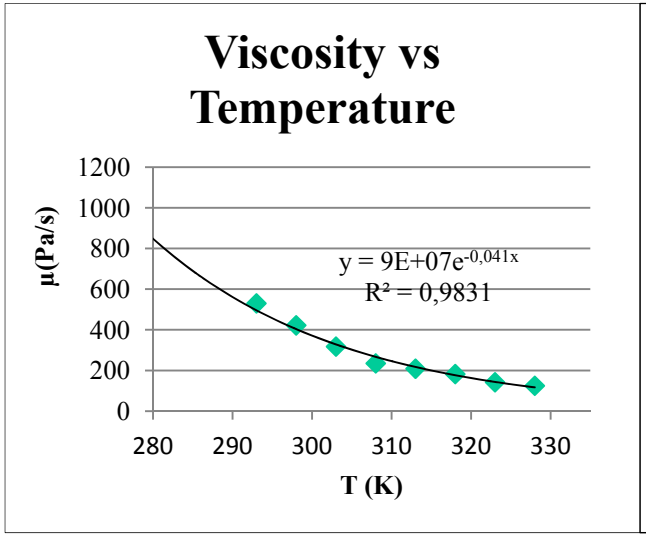


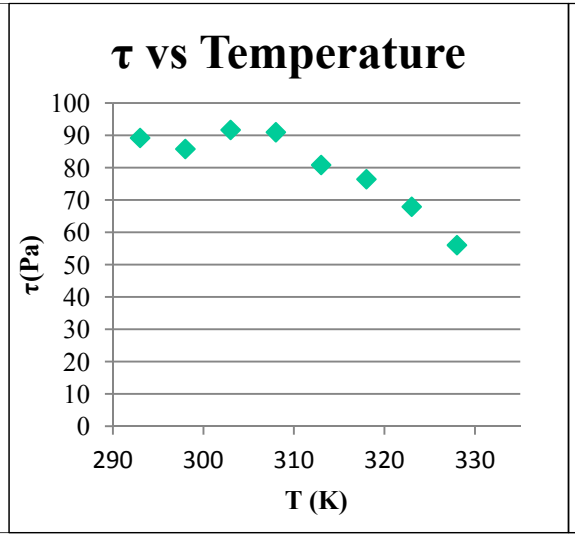


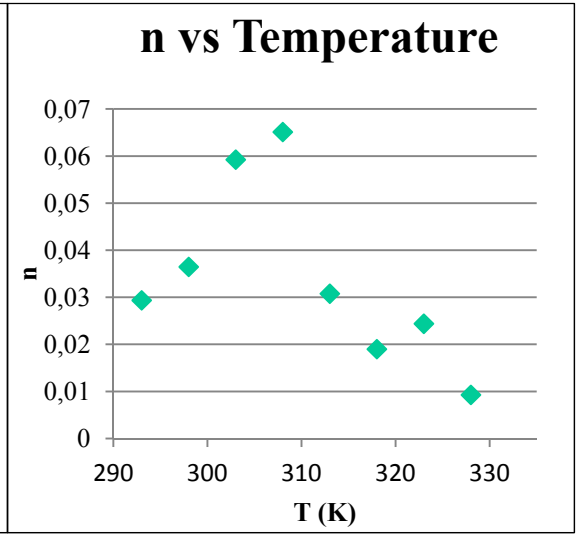




Temperature dependence of parameters for Arctan model







- Exponential trend for viscosity
- Fall in τ between 35 and 40 °C
- No temperature dependence for n

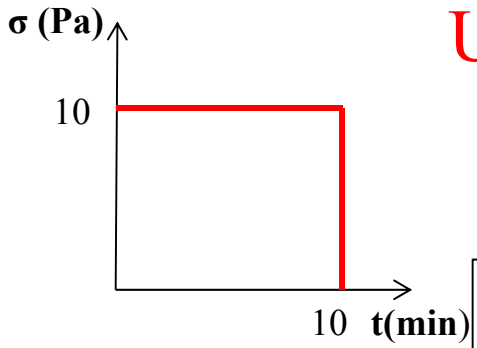
T(°C)	μ(Pa/s)	n	τ(Pa)
20	530	0,029	89
25	422	0,036	86
30	317	0,059	92
35	235	0,065	91
40	208	0,030	81
45	182	0,019	76
50	142	0,024	68
55	124	0,0093	56

