

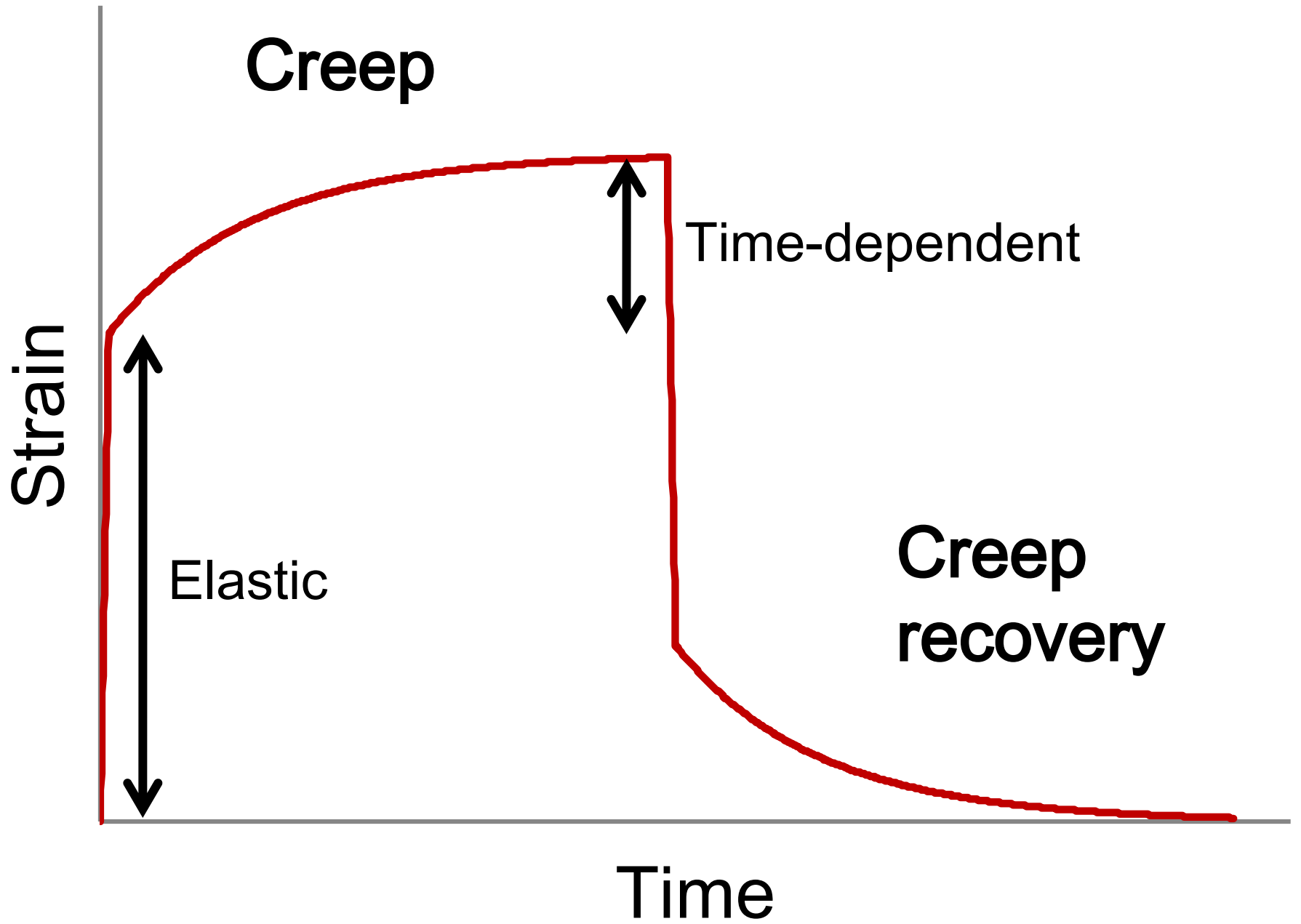


**DANISH
TECHNOLOGICAL
INSTITUTE**

Numerical modelling of softwood time-dependent behaviour based on microstructure

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Industrial PhD-candidate



Why yet
another model



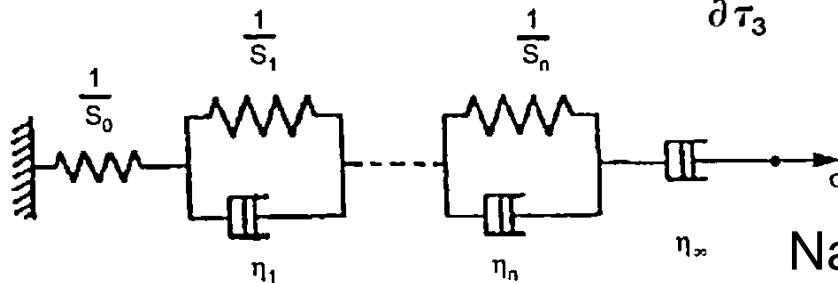
Swelling
Creep
Mechano-
sorption
Fracture



TOP-DOWN



$$\begin{aligned} \varepsilon(t) = & \int_0^t S_1(t-\tau_1) \frac{\partial \sigma(\tau_1)}{\partial \tau_1} d\tau_1 \\ & + \int_0^t \int_0^t S_2(t-\tau_1, t-\tau_2) \frac{\partial \sigma(\tau_1)}{\partial \tau_1} \frac{\partial \sigma(\tau_2)}{\partial \tau_2} d\tau_1 d\tau_2 \\ & + \int_0^t \int_0^t \int_0^t S_3(t-\tau_1, t-\tau_2, t-\tau_3) \frac{\partial \sigma(\tau_1)}{\partial \tau_1} \frac{\partial \sigma(\tau_2)}{\partial \tau_2} \\ & \frac{\partial \sigma(\tau_3)}{\partial \tau_3} d\tau_1 d\tau_2 d\tau_3 + \dots \end{aligned}$$



