# Lab Experiment # 2

# Tensile Testing of Metals

The City College of New York
Department of Mechanical Engineering

Sarah Liu
Andrei Fershalov
S1 (2PS)-G2
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**Objective**

The tensile testing of metal lab looked to apply tensile stress at different displacement rate on both aluminum and steel specimens to observe the changes to their mechanical properties. A stress-strain curve is obtained using the gather elongation changes at different loadings to then determine their mechanical properties (yield strength, elastic modulus, tensile strength, elongation percent.

**Equipment/Materials**

- Instron testing machine (Tensile testing machine)
- Extensometer (for more accurate displacement readings)
- Merlin (Data Acquisition software)
- Caliber (Specimen measurement)
- 2 Aluminum Specimen (Alloy 2024-T351).
- 2 Steel 1020 Specimen (Hot Rolled Steel ASTM-A36)

**Experimental Procedure**

1. For all 4 metal specimens used in this lab, mark a 75 mm distance as the gage length and measure the initial diameter of the narrow portion. Each metal type will be tested at two different displacement rates (5 mm/min and 50 mm/min). Record the data for all corresponding material and displacement rate using the caliber
2. Take your first specimen and input the corresponding data related to the specimen into the Merlin software.
3. Place your specimen into the Instron Testing machine, with one end of the specimen in the fixed grip and the other onto the moving grip. Tighten each end securely.
4. For displacement rate of 5 mm/min (the 50 mm/min is omitted to avoid equipment damage), mount the extensometer onto the specimen.
5. Conduct the test, where the extensometer is removed prior to reaching 10% (for the 5 mm/min displacement rate), making note of when the data stops due to removal of the extensometer
6. Repeat the test for all 4 specimens
7. Record the gage length and diameter of specimen at the fracture point
8. Using the data collected, determine the elastic modulus, yield point, ultimate tensile strength and percent elongation.

**Experimental Results**

The equations that will be used to determine the different mechanical properties as well as to plot the engineering and true stress vs strain curves found for each specimen are as follows:

$$Ultimate\ Strength\ (\sigma_{ult}) = \frac{F_{max}}{A_0}$$

$$Elastic\ Modulus\ (E) = \frac{\Delta\sigma}{\Delta\varepsilon}$$

$$Elongation\ \ (EL) = \frac{l_f - l_0}{l_0} * 100\%$$

$$Reducation\ Area\ (RA) = \frac{A_0 - \ A_f}{A_0} * 100\%$$

$$Poisson's\ Ratio\ (v) = (\frac{d_f - \ d_0}{d_0})/(\frac{l_f - l_0}{l_0})$$

$$0.2\%\ Yield\ Stress = \ \varepsilon * \ E$$

$$0.2\%\ Yield\ Strain = \ \varepsilon + 0.002$$

$$\sigma_{true} = \ \sigma\ (\varepsilon + 1)$$

$$\varepsilon_{true} = \ ln(\varepsilon + 1)$$

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|---|---|---|---|---|
| **Date** | | 9/10/24 | **Displacement Rate (mm/min)** | 5 |
| **Material** | | Aluminum | **Extensometer** | yes |
| **Specimen Number** | | 1 | **Date file name** | Al_low_rate |
| **Diameter (mm)** | **initial** | 8.57 | **Fracture Diameter (mm)** | 6.96 |
| | **final** | 8.25 | | |
| **Gage Length (mm)** | **initial** | 75 | | |
| | **final** | 89.64 | | |

| | | | |
|---|---|---|---|
| **Date** | 9/10/24 | **Displacement Rate (mm/min)** | 50 |
| **Material** | Aluminum | **Extensometer** | no |
| **Specimen Number** | 2 | **Date file name** | Al_high_rate |

| | | | | |
|---|---|---|---|---|
| **Diameter (mm)** | **initial** | 8.57 | **Fracture Diameter (mm)** | 7.07 |
| | **final** | 8.27 | | |
| **Gage Length (mm)** | **initial** | 75 | | |
| | **final** | 87.95 | | |

