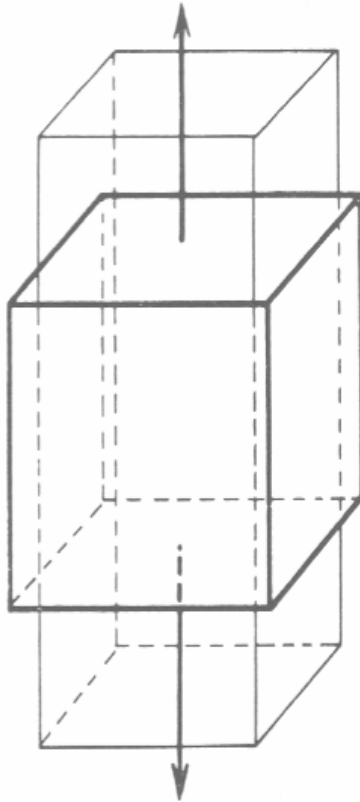


M4: Elastizität und Viskoelastizität

Hookesches Gesetz $\sigma = E\varepsilon$

Spannung $\frac{F}{A}$ Elastizitätsmodul „Young's modulus“ $\frac{d\sigma}{d\varepsilon}$ Dehnung $\frac{\Delta l}{l}$

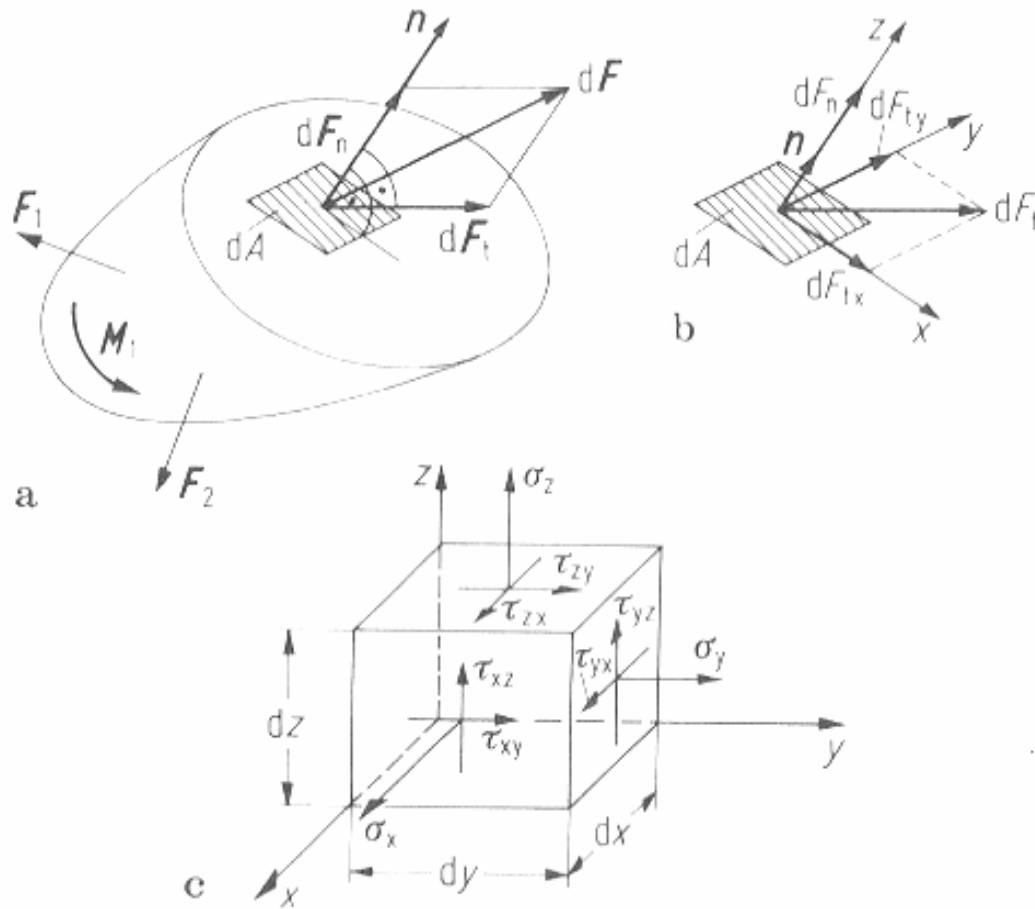
Querkontraktion



Poisson-Zahl

$$\mu = -\frac{\Delta d / d}{\Delta l / l}$$

Spannung und Dehnung allgemein: Tensoren (Matrizen)



