Exercise: Measurement of mechanical properties of soft tissues - Tensile test

Tasks:

1.) Prepare samples of ligaments and tendons.
2.) Measure their geometric properties.
3.) Perform a tensile test.
4.) Evaluate their stiffness and Young's modulus, ultimate tensile strength, yield strength, strain at ultimate tensile strength, and strain at yield point.
5.) Compare the properties of ligaments and tendons.
6.) Compare the elastic moduli calculated from stiffness with the Young's modulus calculated from Hooke's law.
7.) Discuss the results.

Key words: stiffness, Young's modulus of elasticity, stress, strain diagram, tensile test

Introduction:

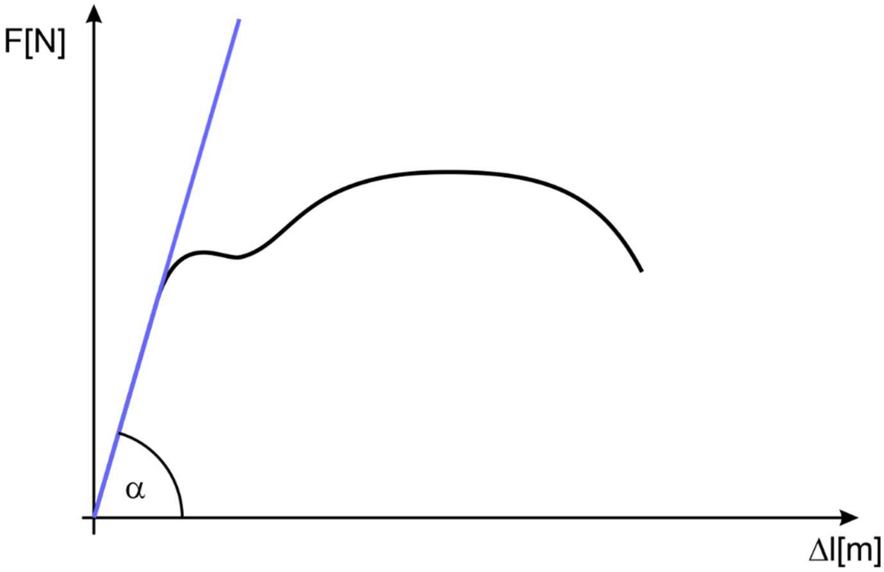
σ - stress [Pa]

ε – strain [-]

k-stiffness [N/m]

E - Young's modulus of elasticity [Pa]

The mechanical properties of materials can only be obtained experimentally. The tensile test is a standard test for obtaining the mechanical properties of various materials, including soft tissues. Tensile testing is based on tensile loading (tensile force) and monitoring the response of the material to this load.



Several parameters can be obtained from this dependence, of which the stiffness parameter k[N/m] is probably the most important.

$$k = tg\alpha = \frac{\Delta F}{\Delta l},$$

where F [N] is the loading force and Δl[m] is the change in length. From the above it is clear that *k* is the slope of the line in the linear part of the diagram. However, we do not define the stiffness only in the linear part of the diagram, but the stiffness is a parameter that can be defined at every point of the diagram, as the tangent line of this diagram.

The dependence of force on deformation can then be recalculated to the dependence of stress on relative elongation, from which the so-called stress-strain diagram can be derived.

Stress is defined as the force divided by cross section.

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

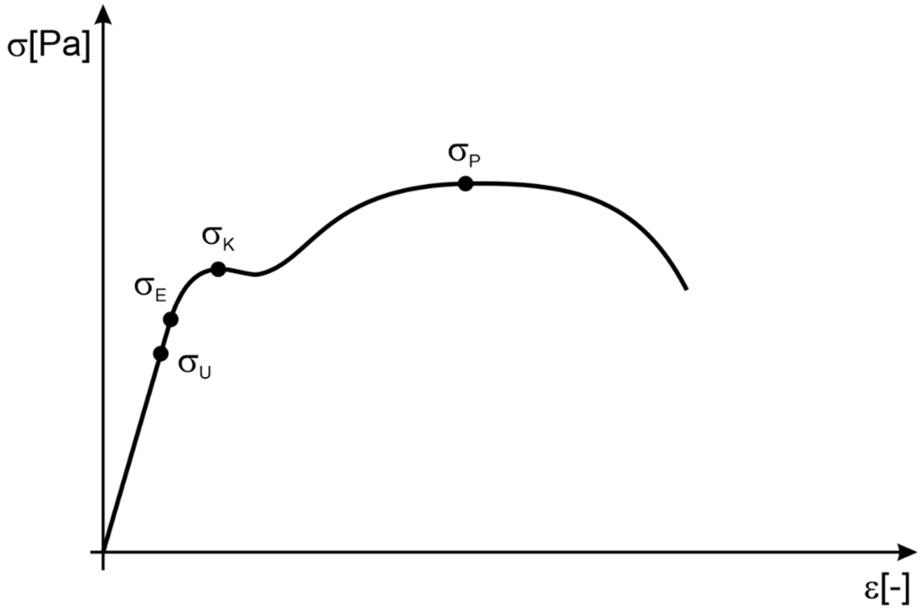
where F [N] is the loading force and A[m^2] is the cross-sectional area.