Navi & Stanzl-Tschegg (2009)

PRO

Can reproduce a
wide range of
experimental
results



(Typically) lacks
physical meaning

CON



**Hypothesis
about the
actual
physical
processes**

**BOTTOM-
UP**

PRO

Based on
hypotheses of
the actual
physical
processes



(Typically) cannot
reproduce
complex behaviour

CON

**What causes
time-dependency**

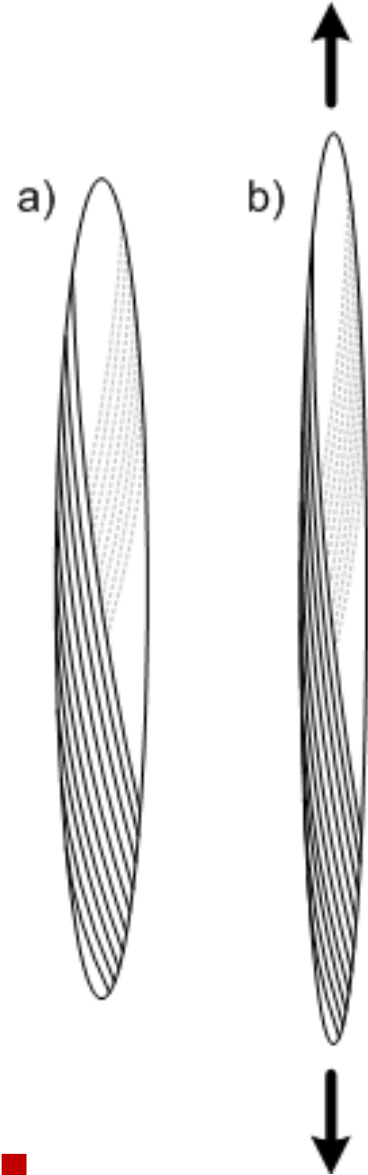


Sliding of the microfibrils past each other

Balashov et al. (1957)

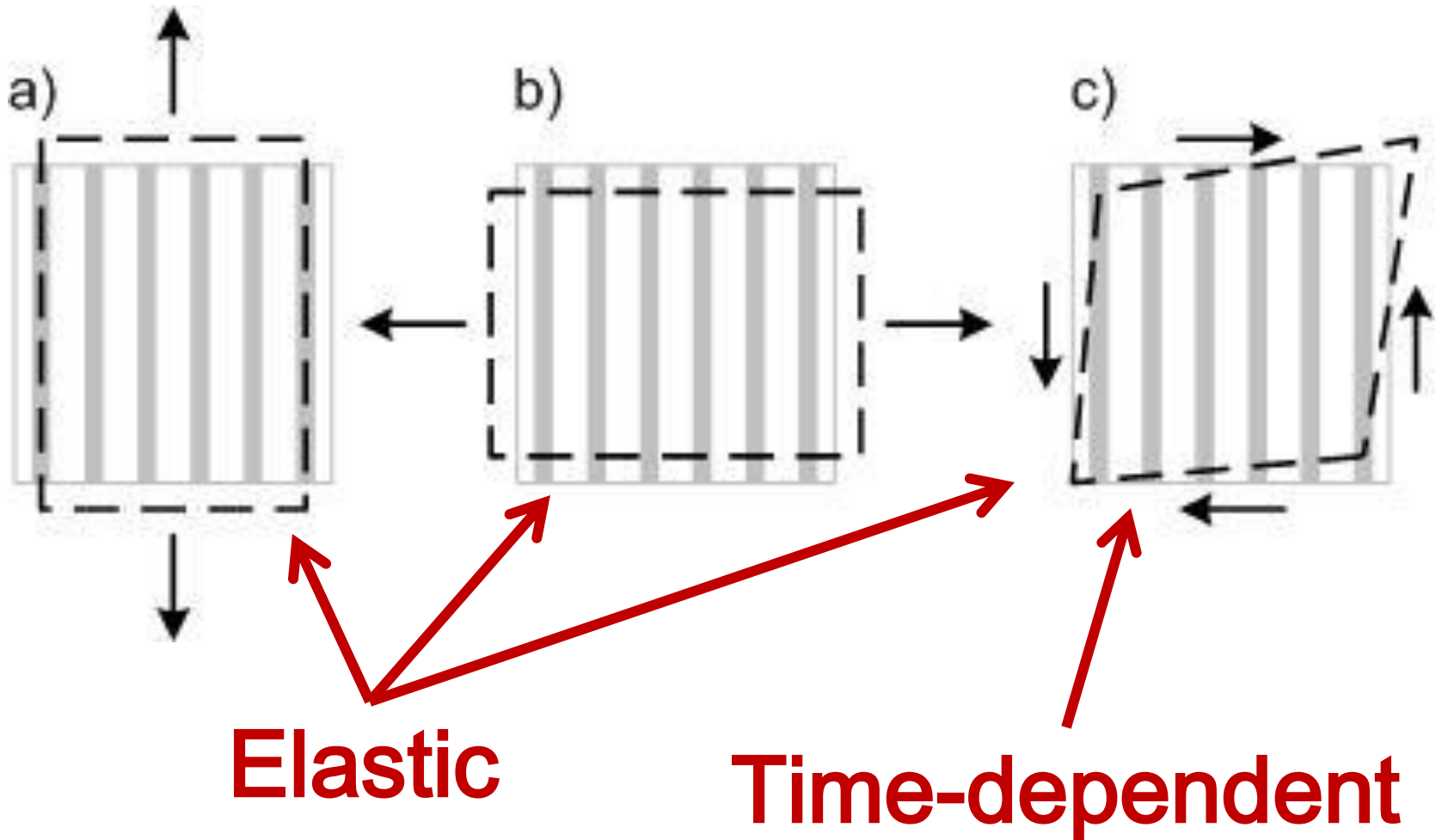
Lotfy et al. (1972)

