New Ideas. New Materials.

UNIVERSITÄT DES SAARLANDES

INM

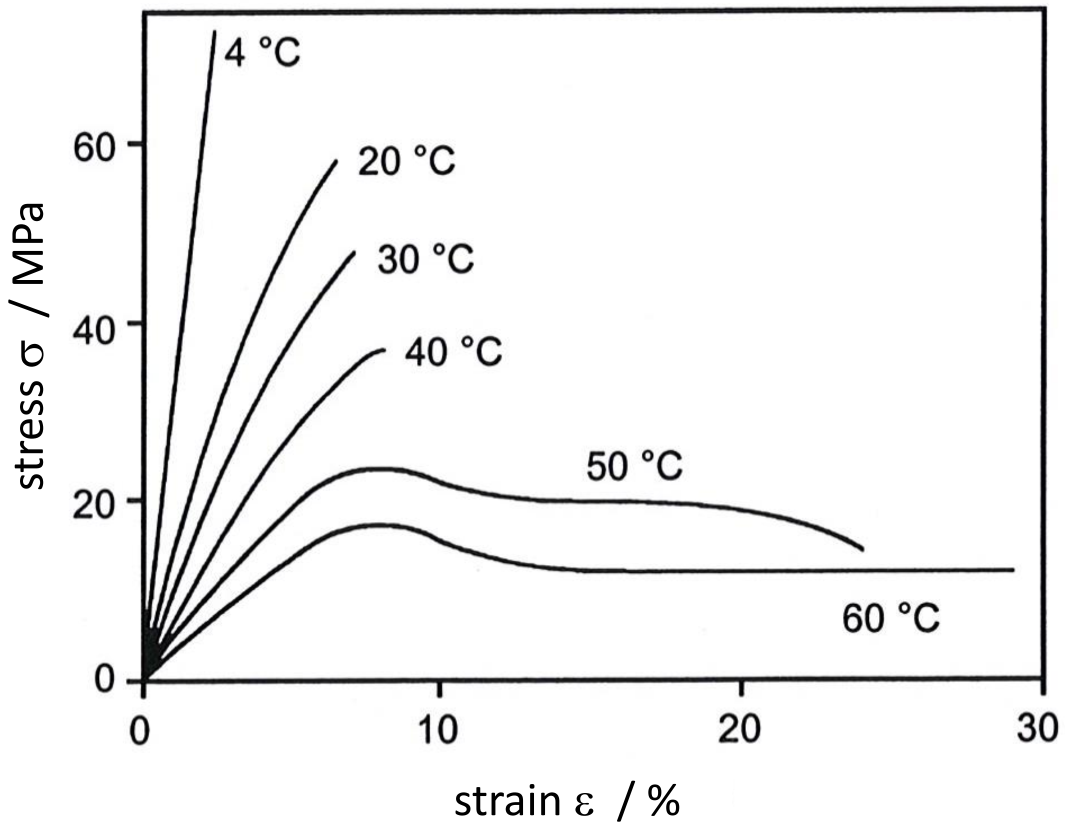
TECHNOLOGIE POLYMERE & KOMPOSITE

MC07, UdS WS 2019/2020

Chapter 5: Visco-elastic behaviour

Temperature dependence in stress strain behaviour

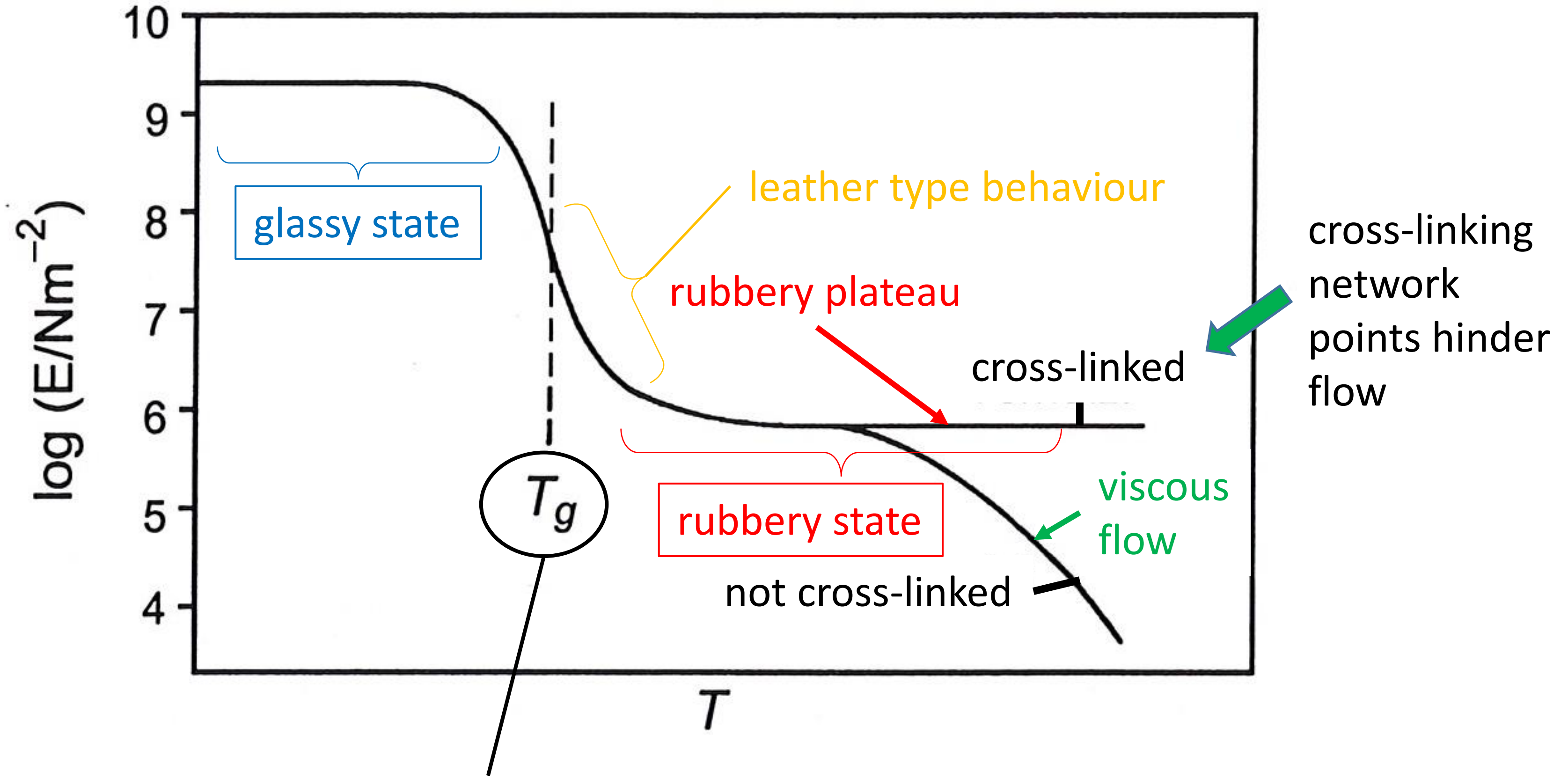
example: PMMA (polymethylmethacrylate)



! polymers are visco-elastic materials → time temperature equivalence !