$$\sigma = E\varepsilon$$

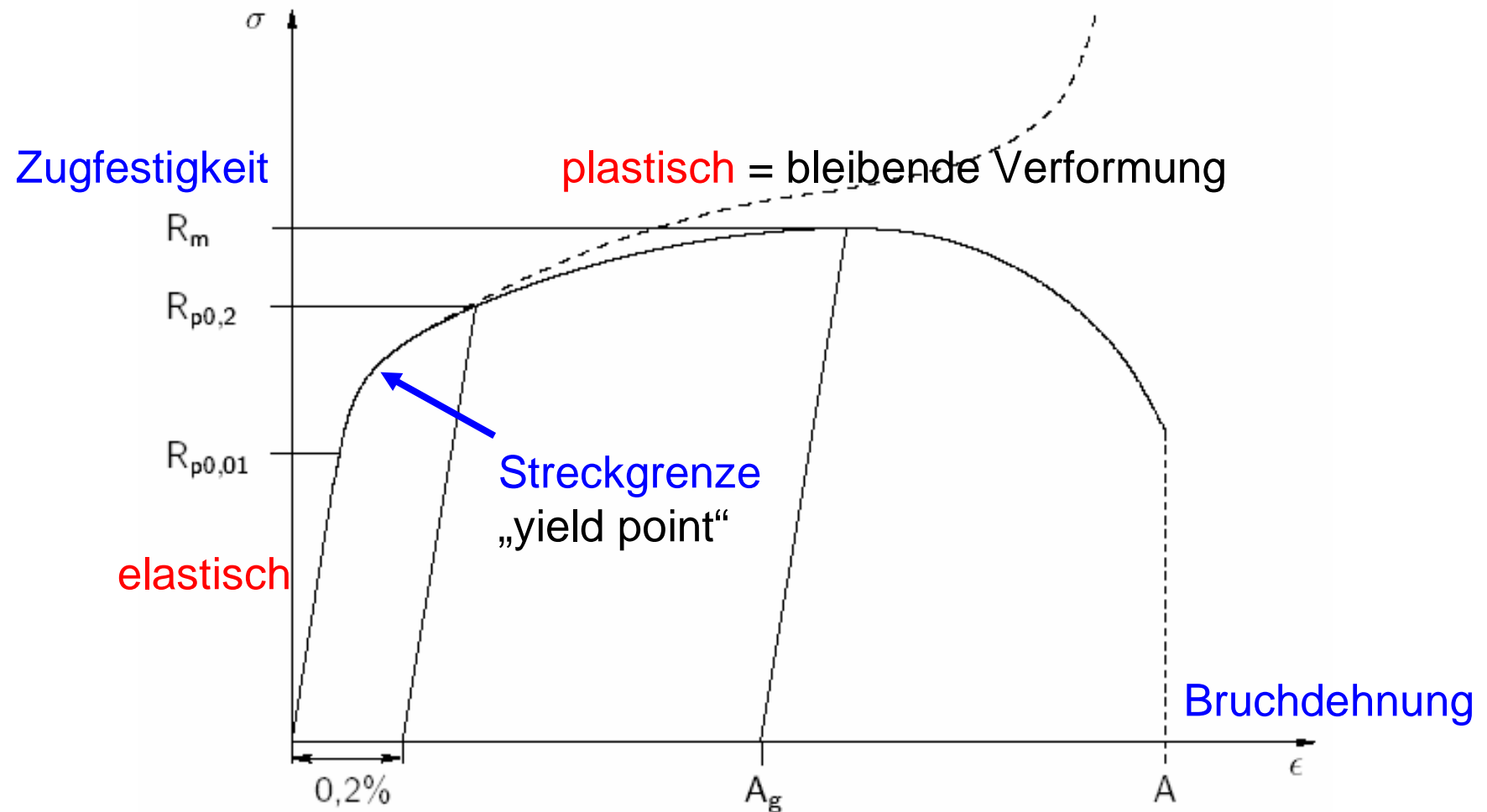
$$\tau = G\gamma$$

Scherspannung, -modul, -winkel

$$\begin{pmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{yz} \\ \gamma_{zx} \\ \gamma_{xy} \end{pmatrix} := \begin{pmatrix} s_{11} & s_{12} & s_{13} & s_{14} & s_{15} & s_{16} \\ s_{21} & s_{22} & s_{23} & s_{24} & s_{25} & s_{26} \\ s_{31} & s_{32} & s_{33} & s_{34} & s_{35} & s_{36} \\ s_{41} & s_{42} & s_{43} & s_{44} & s_{45} & s_{46} \\ s_{51} & s_{52} & s_{53} & s_{54} & s_{55} & s_{56} \\ s_{61} & s_{62} & s_{63} & s_{64} & s_{65} & s_{66} \end{pmatrix} \cdot \begin{pmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{yz} \\ \tau_{zx} \\ \tau_{xy} \end{pmatrix}$$

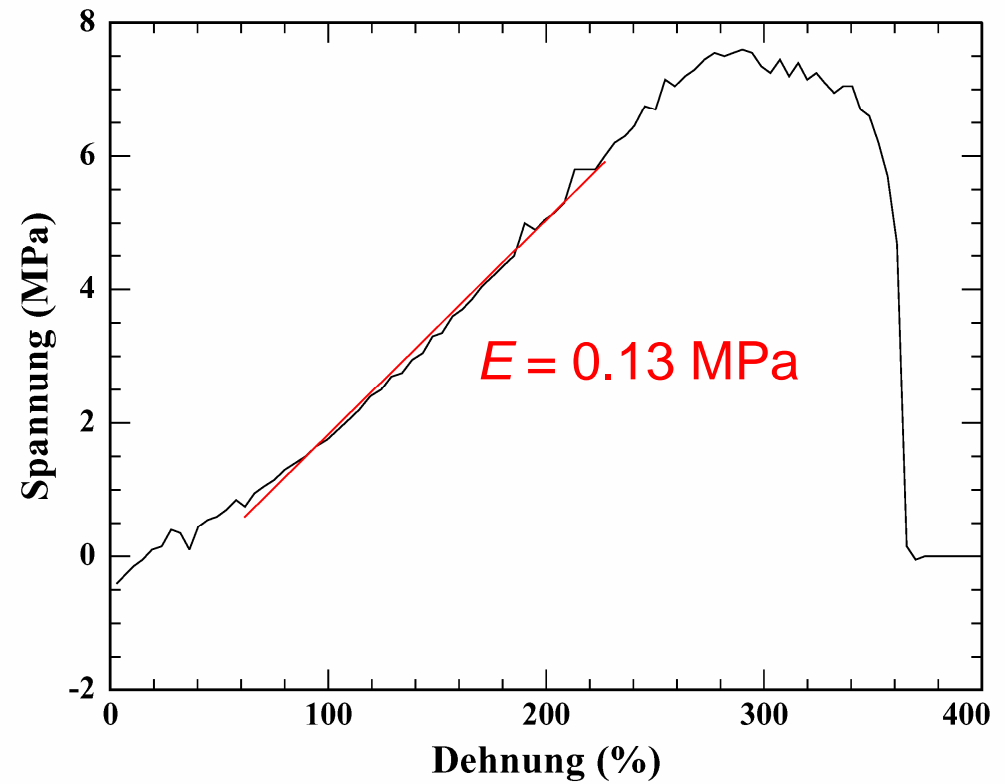
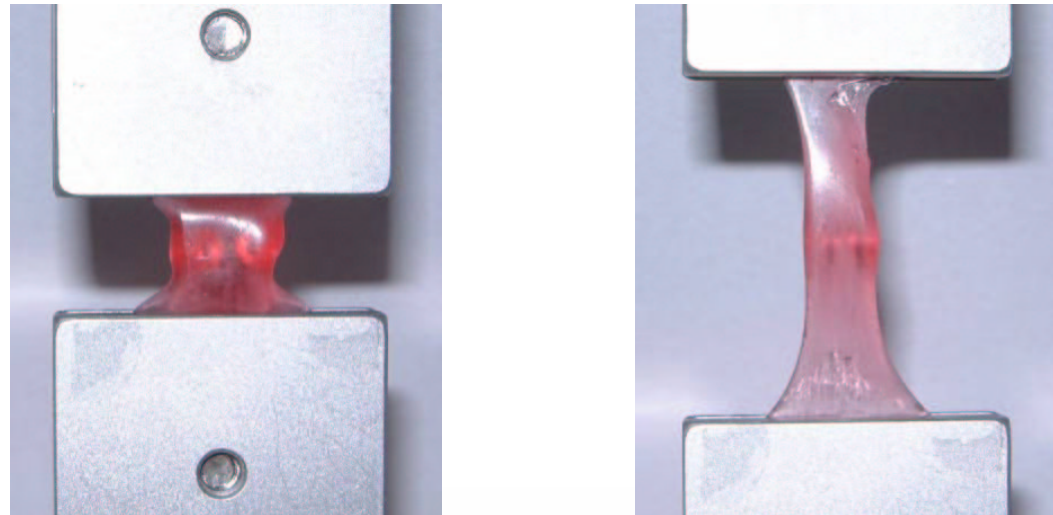
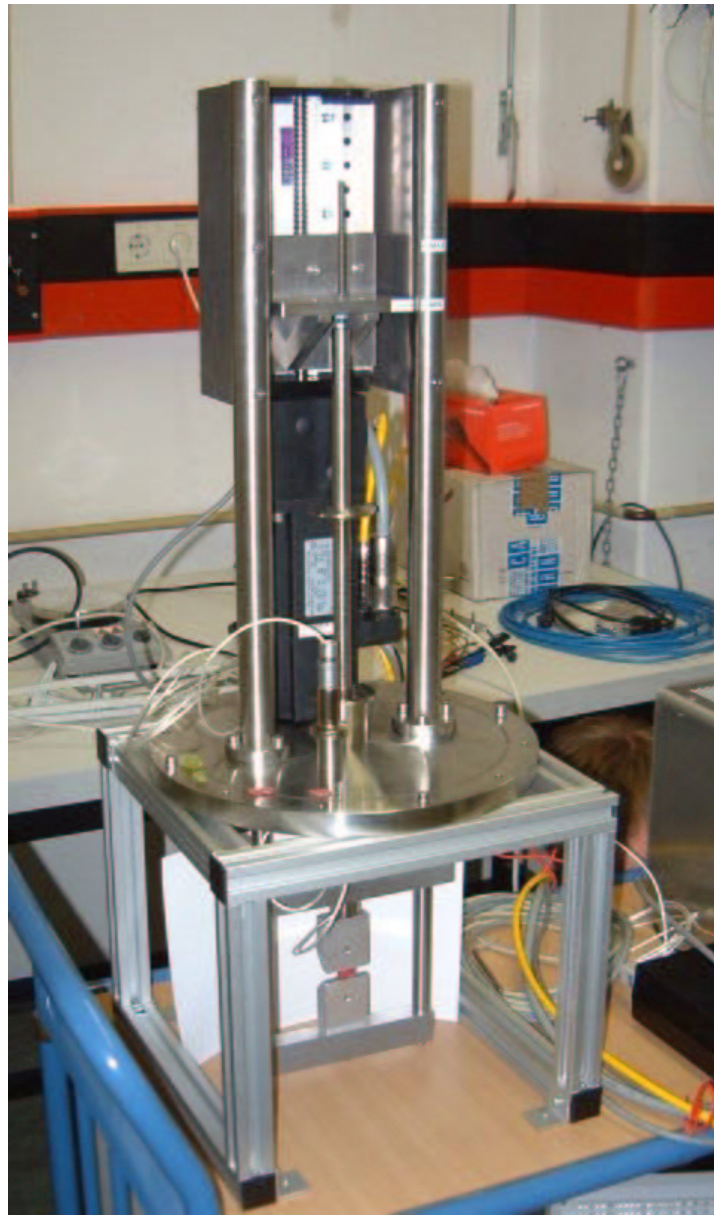
Dubbel,
Taschenbuch für den Maschinenbau

