Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

COMPUTATIONAL MECHANICS
GROUP

Lab course session

Compact tension test

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Lecturer:
Dr. Pietro Carrara

TA:
Veit Schönherr

1 Introduction

The fracture properties of materials are determined by performing tests on notched specimens, among which the compact tension (CT) specimen is one of the most used. In this session, we focus on a CT test to determine the following physical quantities:

- Fracture toughness (K_{Ic})
- Critical energy release rate (G_c)

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 apply tensile, compressive, or bending loads. In this session, we deal with a tensile setup. The data obtained from this test are the load (F) measured by the load cell and the machine displacement (d). A typical load-displacement curve for a CT specimen is shown in Figure 2. The peak load (F_c) is indicated with a red circle on the plot. Having the peak load, one can obtain the fracture toughness (K_{Ic}) and the critical energy release rate (G_c) as follows:

$$K_{\mathrm{Ic}} = \frac{F_c}{B}\sqrt{\frac{\pi}{W}}\, f(\frac{a}{W})\,, \tag{1a}$$

$$G_c = \frac{K_{\mathrm{Ic}}^2}{E} \quad \text{(plane stress condition)}\,, \tag{1b}$$

where B, W and a are thickness, (pseudo-)width and (pre-)crack length, respectively (as indicated in Figure 3). E is the Young's modulus that you can easily find on the internet. The geometry factor $f(a/W)$ is an empirical non-dimensional quantity that can be obtained from handbooks or specific literature. Note that, being the non-dimensional geometric factor an empiric formula, it might slightly vary from Equation 1a and it comes with specific requirements and/or limitations. Refer to Appendix A as a credible source for obtaining the geometry factor.

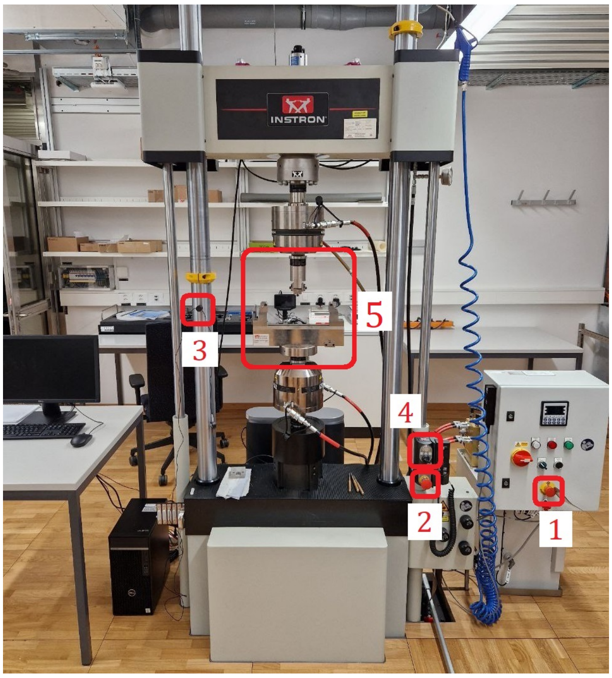


Figure 1: INSTRON universal testing machine. #1, 2: Stop emergency buttons; #3: Holder for securing the wire of the crack-mouth opening displacement gauge; #4: The switch for setting the power mode of the machine; #5: The fixtures of the machine.

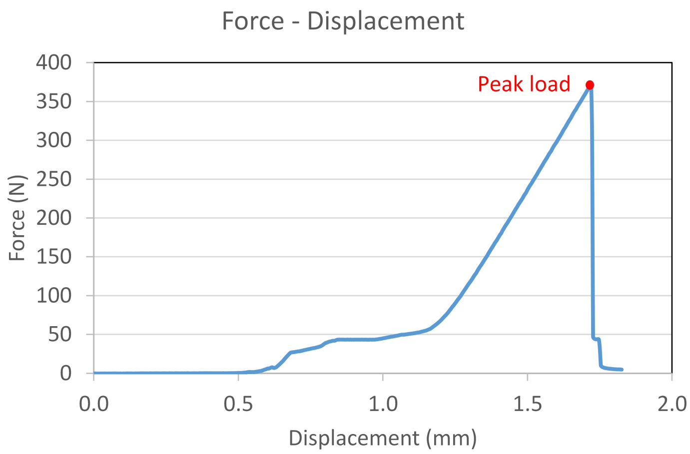


Figure 2: A typical load-displacement curve for a fracture mechanics test with the CT specimen.