| | | | | |
|---|---|---|---|---|
| **Date** | | 9/10/24 | **Displacement Rate (mm/min)** | 5 |
| **Material** | | Steel | **Extensometer** | yes |
| **Specimen Number** | | 3 | **Date file name** | Stl_low_rate |
| **Diameter (mm)** | **initial** | 8.54 | **Fracture Diameter (mm)** | 5.48 |
| | **final** | 8.47 | | |
| **Gage Length (mm)** | **initial** | 75 | | |
| | **final** | 80.72 | | |

| | | | | |
|---|---|---|---|---|
| **Date** | | 9/10/24 | **Displacement Rate (mm/min)** | 50 |
| **Material** | | Steel | **Extensometer** | no |
| **Specimen Number** | | 4 | **Date file name** | Stl_high_rate |
| **Diameter (mm)** | **initial** | 8.59 | **Fracture Diameter (mm)** | 5.95 |
| | **final** | 8.57 | | |

| | | | | |
|---|---|---|---|---|
| **Gage Length (mm)** | **initial** | 75 | | |
| | **final** | 81.05 | | |

Table 1: Testing data corresponding to each tested specimen

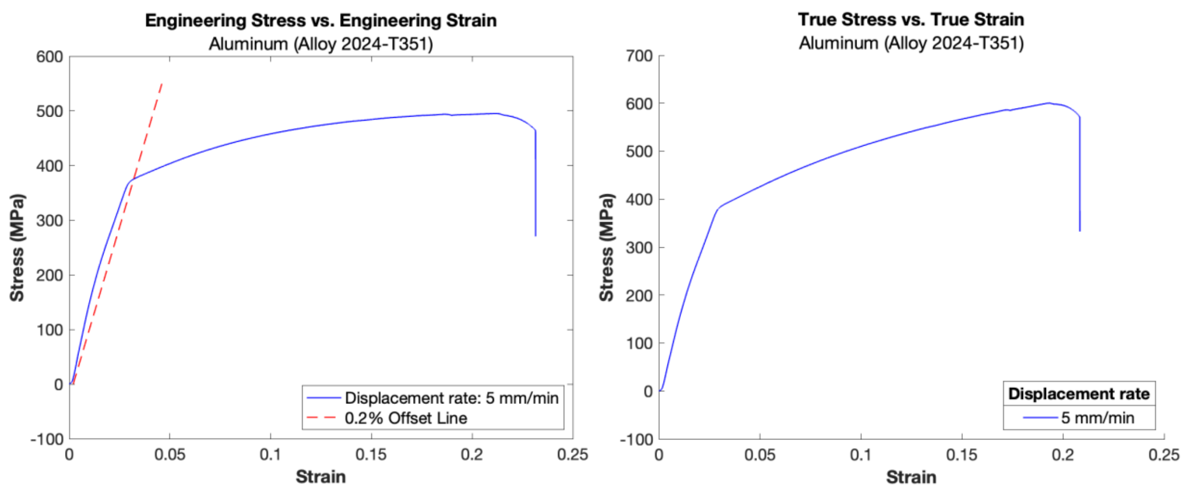


Figure 1: Specimen 1 Engineering stress strain curve (left) and True stress strain curve (right) under tension at a displacement rate of 5 mm/min

$$\sigma_{ult} = 494.418\ MPa$$

$$E_{true} = \frac{382.576\ MPa}{0.03004}$$

$$E_{true} = 12.733\ GPa$$

$$E_{eng} = \frac{366.47\ MPa}{0.0293447}$$

$$E_{eng} = 12.488\ GPa$$

$$EL = \frac{89.64\ mm - 75\ mm}{89.64\ mm} * 100\%$$

$$EL = 16.33\ \%$$

$$RA = \frac{(4.285^2\pi) - (4.125^2\pi)}{(4.285^2\pi)} * 100\%$$

$$RA = 7.33\ \%$$

$$v = \left(\frac{8.25\,mm - 8.57\,mm}{8.57\,mm}\right) / \left(\frac{89.64\,mm - 75\,mm}{89.64\,mm}\right)$$