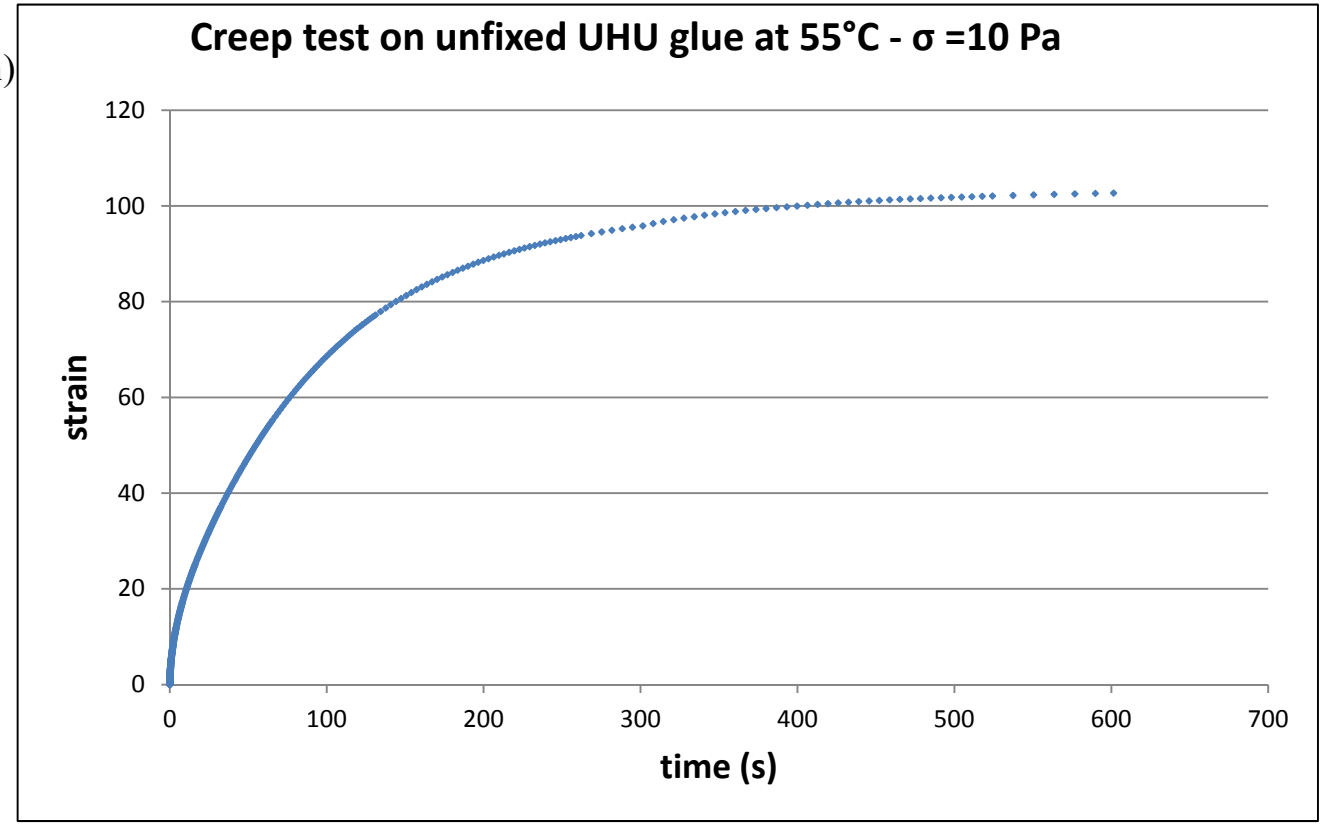
Strain gages' adhesive

- Adhesive Kyowa CC33A
- BAM (Federal Institute for Material Research and Testing)

  Special thanks to Tabea Wilk
- Drop tests on containers
- Response at high temperatures? (150°C – 200°C)

UHU glue : Hardening process





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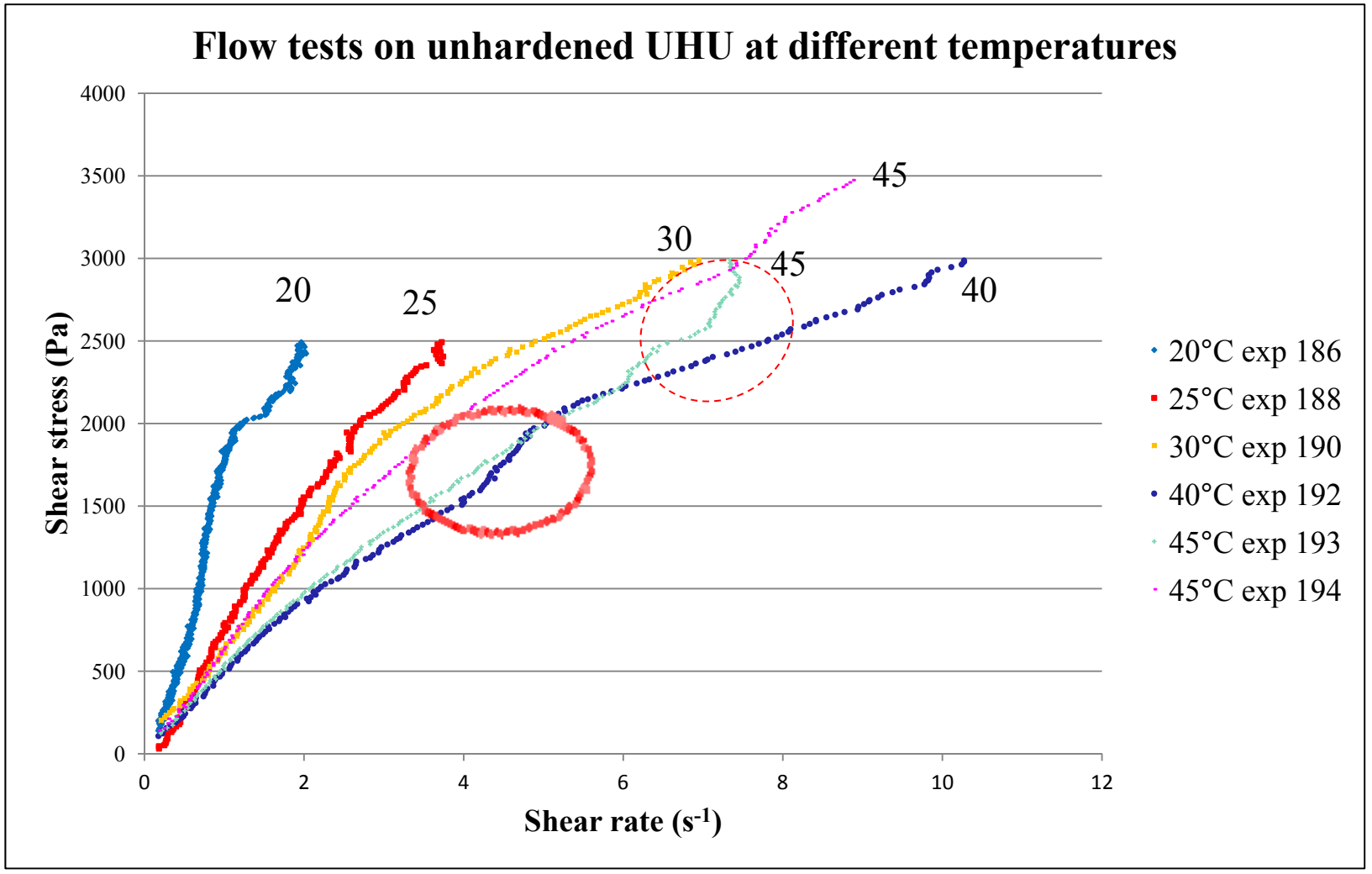

