

Lab course session

Three-point bending test

January 2024

1 Introduction

The mechanical properties of materials are determined by performing carefully designed laboratory experiments aimed at inducing a certain state of stress or deformation in the studied material. The present lab session deals with a three-point-bending test to obtain the following material parameter

- Stress vs. engineering strain curve and stress vs. real strain curve
- Flexural strength (σ_F)
- Flexural modulus (E_{flex})

To perform the test, we use a universal testing machine by INSTRON (Model 8862 with ± 100 kN loading capacity) as shown in Figure 1. The type of fixtures used in this machine can be changed to accommodate tensile, compressive, and bending experiments. The data obtained from this test are the load (F) measured by the load cell, the machine displacement (d) and, if a crack-mouth opening displacement (CMOD) gauge is installed, the elongation Δ of a portion of material with length equal to the gauge length L_G (in our case $L_G = 10$ mm). A typical load-displacement curve under three-point bending experiment is shown in Figure 2.

Following Bernoulli's beam theory, the distribution of loads along the longitudinal axes is such that the half-span section is loaded in bending only (shear force vanishes) and carries the highest value of bending moment M , which reads

$$M = \frac{FS}{4}, \quad (1)$$

where S is the span length (i.e., the distance between the two bottom roller supports). From this point on, we will focus on the behavior of the mid-span section.

The (engineering) stress and strain related to the mid-span section can be calculated as

$$\sigma = \frac{6M}{bh^2}, \quad (2a)$$

$$\varepsilon = \frac{\Delta}{L_G}, \quad (2b)$$

where b and h are the width and height of the beam, respectively. Equation 2a illustrates the dependency of the bending stress to the bending moment M . The real strain can be obtained as

$$\varepsilon = \frac{\Delta}{L_G + \Delta} = 1 + \frac{\Delta}{L_G} = 1 + \varepsilon. \quad (3)$$

To find the flexural strength of the material, the peak load (F_{max}) (designated with a red circle in Figure 2) must be substituted in Equation 1 to obtain M_{max} , which can then be used in Equation 2a to determine the flexural strength (σ_F). Also, to identify the flexural modulus of the tested material, it is customary to consider as linear elastic region the part of the engineering strain vs. stress curve within a range of 20% – 60% of the peak load. Therefore, the flexural modulus E_{flex} can be obtained as the slope of the linear relation best-fitted to the linear range of the stress-strain data points.

2 Specimen

The specimen used for the three-point bending test is a beam similar to the one sketched in Figure 3. The use of a span much larger than the cross-sectional height is intended to mitigate the effects of shear deformation and to replicate the assumptions of the Euler-Bernoulli beam theory. In a three-point bending experiment, the beam is placed on two roller supports while an upper loading roller applies the bending load F . For a brittle material, we expect a monotonic increment of the load until the peak, after which the beam usually fails abruptly by splitting in two halves.

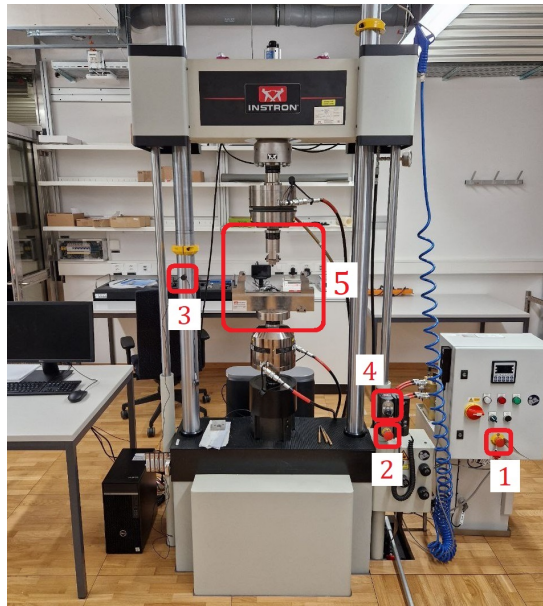


Figure 1: INSTRON universal testing machine. #1, 2: Stop emergency buttons; #3: Holder for securing the wire of the crack-mouth opening displacement gauge; #4: The switch for setting the power mode of the machine; #5: The fixtures of the machine.