Elastic modulus vs temperature

general behaviour of thermoplastic materials and influence of cross-linking

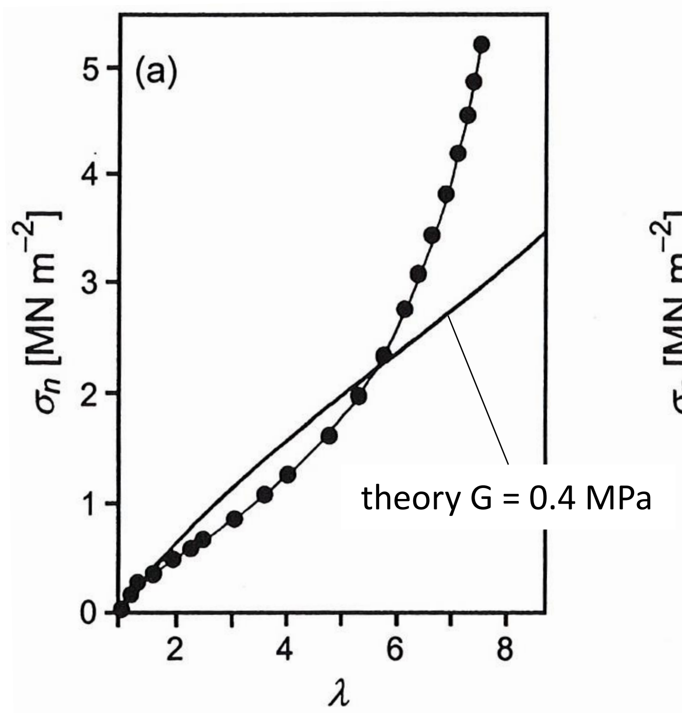


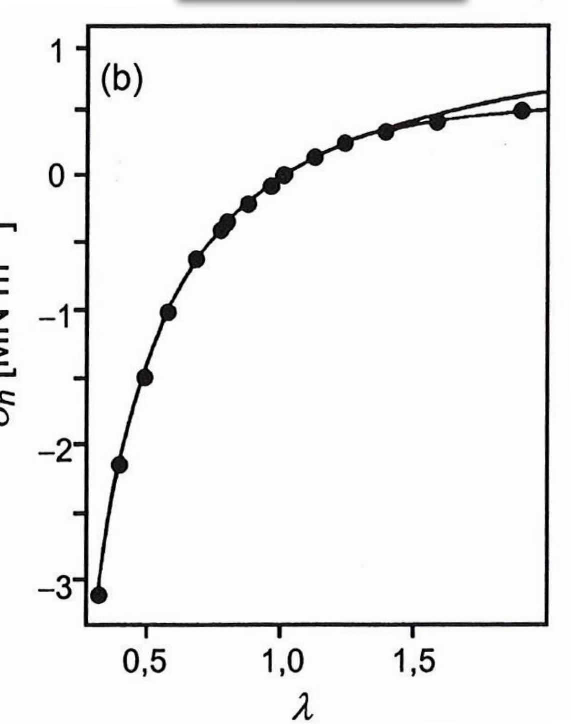
glass transition temperature

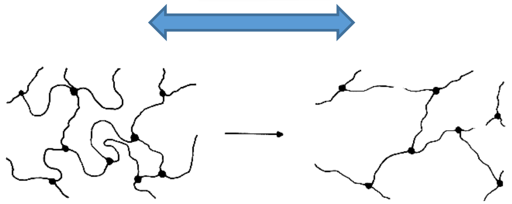
Stress strain for elastomers (elastic behaviour)

tensile

compression

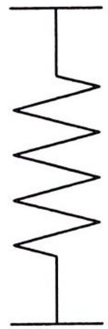
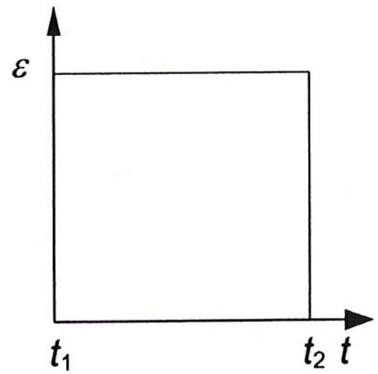
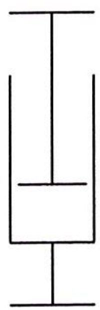
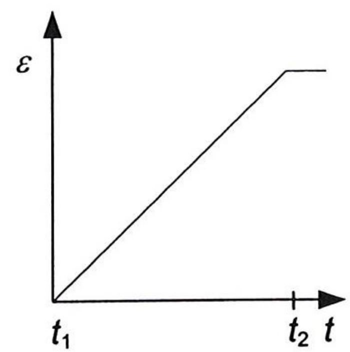