$$v = 0.229$$

Yield point observed at stress of $375.048\ MPa$

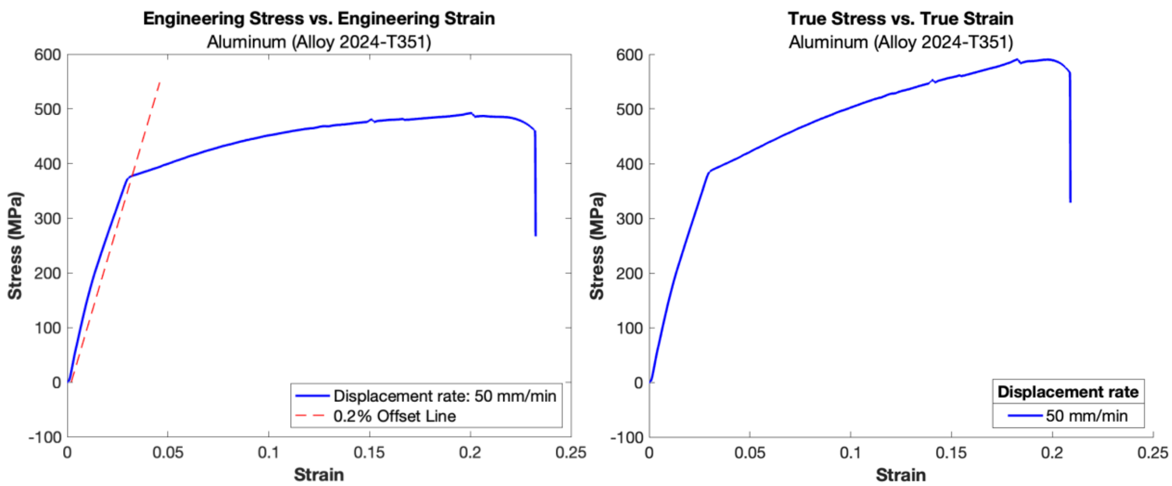


Figure 2: Specimen 2 Engineering stress strain curve (left) and True stress strain curve (right) under tension at a displacement rate of 50 mm/min

$$\sigma_{ult} = 489.612\ MPa$$

$$E_{true} = \frac{385.251\ MPa}{0.02999}$$

$$E_{true} = 12.845\ GPa$$

$$E_{eng} = \frac{373.87\ MPa}{0.0304416}$$

$$E_{eng} = 12.281\ GPa$$

$$EL = \frac{87.95\,mm - 75\,mm}{87.95\,mm} * 100\%$$

$$EL = 14.724\ \%$$

$$RA = \frac{(4.285^2\pi) - (4.135^2\pi)}{(4.285^2\pi)} * 100\%$$

$$RA = 6.879\%$$

$$v = (\frac{8.27\ mm - \ 8.57mm}{8.57\ mm})/\frac{87.95\ mm - 75\ mm}{87.95\ mm})$$

