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VISCOPLASTIC STRAIN DEVELOPMENT IN STRESS CONTROLLED TENSILE LOADING: EFFECT OF TEMPERATURE

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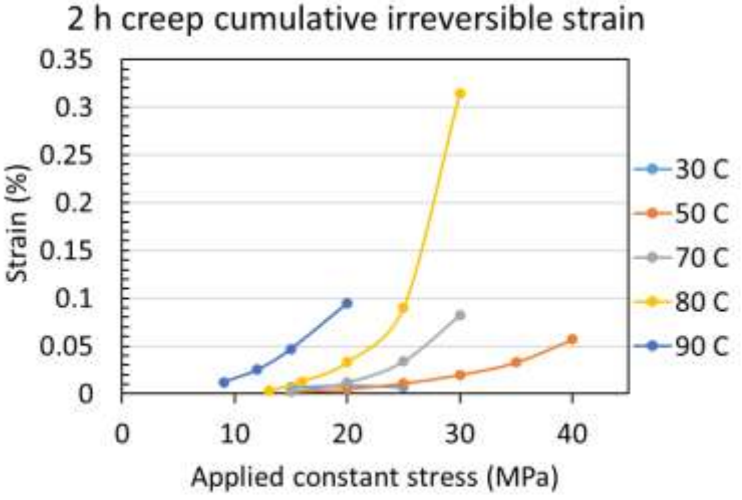
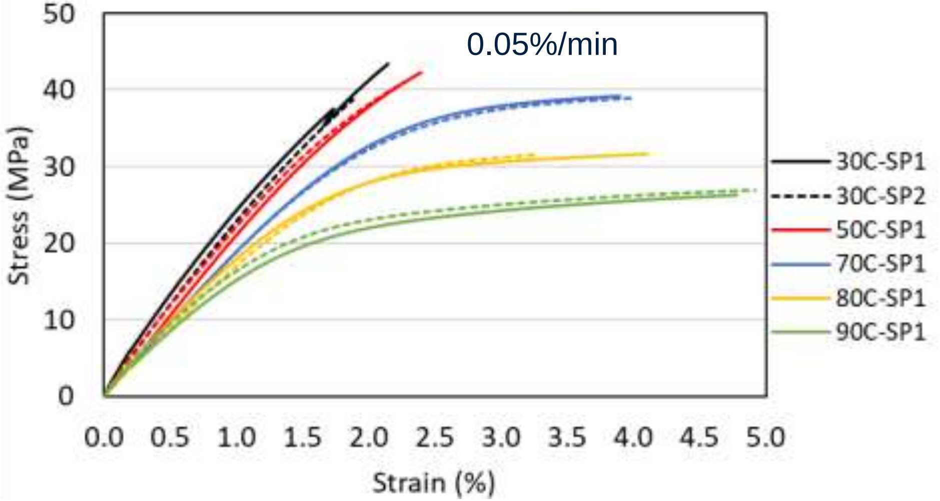
Motivation/The Big Picture





Viscoelasticity (VE) *Viscoplasticity (VP)*

- Material model: decomposition of strain components

$$\varepsilon = \varepsilon_{el} + g_1 \int_0^t \Delta S(\psi - \psi') \frac{d(g_2\sigma)}{d\tau} d\tau + \varepsilon_{VP}(\sigma, t)$$

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VP-strain Analysis in Focus

- Generalized VP strain model based on Zapas

$$\varepsilon_{VP}(\sigma,t) = C_{VP}\left\{\int_0^{\frac{t}{t^*}} \Phi(\sigma(\tau))d\tau\right\}^m$$

- Zapas [*] suggested a power function

$$\varepsilon_{VP}(\sigma,t) = C_{VP}\left\{\int_0^{\frac{t}{t^*}} \left(\frac{\sigma(\tau)}{\sigma^*}\right)^M d\tau\right\}^m$$

C_{VP}, M, m
Experimentally determined material parameters

t^*,σ^*
Normalizing parameters

[*] Zapas, L. J., Crissman, J. M. Creep and recovery behaviour of ultra-high molecular weight polyethylene in the region of small uniaxial deformations, Polymer (Guildf), 25, 1984, 57

- How do VP parameters depend on temperature?