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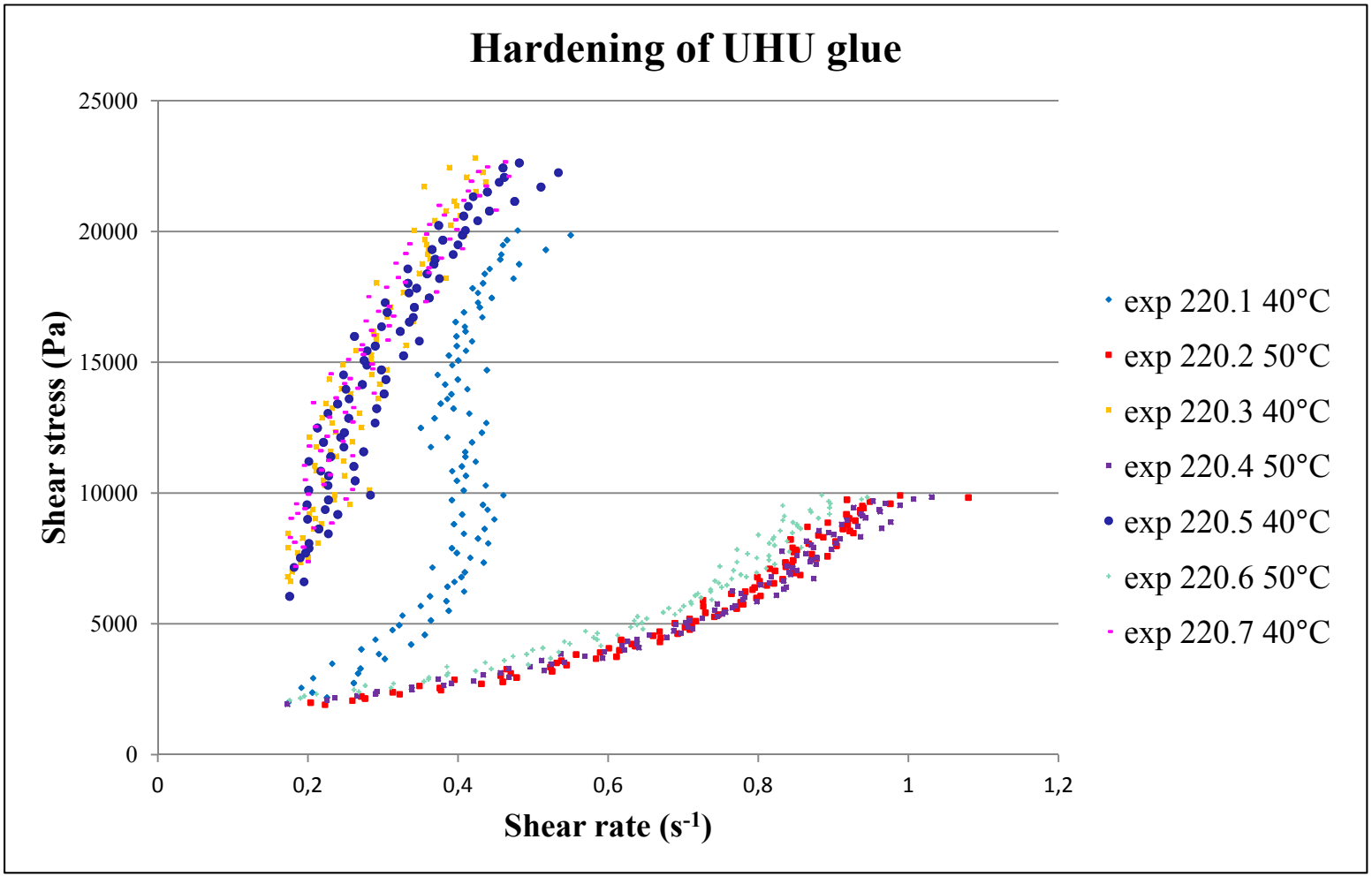
