

Rubber Elasticity

Goal

Understanding of the rubber elastic properties of slightly cross-linked polymers
(temperature dependence, entropy elasticity, theoretical bases, modulus of elasticity)

Task definitions

1. Measurement of stress-strain values for a cross-linked and fumed silica (SiO_2) filled silicon rubber (PDMS) at 30, 50, 70 and 90 °C
2. Graph and analysis of the values
3. Answering of supplementary questions

Add a table of relevant values for each task!

Experimental Setup

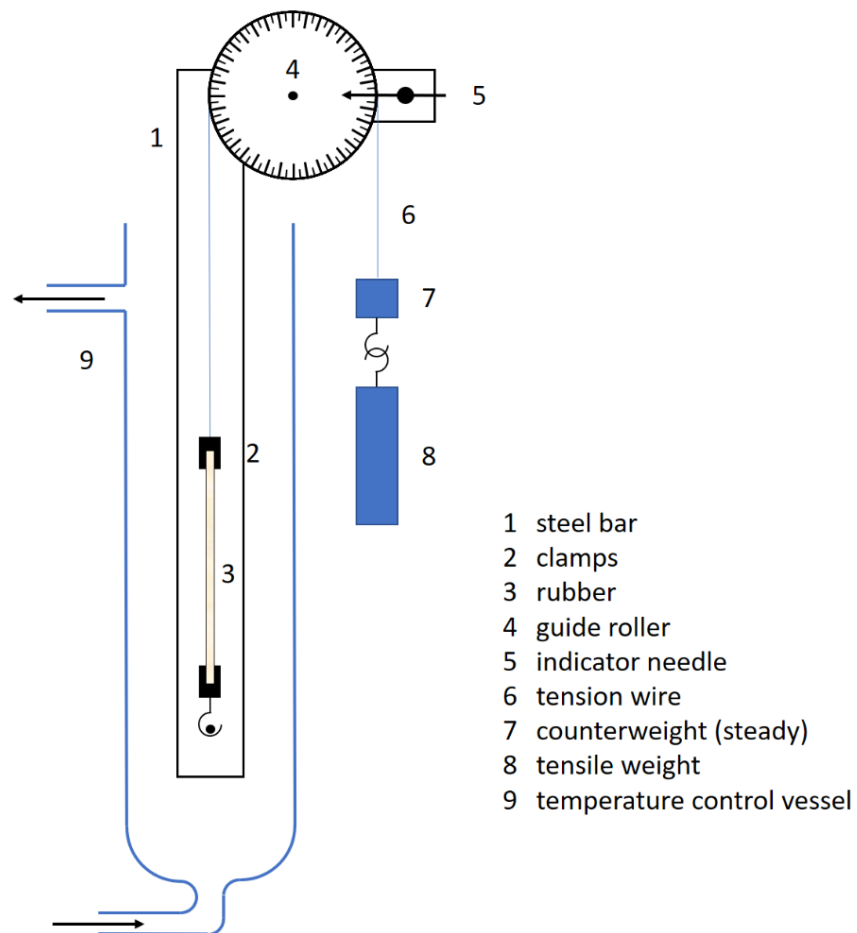


Figure 1: Illustration of the experimental setup

The device consists of a steel bar (1), which has an iron pin on the lower end. The iron pin fixes one side of the sample (3). On the upper end of the iron bar there is a scaled guide roller (4). The rubber sample (3) is stuck between two bolted clamps (2). The upper clamp is connected to a thin Cr-Ni-wire ($d = 0.2 \text{ mm}$), which is led over the guide roller (4) and has a counterweight (7) to counter the weight of the small clamps (2). The main part dives in water to fix the temperature of the setup. The water temperature is constant, due to the constant waterflow and the temperature control system.

Recording of the measured data

A weight set of brass cylinders will be used to gain exactly known forces. The required weights will be attached on the hook. The combinations from weight number "1" to "6" give the 15 different forces between 0.286 and 7.342 N. Every new rubber sample should be stretched 15 min with the maximum force.