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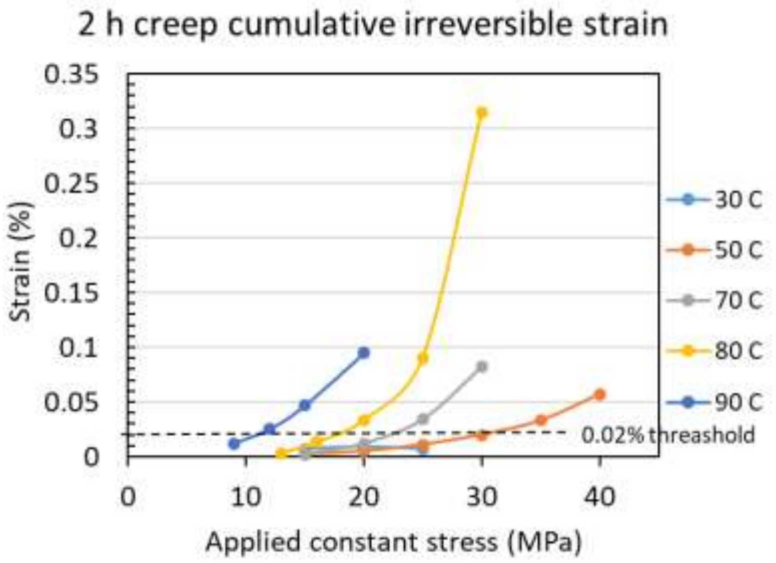
Objectives

$$\varepsilon_{VP}(\sigma,t) = C_{VP}\left\{\int_0^{\frac{t}{t^*}}\left(\frac{\sigma(\tau)}{\sigma^*}\right)^M d\tau\right\}^m \qquad \varepsilon_{V}$$



- Check which sub-model is better (Za
- Develop methodology to determine T
- Analyze T-dependence
- Validation of methodology

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Material and Procedures

Araldite® LY 5052/ Aradur® 5052 epoxy system
resin/hardener 100/38 wt/wt
Cured @ RT for 24 h + post cured @ 105 ℃ for 4 h

- Annealing @ 150℃ (Tg+20℃) for 40 min + ageing @ 80℃ for 15 days
- Iso-thermal, short-term, creep-recovery tests in tension
- UTM Instron 3366, 10 kN load cell, and extensometer
- Single specimen approach [*] at multiple increasing constant stresses
- Load controlled mode, without removing specimen from machine.

[*] Pupure, L., Varna, J., Joffe, R. On viscoplasticity characterization of natural fibres with high variability, Advanced Composite Letters, 24, 2015, 125.

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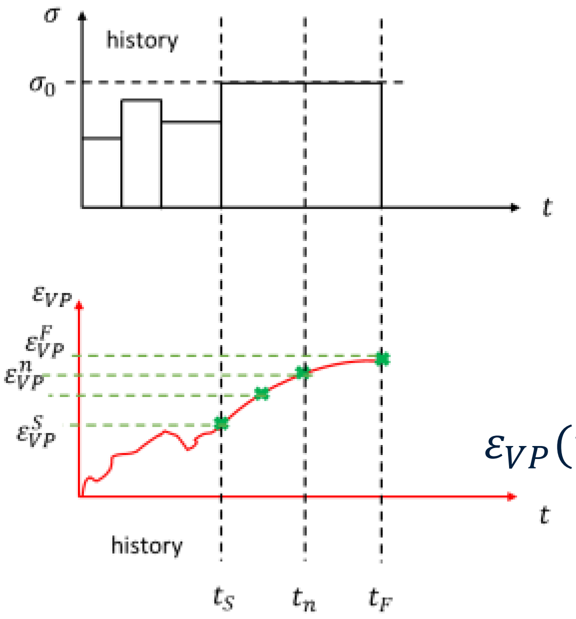
Methodology for Parameters Determination



- During time interval from $t = -\infty$ to $t = t_S$ VP strain has developed = ε_{VP}^S (known)
- Short term creep/recovery tests for a total of 2 h at const. σ_0 and T_0