Olsson & Salmén (2001)



sliding = shearing

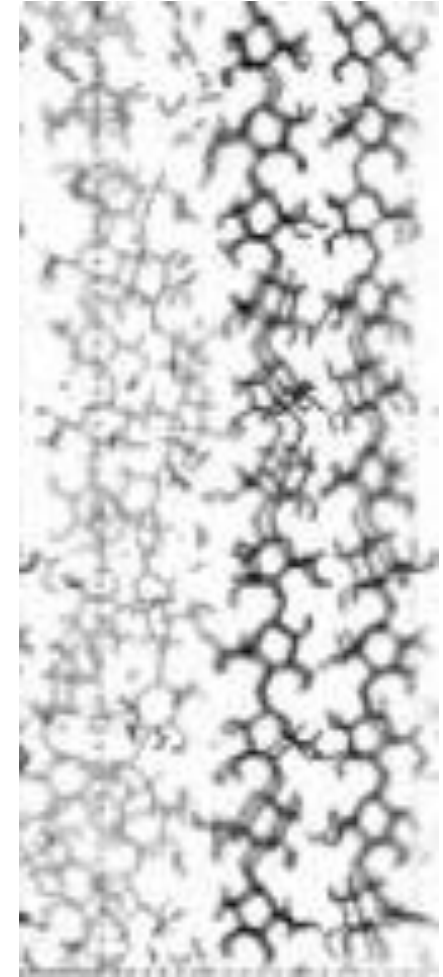
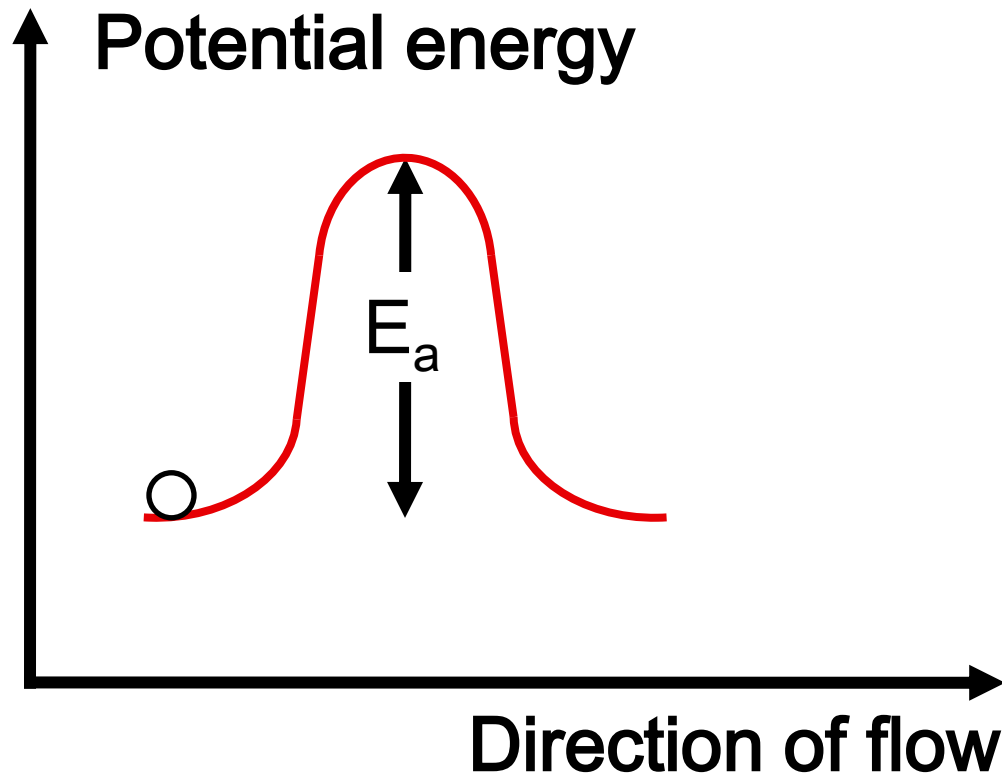
Local deformation modes