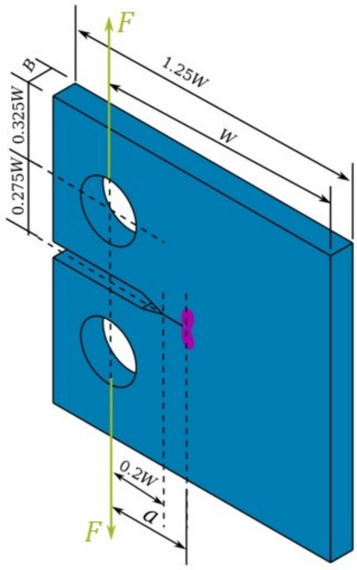


Figure 3: Compact tension specimen for tensile fracture test and its key dimensions.

2 Specimen

A schematic of the compact tension (CT) specimen is represented in Figure 3. During the tensile fracture test, the CT specimen is loaded via two rigid pins passing through the holes illustrated in Figure 3. The failure of the specimens happens when the load reached its maximum (i.e., at $F = F_c$) and the edge crack propagates abruptly and the specimen breaks into two parts. Due to the symmetry in loading and geometry, and thanks to the isotropy of the material, the crack propagates in a co-planar fashion (i.e., with no deviations/kinking).

2.1 Specimen preparation and dimensions

The CT specimens have already been manufactured and are available in the lab. Pick one specimen and use a caliper to measure the following dimensions:

- Length of each pre-crack (a): ...... mm
- (Pseudo-)width of the specimen (W): ...... mm
- Thickness of the specimen (B): ...... mm

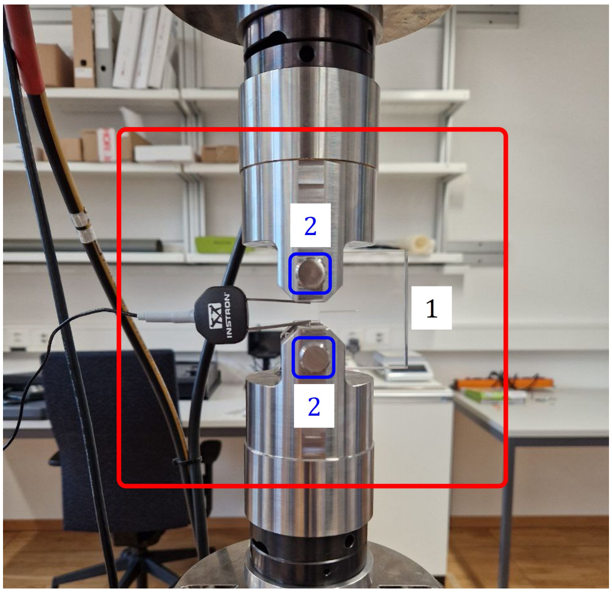


Figure 4: Fixtures configuration and positioning of the CT specimen. The red rectangle indicates the specimen (#1) along with the loading pins (#2). The CMOD gauge can be disregarded as we do not employ it for the current lab session.

3 Test setup and execution

3.1 Safety measures

To ensure the safety of the group members, please follow the indications of the present guidelines and of the supervisor very carefully. In case of emergency, press one of the two red buttons marked with $\#1, 2$ in Figure 1 to immediately stop the machine. 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 need to be be used to run the machine.