History part | Developing part

$$\varepsilon_{VP}(t) = C_{VP}\left\{\int_0^{\frac{t_S}{t^*}}\left(\frac{\sigma(\tau)-\sigma_y}{\sigma^*}\right)^M d\tau + \int_{\frac{t_S}{t^*}}^{\frac{t}{t^*}}\left(\frac{\sigma_0-\sigma_y}{\sigma^*}\right)^M d\tau\right\}^m$$

$$\left(\frac{\varepsilon_{VP}^S}{C_{VP}}\right)^{1/m}$$

If m is selected correctly the relationship has to be linear with respect to time

$$(\varepsilon_{VP}(t))^{1/m} - (\varepsilon_{VP}^S)^{1/m} = (C_{VP})^{1/m}\left(\frac{\sigma_0-\sigma_y}{\sigma^*}\right)^M \frac{t-t_S}{t^*}$$

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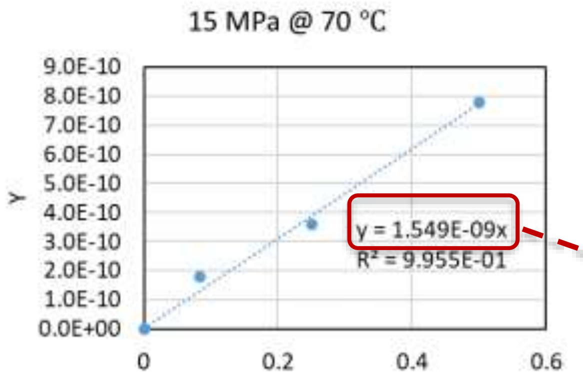
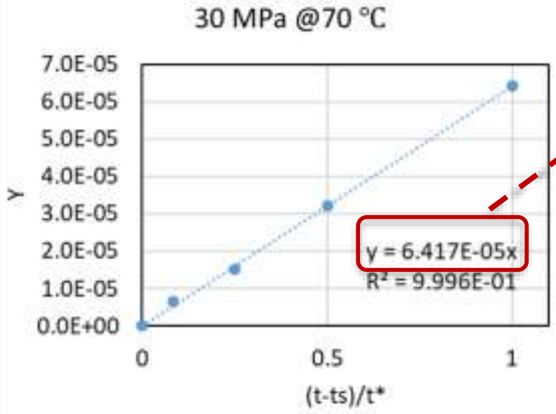
Averaging *m* for Different σ at given T

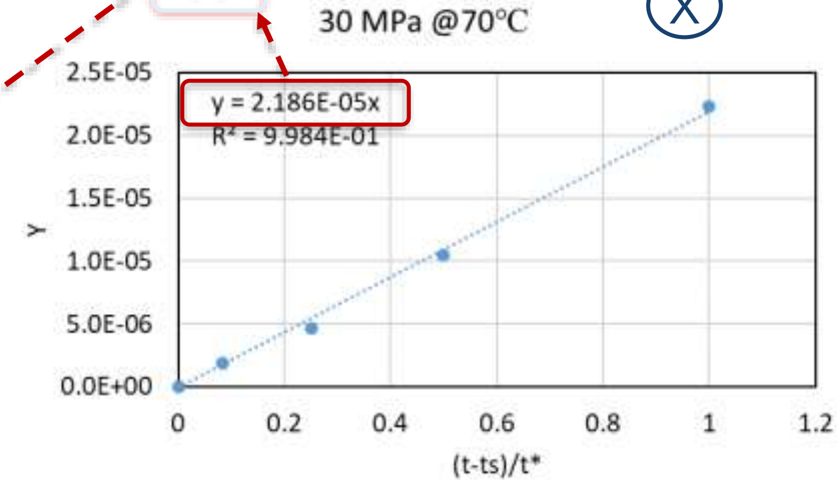
$$\left(\varepsilon_{VP}(t)\right)^{1/m} - \left(\varepsilon_{VP}^{S}\right)^{1/m} = \left(C_{VP}\right)^{1/m} \left(\frac{\sigma_0-\sigma_y}{\sigma^*}\right)^{M} \frac{t-t_s}{t^*}$$