**What controls
the shearing**

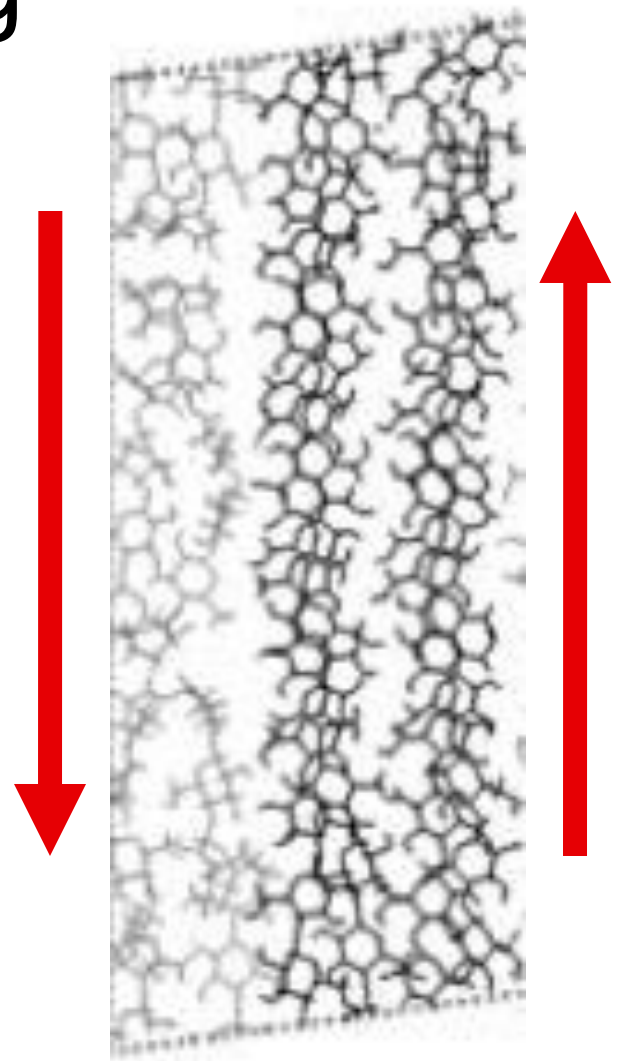
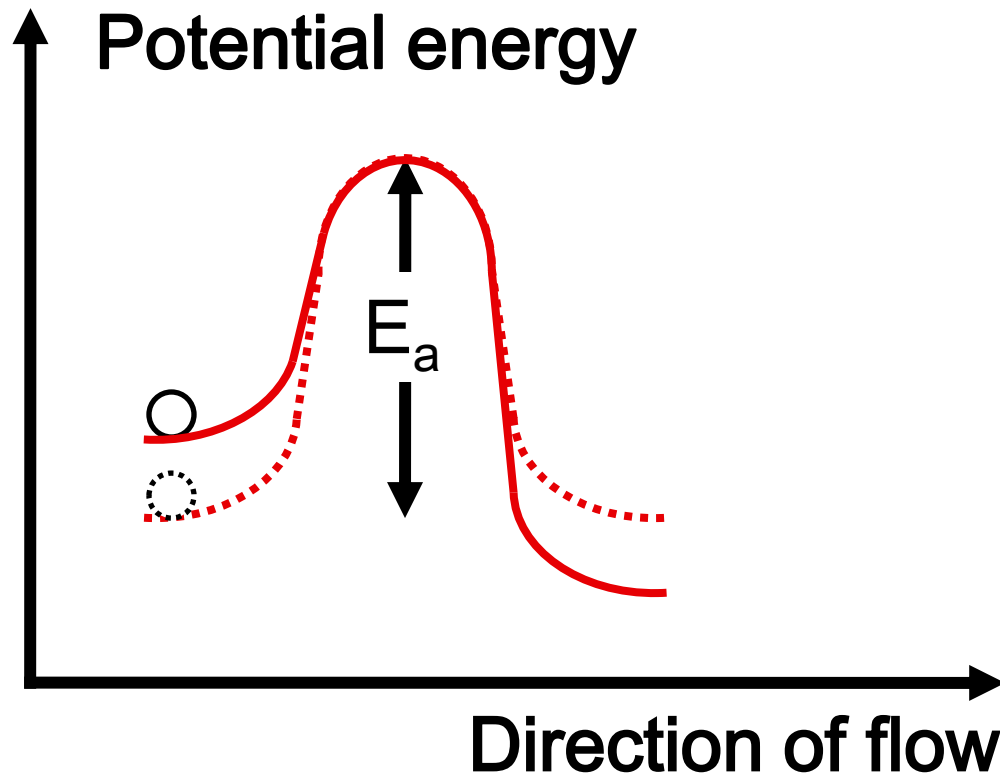


Breaking and re-forming of hydrogen bonds



Navi et al. (2002)

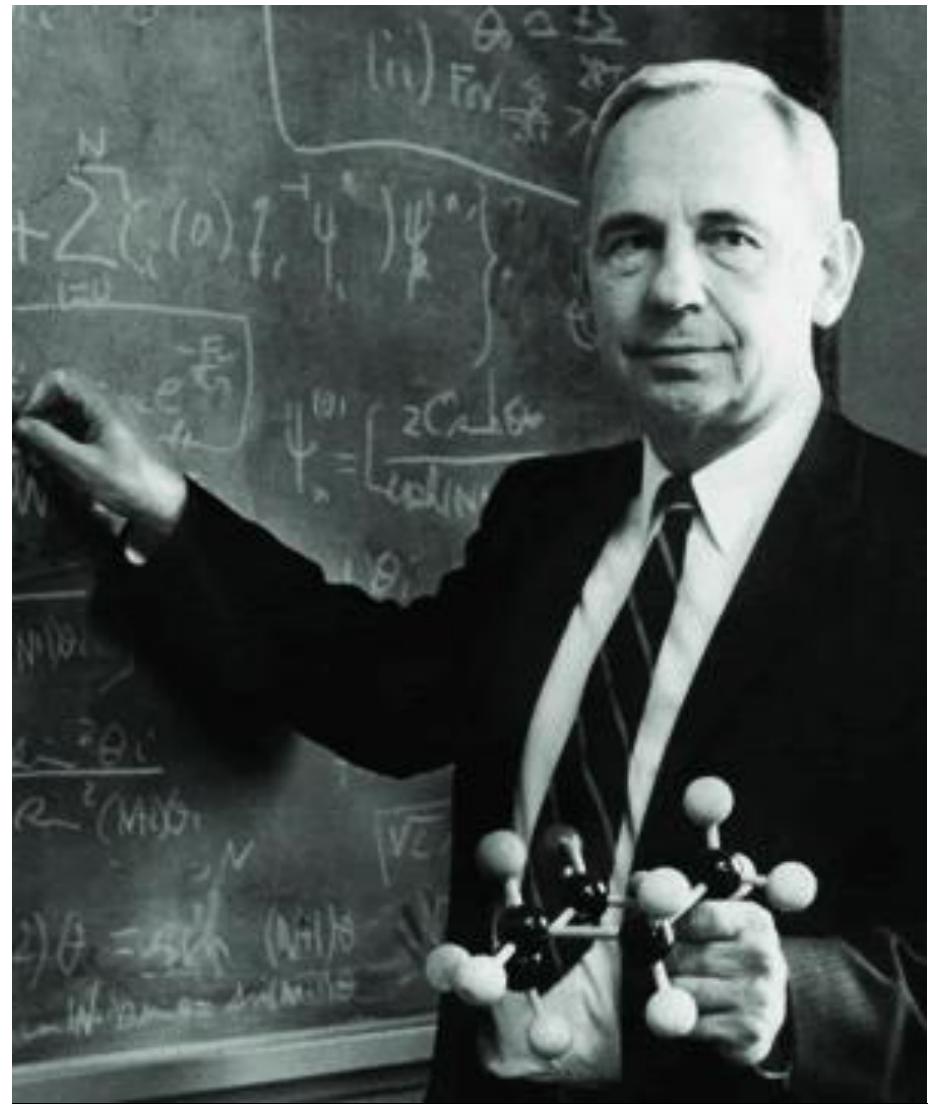
Breaking and re-forming of hydrogen bonds