3.2 Fixtures and specimen positioning

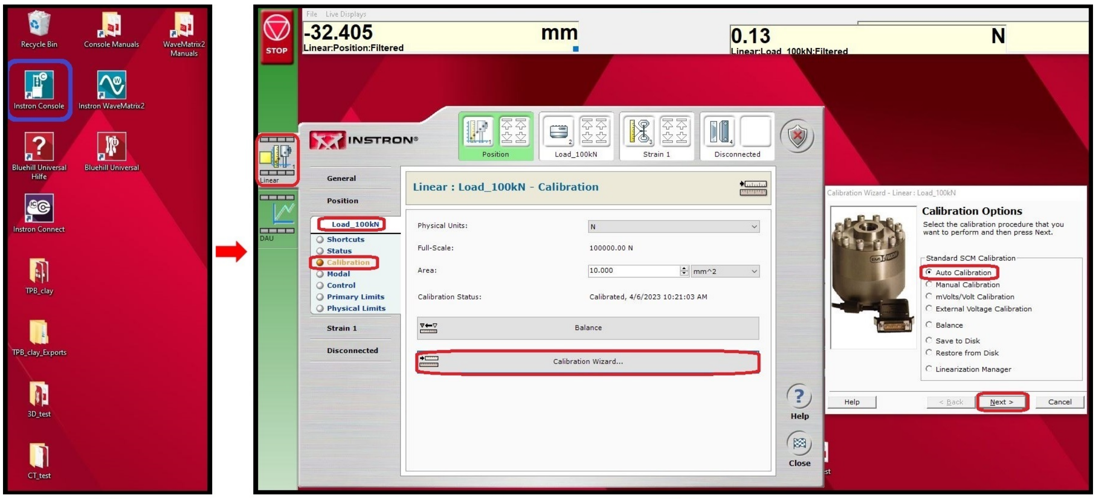
Put the machine in standby mode via rotating the switch denoted by #4 (in Figure 1) to its leftmost position. If not already mounted, change the fixtures of the machine with the help of the supervisor (#5 in Figure 1) and install the ones suitable for compact tension specimens, as demonstrated in Figure 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. Bring down/up the actuator of the machine to adjust the distance between the upper and lower pins so that is close to the distance between the holes in the specimen. Put the machine back in standby mode. Install the loading pins into the holes of the CT specimen. In case of difficulty, adjust the distance between the two pins again so that the pins can be inserted without forcing them in position.

3.3 Settings of the machine and running the test

Once the pins are mounted on the CT specimen, 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.



(a) (b)

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

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.
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_CT* and select it (Figure 6 (c)). This method has been already created with specific considerations for the tensile fracture test on CT specimens.
4. Go to the *Method* tab (see Figure 6 (d)). Under *Test Control* select *Test*. Make sure that the test is displacement-controlled whereby *Control mode 1* should be set to *Displacement*. Furthermore, double-check that *Rate 1* is <u>not more than</u> 500 μm/min. Also, go to *Export* tab (Figure 6 (e)) 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 (f), 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 behavior 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 remove the broken specimen by removing the pins.

4 Questions and analysis of data

Using the data obtained from your experiment, we ask you to prepare an individual lab report including the following information

1. Load vs. the displacement of the machine.
2. Refer to Appendix A and look for a suitable geometry factor $f(a/W)$ for the compact tension specimen under tensile loading.
3. Find the peak load, show it on your load-displacement curve, and calculate the fracture toughness.
4. The critical energy release rate.

Figure 6: (a) Running the Bluehill Universal software; (b) defining a new test; (c) selecting the suitable method; (d) controlling the test and rate; (e) defining the export path for the test data; (f) balancing all the readings and running the test.

Appendix A: Geometry factor [1]