schematische Spannungs-Dehnungs-Kurve

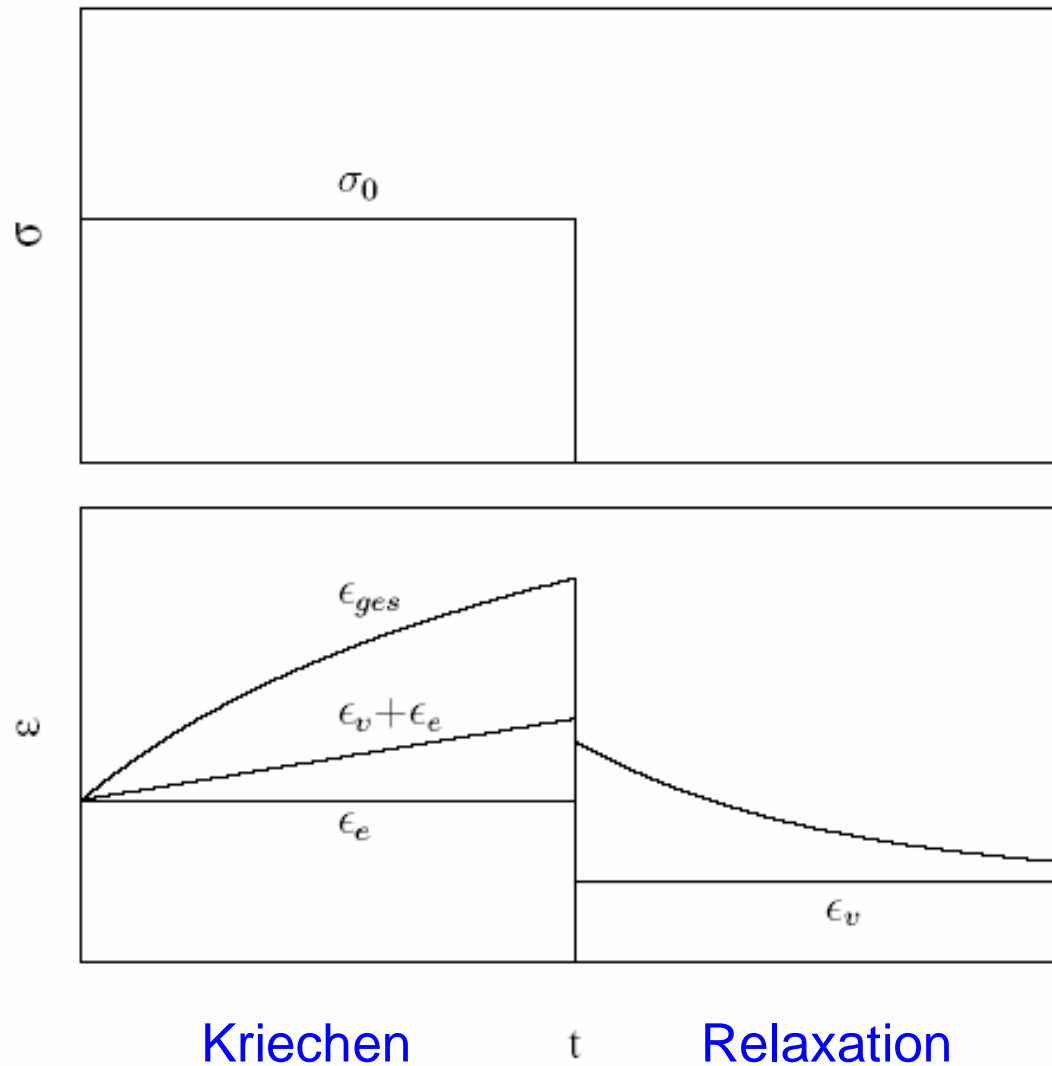


Bruchenergie:
$$W = \int F \, dl = \int \sigma A l \, d\epsilon = V \int \sigma \, d\epsilon$$

