MEC- E6007 - Mechanical Testing of Materials

Laboratory Exercise 3: Standardized Testing

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May 13th 2024

Table of Contents

1 Introduction

This report documents a tensile test performed on a metallic material, which was selected by the student group. The experiment aimed to determine the material's Young's Modulus, Poisson's ratio, yield strength, and tensile strength, as well as plot the engineering stress-strain curve for the report. The tensile test was conducted according to the ISO 527-1 standards. Furthermore, in this report,

2 Theory

Tensile testing is a widely used method for characterizing materials by evaluating their mechanical behavior under uniaxial tensile loading conditions. The primary objective of tensile testing is to determine the material's response to applied stress, which can be used to assess various properties like strength, stiffness, and ductility. These properties are critical for engineering applications, such as material selection and design.

- Stress (σ) is the load applied per unit area:

$$\sigma = \frac{F}{A} \tag{1}$$

  Where F is the applied load and A is the cross-sectional area of the specimen.

- Strain (ε) is the relative change in the material's length:

$$\varepsilon = \frac{\Delta L}{L_o} \tag{2}$$

  where ΔL is the length deviation, and L_0 is the initial length of the specimen.

- The modulus of elasticity (E) is the relationship between stress and strain in the elastic region of the stress-strain curve. It can be determined using Hooke's Law:

$$E = \sigma/\varepsilon \tag{3}$$

- The yield strength (σ_y) of a material is the maximum stress a material can withstand without entering the plastic region of the stress-strain curve and permanently deforming.
- Ultimate Tensile Strength (σ_u) is the maximum stress the material can withstand without breaking.
- Ductility and Brittle Behavior: Materials can be classified as ductile, or brittle based on their response to tensile loading. Ductile materials exhibit substantial plastic deformation before failure, while brittle materials fracture with little to no plastic deformation.
- Poisson's Ratio (ν) describes the material's propensity for lateral contraction as it elongates under tensile stress. It is defined as the negative ratio of lateral strain (ε_{lat}) to longitudinal strain (ε_{long}):

$$\nu = -\frac{\varepsilon_{lat}}{\varepsilon_{long}} \tag{4}$$

3 Methods

3.1 Experimental setup

The tensile test was performed on a MTS Insight Electromechanical 30 kN Standard Length testing machine, as presented in Figure 1. The test was made using MTS's own TestSuite software. An external extensometer, as presented in Figure 2, was utilized for measuring the axial strain. The specimen of interest was made of oxygen-free copper (Cu-OF), with the dimensions given in Table 1. A Kyowa KFGS-5-120-C1-11 L1M2R, with the specifications given in Figure 3, was used for measuring the horizontal strain of the specimen to calculate the Poisson's ratio. The strain gauge was attached onto a slightly ruffed and thoroughly cleaned surface at the middle of the specimen.

Figure 1. Tensile testing machine used during tensile testing.

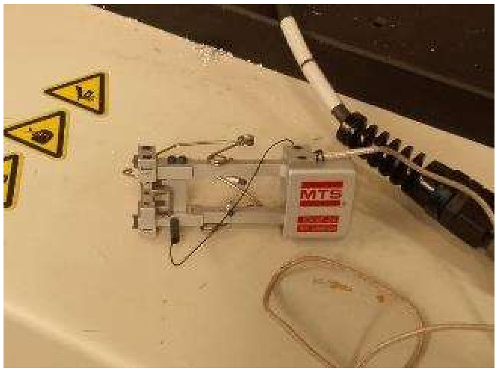

Figure 2. External extensometer used for vertical strain measurement.

Table 1. Specimen dimensions.

Property	Value	Unit
Gauge Length	112	mm
Total Length	202	mm
Grip Length	45	mm
Width	20 ±0.05	mm
Thickness	1.5	mm

