LAB 1 - Uniaxial Tensile Test
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- **OBJECTIVE :**

Perform a *uniaxial tension test* on a dog-bone-shaped tensile specimen. Plot stress vs. strain curve for the specimen and analyze material behavior by identifying key material parameters.

- **INTRODUCTION AND THEORY :**

This is an ASTM E8 test: The ASTM E8 method covers the **tension testing of metallic materials in any form at room temperature**, specifically, the methods of determination of yield strength, yield point, tensile strength, and elongation.

A uniaxial Tensile test is used to characterize the engineering material and here we will find how the material deforms when it is elongated axially. We will observe how the material deforms in the elastic region elastoplastic region, ultimate tensile stress, and how the material fractures at the end.
When stresses are applied uniaxially (along X say), we have:

$$\sigma_{xx} = E * \varepsilon_{xx}$$

σ_{xx} -- Stress along X-axis
ϵ_{xx} -- Strain along X-axis
E -- Young's Modulus (or Shear Modulus)

From the data points of the experiment we will plot the stress vs strain curve which will be used to characterize the following mechanical properties of the material:

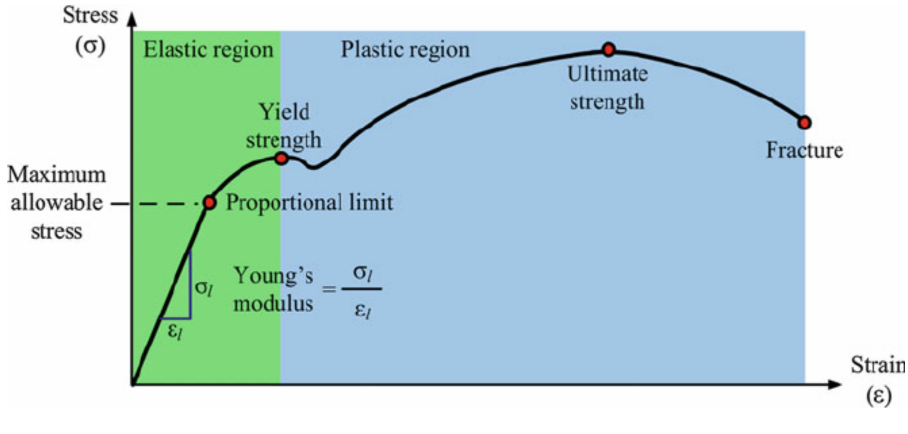
1. ***modulus of elasticity (E)***
2. ***Yield strength***
3. ***Ultimate Tensile Stress***
4. ***Fracture Point***
5. ***The toughness of the material***
6. ***Ductility of the material.***

We are provided a cylindrical dog bone-shaped specimen (made up of Aluminium 6000 series alloy). Computer Controlled Screw driven electromechanical Universal Testing Machine (UTM) is used for Uniaxial Tensile testing.
There are two methods to measure the strain:

1. By using the Deformation of the upper crosshead (of the UTM)
2. Using extensometer

$$strain, \varepsilon = \frac{\Delta(length)}{original\ length}$$

- General Strain vs Stress curve (for Metal) :