Navi et al. (2002)

Deformation kinetics

$$\frac{d\varepsilon_v}{dt} = A \cdot 2\sinh(B\sigma)$$

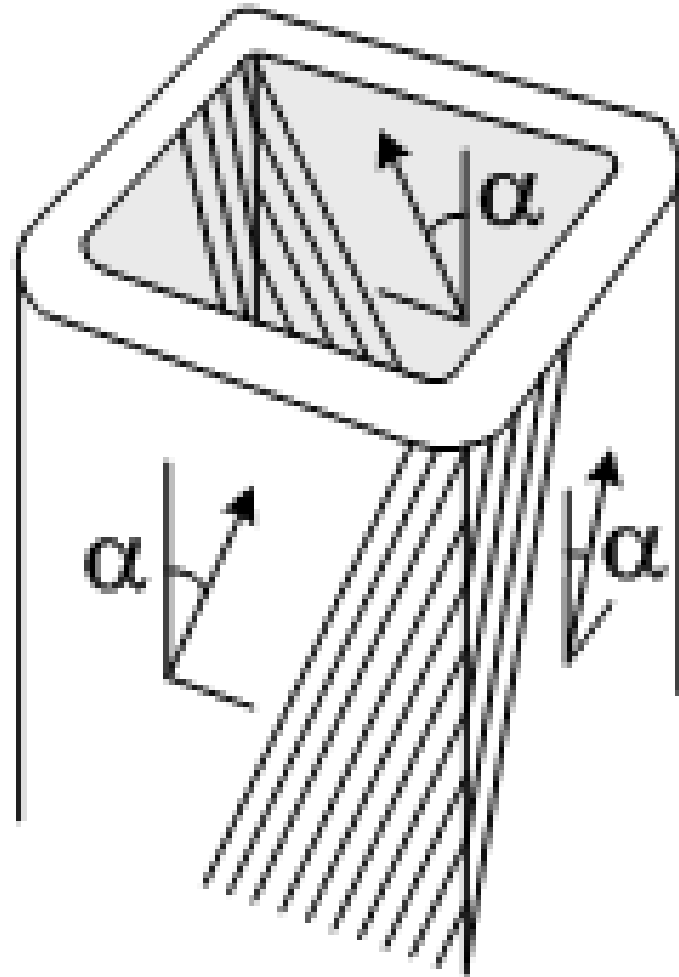


Prof. Henry Eyring
(1901-1981)

Putting the
pieces together

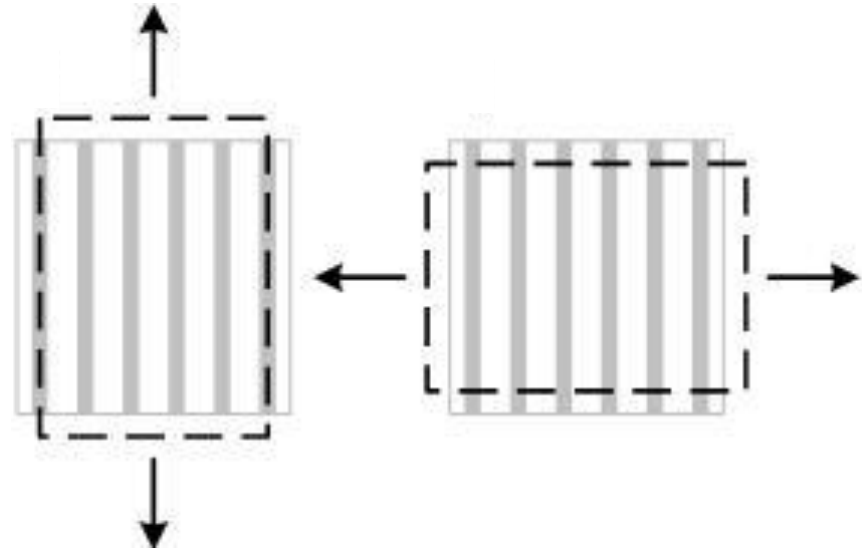
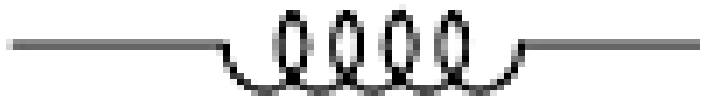


