Report for 3D/4D Printing of Soft Materials

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Q1 - Problem statement

Estimate the Young's modulus E (Pa) of a rubber band in the following situation. F: force, $100\,\mathrm{gf} \approx 1\,\mathrm{N}$. A: area, $1\,\mathrm{mm}^2 = 1 \times 10^{-6}\,\mathrm{m}^2$. ($1\,\mathrm{Pa} = 1\,\mathrm{N}/\mathrm{m}^2$.) Strain: $\epsilon = 3$.

Solution

Young's modulus is defined as the ratio of stress to strain:

$$E = \frac{\sigma}{\varepsilon} \tag{1}$$

where σ is the stress, F is the force, and A is the area. The stress is defined as:

$$\sigma = \frac{F}{A} \tag{2}$$

With the given values, we can calculate the Young's modulus as follows:

$$\begin{aligned} \sigma &= \frac{F}{A} = \frac{1\,\mathrm{N}}{1 \times 10^{-6}\,\mathrm{m}^2} = 1 \times 10^{6}\,\mathrm{Pa} \\ E &= \frac{\sigma}{\varepsilon} = \frac{1 \times 10^{6}}{3} = 3.33 \times 10^{5}\,\mathrm{Pa} \end{aligned} \tag{3}$$

So, the Young's modulus of the rubber band is $3.33 \times 10^{5}\,\mathrm{Pa}$.

Q2 - Problem statement

Estimate the chain density per unit volume ν in the rubber band of **Q1**, at $300\,\mathrm{K}$, where the rubber band behaves as an ideal rubber. Additionally, estimate the volume of a chain in the rubber band.

Solution

The chain density per unit volume ν is defined as:

$$\nu = \frac{E}{3 \times K_b \times T} \tag{4}$$

where E is the Young's modulus from **Q1**, K_b is the Boltzmann constant $1.38 \times 10^{-23}\,\mathrm{J/K}$, and T is the temperature $300\,\mathrm{K}$. With the given values, we can calculate the chain density per unit volume as follows:

$$\nu = \frac{3.33 \times 10^{5}}{3 \times 1.38 \times 10^{-23} \times 300} \approx 2.68 \times 10^{25}\,\mathrm{m}^{-3} \tag{5}$$

The volume of a chain in the rubber band is defined as:

$$V = \frac{1}{\nu} \tag{6}$$

So, the volume of a chain in the rubber band is:

$$V = \frac{1}{2.68 \times 10^{25}} \approx 3.73 \times 10^{-26}\,\mathrm{m}^3 \tag{7}$$

Q3 - Problem statement

Estimate the molecular weight M_w of the chain in the rubber band of **Q1**, when the density of the rubber is $0.6\,\mathrm{g/cm^3}$.

Solution

The molecular weight M_w of the chain is defined as:

$$M_w = \frac{N_A \times \rho}{\nu} \tag{8}$$

Where N_A is the Avogadro constant $6.02 \times 10^{23}\,\mathrm{mol^{-1}}$, ρ is the density of the rubber $0.6\,\mathrm{g/cm^3}$, and ν is the chain density per unit volume from **Q2**. With the given values, we can calculate the molecular weight of the chain as follows:

$$M_w = \frac{6.02 \times 10^{23} \times 0.6}{2.68 \times 10^{25}} \approx 1.35 \times 10^4\,\mathrm{g/mol} \tag{9}$$

Q4 - Problem statement

Estimate the polymerization degree N of the rubber band of **Q1** made from isoprene, where the molecular weight of isoprene $C_5H_8 \approx 70\,\mathrm{g/mol}$.

Solution

The polymerization degree N of the rubber band is defined as:

$$N = \frac{M_w}{M} \tag{10}$$

where M_w is the molecular weight of the chain from **Q3**, and M is the molecular weight of isoprene $70\,\mathrm{g/mol}$.

With the given values, we can calculate the polymerization degree of the rubber band as follows:

$$N = \frac{1.35 \times 10^4}{70} \approx 193 \tag{11}$$

Q5 - Problem statement

Estimate the radius of the chain R_{Gauss} in the rubber band of **Q1** swollen in toluene based on the ideal chain (Gauss chain) model, where the segment size $a = 0.3\,\text{nm}$.

Solution

The radius of the chain R_{Gauss} in the rubber band is defined as:

$$R_{\text{Gauss}} = a \times \sqrt{N} \tag{12}$$

where $a = 0.3\,\text{nm}$ is the segment size, and N is the polymerization degree of the rubber band from **Q4**. With the given values, we can calculate the radius of the chain in the rubber band as follows:

$$R_{\text{Gauss}} = 0.3 \times \sqrt{193} \approx 4.146\,\text{nm} \tag{13}$$

Q6 - Problem statement

Estimate the Flory radius of the chain R_{Flory} in the rubber band of **Q1** swollen in toluene based on the real chain model, where the segment size $a = 0.3\,\text{nm}$.

Solution

The radius of the chain R_{Flory} in the rubber band is defined as:

$$R_{\text{Flory}} = a \times N^{3/5} \tag{14}$$

where $a = 0.3\,\text{nm}$ is the segment size, and N is the polymerization degree of the rubber band from **Q4**. With the given values, we can calculate the radius of the chain in the rubber band as follows:

$$R_{\text{Flory}} = 0.3 \times 193^{3/5} \approx 7.01\,\text{nm} \tag{15}$$

Q7 - Problem statement

Finally, please write down your impressions of this class. It can be in Japanese.

Solution

This class was very interesting. I particularly appreciated the balance between theory and practice regarding 3D/4D printing of soft materials. The lectures were very comprehensive, and I was able to deepen my understanding through real-world applications. However, due to time constraints, I felt that I needed a bit more time to fully grasp all the concepts. I look forward to continuing my studies in this field. Thank you very much.