$v = 0.2377$

Yield point observed at stress of 377.348 $MPa$

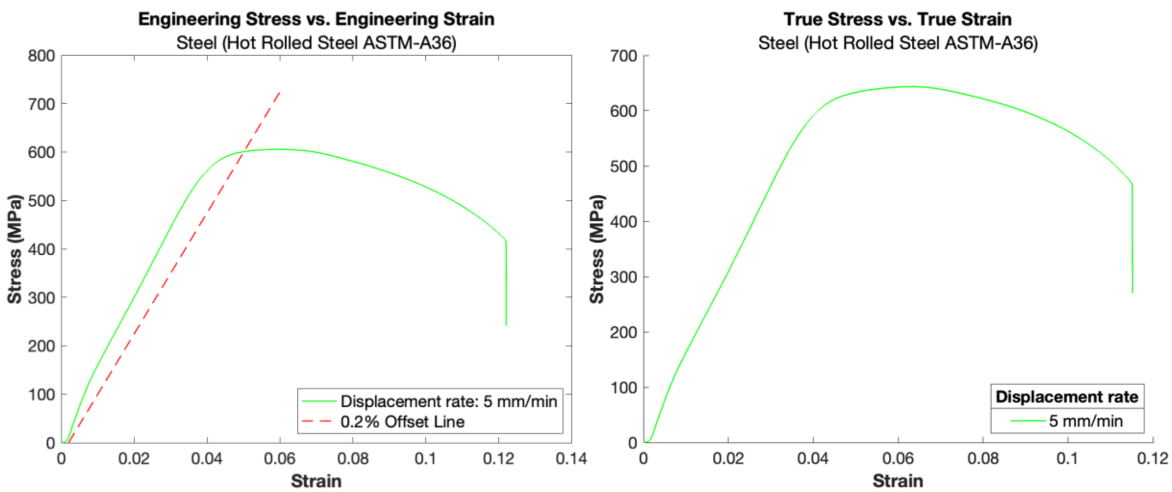


Figure 3: Specimen 3 Engineering stress strain curve (left) and True stress strain curve (right) under tension at a displacement rate of 5 mm/min

$\sigma_{ult} = \ 605.43\ MPa$

$$E_{true} = \frac{603.279MPa}{0.0416438}$$

$E_{true} = 14.486\ GPa$

$$E_{eng} = \frac{597.612\ MPa}{0.0461224}$$

$Eeng$=12.957 $GPa$

$EL$= 80.72 $mm$−75 $mm$80.72 $mm$∗100%

$EL$=7.086%

$RA$= (4.272$\pi$)− (4.2352$\pi$)(4.272$\pi$)∗100%

$RA$=1.633 %

$v$=(8.54 $mm$− 8.47$mm$8.47 $mm$ )/(80.72 $mm$−75 $mm$80.72 $mm$)

$v$=0.11567

Yield point observed at stress of $601.204\ MPa$

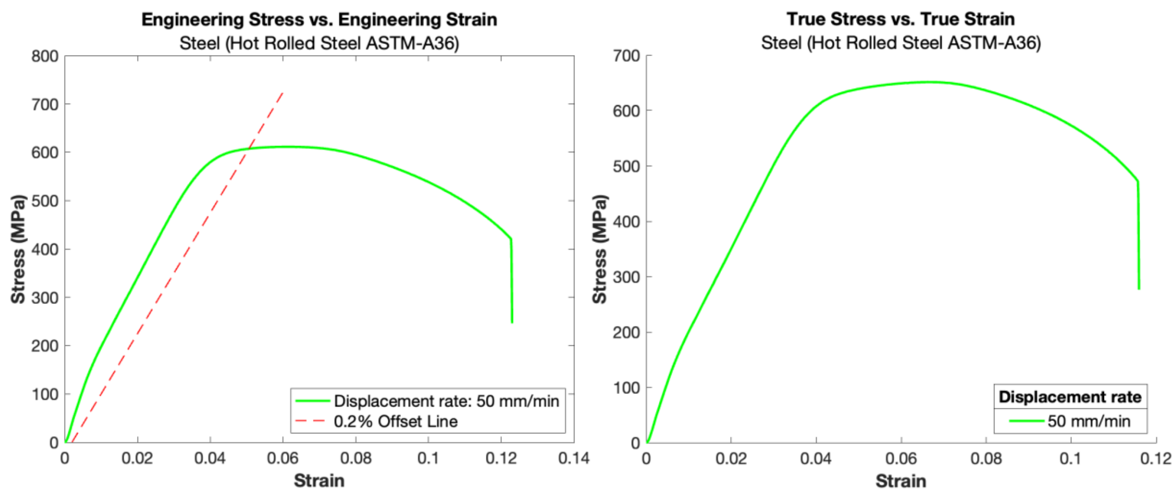


Figure 4: Specimen 4 Engineering stress strain curve (left) and True stress strain curve (right) under tension at a displacement rate of 50 mm/min