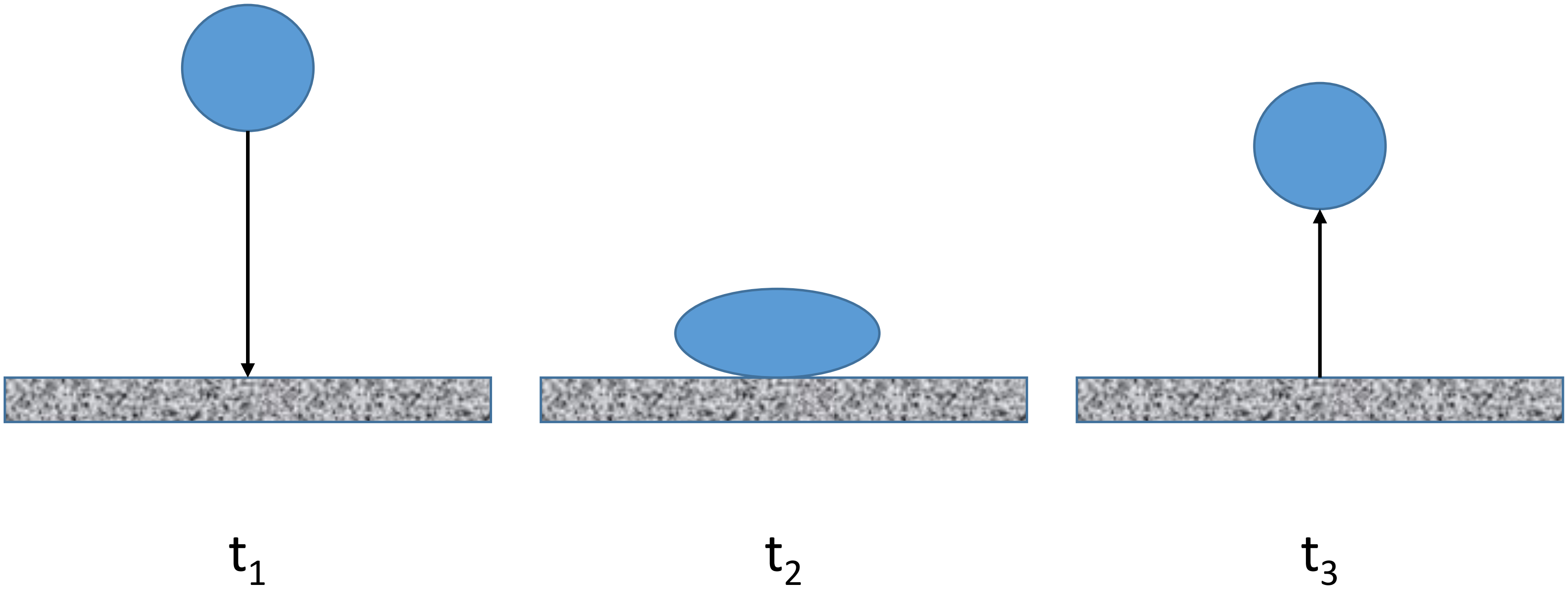


e.g. tensile mode:
- stress increases for higher strain
- covalent network points hinder slippage between chains
- elastic energy can be restored when strain is released
- entropy elasticity

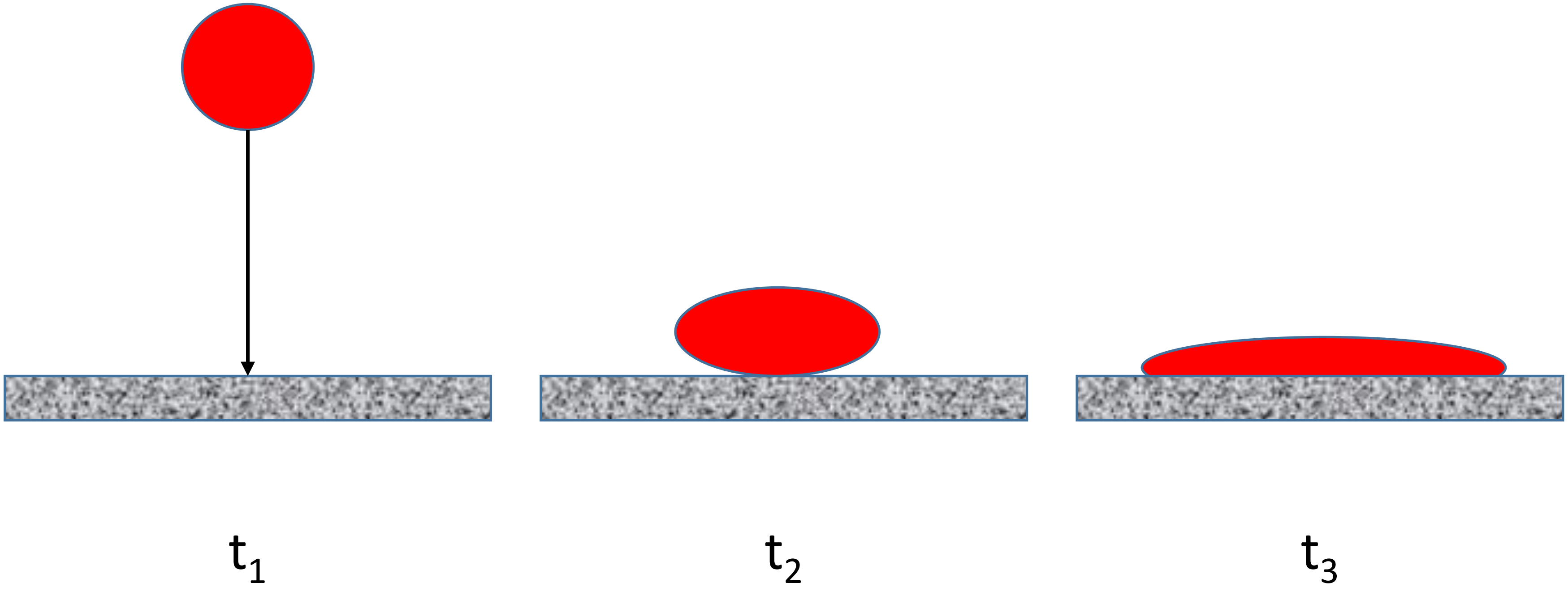
Models to describe molecular mechanisms in polymers

	model		strain over time	
elastic part	spring			Hooke‘s behaviour $\sigma = E * \varepsilon$ $\frac{d\sigma}{dt} = E\frac{d\varepsilon}{dt}$
viscous part	dashpot			Newtonian behaviour $\sigma = \eta\frac{d\varepsilon}{dt}$