Mechanische Eigenschaften von Gummibärchen



Zeitabhängigkeit der Dehnung: **Viskoelastizität**



ϵ_e : **elastisch**

$$\epsilon_e(t) = \frac{\sigma}{E_e}$$

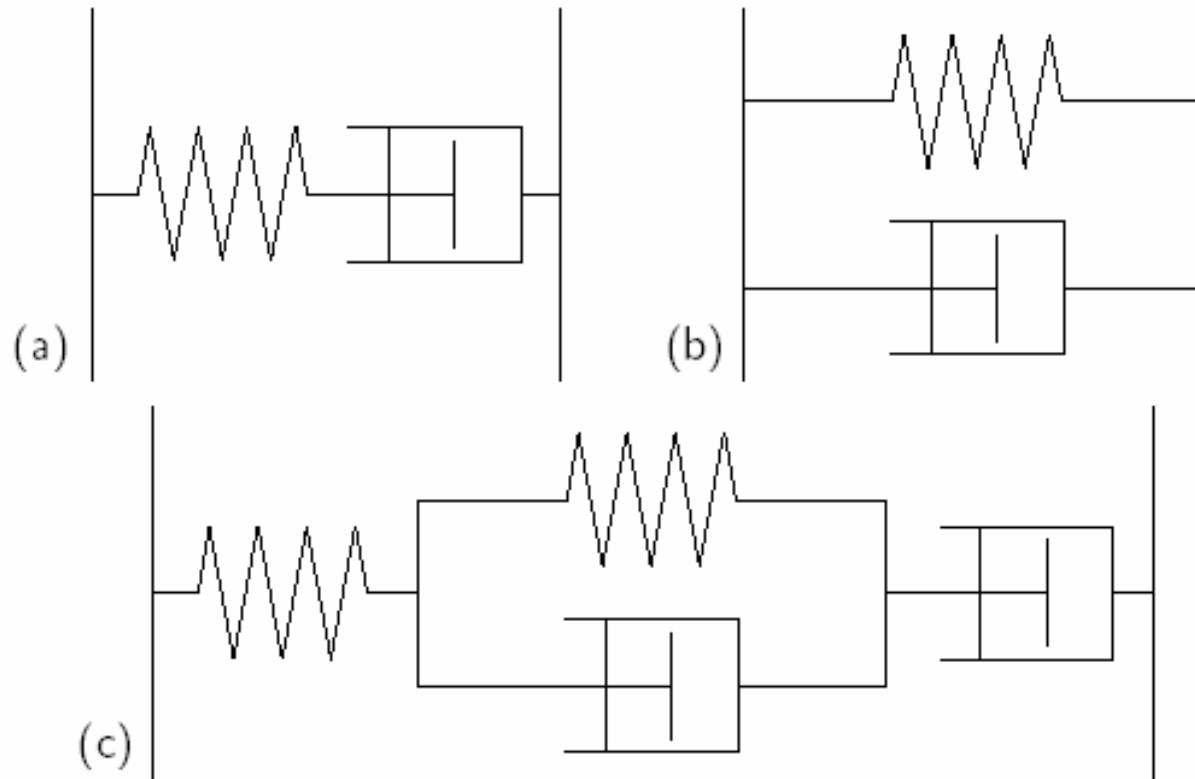
ϵ_v : **plastisch** (viskos)

$$\epsilon_v(t) = \frac{\sigma}{\eta} t$$

ϵ_r : **viskoelastisch** (relaxierend)

$$\epsilon_r(t) = \frac{\sigma}{E_r} (1 - e^{-t/\tau})$$

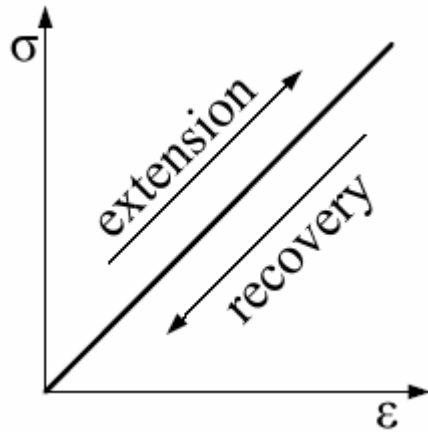
Modelle: Kombination von Federn (Hooke) und Dämpfern



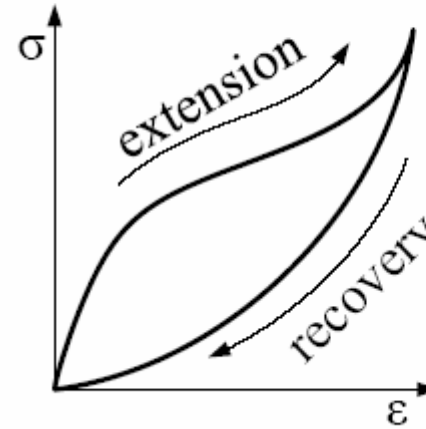
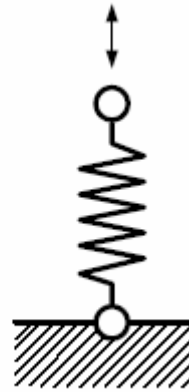
a) Maxwell-Modell: elastisch-plastisch

b) Voigt-Kelvin-Modell: viskoelastisch

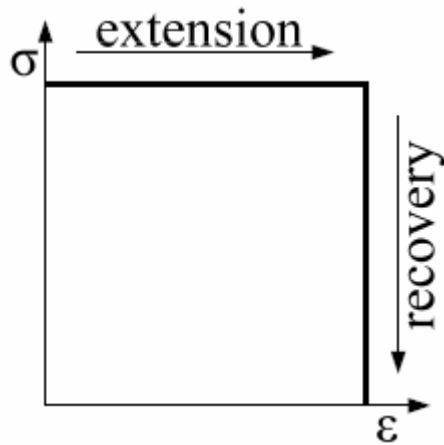
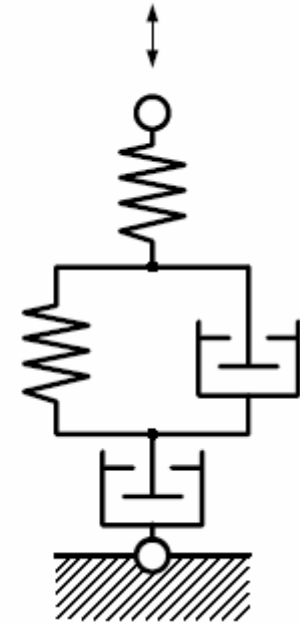
c) Burger-Modell: allgemeiner Fall