The strain is then defined as the ratio of the change in length to the original length, resulting in a dimensionless number.

$$\varepsilon = \frac{\Delta l}{l_0} = \frac{l - l_0}{l_0}$$

If we multiply this proportional extension by 100, we get the percentage value shows the percentage elongation of the material relative to its original length.

We can then find many values from the tensile test diagram. In the picture you can see the ideal mild steel diagram. For biological materials, this diagram is slightly different and generally does not contain such a significant yield (the area around the yield limit σ_K).



σ_U- limit of proportionality

σ_E- elasticity limit

σ_K- yield limit

σ_P- tensile strength

The limit of proportionality is the limit up to which the so-called Hooke (linear) behaviour of the material applies. The elasticity limit is the limit that limits the elastic behaviour of the material, i.e. the point to which no residual deformation remains and the material returns to its original shape after being relieved. The yield point is then the point where the first damage to the material occurs. The tensile strength is the point where the collapse of the material occurs and therefore its destruction.

A very interesting part of the stress-strain diagram is the linear segment bounded by the proportional limit. In this region, the so-called Hooke's law applies, which describes the material's linear behaviour.

$$\sigma = E\varepsilon$$

It follows from the above that Young's modulus of elasticity E represents the direction of the linear part of the stress-strain diagram and can therefore be calculated from the following relation.

$$E = \frac{\Delta\sigma}{\Delta\varepsilon}$$

Or as a tangent line through the linear part of the diagram.

The relationship between stiffness and Young's modulus can also be used to calculate Young's modulus of elasticity.

$$E = \frac{k \cdot l}{A}$$

Required equipment: Scalpel, scissors, tweezers, forceps, steel ruler, tear tester..

Instructions:

Measurement of the mechanical properties of soft tissues:

1. Prepare the sample
    - Cut samples from tissue of the maximum possible length (as feasible), with a constant

width and thickness (as feasible). Ensure that the cut segment is not damaged in any way.

- From the prepared samples, cut a thin slice of material from which you will subsequently determine (estimate) the cross-sectional area. The cut must be perpendicular to the loading axis.

2. Determine the sample geometry
   - Measure the length of each sample
   - Calculate the cross-sectional area from the cut slice of each sample. For the calculation, you can use a model geometry such as a rectangle, circle, or ellipse, depending on the sample's characteristics.
3. Clamp the sample in the jaws of the tear tester.
   - Ensure that the sample is clamped so that it is perpendicular to the jaws
   - Ensure that it is neither overtightened nor loose.
   - If the sample is overtightened or loosened, move the jaws so that the force sensor indicates 0N
   - Record the initial length (mark indicating the measured length or the distance between the jaws)
4. Perform a tensile test.
   - Recommendation: Record a video of the test process to detect any unforeseen errors in the test, such as slipping of the sample from the jaws, etc.
5. Export the data to CSV format
6. Repeat steps 3-5 for each sample.
7. Evaluate the experiment data
   - You can use any software for experiment evaluation
   - MS Excel contains sufficient functions for the evaluation.
   - Determine the stiffness value from the linear portion of the F=f(Δl) dependance
   - Calculate the stress σ throughout the loading process (use the initial cross-sectional area measured in step 2)
   - Calculate the proportional elongation throughout the loading process (substitute l_0 with the distance measured in step 3)
   - From the stress-strain diagram, determine all parameters (limits) that you can read (see figure on page 2) – it may happen that the curve's shape causes some parameters to overlap.
   - Determine the Young's modulus value from the linear portion of the stress-strain diagram
   - Calculate the Young's modulus value from the stiffness calculated from the linear dependence F=f(Δl)
   - Repeat step 7 for all measured data
8. Prepare a measurement protocol, including>
   - Hypothesis (how you expect the mechanical properties of ligaments and tendons to differ)
   - Methodology (identification and description of samples, procedure for preparing samples, measurement procedure, chosen loading regime, instruments used, data processing method)

- Results (summary of the experiment results)
- Discussion and interpretation of results (Discuss how the results of individual samples differ from each other, any influencing factors, etc.)
- Conclusions (Summarise the entire experiment)