Exercise: Measurement of mechanical properties of soft tissues – dynamic test

Objectives:

1.) Prepare samples of ligaments and tendons.
2.) Measure their geometric properties.
3.) Perform a dynamic test at two different frequencies with the same amplitude.
4.) Evaluate their stiffness and the density of dissipated energy.
5.) Compare the properties of ligaments and tendons.
6.) Compare how the material behaviour will differ at different frequencies.
7.) Discuss the results.

Keywords: Rheology, Viscoelasticity, Hysteresis loop, Strain energy, Strain energy density

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Introduction:

In addition to elastic behaviour (which can be expressed using the stiffness parameters k or its equivalent modulus of elasticity E), materials can also observe various other modes of behaviour. Most biological tissues have a so-called viscoelastic behaviour. For viscoelastic materials, the response to loading depends on both the load value itself and the loading speed. Due to this, a phenomenon called hysteresis occurs during cyclic loading. In this phenomenon, there is a difference between a loading and unloading curve.

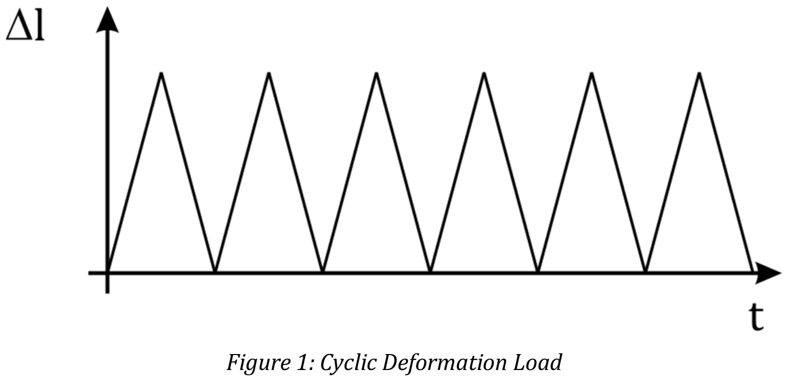

Figure 1: Cyclic Deformation Load

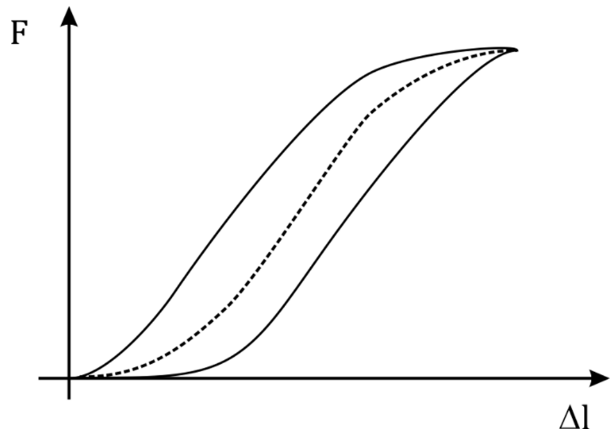

Figure 2 Typical hysteresis curve of force-deformation dependencies

Several parameters can be read from the hysteresis curve. If we consider that loading and unloading take place at the same but opposite speed, then with a certain neglect, we can determine the stiffness as the direction of the tangent, the linear part of the middle curve of the hysteresis loop. Another parameter can be the dissipation energy, which is given by the area inside the hysteresis curve. In the case of viscoelastic materials, this energy determines the damping ability of the viscoelastic material.

However, both parameters depend on the dimensions of the sample. Therefore, it is more appropriate to convert force and deformation into stress and strain.

Stress is defined as 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 which shows the percentage elongation of the material relative to its original length.

After this modification, we get the following dependency.

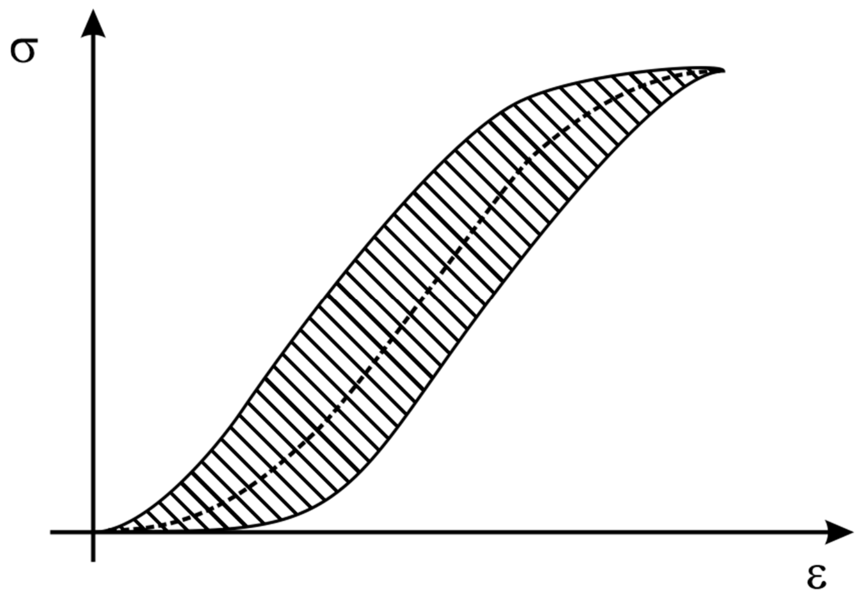

Figure 3 Hysteresis curve of tension - strain

From this dependence, we can then obtain the modulus of elasticity in the same way as for the force-deformation-stiffness curve. The area defined by the hysteresis loop (hatched part in Fig. 3) then defines the value of the deformation energy density.

Necessary equipment: Scalpel, scissors, tweezers, ripper, steel ruler, ripper.

Instructions:

Determining the Mechanical Properties of Soft Tissues:

- 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 of the cut slice of each sample. For the calculation, you can use model geometry such as a rectangle, circle, or ellipse, depending on the characteristics of the sample.
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 dynamic test
    - Load the material for 10 cycles
    - Choose loading regimes considering the sample size – consult with the instructor
    - 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. Evaluate the experiment data
    - You can use any software for experiment evaluation.
    - MS Excel contains sufficient functions for the evaluation.
    - Determine the average curve of the hysteresis loop from the force-deformation dependence and determine the material stiffness.
    - Calculate the stress σ throughout the loading process (use the initial cross-sectional area measured in step 2)
    - Calculate proportional elongation throughout the loading process (substitute l_0 with the distance measured in step 3))
    - From the stress-strain dependence, determine the average curve, the elastic modulus, and the value of the density of dissipated energy for the measured sample.

7. 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 and why the results of individual samples differ from each other, any influencing factors, etc.)
        - Discuss how the curve might change at a higher loading rate.
    - Conclusion (Summarise the entire experiment)