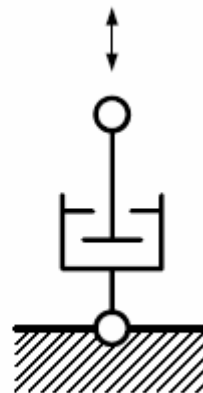
ideal elastisch



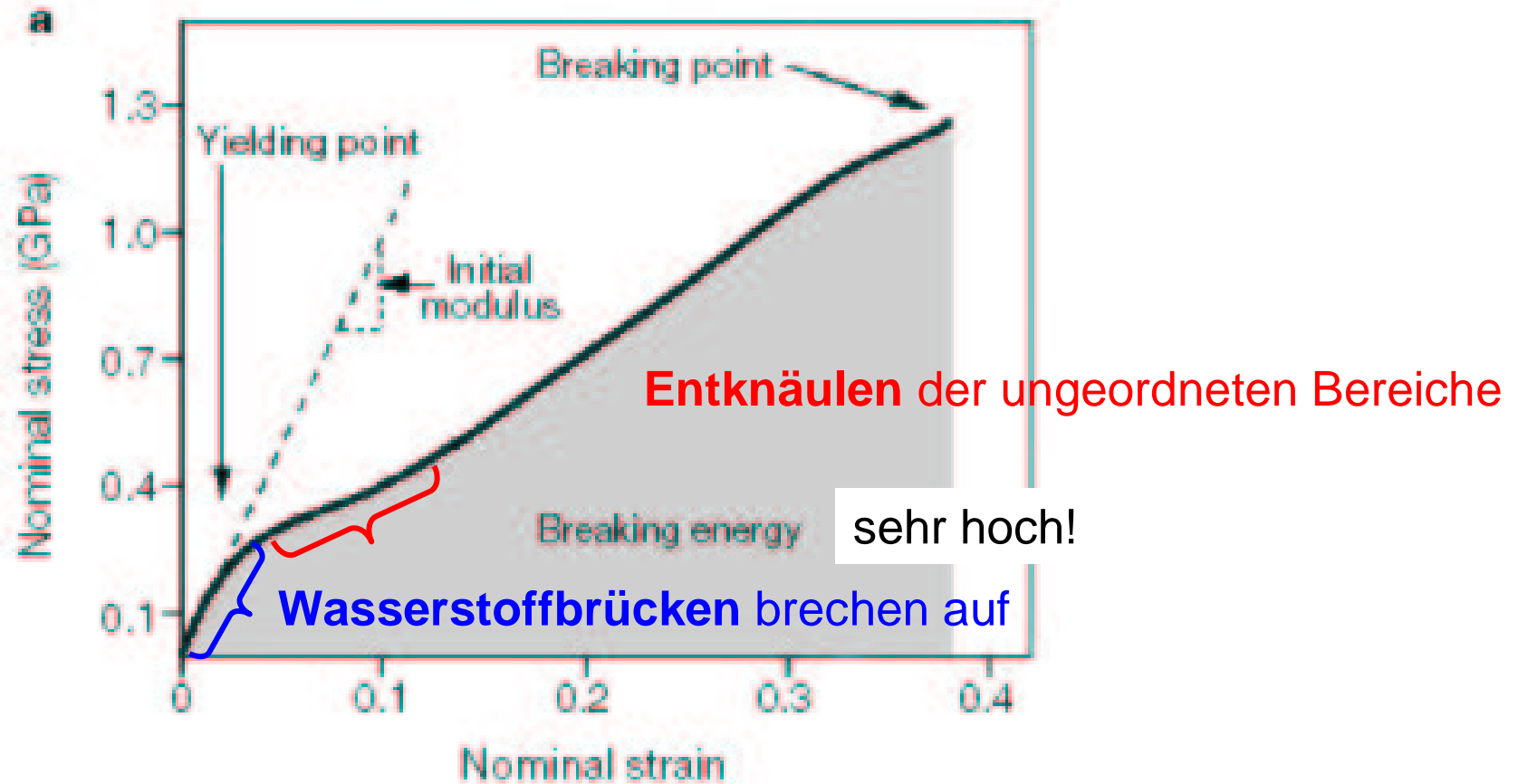
ideal linear viskoelastisch



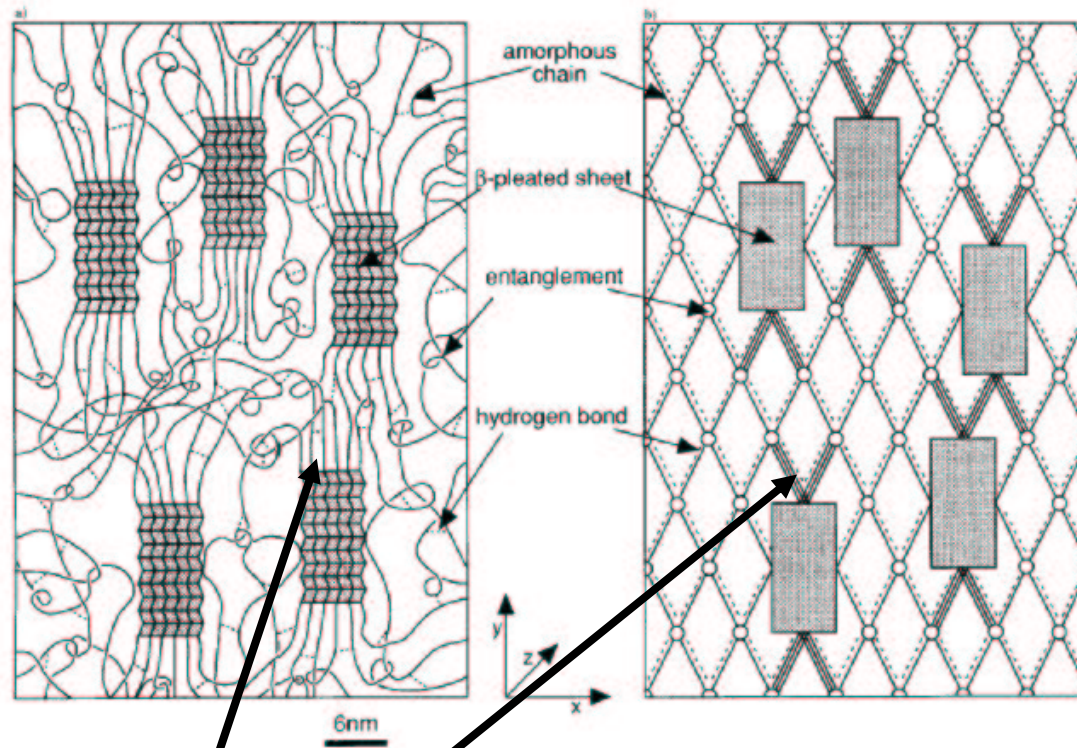
Flüssigkeit: komplette plastische Verformung