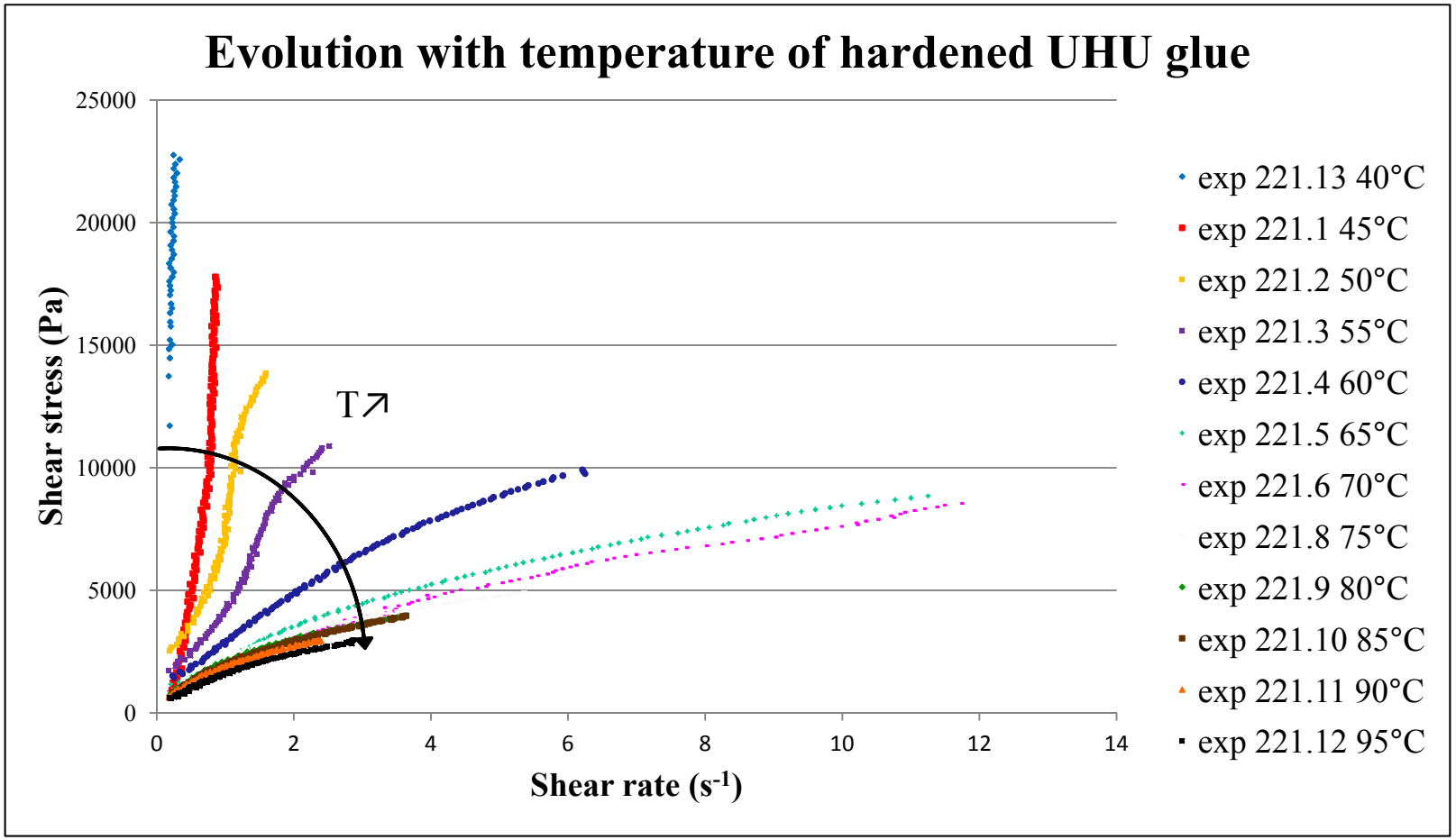
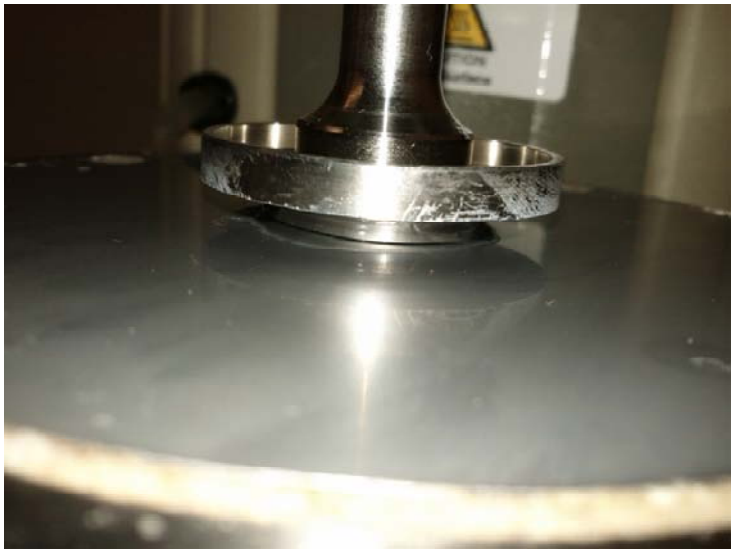