2.1 Specimen preparation

Beams are already available in the lab. Pick one beam and mark the positions of supports and loading line on it. The support span should measure $S = 250$ mm and the loading point must be applied at midspan. Try to mark both the front and back sides of the beam so to facilitate positioning. To mount the CMOD gauge in order to measure the beam extension at the mid-section, we firstly need to install two *knives* on the specimen. To this end, mark the positions where the knives must be installed at the center of the bottom side of the beam (i.e., the face opposing the loaded face) accounting for a $w_0 = 10$ mm gap between the edges. Afterwards, use super glue to rigidly attach both knives to the specimen. The specimen is now ready for the experiment.

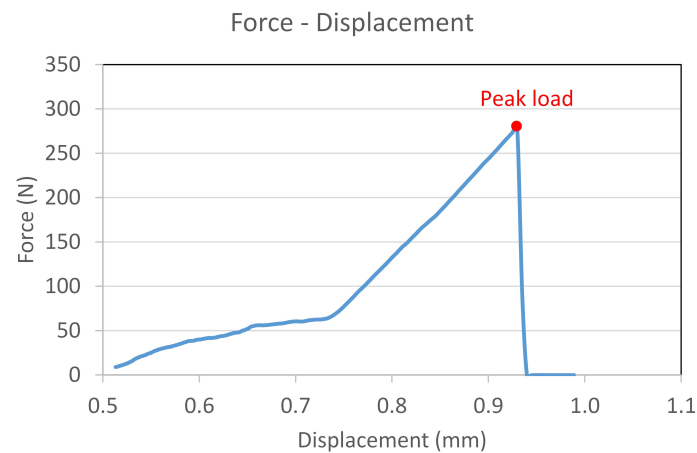


Figure 2: A typical load-displacement curve for a three-point bending test.

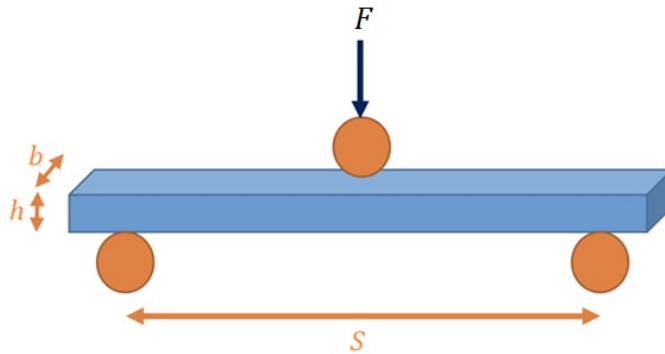


Figure 3: Schematic representation of the long-span beam used for the three-point bending test.

2.2 Specimen dimensions

Use a calliper to measure the following dimensions:

- Width of the beam (b): mm
- Height of the beam (h): mm
- Gauge length, i.e. initial distance between the centres of knives (L_G): mm

3 Test setup and execution

3.1 Safety measures

To ensure the safety of yourself and your group members, please follow the indications of the present guidelines and of the supervisor very carefully. In case of an emergency situation with the machine, press one of the two red buttons marked with #1,2 in Figure 1. Wear **protective glasses** before you start working in the lab.

To work with the grips and fixtures of the machine, or to position the specimen inside the grips, make sure that the machine is in **standby** mode. To change the power mode of the machine, use the switch represented by #4 in Figure 1. The left status is for *standby* mode. The middle one is for *low-power* mode, which can be used to run the machine with the hand controller. The right status is for *high-power* mode where the computer software can be used to run the machine.