Mikroskopische Erklärung des Spannungs-Dehnungs-Diagramms von Spinnenseide



Neuestes Morphologie-Modell für Spinnenseide

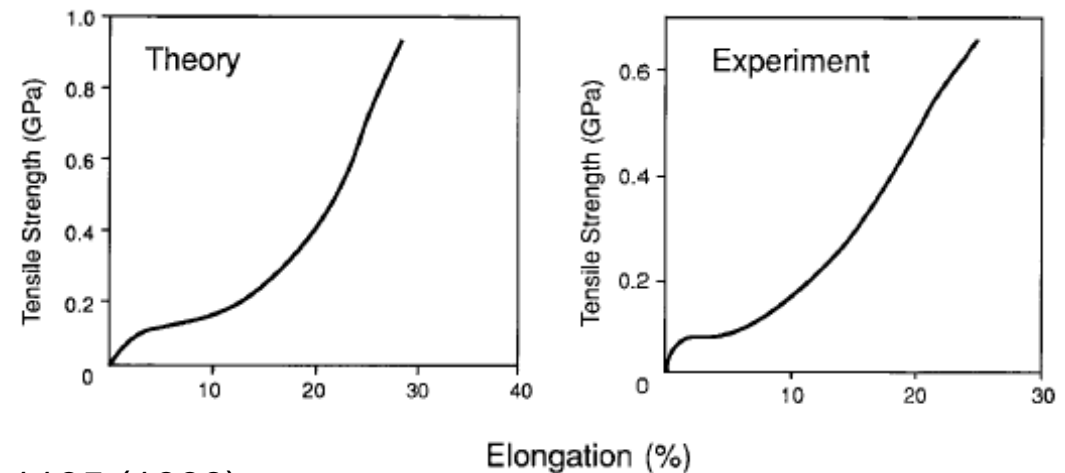


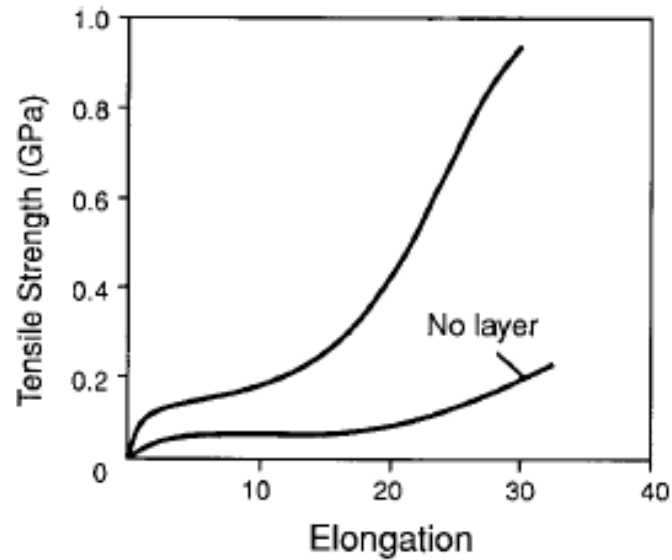
Schicht:
„orientiert amorph“

Elastizitätsmoduli:

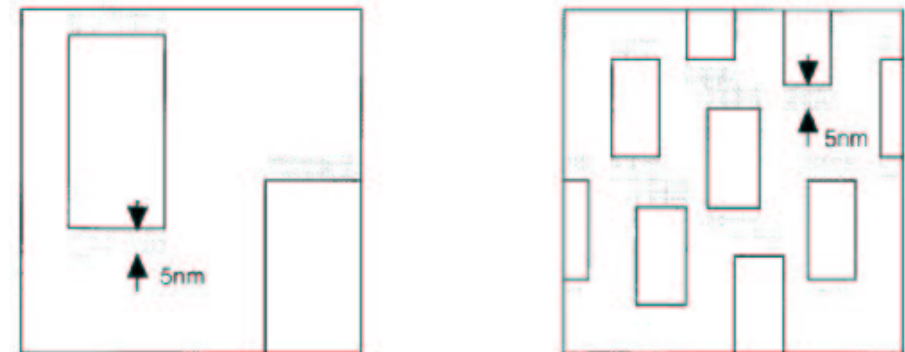
- Kristalle 160 GPa
- H-Brücken 4 GPa
- Schicht 24 GPa

Spannungs- Dehnungs-Diagramme

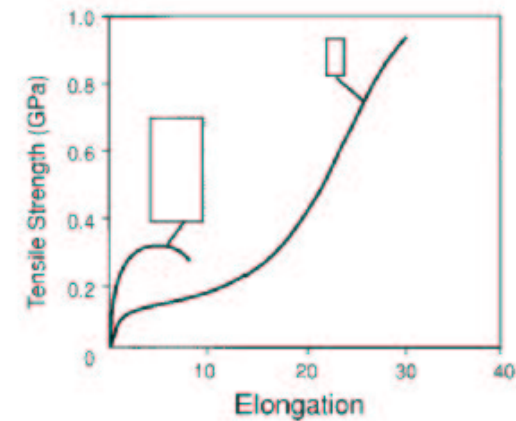




Verstärkungswirkung der Schicht



Abhängigkeit der mechanischen
Eigenschaften vom
Größenverhältnis Schicht / Kristall



Mechanische Eigenschaften künstlicher Spinnseide

Table 1. Comparison of the mechanical properties of rc-spider silk fibers with those of native silk. M, 75% methanol; W, water; NA, not applicable.

Sample	Draw	Draw ratio	Toughness (gpd)	Modulus (gpd)	% Strain break	Tenacity (gpd)	<i>n</i>
ADF-3, sample 1	M/W	5	0.895	42.8	59.6	1.91	7
ADF-3, sample-2	M/W	5	0.850	110.6	43.4	2.26	7
ADF-3, sample-3	M	4	0.645	63.2	45.0	1.8	5
<i>Araneus</i> , dragline	NA	NA	0.6–1.3	38–76	19–30	7–11	20