Y — A — X





when best m is different for each stress



m is average and constant for all stresses

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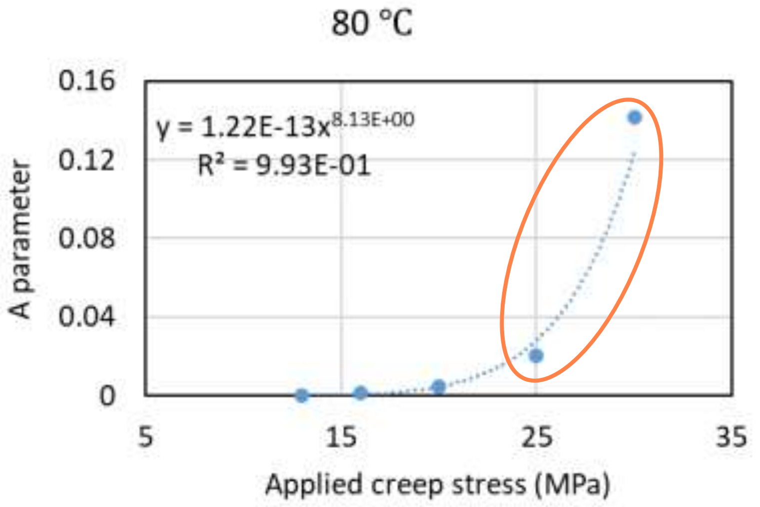
Using A and m to find C_{VP}, M at a given T

$$\varepsilon_{VP}(\sigma,t) = C_{VP}\left\{\int_0^{\frac{t}{t^*}}\left(\frac{\sigma(\tau)-\sigma_y}{\sigma^*}\right)^M d\tau\right\}^m$$

- Power function relationship
- Linear relationship on a log-log scale
- Example for when σ_y =0

$$A = (C_{VP})^{\frac{1}{m_{avg.}}}\left(\frac{\sigma_0-\sigma_y}{\sigma^*}\right)^M$$

$$\log A = \log((C_{VP})^{\frac{1}{m_{avg.}}}) + \text{M}\log\left(\frac{\sigma_0-\sigma_y}{\sigma^*}\right)$$

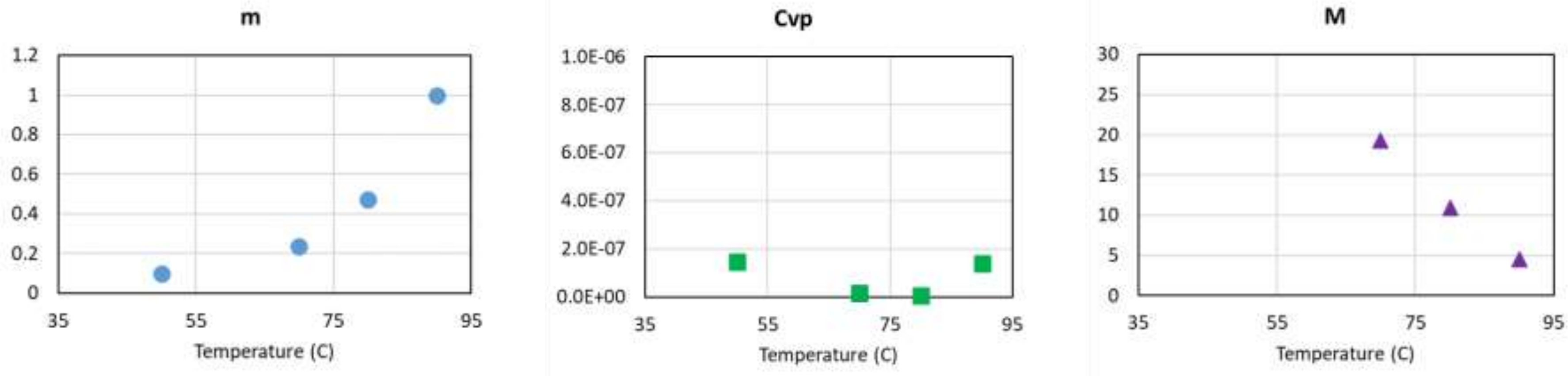


Do this for multiple temperatures (T-dependence)