Test on hardened glue



Strain gages' adhesive



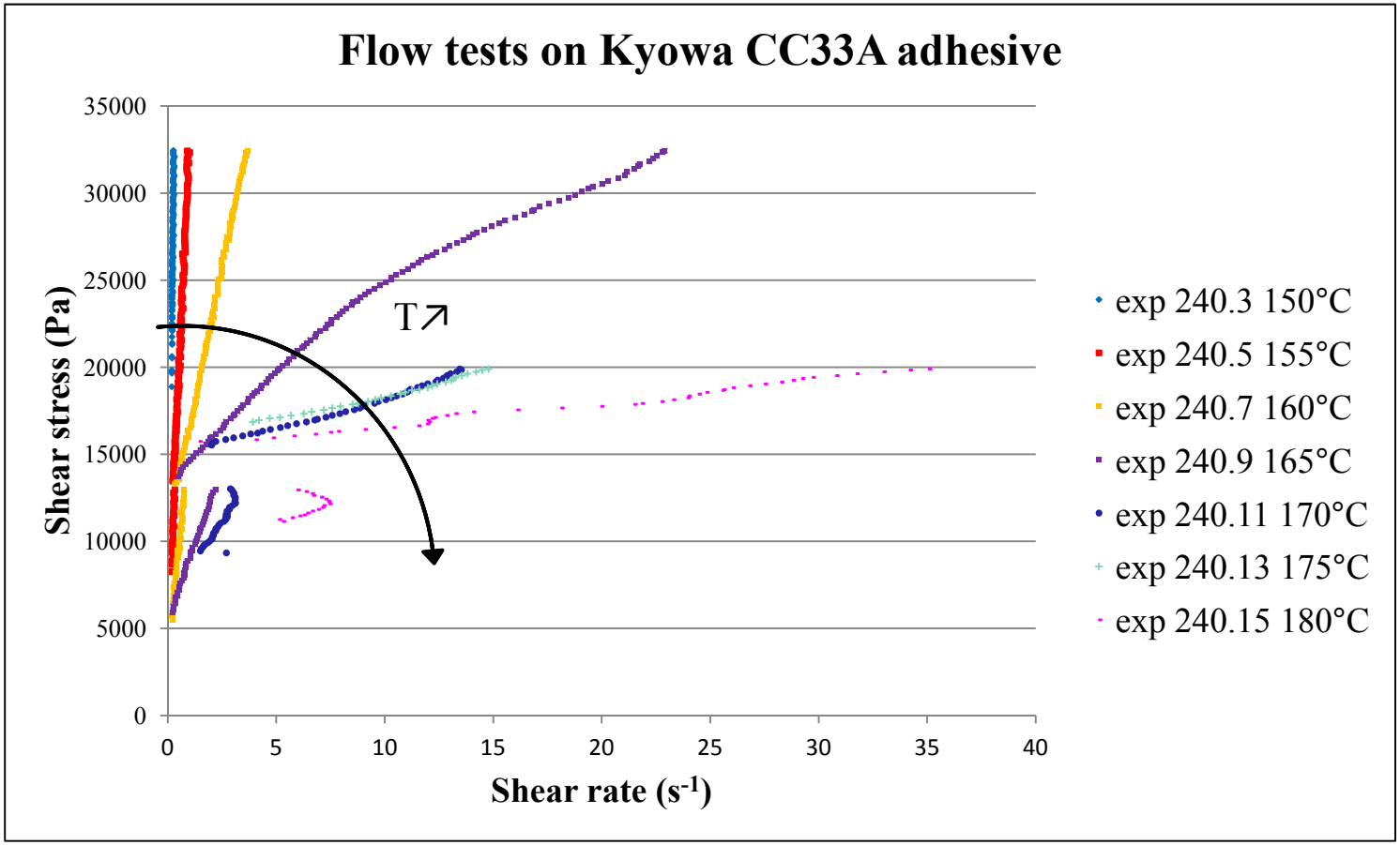
- Parallel-plate geometry

  diameter = 2.5 cm
- Thickness of the sample = 20 μm

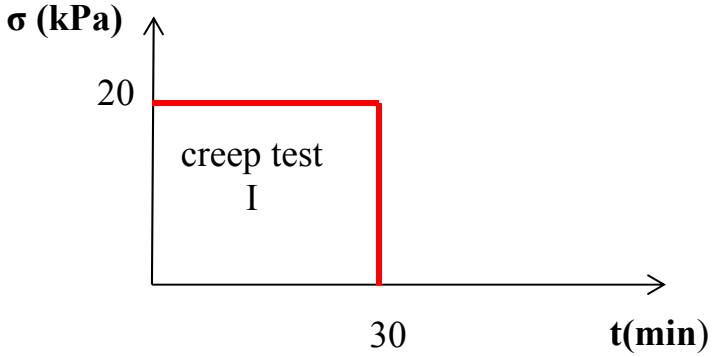
$\Rightarrow$ Small diameter and thickness as $\dot{\gamma} = \frac{R\omega}{h}$.

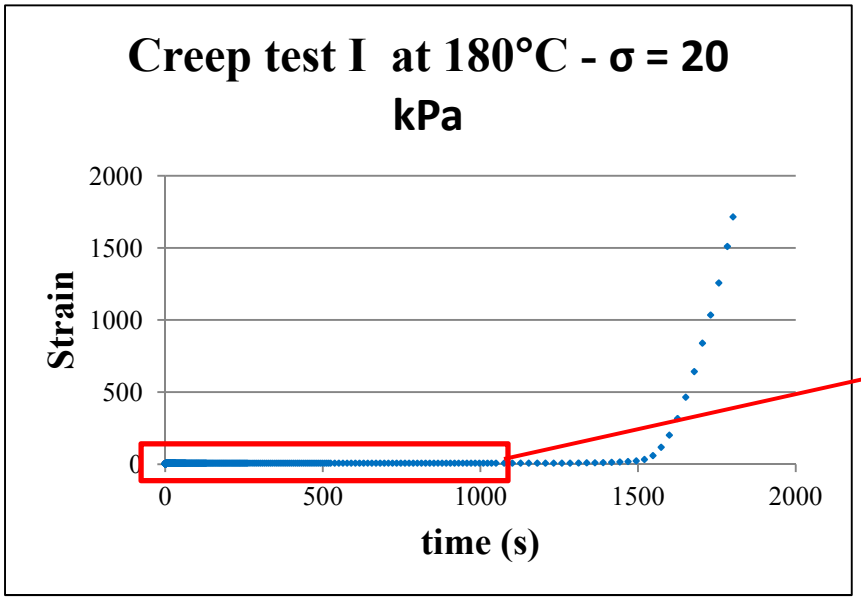
- No problem of hardening as for UHU glue
- Much stiffer than UHU glue