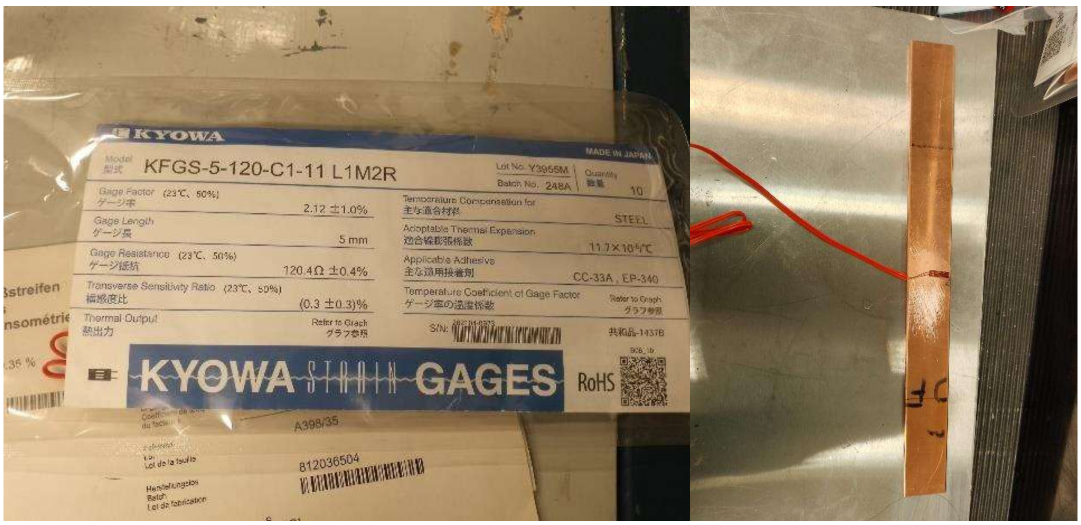

Figure 3. Strain gauge specifications and placement on the specimen.

3.2 Test procedure

The general steps for performing a tensile test with an external strain gauge and extensometer are as follows:

1. Fabricate the specimens into suitable dimensions and tolerances. These should conform with the standards used.
2. Mark the grip lengths of about 45mm on both ends of the specimen.
3. Measure the gauge length of the specimens.
4. Grind the area where the external strain gauge is to be placed with A320 grit grinding paper.
5. Clean the grinded area in straight line motions, always replacing the cleaning pad after every stroke.
6. Apply glue to the cleaned area.
7. Press and hold the strain gauge in the desired position and orientation for one minute.
8. (Optional) Add a strain relief by gluing the wires to the specimen.

9. Paste a protection layer on top of the strain gauge.
10. Connect strain gauge wires to the DAQ system.
11. Place the specimen in the tensile testing machine and close the grips.
12. Set the strain gauge factor in the software, in our case it was set to 2.12.
13. Set the specimen dimensions in the software.
14. Set test speed in the software, in our case a initial test speed of 1.7 mm/min and final test speed of 6 mm/min was used.
15. Execute zero balance option.
16. Start the test.

4 Results

From the tensile test, it can be observed that the necking occurred at two regions of the test specimen, one in the gauge length region of the specimen and the other in the region where the specimen was gripped. The fracture occurred in the region of the specimen where it was gripped, as seen in Figure 4. Possible reasons for the undesired fracture position will be discussed in the next section. The gathered data from the test was analyzed using the equations described earlier. The results were plotted into a stress-strain graph, as shown in Figure 5. The calculated mechanical properties are presented in Table 2. Furthermore, the specimen stress-strain graph shows that it is very ductile since the observed elongation to fracture was about 32.5 % of the original length.

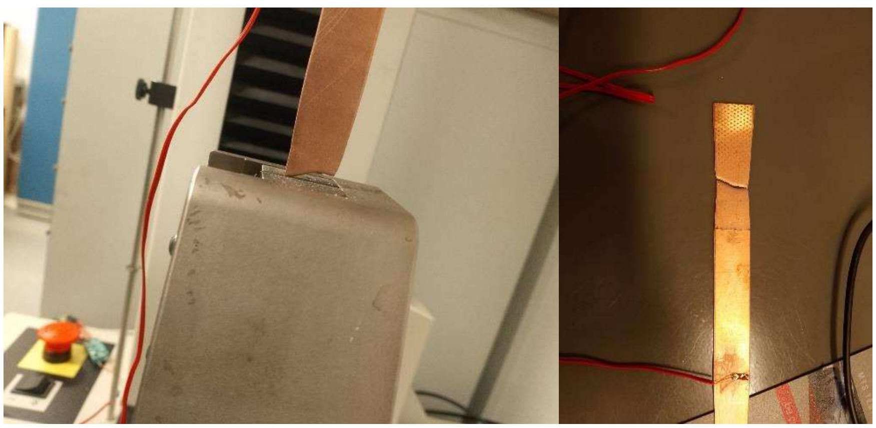

Figure 4. Fracture point of the specimen.