VP Parameters as a Function of Temperature

$$\varepsilon_{VP}(\sigma,t) = C_{VP}\left\{\int_0^{\frac{t}{t^*}}\left(\frac{\sigma(\tau)-\sigma_y}{\sigma^*}\right)^M d\tau\right\}^m$$

$$\sigma_y = 0$$



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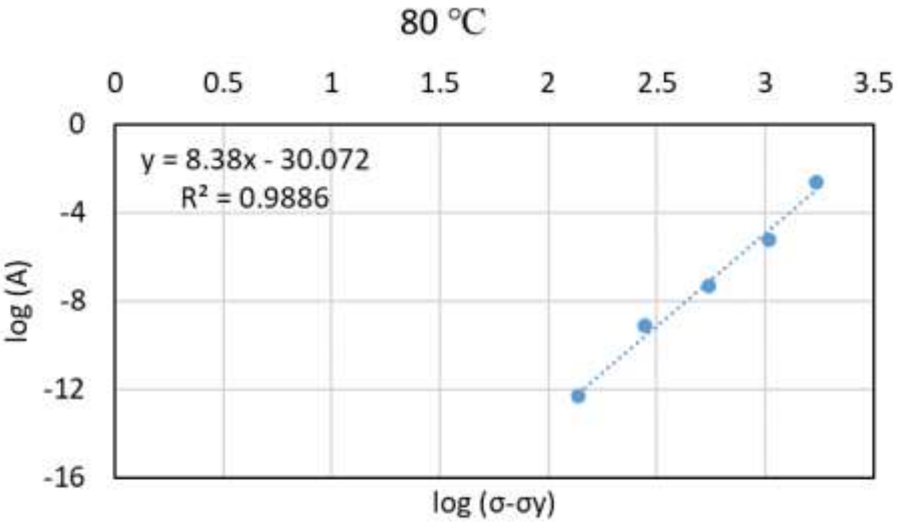
Finding σ_y

$$A = (C_{VP})^{\frac{1}{m_{avg.}}} \left(\frac{\sigma_0 - \sigma_y}{\sigma^*}\right)^M$$

$$\log A = \log((C_{VP})^{\frac{1}{m_{avg.}}}) + \mathrm{M}\log\left(\frac{\sigma_0 - \sigma_y}{\sigma^*}\right)$$

$$\sigma_y \neq 0$$



- Change σ_y until best linearity is achieved
- Do this for all temperatures

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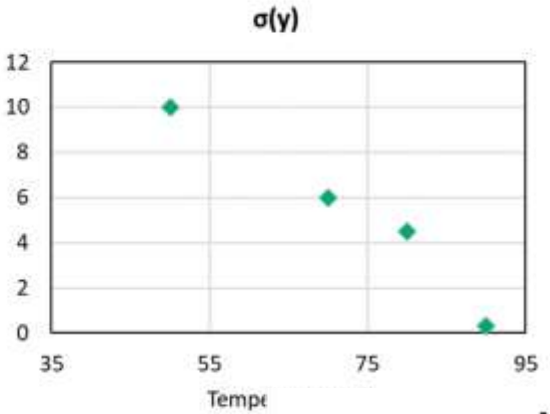
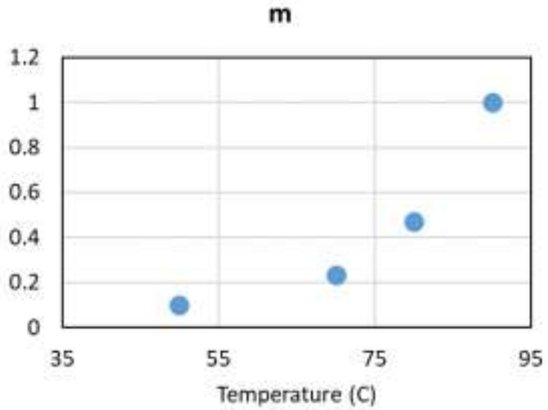
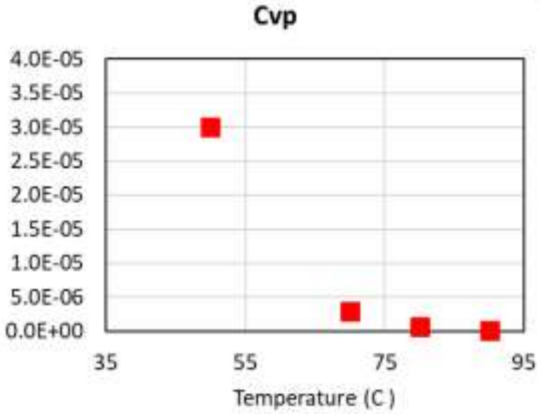
VP Parameters as a Function of Temperature