2.19 Stress Analysis Results for Common Test Specimen Configurations 61

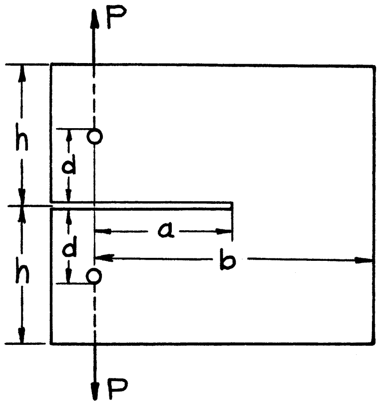
THE COMPACT TENSION TEST SPECIMEN

$$K_I = \sigma\sqrt{a}\, F_I(a/b, h/b, d/h)$$

where $\sigma = P/b$

or $K_I = \sigma_N \sqrt{b-a}\, F_2(a/b, h/b, d/h)$

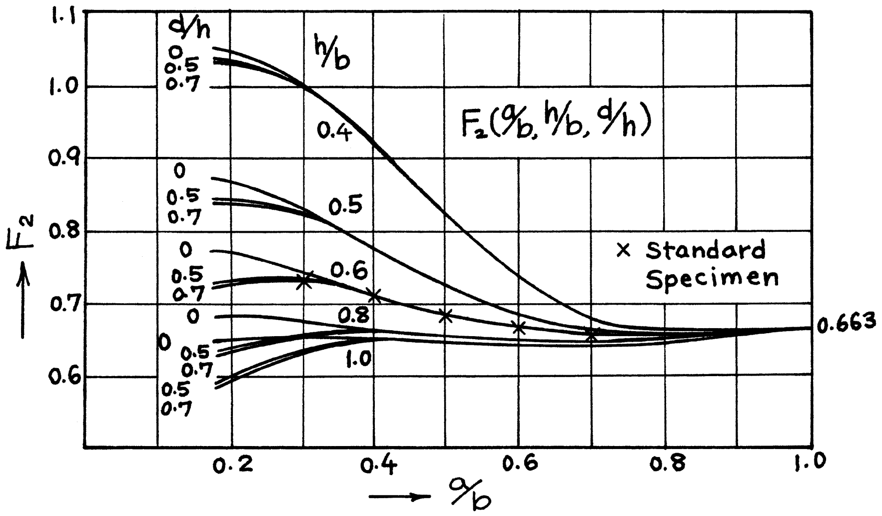
where
$$\sigma_N = \underset{Tension}{\sigma_N} + \underset{Bending}{\sigma_N} = \frac{P}{b-a} + \frac{6P\left(a + \frac{b-a}{2}\right)}{(b-a)^2} = \frac{2P(2b+a)}{(b-a)^2}$$



Numerical Values of F_2

$$\left(F_1 = \frac{2(2 + a/b)}{(1 - a/b)^{3/2}} \cdot \frac{1}{\sqrt{a/b}} \cdot F_2\right)$$

The curves in the following figure have better than 1% accuracy.



Method: Boundary Collocation Method
References: **Gross 1970; Srawley 1972**

[1]Adopted from Tada H., Paris P.C. and Irwin G.R., *The Stress Analysis of Cracks Handbook*, EngineeringPro collection, ASME Press, 2000.

Standard Specimen (ASTM Standard E-399-72)

Standard geometry of compact tension specimen is shown below.

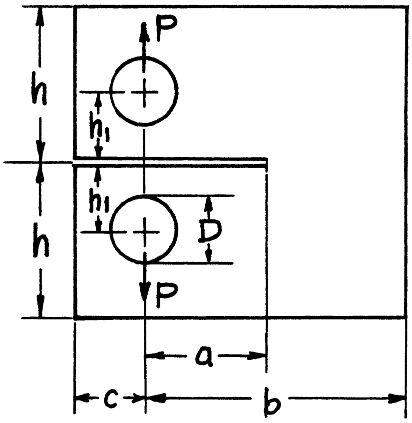
h = 0.6b

h_1 = 0.275b

D = 0.25b

c = 0.25b

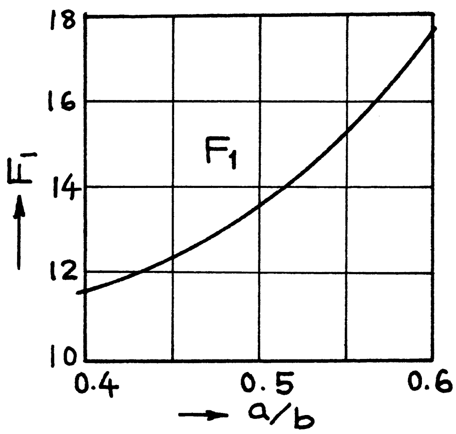
(Thickness = b/2)



A. Stress Intensity Factor

The F_2 values for the standard specimen are plotted in the previous graph. For the range $0.4 \le a/b \le 0.6$, the values of F_1 are plotted.

Note: $F_2 \simeq F_2(a/b,\ 0.6,\ 0.7)$



Empirical Formula

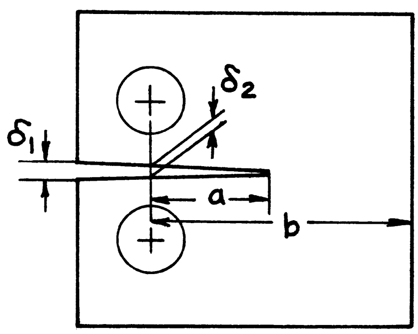
For the standard specimen, the following formula has 0.5% accuracy for $a/b > 0.2$ (**Srawley 1976**).

$$F_2(a/b) = 0.443 + 2.32(a/b) - 6.66(a/b)^2 + 7.36(a/b)^3 - 2.8(a/b)^4$$

B. Displacements

Opening at Crack Edge

$$\delta_1 = \frac{P}{E'} V_1(a/b)$$



Opening at Loadline

$$\delta_2 = \frac{P}{E'} V_2(a/b)$$