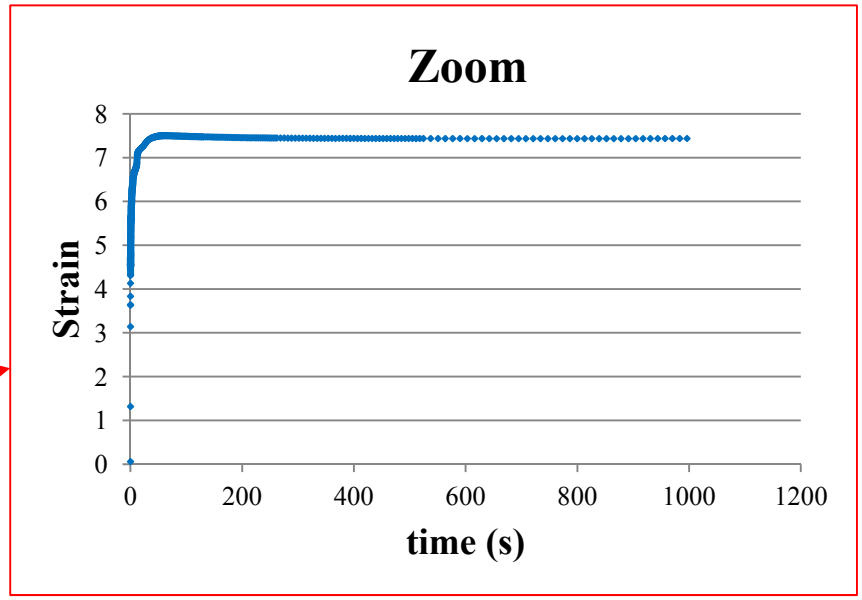
Strain Gages´ adhesive



Resistance to Temperature







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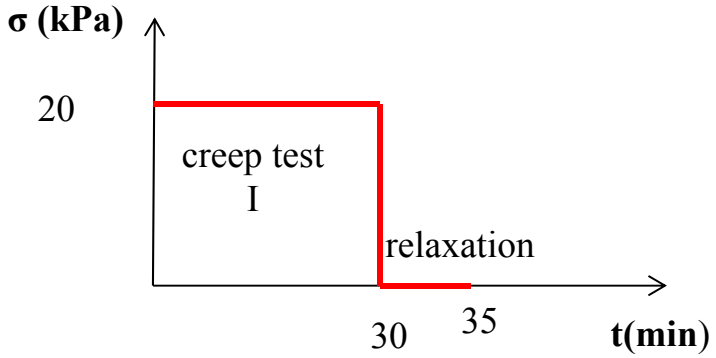