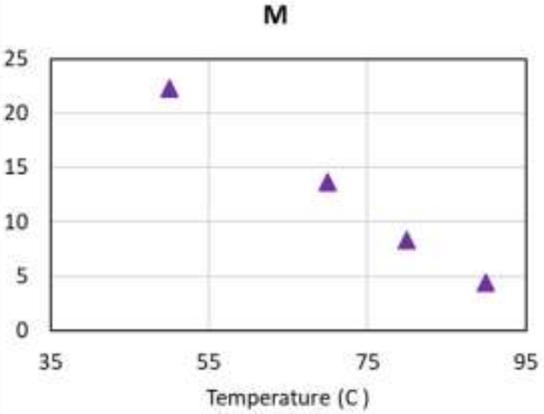
$$\varepsilon_{VP}(\sigma,t) = C_{VP}\left\{\int_0^{\frac{t}{t^*}}\left(\frac{\sigma(\tau)-\sigma_y}{\sigma^*}\right)^M d\tau\right\}^m$$

$$\sigma_y \neq 0$$









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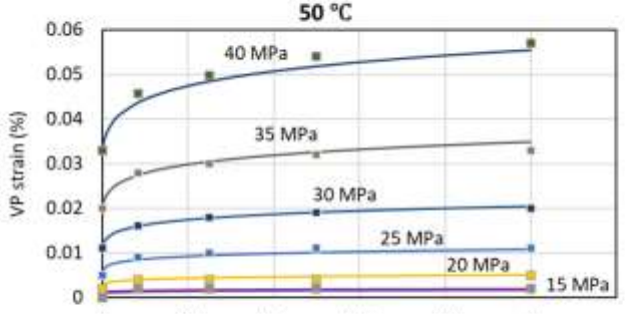
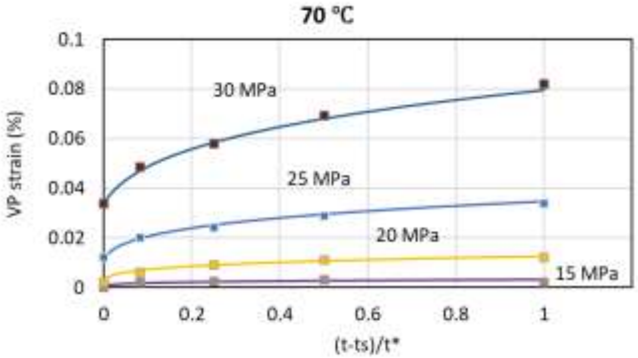
Validation Simulations of VP-strains

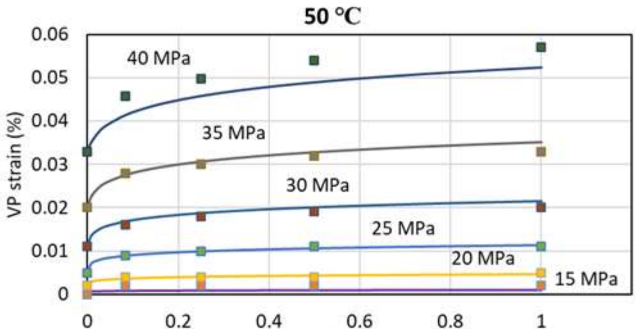
$$\varepsilon_{VP}(t) = C_{VP}\left\{\left(\frac{\varepsilon_{VP}^{s}}{C_{VP}}\right)^{1/m} + \left(\frac{\sigma_0}{\sigma^*}\right)^{M}\frac{t-t_s}{t^*}\right\}^{m}$$