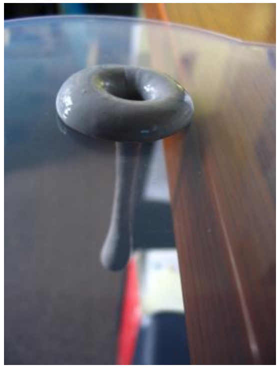
Elastic behaviour



Viscous behaviour



Extreme visco-elastic behaviour: „silly putty“

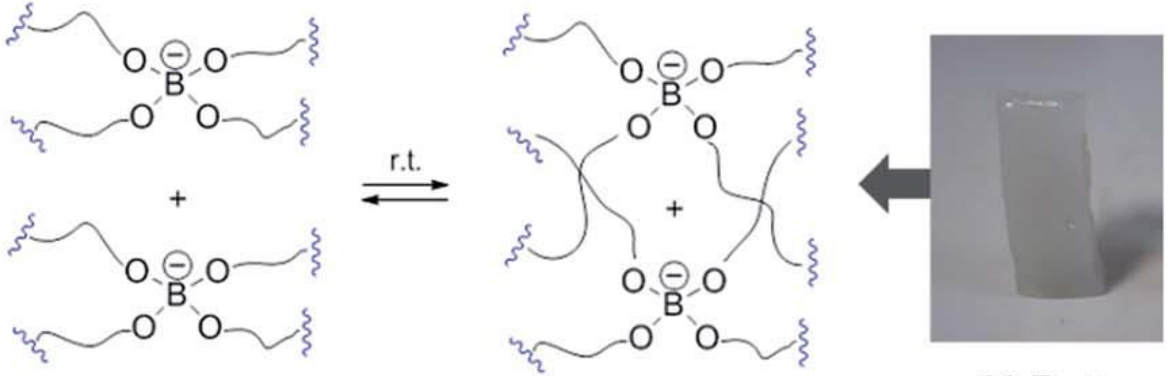


- non-newtownian viscosity

- long loading times
  - viscous flow (creep)
- short loading times
  - elastic behaviour
- extrem short loading times
  - brittle behaviour

Extreme visco-elastic behaviour

- mixture of:
  - 65% HO-PDMS-OH terminated with $B(OH)_3$
  - 17% silica
  - 9% Thixatrol ST (castor oil or derivative)
  - 4% PDMS
  - 1% decamethyl cyclopentasiloxane
  - 1% glycerine
  - 1% TiO_2



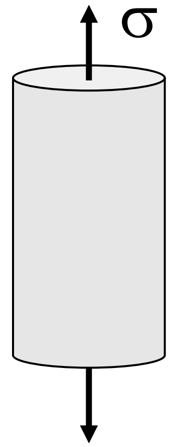
Creep behaviour

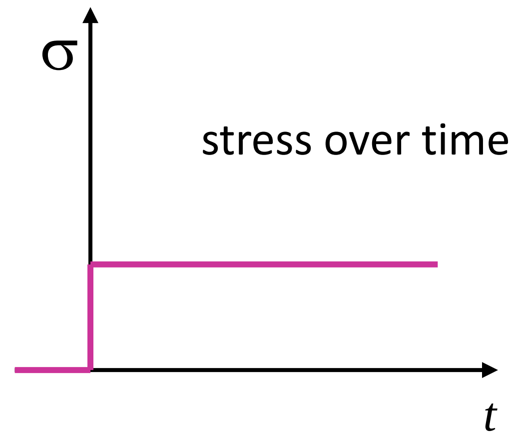
- strain ε is dependent on:
  - stress σ
  - temperature T
  - time t

$$\varepsilon = f(\sigma, T, t)$$

- time and temperature dependent deformation processes are called **creep** behaviour

Creep behaviour





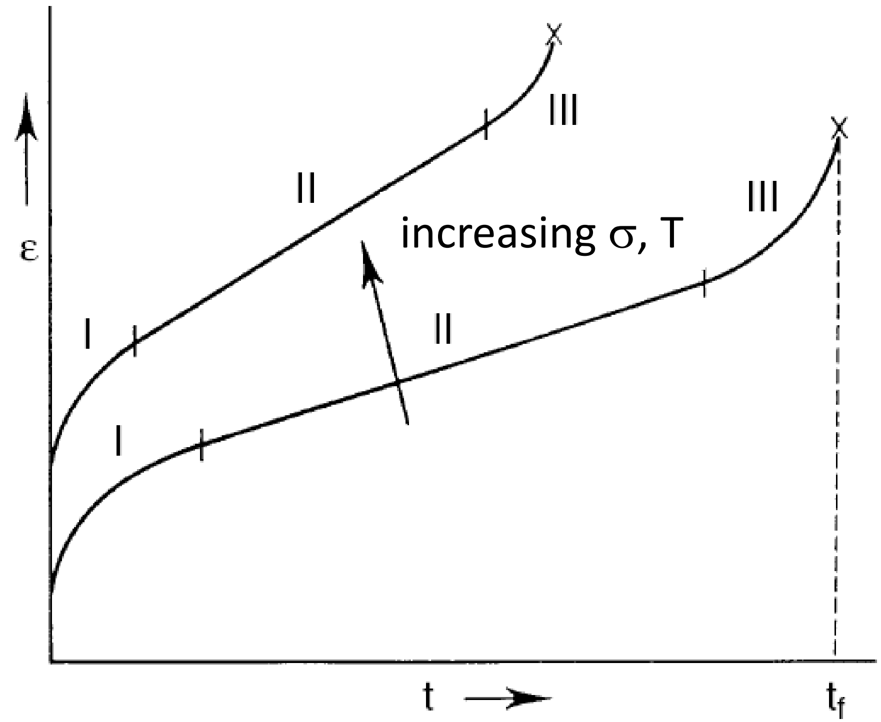
primary creep (I)

- creep velocity can decrease because of solidification mechanisms $\varepsilon_I = \alpha \log t$

stationary creep (II)

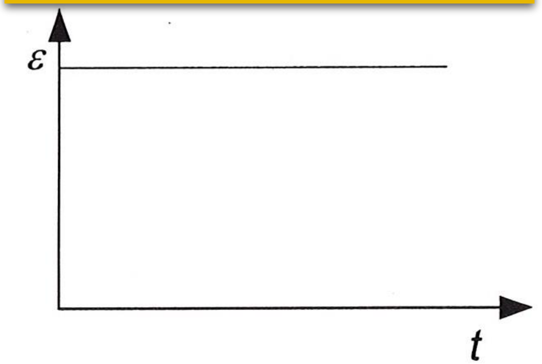
- dynamic equilibrium between weakening and re-solidification $\varepsilon_{II} = \alpha \log t$