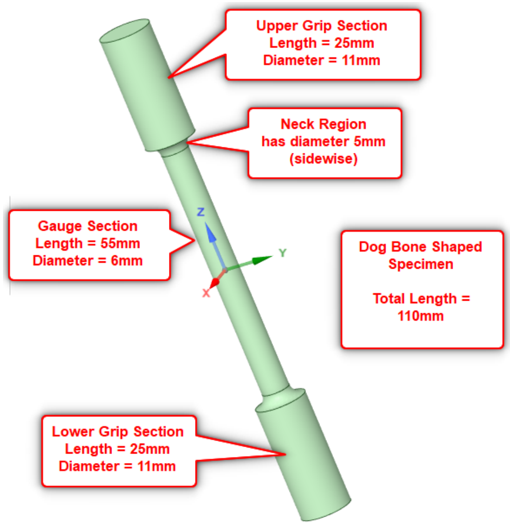


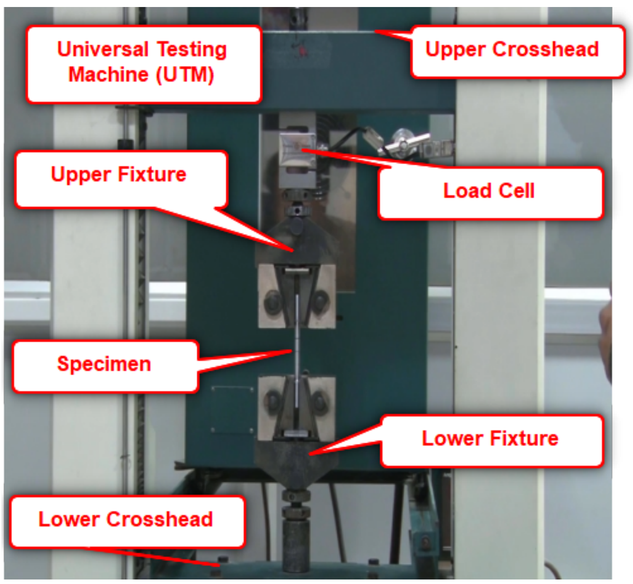
- Concept of Engineering and True - Stress and Strain :

P = load	P = load
A_o = initial cross-sectional area	A_i = instantaneous cross-sectional area
Engineering Stress = s = P/A_o	**True Stress = σ = P/A_i**
l_o = initial length of gauge section	l_i = instantaneous gauge length
l = length of deformed gauge section	l_o = initial length of gauge section
Δl = l - l_o = change of length of gauge section	
Engineering Strain = e = (l-l_o)/l_o = Dl/l_o	**True Strain = ε = ln (A_o/A_i) = ln (l_i/l_o)**
Converting Engineering Stress to True Stress:	**σ= s (1+e)**
Converting Engineering Strain to True Strain:	**ε = ln (1+e)**

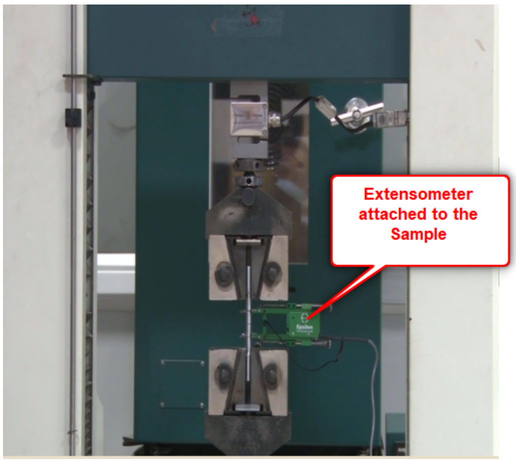
- **EQUIPMENT AND OPERATING CONDITIONS :**
    1. Dog-bone shaped test specimen (made up of Aluminium - 6000 series alloy)
        - Length of the Gauge = 55mm
        - Length of the Upper Grip = 25mm
        - Length of the Lower Grip = 25mm
        - (sidewise) Radius of the Neck section = 2.5mm
            - Total Length of the Specimen = (25 + 2.5 + 55 + 2.5 + 25)mm = 110mm

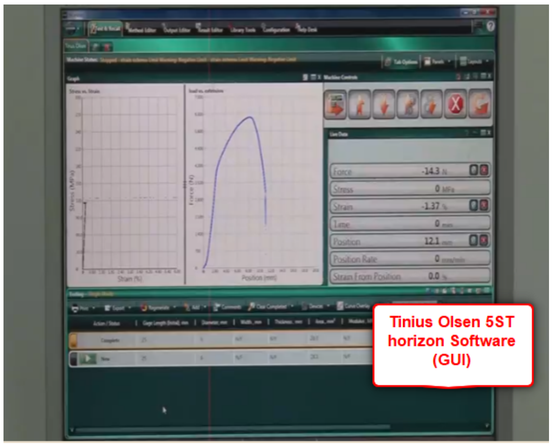
    2. Computer-controlled Tinius Olsen Universal Testing Machine (UTM)
       UTM consists of several parts:
        - Lower Crosshead -- Fixed
        - Upper Crosshead -- Movable. It senses the deformation in the material
        - Lower fixtures
        - Upper fixtures
        - Load cell -- senses (measures) the applied load