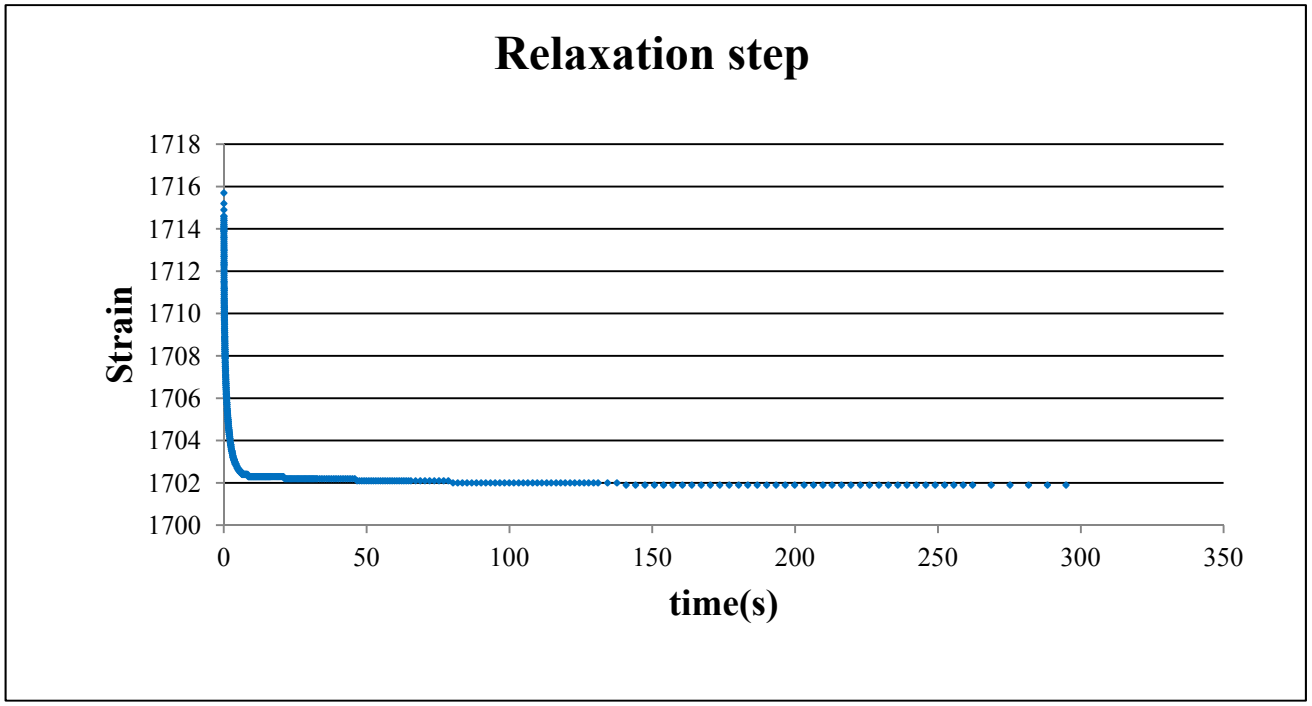

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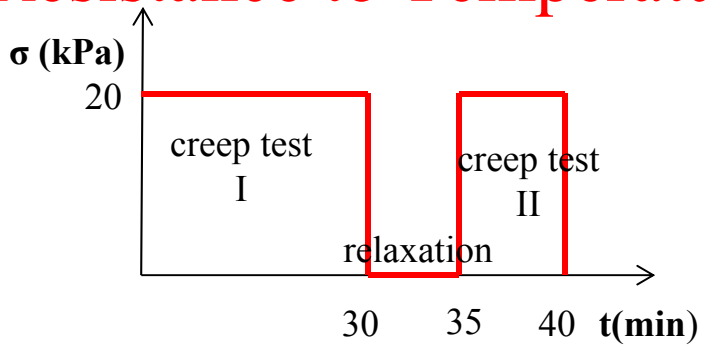
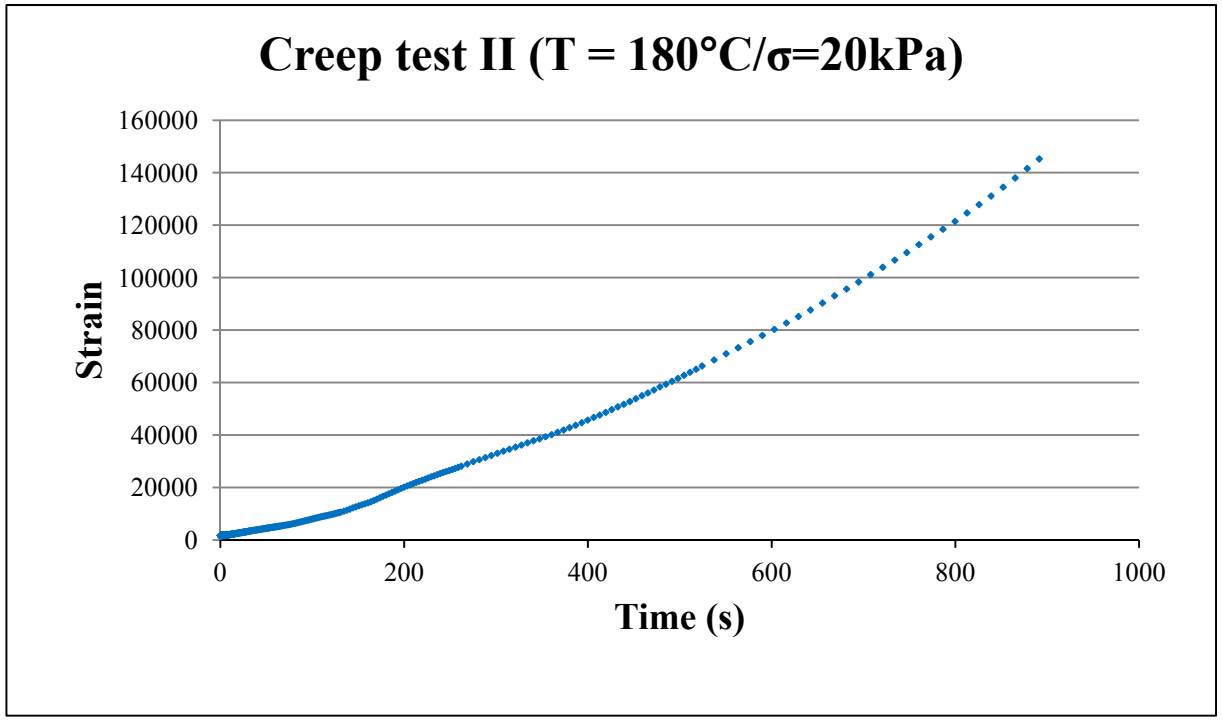
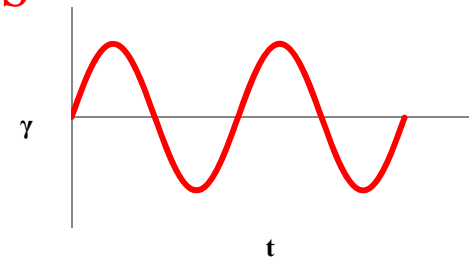




Oscillatory tests

- **Input:** $\gamma = \gamma_0 \sin(\omega t)$ (1)

γ_0 constant, ramp of frequency ω



- **Output:** G' and G'' defined as: $\sigma = \gamma_0 (G' \sin(\omega t) + G'' \cos(\omega t))$

- $\dot{\gamma} = \gamma_0 \omega \cos(\omega t)$ and (1) => $\sigma = G' \gamma + \frac{G''}{\omega} \dot{\gamma}$

- Purely elastic material: $G'' = 0$ and $G' = G$.

- Newtonian material: $G' = 0$ and $G'' = \mu\omega$.