The first measuring cycle will be recorded at 30 °C. After 5 min of relaxing time at 30 °C the guide roller will be set up to position zero. During one measuring cycle the force will increase in 15 steps until 7.342 N and every new expansion Δl will be recorded at the graduated scale after 45 seconds. This couple of data will gain the upward curve of the force-expansion-diagram. Afterwards, the rubber sample will be relaxed in the same 15 steps until 0 N and Δl will be recorded after the same waiting time of 45 seconds. These are the data for the downward curve.

It is important to observe that the scaled guide roller never slips during the changing of two different weights. That would destroy one whole cycle of measuring. The easiest way to prevent the slipping is to hold the clamps during the weight changing and let the weight slowly down afterwards. The rubber will change its length easier if the student softly knocks on the glass.

The data for the other temperatures (50 °C, 70 °C, 90 °C) will be recorded in the same way. It is important to wait 10 minutes after changing the temperature before the next cycle can be started.

Graphical representation and evaluation

Graphical representation of the whole measuring cycles for 30 and 90 °C. Represent the **nominal stress** σ_N (in N/mm^2) as a function of the extension ratio λ .

- 1) Graphical representation of the "downward" curves of 30, 50, 70 und 90 °C with σ (in N/mm^2) as a function of $(\lambda - \frac{1}{\lambda^2})$. Are your graphical results equal to the theory?

- 2) Determine the molar mass and the degree of polymerization by using your results in the scope of the Neo-Hooke's rule. You must determine an **average** for the molar mass and degree of polymerization, because you have only a few datasets in the necessary scope (normally 3 to 4 points). Necessary information:

$$\langle T \rangle = 333 \text{ K}, \langle \rho_{(333\text{K})} \rangle = 1467.1 \text{ kg/m}^3, R = 8.3144 \text{ J}\cdot\text{K}^{-1}\cdot\text{Mol}^{-1}$$

structural unit of the network: $-\text{O-Si}(\text{CH}_3)_2-$

- 3) Make a lookup table for the stress σ against \mathbf{T} for $l = 1.25, 1.50, 1.75$ and 2.0 (take the values directly from the downward curve) and plot the results in four curves with their fitted regression functions in one diagram. Calculate the share of internal intramolecular energy from the temperature coefficient of the stress.

$$\frac{f_U}{f} = \frac{\sigma_U}{\sigma} = 1 - \frac{\langle T \rangle}{\langle \sigma \rangle} \cdot \left(\frac{\Delta \sigma}{\Delta T} \right)_{P,\lambda} + \frac{\beta \langle T \rangle}{3}$$

$\langle T \rangle = 333 \text{ K}$, $\langle \sigma \rangle =$ average of σ on a constant λ for all temperature values

$\beta = 9.16 \cdot 10^{-4} \cdot \text{K}^{-1}$ (coefficient of thermal expansion for PDMS)

Now make a comparison with the entropy-elastic contribution: $\frac{f_s}{f} = 1 - \frac{f_U}{f}$.

- 4) Choose one of the downward curves ($50 \text{ }^\circ\text{C}$ or $70 \text{ }^\circ\text{C}$). Draw your curve together with the two theoretical curves for the Neo-Hooke's rule and the empirical calculated curve from Mooney-Rivlin in one diagram (**nominal stress** σ_N against the expansion λ) [Determine the parameters either by a general fit or by a respectively suitable linearized application. You must follow the range of validity for filled elastomers on each path]. Compare the resulting initial **Young's modulus** E_0 with the value of other materials.

Additional questions about the characteristics of single chains

- a) What are the most important conditions for entropy-driven elasticity, which also a single chain must follow? Why do elastomers show an energy-elastic behaviour below the glass temperature? Which condition mainly results in major deviations from the theory?
- b) What does the energy-elastic driven force stand for, which also applies to low forces? Which sign does this contribution of the force have?

Additional questions about the elastic network

- c) Why does the **Young's modulus** grow with an increasing degree of interconnection?
- d) What is the most important reason for the deviation from the Neo-Hooke's rule, i.e. the deviation from the ideal theory for ideal networks which already starts by small expansions?
- e) Hysteresis occurs for many elastomers during cyclic deformation. One of the reasons depends on temporally behavior of elastomers, another reason is based on the energy-elastic share through two different effects. Which behavior and which effects are those? Why is there every time a hysteresis ($\sigma_{up} > \sigma_{down}$) and why does the effect depend from temperature?