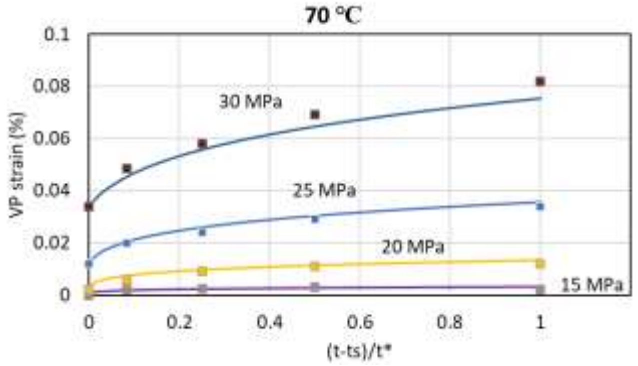
$$\varepsilon_{VP}(t) = C_{VP}\left\{\left(\frac{\varepsilon_{VP}^{s}}{C_{VP}}\right)^{1/m} + \left(\frac{\sigma_0-\sigma_y}{\sigma^*}\right)^{M}\frac{t-t_s}{t^*}\right\}^{m}$$





ε_{VP}^{s} is experimental value
Solid lines: simulations
Symbols: experiments





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Conclusions

- All objectives have been met
- Description of the data is satisfactory
- Threshold stress decreases with T
- VP-strain rate (parameter m) increases with T
- Threshold stress is not needed – no significant difference
- Power function for stress dependence might not be the best function to fit the data
- The current analysis is for short term VP development, long term and instant behavior might differ

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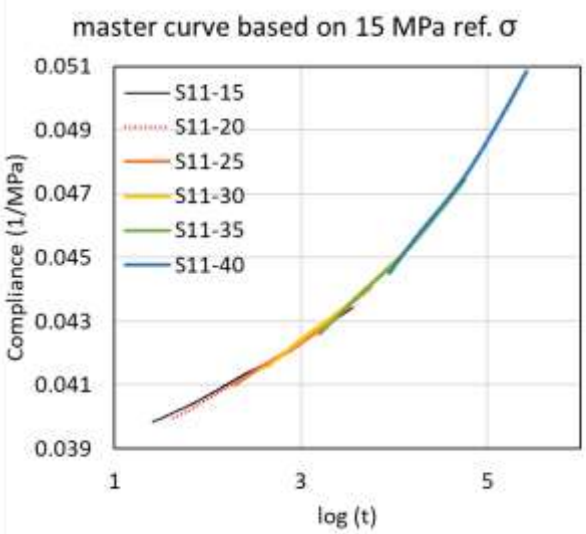
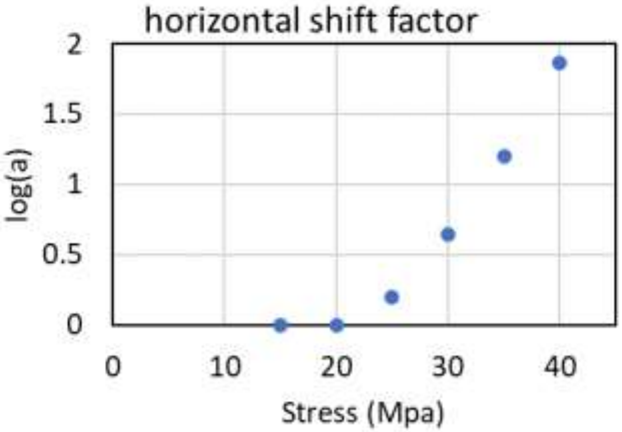
Sneak Peek to Future Work

- Try exponential function $e^{k(\sigma_\tau - \sigma_y)} - 1$
- Analysis of the lateral contraction VP strains (Poisson's effect)
- Nonlinear VE analysis and shift factors with respect to σ





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The audience for listening

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