3.2 Fixtures, specimen positioning and CMOD installation

Put the machine in standby mode via rotating the switch denoted by #4 (in Figure 1) to its leftmost position. With the help of the present supervisor, change the fixtures of the machine (#5 in Figure 1) and install the ones suitable for the three-point bending test, as demonstrated in Figure 4. Put the machine in the low-power mode by rotating the switch denoted by #4 to the middle position and by pushing the green flashing button until the light becomes static. Move the actuator of the machine in order to have the upper roller close to the beam. Put the machine back in standby mode. Put small pieces of Teflon sheet on the supporting rollers as well as on top of the specimen at the loading point; the Teflon sheets reduce the friction between the specimen surface and the rollers, therefore improving the reliability of the measurements. Install the beam on the supporting rollers (with Teflon sheet in-between) and make sure your marks on the specimen correspond with the centre of the rollers. Moreover, assure the out-of-plane centring of the specimen by checking that the distance from the beam faces to the flat faces of the supporting rollers are equal for the two supports. As for the last step, mount the CMOD gauge on the knives that you previously glued to the specimen (see the illustration: #4 in Figure 4).

Attention: Since the CMOD gauge is very precise and expensive equipment, please make sure to deal with it with extra care. Particularly, please secure the wire by positioning it inside the groove of the

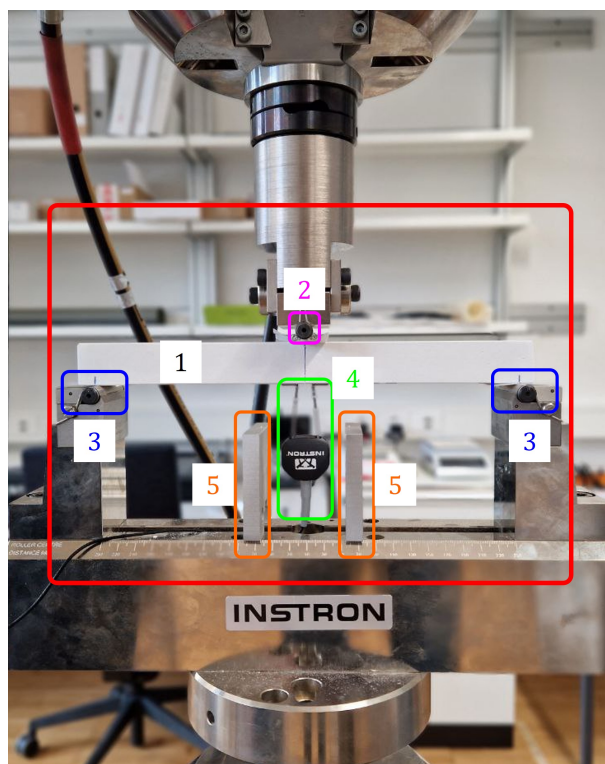


Figure 4: Fixtures configuration and positioning of the beam. The red rectangle indicates the specimen (#1) along with the loading (#2) and supporting (#3) rollers, the mounted CMOD gauge (#4), and two dummy workpieces (#5) to save the CMOD gauge from possible damage.

cylindrical black holder on the left column of the machine (see #3 in Figure 1). Also, position two dummy workpieces under the beam to protect the CMOD gauge from collapsing beam sections (#5 in Figure 4)).

3.3 Settings of the machine and running the test

Once the beam is positioned on the supports, it is time to start with the main part of the test.

Do the following steps:

1. Run *Instron Console* software (see Figure 5 (a)). Change the running status of the machine to high-power via rotating the switch denoted by #4 (in Figure 1) to its right-most position.
2. In Console, in *Linear*, press *Load_100kN* and then select *Calibration*. Run the *Calibration Wizard* and chose *Auto Calibration* to automatically calibrate the load cell (Figure 5 (b)). Follow on-screen instructions and wait for the calibration process to finish. Repeat the same procedure to calibrate the CMOD gauge, by clicking on *Strain 1* (right beneath *Load_100kN*).
3. Run *Bluehill Universal* software (Figure 6 (a)). Click on *Test* (Figure 6 (b)) and from the *New sample* section, look for the existing method *ExpMech_3PB* and select it (Figure 6 (c)). This method has been already created with specific considerations for the three-point bending test.
4. Go to the *Method* tab (see Figure 6 (d)). Under *Test Control* select *Pre-Test* and based on Figure 6 (d), check that a rate less than or equal to 500 $\mu\text{m}/\text{min}$ under *Displacement* control mode is assigned, and that, the force limit for transferring to the main test is 10 N. The pre-test is meant to bring the specimen in contact with the upper loading support. Next, under *Test Control* and *Test*, make sure that the test is displacement-controlled whereby *Control mode 1* should be set to *Displacement* (Figure 6 (e)). Furthermore, double-check that *Rate 1* is not more than 100 $\mu\text{m}/\text{min}$. Also, go to *Export* tab (Figure 6 (f)) and define a directory for saving the test data for your group (preferably inside `C:\Users\ETH ZURICH\Desktop\ExpMech\StudentsTests\GroupNumber`).

5. According to Figure 6 (g), go back to the *Test* tab and click on *Balance all* so that all the readings from the sensors become zero. To begin the experiment, press the *Start* button.
6. Observe the live graphs on the screen and check the linear elastic behaviour that, for a brittle material, lasts almost until failure. Wait until the test completes when the specimen breaks into two pieces. Put the machine in standby mode and gather the specimen broken parts from the machine and its surroundings, and put them all on the table.

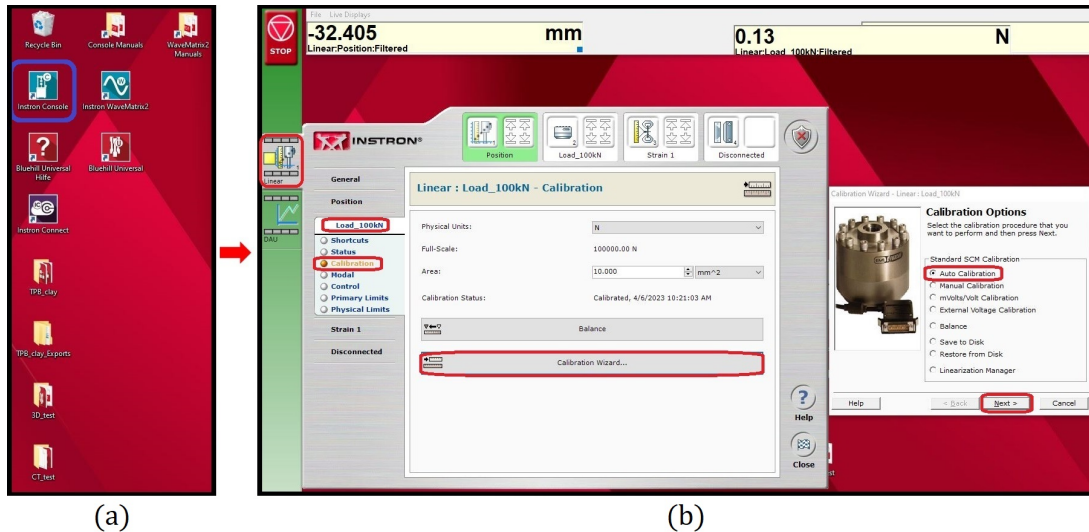


Figure 5: (a) Running the Instron Console software and (b) auto-calibrating the load cell.

4 Questions and analysis of data

Using the data obtained from your experiment, we ask you to prepare an individual lab report (**max 3 pages**) including the following information

1. Load vs. the displacement of the machine.
2. Load vs. the CMOD gauge measurement.
3. Peak load (show it on your load-displacement curve) and calculate the flexural strength.
4. Stress vs. engineering strain curve (corresponding to the CMOD gauge measurement).
5. Stress vs. real strain curve (corresponding to the CMOD gauge measurement).
6. Flexural modulus.