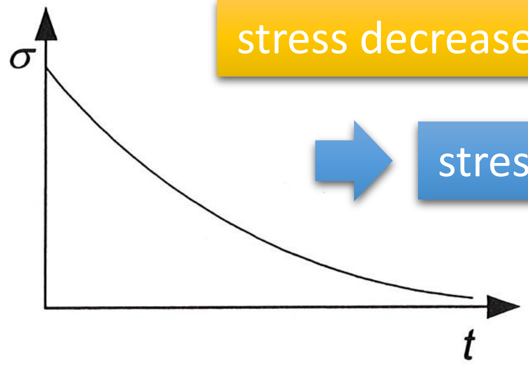
tertiary creep (III)



The visco-elastic response under constant strain and constant stress

constant strain over time

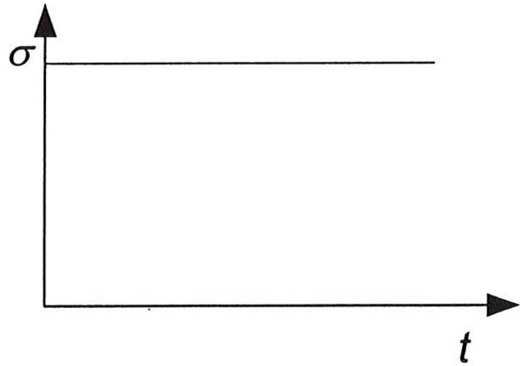


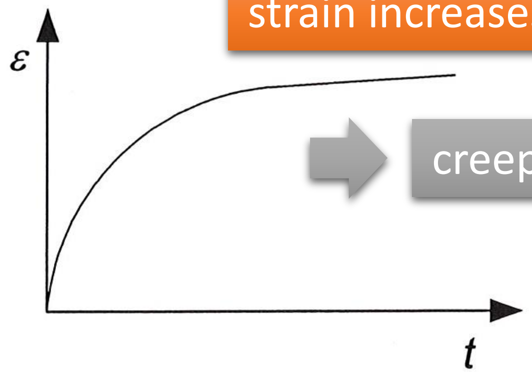


stress decreases in sample

→ stress relaxation

constant stress over time

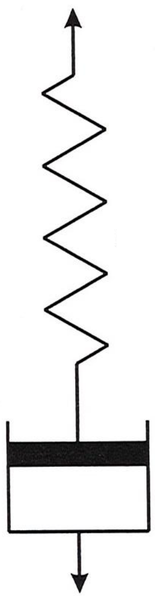




strain increases in sample

→ creep behaviour

Maxwell model: Spring and dash-pot in series



symbol for

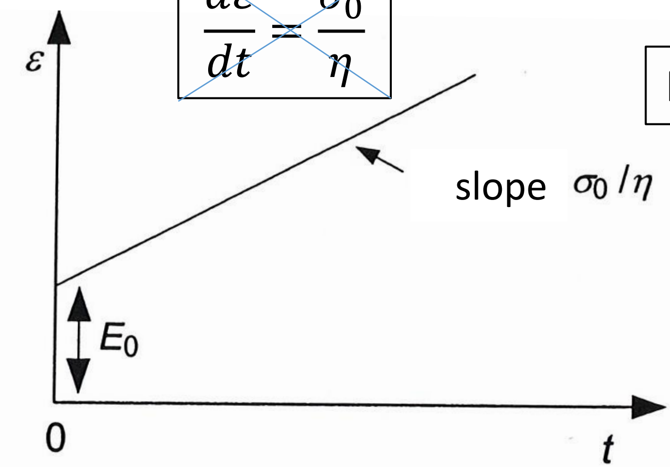
elastic modulus E

viscosity η

$$\frac{d\varepsilon}{dt} = \frac{1}{E}\frac{d\sigma}{dt} + \frac{\sigma}{\eta}$$