    3. Compatible Software installed in Computer (Tinius Olsen 5ST horizon)
    4. Extensometer
        - Its knobs are placed 25mm apart. It measures the deflection of the specimen between these two points
    - Crosshead Velocity for this test ≈ 1 mm/min





- **PROCEDURE AND MEASUREMENT :**

1. Switch on the 10 kN Tinius Olsen universal testing machine (UTM).
2. Hold the dog-bone-shaped test specimen at the UTM grips and carefully mount a 25 mm extensometer in between the gauge length region of the specimen.
3. Load the specimen in displacement control mode at 1mm/min Crosshead velocity.
4. We will input all the necessary input parameters in the Tinius Olsen 5ST horizon software compatible with the test system.
4. The software records the load vs. crosshead displacement data and the stress vs. strain data.

5. Once %strain reaches 0.2% one should remove the extensometer from the specimen *(We will be using the Stress vs extensometer data up to this point to calculate the elastic modulus, E)*
6. Continue loading the specimen until failure is observed.

7. Plot the stress vs. strain curve From the .CSV data file.
8. Analyze and discuss the material behavior from the stress-strain plot. Determine the desired material characteristics.

9. Compare the experimental value of elastic modulus with the published data for the specimen-in-consideration. Calculate the percent differences between the measured and published values.

10. Identify sources of errors in your experiments/measurements.

- **RESULTS AND DISCUSSION :**

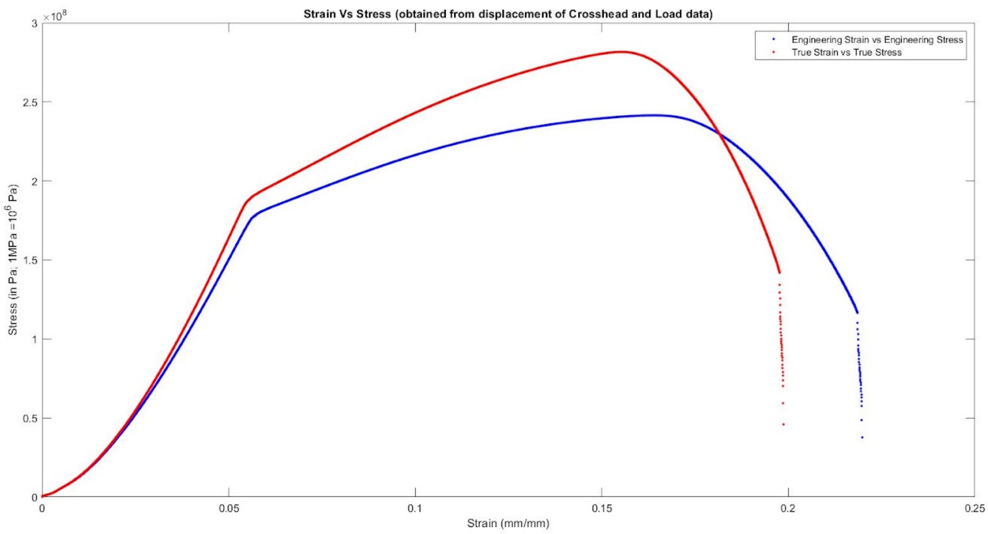
(a) Calculations and Plots

Data Used G1.csv
Total DataPoints in the file -- 5498
Column A -- Time Stamp (in sec)
Column B -- Force data (in N)
Column C -- Displacement of crosshead (in mm)
Column D -- Strain data Calculated by Extensometer (mm/mm)
Column E -- Engineering Stress data; A0 = CrossSection Area of Gauge section (in MPa)

- ***I am using MatLab Script to analyze and plot the Data***

1. Plot of the Stress vs Strain data [all 5498 datapoints]

- obtained using columnB and columnC [strain calculated from Displacement of crosshead]



$$Engineering\ Stress\ = \frac{Force\ (ColumnB)}{A_0}$$

A_0 = Original Cross Section area of the Gauge Section = $\pi * \frac{(0.006)^2}{4}$ m^2