Oscillatory tests

- Fractional Zener model: $\sigma_{ij} + \tau_0^{\alpha} \frac{d^{\alpha}\sigma_{ij}}{dt^{\alpha}} = G_e(\varepsilon_{ij} + \tau_0^{\alpha} \frac{d^{\alpha}\varepsilon_{ij}}{dt^{\alpha}}) + G_0\tau_0^{\beta} \frac{d^{\beta}\varepsilon_{ij}}{dt^{\beta}}$

$$G' = G_e + G_0 \frac{y^{\beta}(\cos(\beta\pi/2) + y^{\alpha}(\cos((\beta-\alpha)\pi/2))}{1 + 2y^{\alpha}\cos(\alpha\pi/2) + y^{2\alpha}}$$

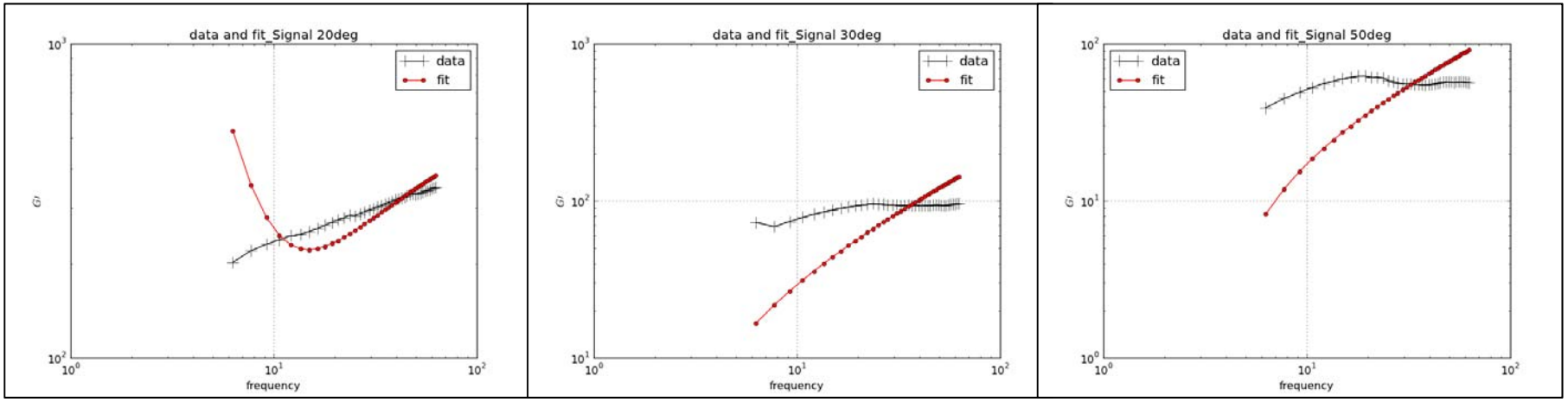
$$G'' = G_0 \frac{y^{\beta}(\sin(\beta\pi/2) + y^{\alpha}(\sin((\beta-\alpha)\pi/2))}{1 + 2y^{\alpha}\cos(\alpha\pi/2) + y^{2\alpha}}$$

$$y = \omega t$$

Chr. Friedrich., *Mechanical stress relaxation in polymers: fractional integral model versus fractional dierential model.*, Journal of Non-Newtonian Fluid Mechanics, 46(23):307 - 314, 1993.

Oscillatory tests

G’



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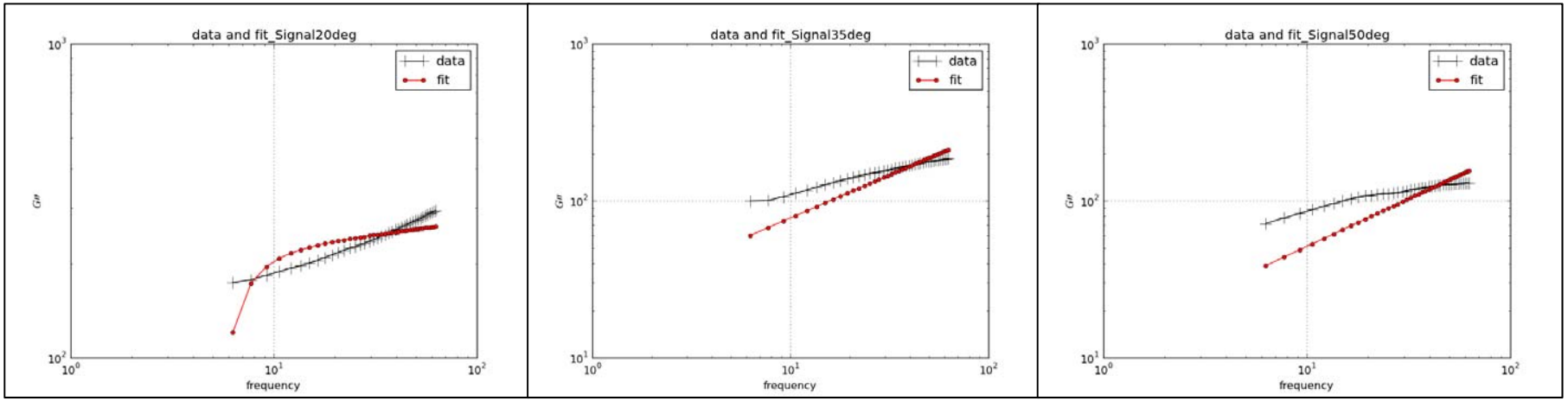

Conclusion

- Arctan and Herschel-Bulkley models does not suit the response of the adhesives

  => New models to be found?

- Strain gages' adhesive difficult to study with this device

- Resistance of the Kyowa adhesive to be seen with creep tests