Model cell geometry and **local** coordinate system



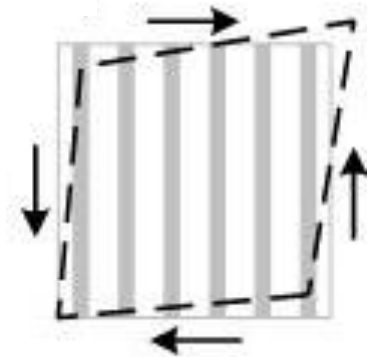
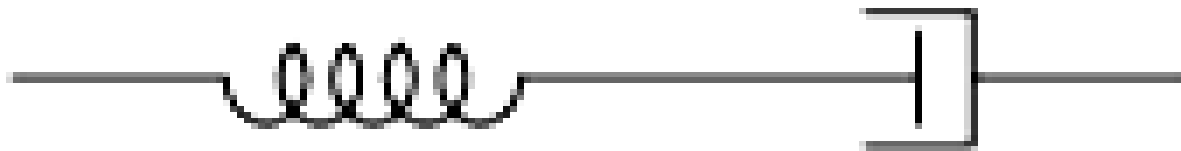
Local normal deformation modes

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

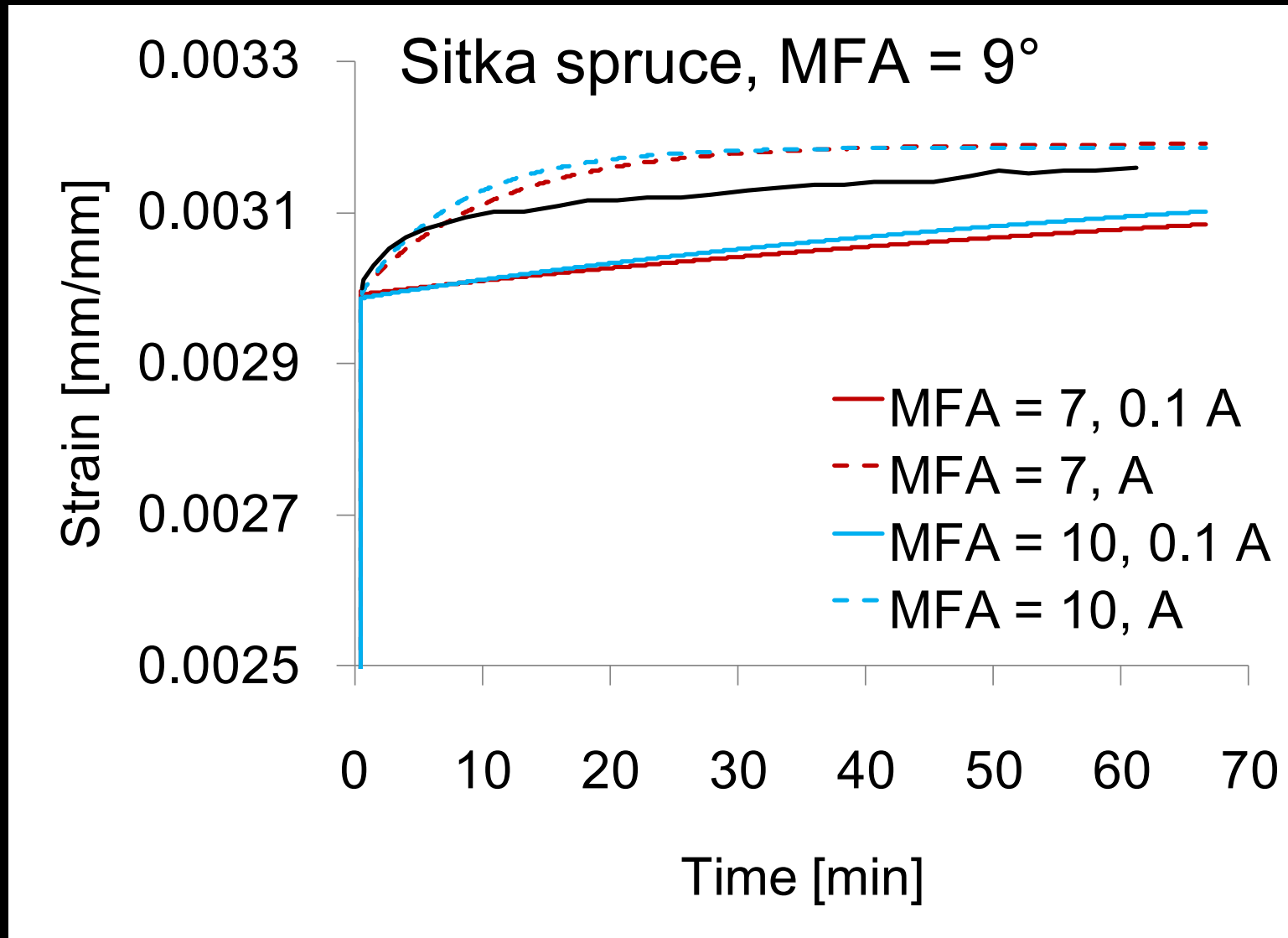


Local shearing modes

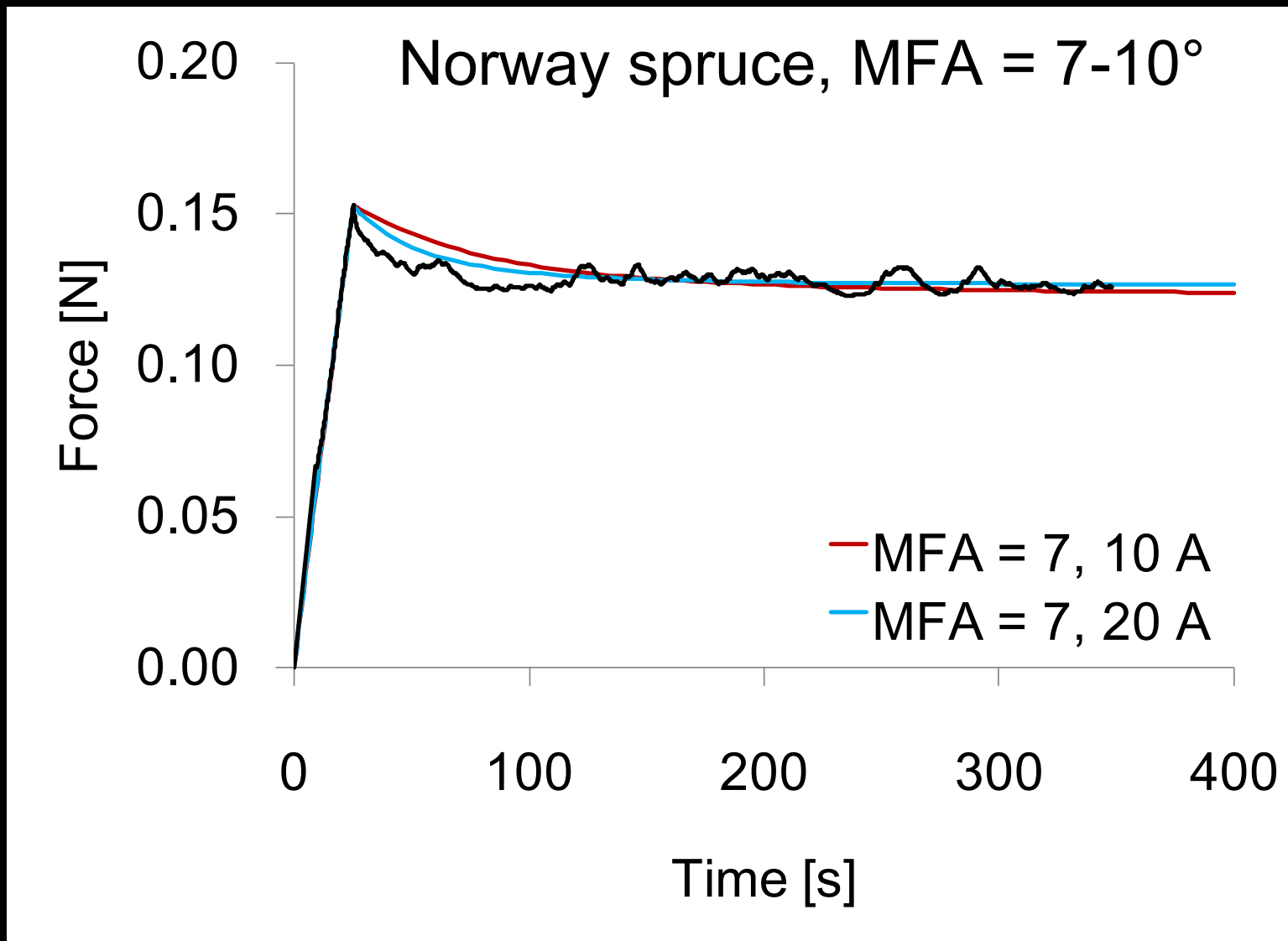
$$\frac{d\varepsilon}{dt} = \frac{1}{E} \frac{d\sigma}{dt} + A \cdot 2 \sinh(B\sigma)$$