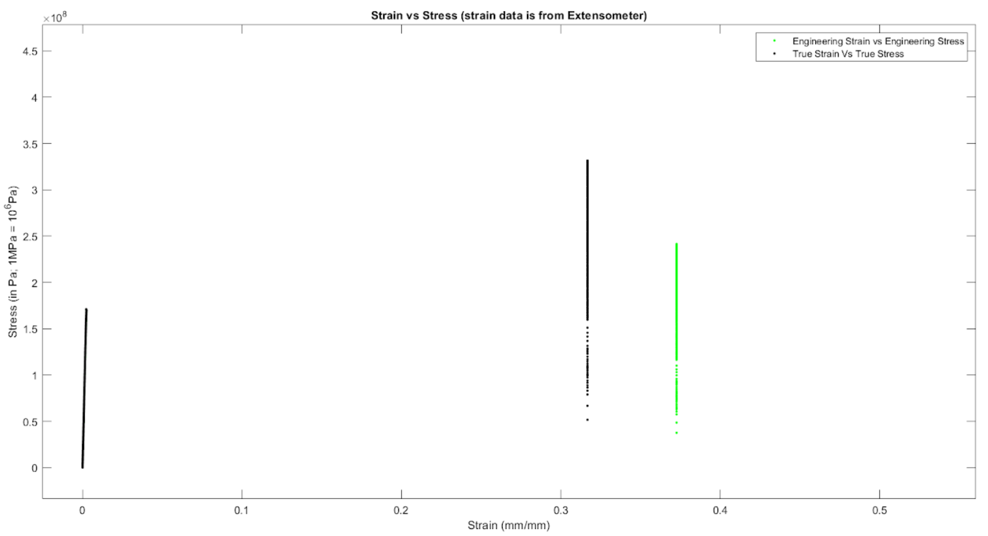
$$Engineering\ Strain\ = \frac{displacement\ data\ of\ crosshead\ (ColumnC)}{L_0}$$

L_0 = Original length of the Dogbone shaped specimen = 55mm **(I am assuming extremely small deformation in the larger cross-section region. However its a very crude approximation)**

$$True\ Stress\ = Engineering\ Stress\ * (1 + Engineering\ Strain)$$

$$True\ Strain\ = ln(1 + Engineering\ Strain)$$

- Obtained using ColumnD and ColumnE [strain calculated from extensometer]

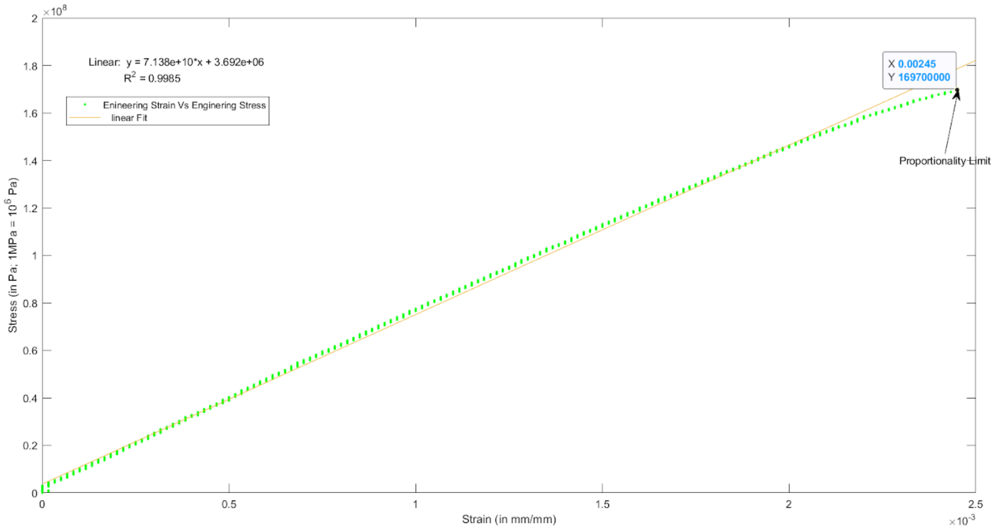


The True Strain and stress overlap with engineering strain vs stress for the first 1385 datapoints

2. Elastic Modulus, E :

Elastic Modulus, E= Slope of the Linear Fit Line (for the region where the material behaves approximately linearly)

We will use the extensometer data for the first 1385 points.