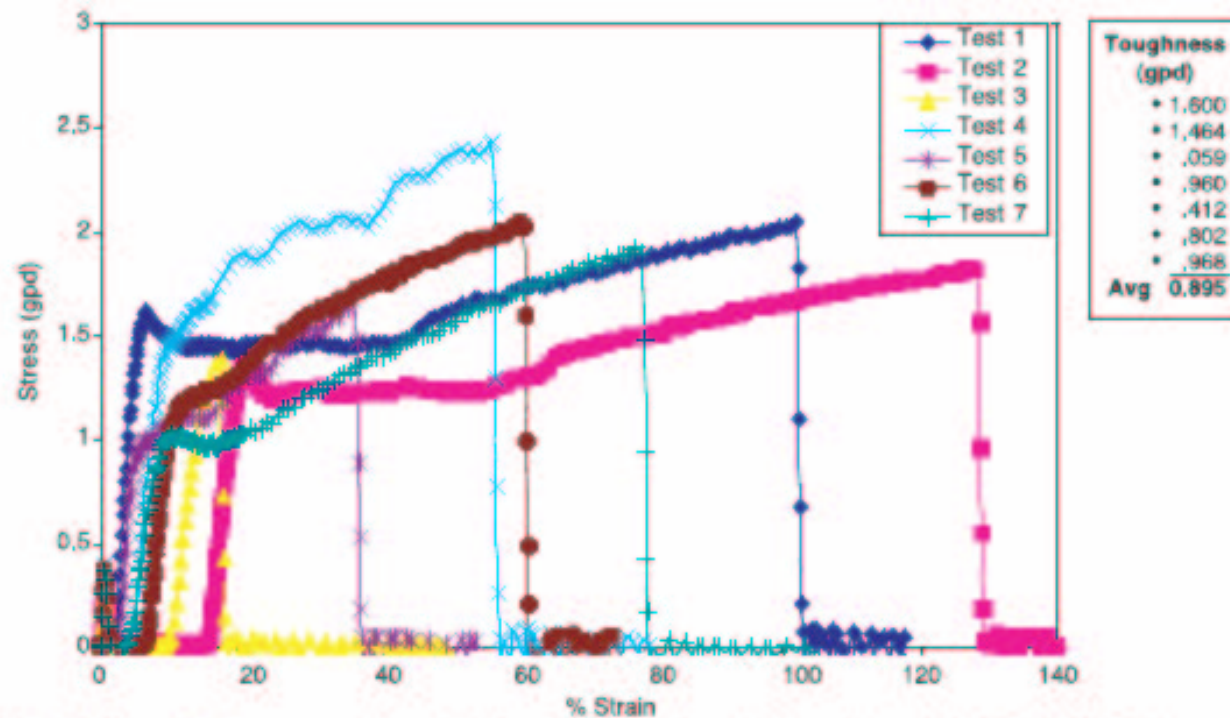
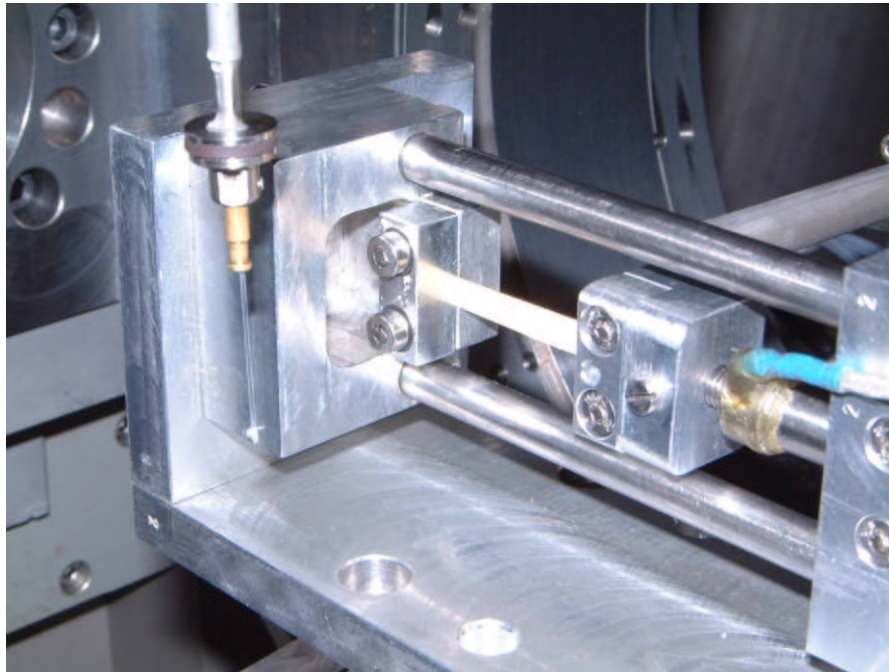


Fig. 5. Stress-strain curves from testing of ADF-3-based fibers (sample 1, Table 1). The curves represent analysis performed on seven different fiber fragments, each 1/2 inch in length.

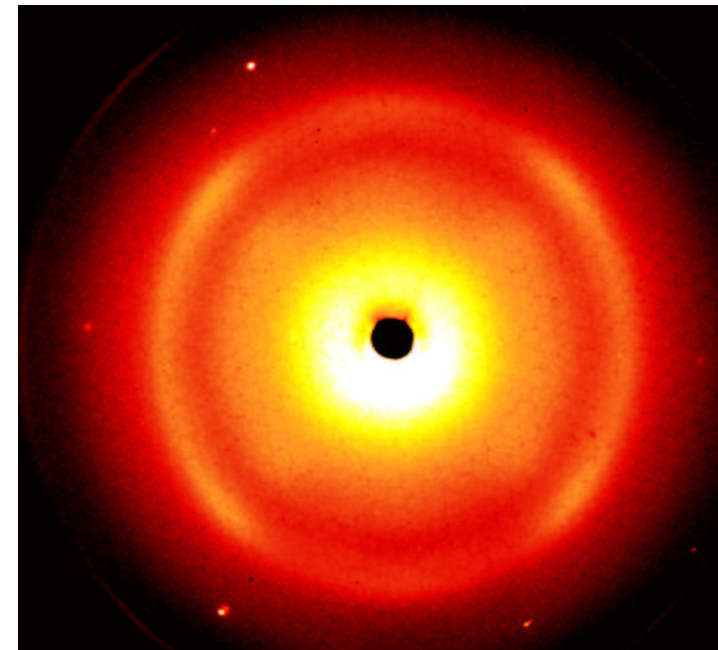
2.1.5 Mechanische Eigenschaften von Holz