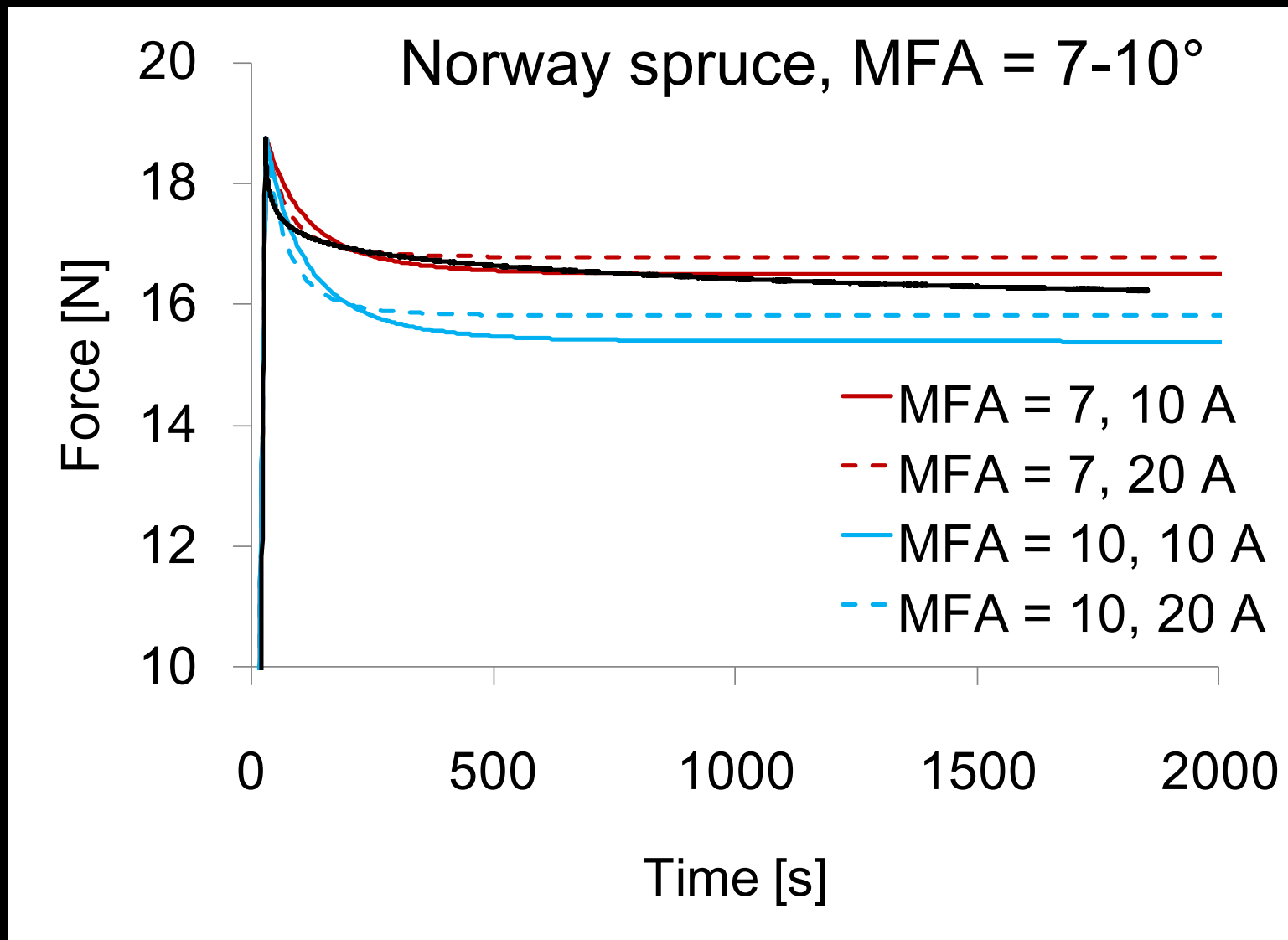
Creep of tissues



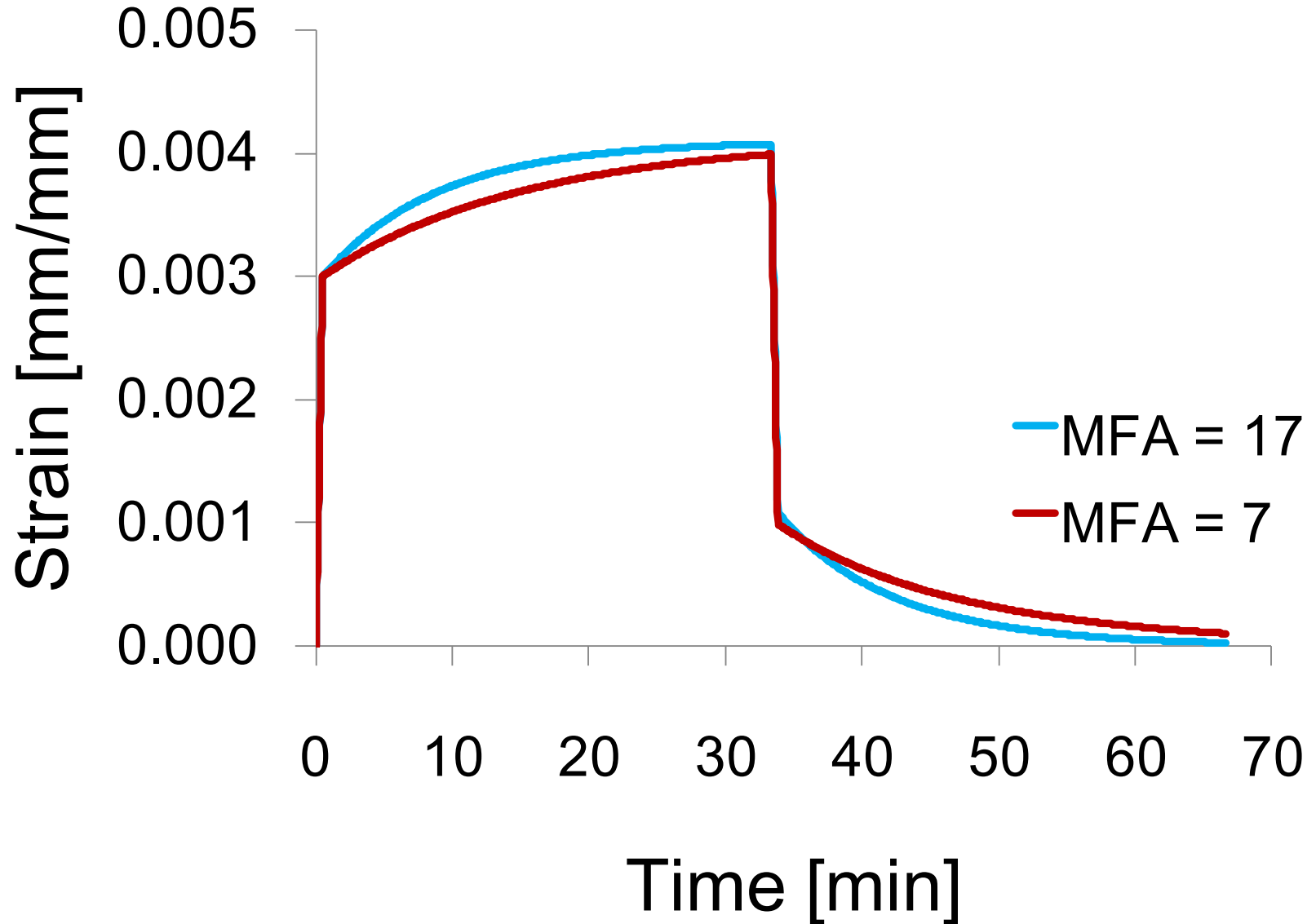
Relaxation of fibres



Relaxation of tissues



Macroscopic visco-elasticity



Conclusions

Physical realistic mechanism causing time-dependency was successfully incorporated in numerical model

Macroscopic apparent visco-elastic behaviour caused by microscopic elastic and viscous components

Thank you!
Any questions