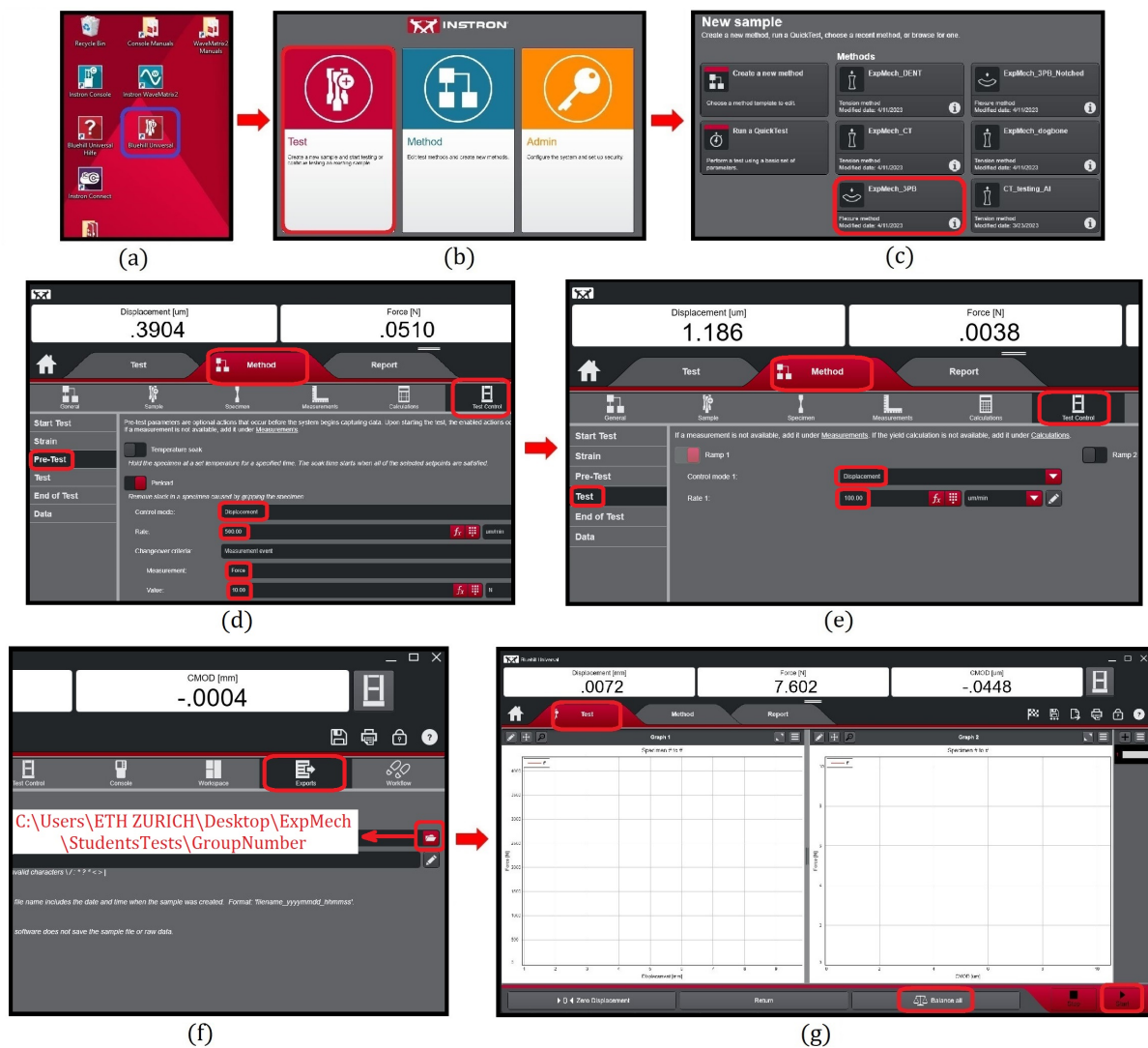


Figure 6: (a) Running the Bluehill Universal software; (b) defining a new test; (c) selecting the suitable method; (d) pre-test and criterion to ensure contact of the specimen and the loading roller; (e) controlling the test and rate; (f) defining the export path for the test data; (g) balancing all the readings and running the test.