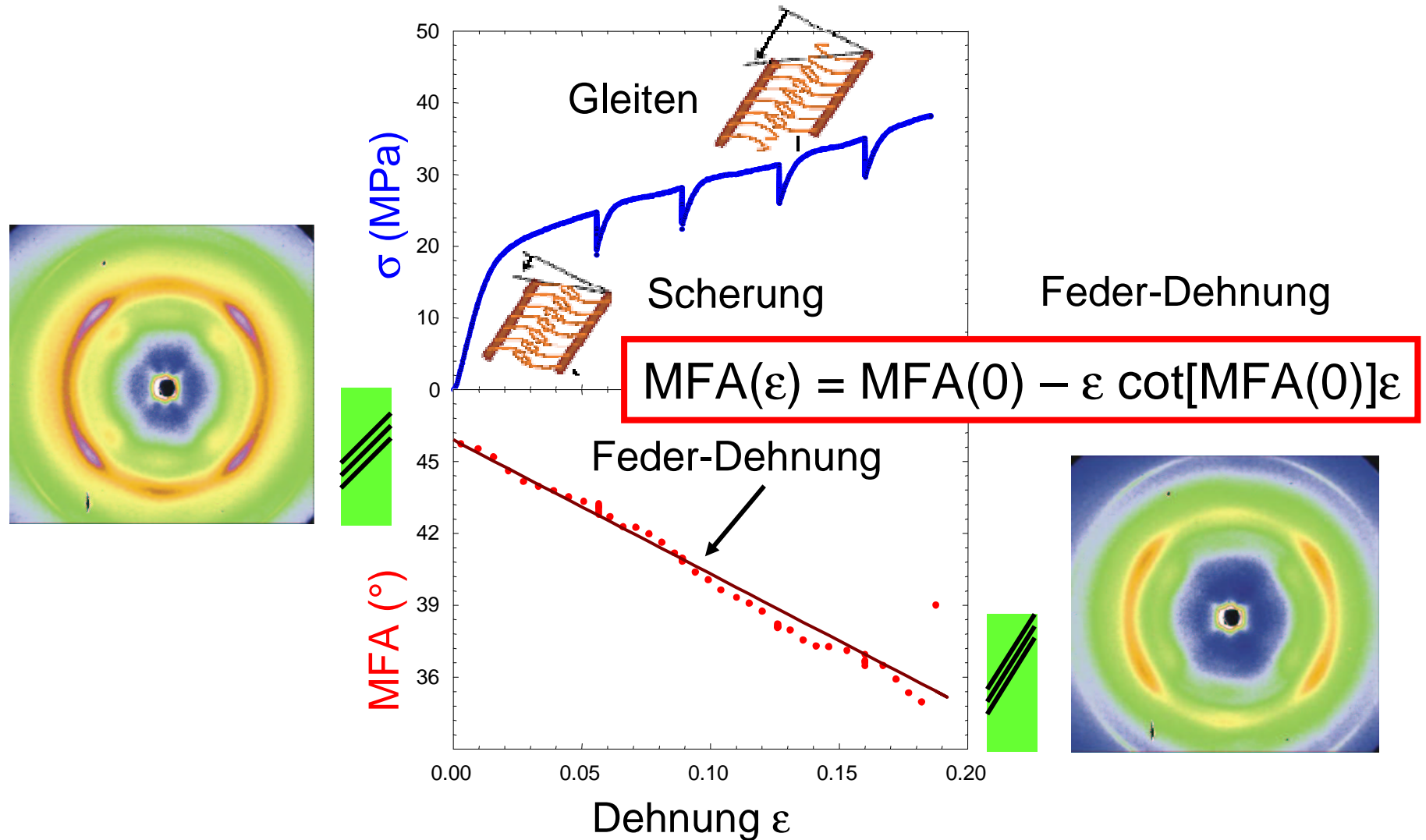
Experimente an Druckholz
(MFA = 46°)



MFA wird unter Zug kleiner!



Mikroskopischer Klettverschluss in Holz?





J. Keckes, I. Burgert, K. Frühmann, M. Müller, K. Kölln, M. Hamilton,
 M. Burghammer, S. V. Roth, S. Stanzl-Tschegg, P. Fratzl.
Nature Mater. **2**, 810-814 (2003)

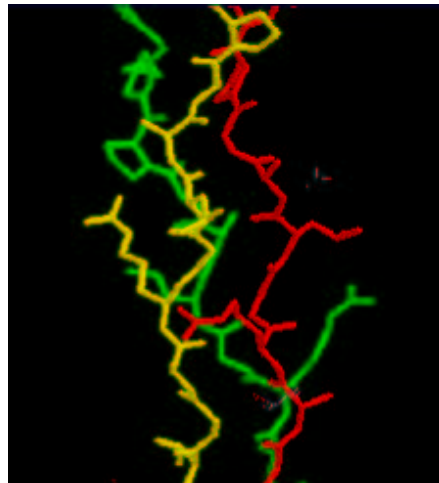
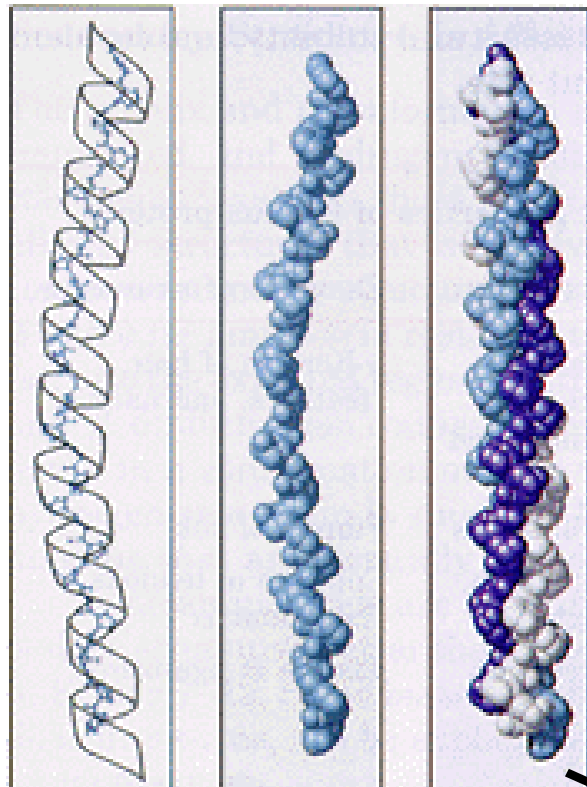
2.4 Collagen

- **häufigstes Protein** im menschlichen Körper:
Bindegewebe, Haut, Sehnen, Knochen ...
- Synthese in **Fibroblasten**: Sekretion, Modifikation, Selbstorganisation

2.4.1 Struktur von Collagen

- wie üblich **hierarchisch**... 
- **Polypeptide**: regelmäßig jede 3. Aminosäure Glycin
Sequenz: Gly-Xaa-Yaa-Gly-Xaa-... (oft Prolin und Lysin) 
- 3 Polypeptide formen gemeinsame α -Helix: **Tropocollagen**
- Tropocollagen: 1.38 nm im Durchmesser, 300 nm lang
- intra- und intermolekulare Bindungen zur Stabilisierung

Struktur von Sehnen / Collagen



Stapelung von Tropocollagen:
 Periode von **64 nm (trocken)**
 bzw. **68 nm (naß)** aus
 Röntgenstreuung