measurement at constant stress

$$\frac{d\varepsilon}{dt} = \frac{\sigma_0}{\eta}$$



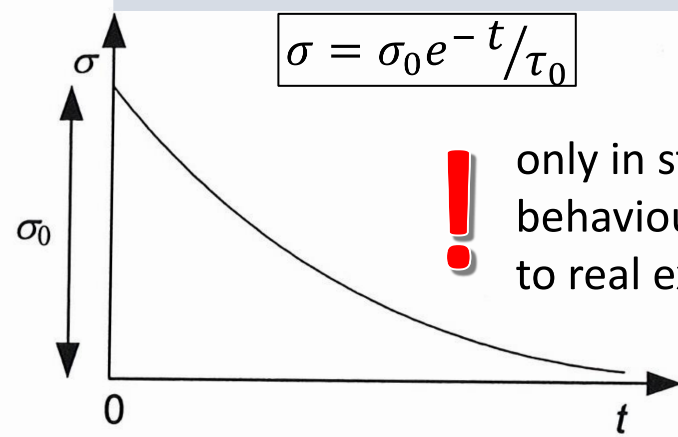
Newtownian flow

⇩

not suitable for visco-elastic behaviour

measurement at constant strain

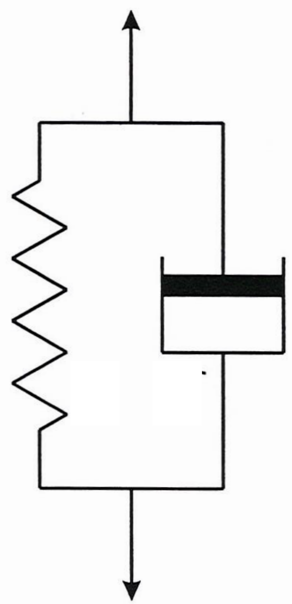
$$\sigma = \sigma_0 e^{-t/\tau_0}$$



stress relaxation

! only in stress relaxation behaviour Maxwell model fits to real experiments

Kelvin-Voigt model: Spring and dash-pot in parallel



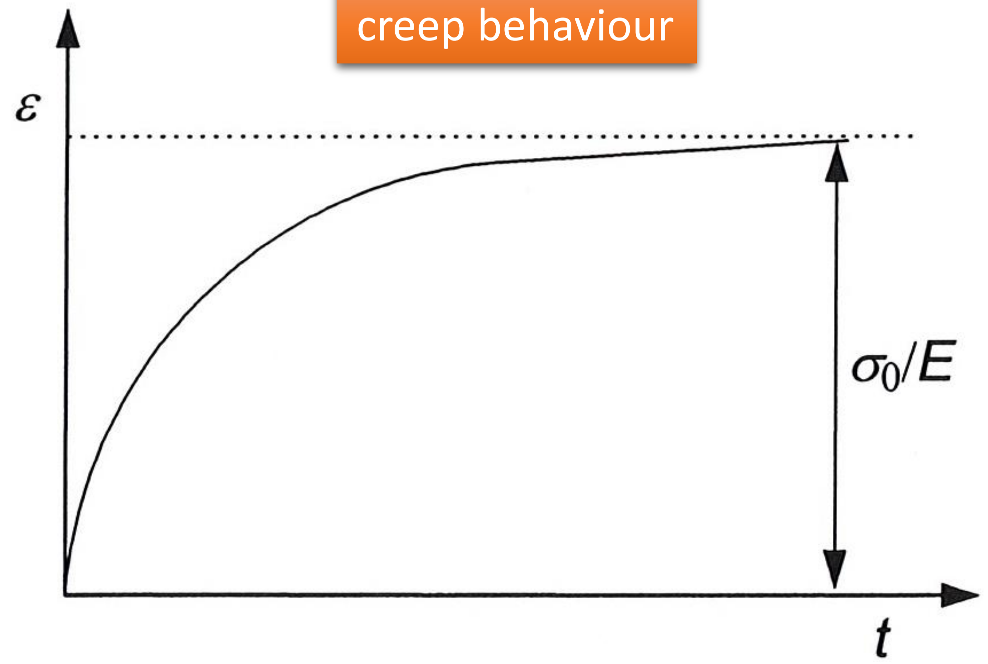
$$\sigma = E\varepsilon + \eta \frac{d\varepsilon}{dt}$$ and $$\frac{d\varepsilon}{dt} = \frac{\sigma}{\eta} - \frac{E\varepsilon}{\eta}$$

measurement at constant stress:

$$\varepsilon = \frac{\sigma_0}{E}\left[1 - e^{-t/\tau_0}\right]$$

τ_0: relaxation time

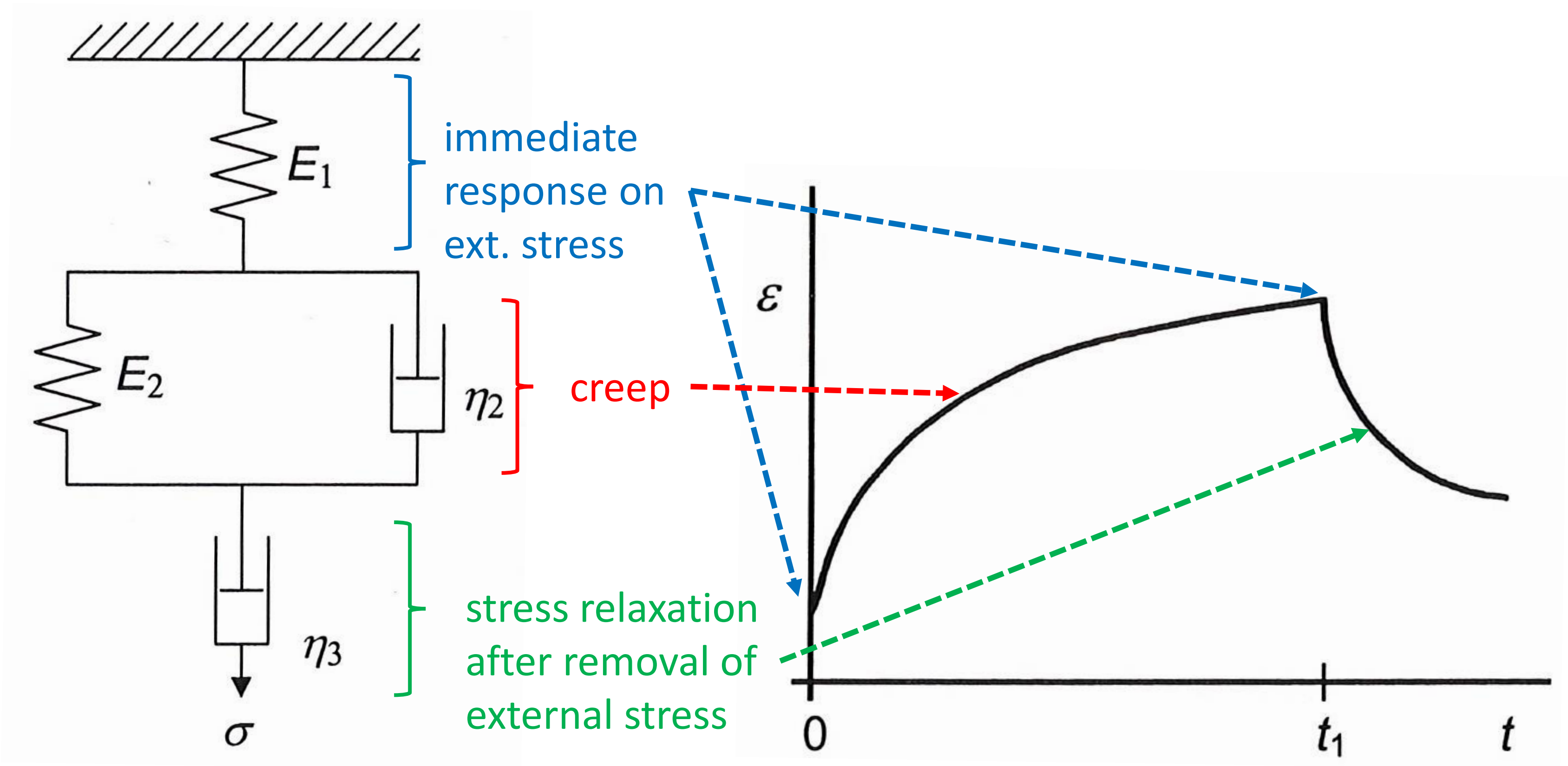
creep behaviour



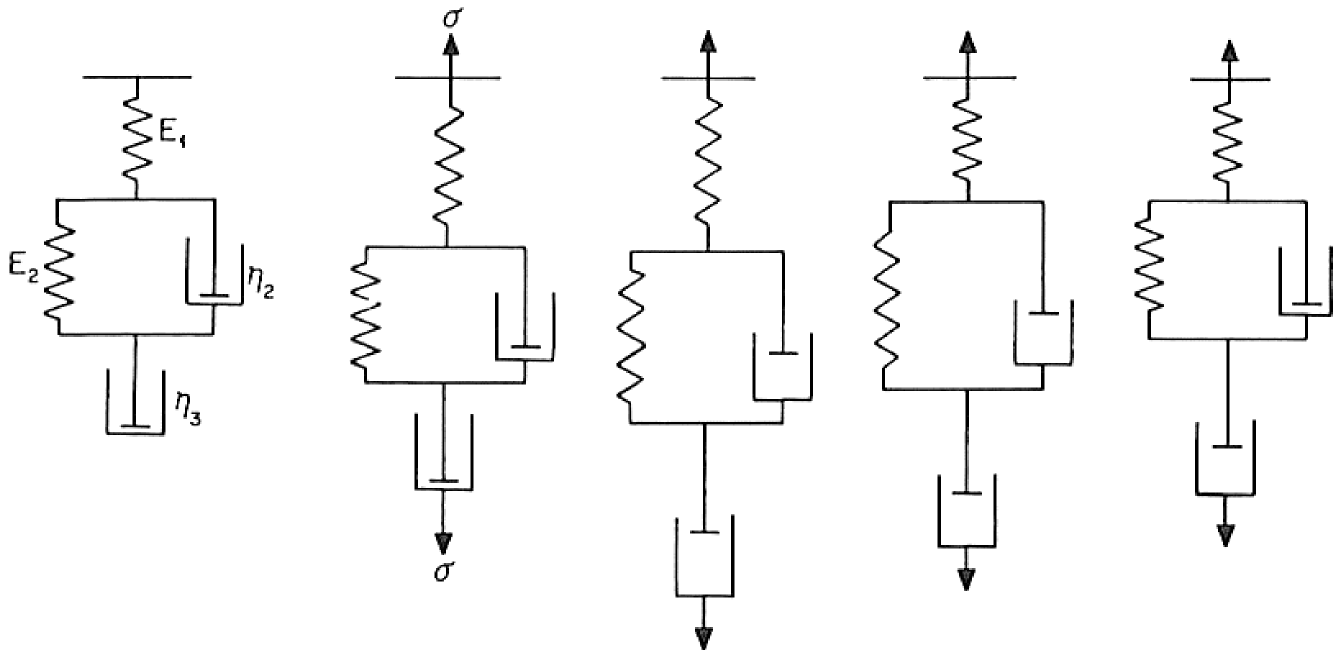
! Kelvin-Voigt model fits well to creep behaviour observed in real experiments

Combinations of serial and parallel elements

improvement of models by combination of
Maxwell and Kelvin-Voigt elements: **Burgers model**

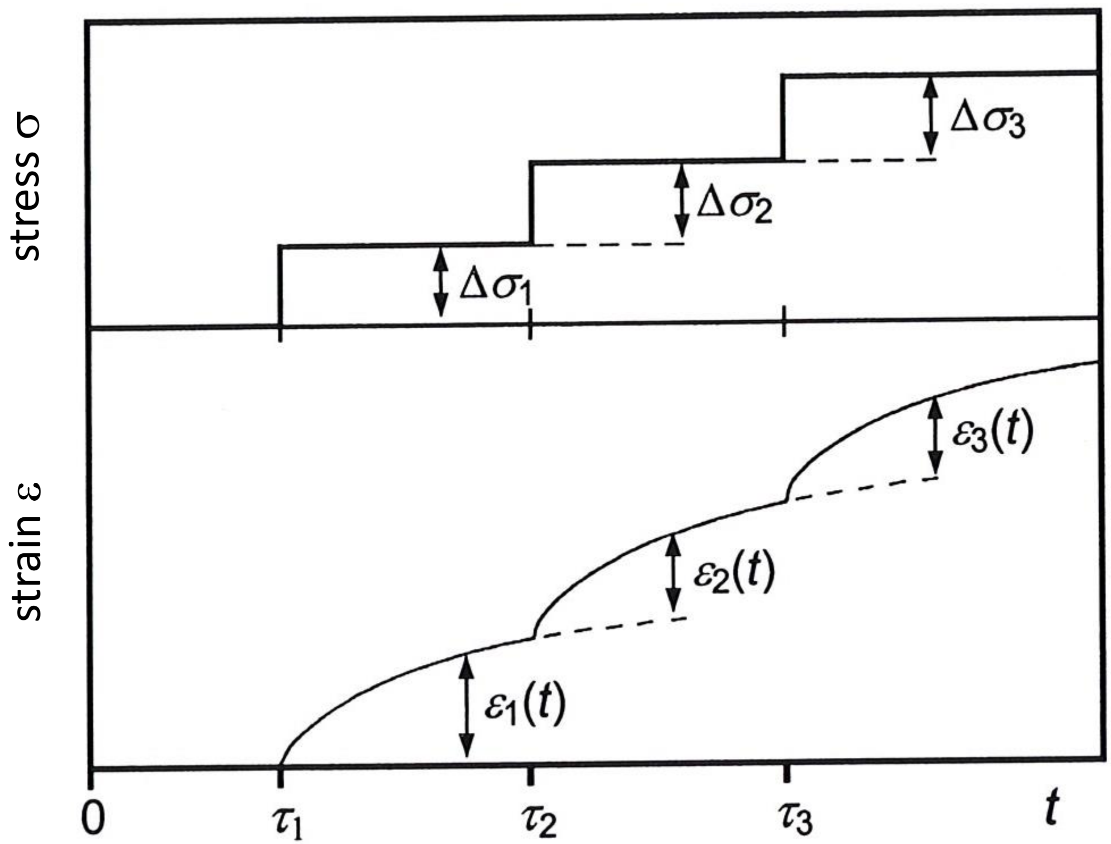


Use of mechanical models to describe creep of polymers



Boltzmann's superposition principle I

strain of a visco-elastic material after several tensile deformations



externally applied stress σ (stepwise increase)

