Non-linear rheological properties of dough

Objective

Measurement of the rheological properties of household dough.

Introduction

Household dough is an example of a material that exhibits a non-linear stress-strain response. In addition, this response is also a function of loading rate. In this exercise, we will perform simple uniaxial extension experiments on household dough (of your choice) to study this nonlinear behavior.

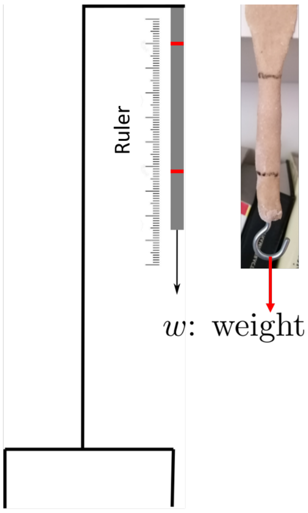
Materials

For this experiment you will need the following,

1. Any flour of your choice and water
2. Oil (any oil would work) to lubricate the surfaces of the sample
3. A ruler or a camera for length and diameter measurements
4. Weights to apply dead load to the sample

Experimental setup

A suggestive schematic of the experimental setup is shown below.



An example of a sample mounted on a shelf

Schematic of a test setup

Procedure

We will split our experimental procedure into three parts

I. Sample preparation

1. Prepare the dough samples by simply mixing flour and water (record the relative ratio of flour to water). Note: Too much water may make the material too viscous. A ratio close to 9:1 (four to water) may be ideal. However, feel free to try out different ratios.
2. Prepare cylindrical samples of similar dimensions (atleast three samples for a given composition). Suggested dimensions are length, L $\simeq$ 50-75 mm and diameter D $\simeq$ 5-10 mm.
3. Label your samples (using a convenient naming system) and measure the dimensions of your samples before testing.

II. Measurement of the non-linear stress-strain response

1. Place markers on the first sample to measure the displacement during the experiment. You may use two lines running parallel to the cross-section of the sample at a specific distance along the tensile axis of the sample or draw a grid (if you feel particularly adventurous and are using a camera!)
2. Coat the sample using oil to ensure that the moisture does not leave the surface of the sample.
3. Using the experimental setup described in the Experimental setup section, mount this sample to the top clamp and attach the weights to the end of the sample.
4. Collect data (in the form of images or readings from the markers and ruler) at periodic time intervals (choose your time intervals according to the rate of loading).
5. From the data collected you should be able to calculate both the extension of the sample and change in cross-sectional area.
6. Repeat the experiment for at least three samples.

II. Changing specimen dimensions

1. The objective of this set of experiments is to change the loading rate without a displacement/ velocity control mechanism.
2. Prepare samples with same lengths as before but two different diameters, one that is double the original diameter and another that is half.
3. For the same composition, repeat the above experiment for the new specimen dimensions (atleast three experiments per specimen type)

Data analysis and presentation

The following relations allow us to characterize the stress-strain-strain rate response of the material.

1. The sample dimensions in the undeformed configuration are denoted using,
   L_o: length, D_o: diameter, and A_o: area of cross-section
2. At every time step where data is collected, the instantaneous dimensions are denoted using,
   $L(t)$: length, $D(t)$: diameter, and $A(t)$: area of cross-section
3. The instantaneous deformation rate of the sample at a time step t_n is calculated as,

$$v(t) = \frac{\Delta L}{\Delta t} = \frac{L(t_n) - L(t_{n-1})}{t_n - t_{n-1}} \tag{1}$$

4. Longitudinal stress

$$\sigma(t) = \frac{4w}{\pi D(t)^2} \tag{2}$$

   where w : weight acting on the sample.

5. Longitudinal true strain,

$$\varepsilon_t(t) = \ln \frac{L(t)}{L_o} = \ln \left(1 + \frac{\Delta L}{L_o}\right) = \ln\left(1 + \varepsilon_e\right) \tag{3}$$

   where ε_e: engineering strain

6. Strain rate,

$$\dot{\varepsilon}(t) = \frac{v(t)}{L(t)} \tag{4}$$

Using the above formulae, for each set of experiments, present the following plots with labels.

1. Stress, strain, strain rate and relative sample volume as a function of time: $\sigma(t)$, $\varepsilon_t(t)$, $\dot{\varepsilon}(t)$ and $V(t)/V_o$
2. Stress-strain relations: $\sigma(t)$ vs $\varepsilon_t(t)$

Discussion

1. Experimental configuration
   (a) Why do we apply oil on the surface of the sample before testing?
   (b) Will your results change if we avoid this step? Explain.
2. Variability in data
   (a) Within a single dataset (one composition and specimen dimension), how much of variability in stress-strain response do you observe? You can present this as the standard deviation of strain at different stress levels (tabulated or a plot).
   (b) List the potential sources of variability
3. Using the relative volume calculations, comment on the compressibility of the material.
4. Stress-strain behavior of the dough samples (use data from a single specimen dimension)
   (a) When deformation occurs under constant load it is called *creep*. Are you performing a creep experiment?
   (b) Within a single experiment, is the stress in your sample constant? Why or why not?
   (c) In general, what does the slope of the stress-strain curve tell us about the material response macroscopically and microscopically? For your dataset, is the slope of the stress-strain curve a constant within one experiment? Why?
   (d) Describe the mechanical response of dough with specific reference to the phenomena discussed previously. How will the response vary with a change in the 1. flour to water ratio and 2. temperature? Why?
5. Effect of loading rate
   (a) Is the average stress-strain response different for different sample dimensions?
   (b) Should the material response be sensitive to sample size and why? Does the data agree with your answer?
   (c) Compare the strain rates, $\dot{\varepsilon}(t)$, measured for the three different sample dimensions. Now comment on stress-strain response as a function of strain rate.
   (d) Suggest a more effective method to control the strain rate in your experiment.