$\sigma_{ult} = 608.449\ Mpa$

$$E_{true} = \frac{606.715MPa}{0.03986}$$

$E_{true} = 15.220\ GPa$

$$E_{eng} = \frac{590.135\ MPa}{0.0428922}$$

$E_{eng} = 13.758\ GPa$

$$EL = \frac{81.05\ mm - 75\ mm}{81.05\ \ mm} * 100\%$$

$EL = 7.465\%$

$$RA = \frac{(4.285^2\pi) - (4.268^2\pi)}{(4.285^2\pi)} * 100\%$$

$RA = 0.792\ \%$

$$v = (\frac{8.57\ mm - 8.59mm}{8.59\ mm})/\frac{81.05\ mm - 75\ mm}{81.05\ \ mm})$$

$v = 0.03119$

Yield point is observed at $607.774\ MPa$

Figure 5: Specimen after breaking with tensile test. The order of the materials are as following: Specimen 4 (top), Specimen 3 ($2^{nd}$ down), Specimen 2 ($3^{rd}$ down) and Specimen 1 (last down).

**Discussion of Results**

This lab looked to find the elastic modulus, Elongation Percent, Reduction in Area and the Poisson's Ratio of aluminum and steel specimen under the displacement rates of 50 mm/min and 5 mm/min. It can be observed that with there is not much of a correlation between the Elastic modulus value and the displacement rates as they do not change in any pattern observed in this experiment. For steel, the E value is observed to be $13.758\ GPa$ and $12.957\ GPa$ at high and low displacement rate and for aluminum, $12.281\ GPa$ and $12.488\ GPa$ at high and low displacement rate. Although this conclusion is trivial as each specimen was only tested once for each displacement rate. To observe for possible correlations, more trials at different displacement rates as well as use of different materials must be considered.

The Poisson's Ratio of Aluminum is found to be 0.2377 and 0.229 for high and low displacement rates respectively. As for steel, the value is observed to be 0.03117 and 0.11567 high and low displacement rates respectively. Steel having a calculated lower Poisson's Ratio classify the material as less likely to have lateral deformation with the applied force. It is important to note due to limited testing, the values found do not tend to match the range of observed Poisson's Ratio of metals in both the aluminum and steel specimens. Typical metal Poisson's Ratio is observed around 0.28 and 0.33 for steel and aluminum respectively [7]. Other sources of these discrepancy can be noted as possible defection during manufacturing and the measurement process.

A higher yield point is observed in both displacement rates of the steel specimen than the aluminum. A higher yield point indicated a likelihood of less plastic deformation region, with brittle materials having even higher yield points. As observed, steel is found to have a yield point at a stress of $597.612\ MPa$ and $590.135 MPa$, and for aluminum, a yield point at stress of $373.87\ MPa$ and $366.47\ MPa$.

**Conclusion**

This lab looks to obtain the different mechanical properties of materials (aluminum and steel) under 2 different displacement rates. Based on the results of this experiment, it can be observed that the mechanical property of a material is dependent on both the displacement rates and strain and stress experienced by the materials. Properties can be derived from such data and can be used to make observations in terms of the materials by a simple tensile test. Through just the collection of data regarding elongations at different loads, simple dimensions of the specimens, the material properties of the specimen can be found to help classify the material itself.

**Review Questions**

**1. What divides the engineering stress-strain curve into two regions, namely, the elastic and plastic regions?**

The yield point signifies the divide between the elastic and plastic region. The yield point, a material property, is the stress in which the specimen can reach before it reaches a plastic deformation. Once a material reaches the plastic region, it cannot return to its original state when the load is removed.

**2. What is the difference between the behavior of the material in the elastic and plastic regions of the engineering stress-strain curve?**

A material in the elastic region does not deform permanently as once the load is removed, it will return to the shape at its resting state. The plastic region is the state at which a plastic (permanent) deformation occurs.