responding strain ε of the sample

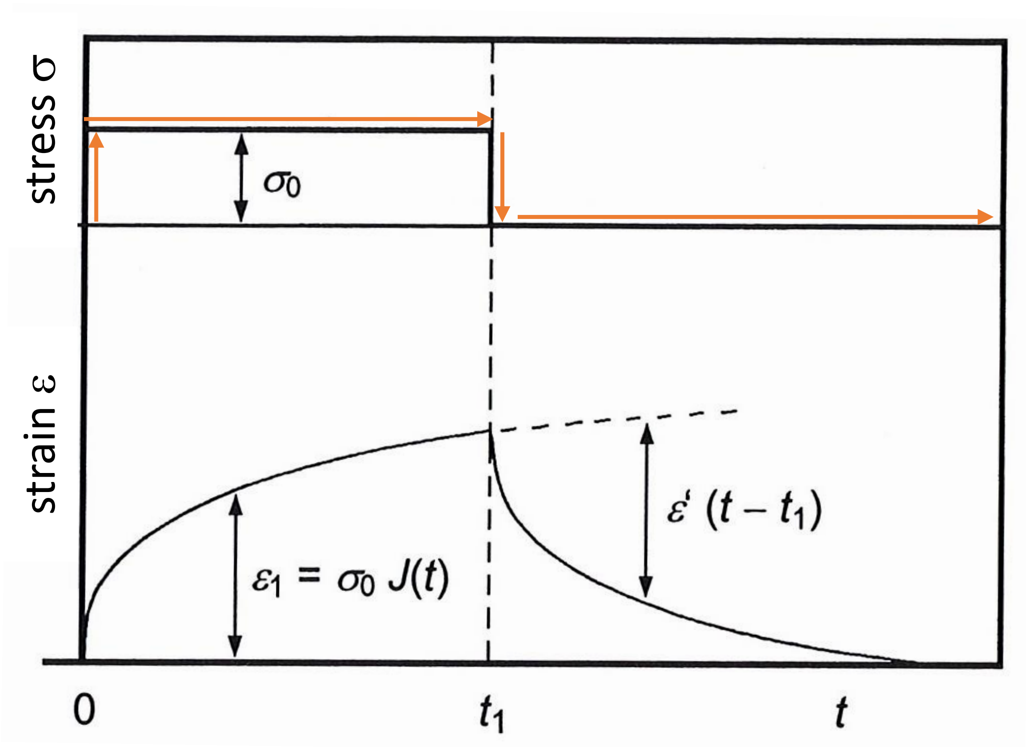
J(t): creep yield

$$\varepsilon(t) = \int_{-\infty}^{t} J(t-\tau)\Delta\sigma(t)$$

the sample responds several times

Boltzmann‘s superposition principle II

strain of a visco-elastic material under temporary tensile load

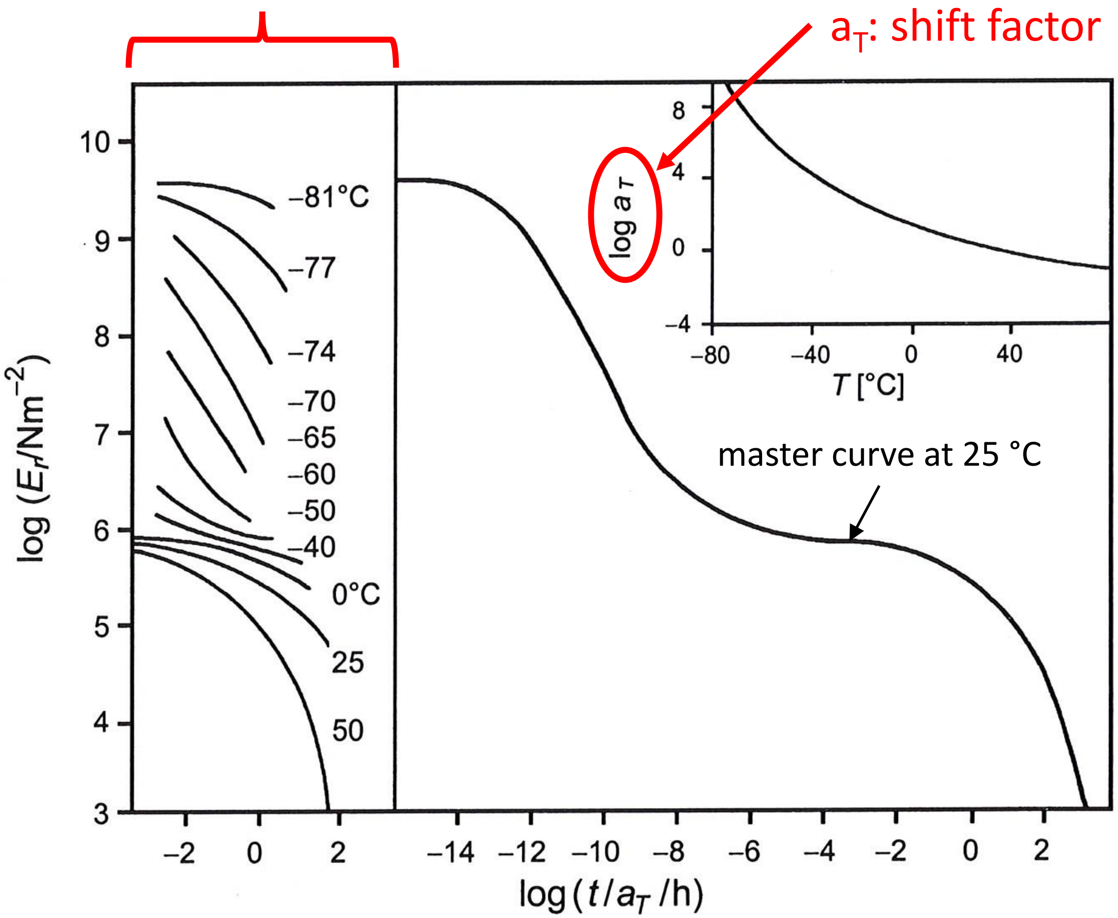


E_r: stress relaxation modulus

$$\sigma(t) = \int_{-\infty}^{t} E_r(t - \tau)\, d\varepsilon(t)$$

all the different deformation steps are separate

Master curve from stress relaxation data



$$log\ a_T = \log t - \log t_0 = log\frac{t}{t_0}$$

Williams, Landel and Ferry

WLF equation

$$\log a_T = \frac{-c_1^g(T - T_g)}{c_2^g + (T - T_g)}$$

$c_1^g = 17.4$ K
$c_2^g = 51.6$ K

visco-elastic materials → time and temperature are equivalent !