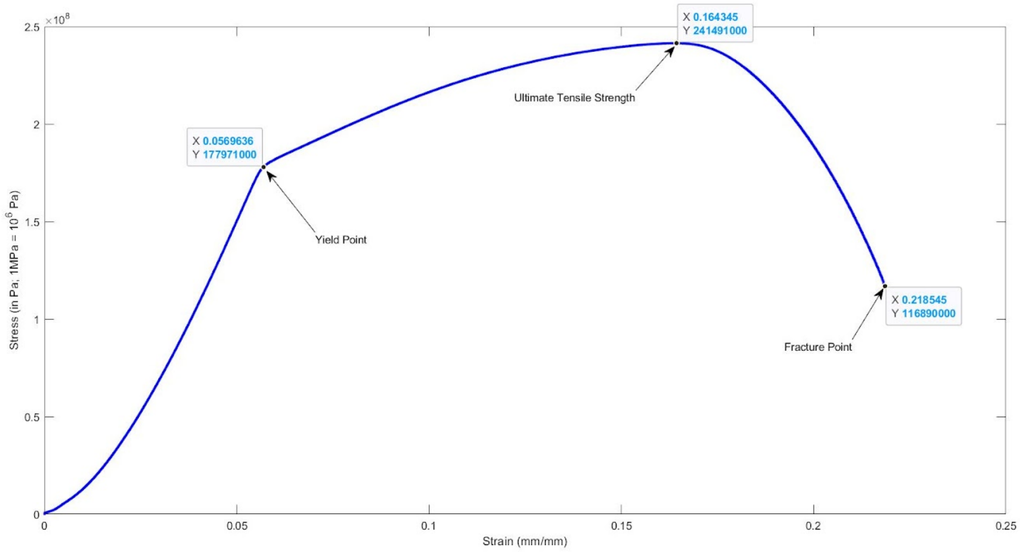
The equation of Linear Fit for the datapoints: $y = 7.138 * 10^{10}\ x\ +\ 3.692 * 10^{6}$
From the slope of the equation: Elastic modulus $E = 7.138 * 10^{10}\ Pa\ =\ 71.38GPa$

Elastic modulus, E = 71.38 GPa

3. Proportionality Limit :
Proportionality Limit is obtained from the above curve as well.

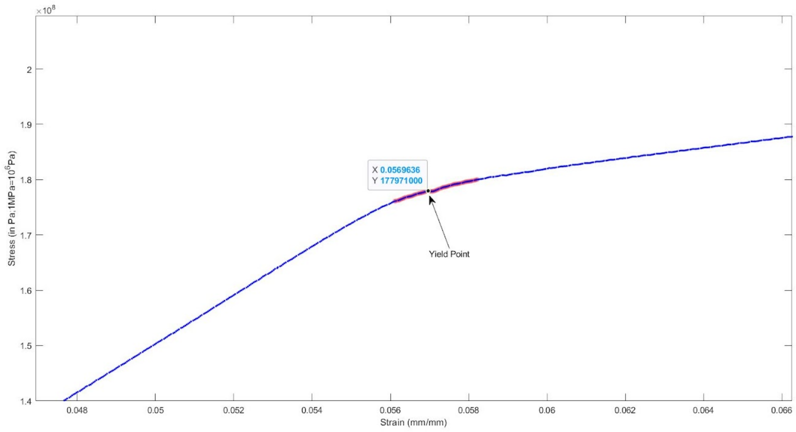
At the Proportionality Limit -
Stress = 169.700000 * 10^6 Pa = 169.700 MPa
Corresponding strain = 0.00245

From now on we will be using the strain calculated from displacement of crosshead data to obtain *Yield Point, UTS, and fracture point*. This is because the Extensometer is released once strain ≈ 0.002.
We will use the first 5467 data points only



Yield Point, UTS, and Fracture Point marked in the Engineering Strain Vs Engineering Stress curve