**3. What measurement should you have taken to be able to plot the true stress-true strain curve?**

The true stress and strain consider the changing cross-sectional area of the material as it is under tension. A measurement of the change in diameter during the testing in tangent with the other measurements must be taken to obtain true curve.

**4. Why does low carbon steel have clear upper and lower yield points? Why doesn't the aluminum have the same? Explain the differences using your knowledge of the alloying and dislocation theories.**

Aluminum and low carbon steel has different crystal structure, resulting in the different yield points observations. A low carbons steel is a BCC (body centric cubic) crystal structure in which dislocations piles up during the plastic deformation regions. The buildup leads to the dislocations to be freed from carbons. A sharp and prominent distinctions of the two-yield point can be observed in this freed region. The alloying of Aluminum does not display the same effects for Aluminum. As Aluminum is an FCC (face centric cubic) structure, in which dislocations move more freely [6].

**5. Did you observe parallel lines inclined about 45o with the horizontal on the surface of the steel specimen, and in the area where necking later took place? What are those lines called? What do they reveal about the mechanism of deformation? Apply Schmid's Law.**

The observed horizontal lines on the specimens (figure 5) are due to shear stress acting upon the specimen. Such lines appear after expensive plastic deformation reaches the critical shear stress values, for a uniaxial load (in which is the case for this experiment) as explained through Schmid's law. [4]

**6. Could you observe any similar lines on the aluminum specimen? What is the mechanism of deformation in this latter case?**

These slip lines can be observed through the Aluminum specimens (figure 5) as well. Such observations can conclude that the two materials experiences similar mechanism.

**7. Obtain the area under the load-extension curve (i.e., energy) for each specimen and divide it by the volume between the gage length in order to obtain the modulus of toughness. Compare the value of plain carbon steel and that of aluminum. Can you draw any conclusion?**

To obtain the area, use of the trapezoidal rule for the area up to the point of fracture in used in the steel and aluminum specimens. For steel at low displacement rate, it is found to be 57.42175 MPa. For aluminum, the area is found to be 67.76004 MPa. The modulus of toughness of the steel per volume is then found to be 13.2727 Pa/m. The modulus of toughness of the aluminum is found to be 15.7728 Pa/m. With the aluminum displaying a higher modulus of toughness, it indicates the material can take on more strain before failure. More energy is absorbed by the material prior to breakage [8].

**8.Looking at the curve indicating the distribution of elongation along the gage length, where did the maximum localized elongation take place?**

It can be observed for the curves that maximum localized elongation occurs around the midpoint of the curve. Such point can be observed to be the starting point to the necking phase in which the material is said to break after reaching that maximum point.

**9. How do you interpret the shape of the above-mentioned curve?**

The curve reaching the point of maximum elongation takes place in the plastic deformation domain of the material. Such region shows an positive correlation to elongation with increase load. Once the curve reaches that maximum elongation point, the curve begins the necking phase. Once necking appears, the material can be observed to break after.

**10. What effect does the high strain rate have on the mechanical properties mentioned below?**

High strain rate indicates a brittle material. Having large strain in a short amount of time means less yielding prior to breakage. That characterizes its mechanical properties of Elastic modulus, elongation percent and modulus of toughness to all decrease due to lower ductility. Yield stress is observed to be increase at high strain rates as the material is more resistant to plastic deformation in brittle materials [5].

**11. Did the high strain rate have an effect on the mode of failure of any of the specimen? Why?**

Higher strain rate causes yielding to occur earlier. To observe if any of the materials are affected by the change in strain rate, the higher displacement rate yield point is compared with the lower displacement rate. As seen in both specimens, the change in yield point is not much different.

## References


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[4] Seeger, A. (2001). Why anomalous slip in body-centred cubic metals? *Materials Science and Engineering: A*, *319–321*, 254–260. https://doi.org/10.1016/s0921-5093(01)00958-3

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