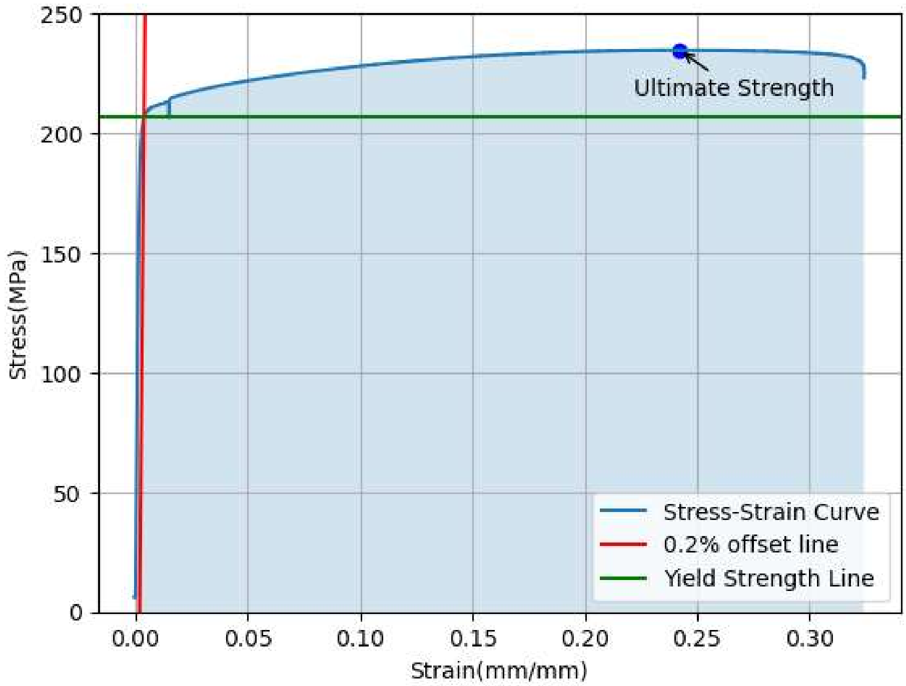

Figure 5. Stress-strain curve for the measured specimen.

Table 2. Calculated mechanical properties for the specimen.

Mechanical Property	**Symbol**	**Value**	**Unit**
Modulus of Elasticity	E	106.2	GPa
Yield Strength	S_y	209.9	MPa
Ultimate Tensile Strength	S_u	254.5	MPa
Ductility	$\%EL$	32.5	%
Elongation at Fracture	A_t	32.4	%
Poisson's ratio	ν	0.29	-
Modulus of Toughness (Simpson's Rule)	u_t	59.0	MPa

5 Discussion

During tensile testing, ideally, stress should be uniformly distributed along the length of the specimen. However, if the stress distribution is non-uniform, areas under higher stress will deform more. This can happen due to several reasons:

- **Grip Design and Application:** If the grips are too tight or their pressure is uneven, they can induce local stresses at the gripping points. These stresses can be significantly higher than those in the middle of the gauge length, leading to early necking and eventual fracture at these locations.
- **Specimen Geometry:** The geometry of the specimen should be designed to ensure that the narrowest section (and therefore the weakest, where failure is expected to occur) is in the middle of the gauge length. If the specimen width or thickness tapers near the grips, or if there is any variation in cross-sectional area, it can lead to higher stress concentrations near the grips. When measuring the width of the specimen it was observed that there was variation of the width along the length of the specimen. The variation is due to the reason that specimens were cut using a cutting machine (most probably using a Guillotine) which could have caused the variation in the width along the length of the specimen.
- **Improper Alignment:** Misalignment of the specimen in the testing machine can lead to bending stresses superimposed on the axial load. This can cause non-uniform loading and higher stress concentrations at certain points, particularly near the grips where the effect of misalignment is often magnified.
- **Friction Between Grips and Specimen:** If there is significant friction between the specimen and the grips, it can restrain the specimen from elongating uniformly. This gripping friction can prevent the portion of the specimen within the grips from elongating as much as the middle section, thereby causing a higher localized deformation and necking near the grips.
- **Data Acquisition from Strain Gauge:** The data that is obtained from the strain gauge is not completely reliable for calculating the Poisson's ratio because after pasting the strain gauge it was observed that the strain gauge direction was not completely perpendicular to the length of the specimen, but was inclined to it at an angle.

6 Conclusions

The specimen given for the test was slightly tapered, which in combination with other possible causes resulted in a fracture between clamping surfaces of the lower clamp. Despite the fracture at a different site in the test, the data was analyzed and aligned well with expected values for the material's mechanical properties. However, further improvements in the data acquired could have been achieved by the precise cutting of the specimen and the correct application of the strain guage.