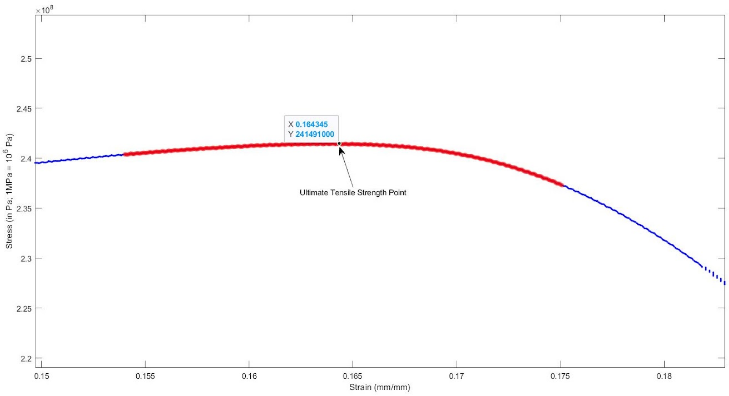
4. Yield Point :



Yield Stress = 177.971000 * 10^6 Pa = 177.971 MPa
Corresponding strain = 0.0569636

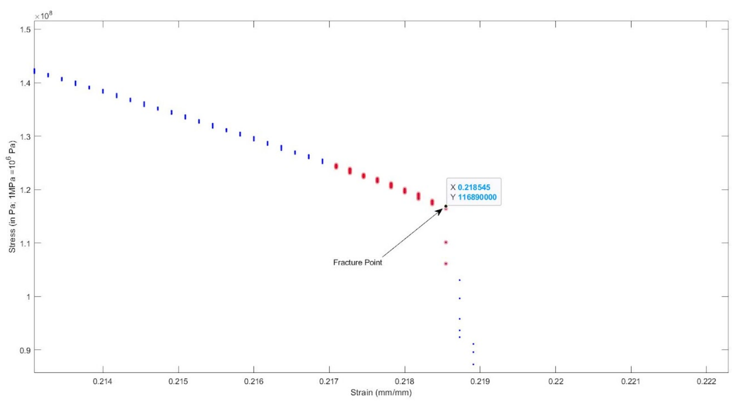
NOTE: In general we use the %0.2 offset method to determine the Yield strength for Aluminum-based alloys. However, I had not used that because there was added complexity in the data due to the removal of the extensometer.

5. Ultimate Tensile Strength :



Ultimate Tensile Stress = 241.491 * 10^6 Pa = 241.491 MPa
Correspoding Strain = 0.164345

6. FracturePoint :



Failure Stress = 116.89 * 10^6 Pa = 116.89 MPa
Corresponding Strain = 0.218545

- Elastic Zone Limit: It is till the Yield Point

- **Plastic Zone Limit:** It starts from the Yield Point and ends at the Fracture Point

b. Discussion and error analysis :

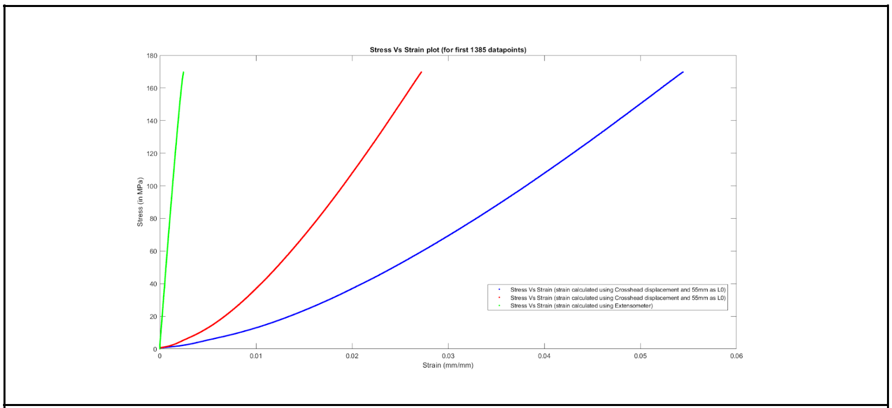
--mechanical properties for an aluminum6061 alloy (collected from Net)--

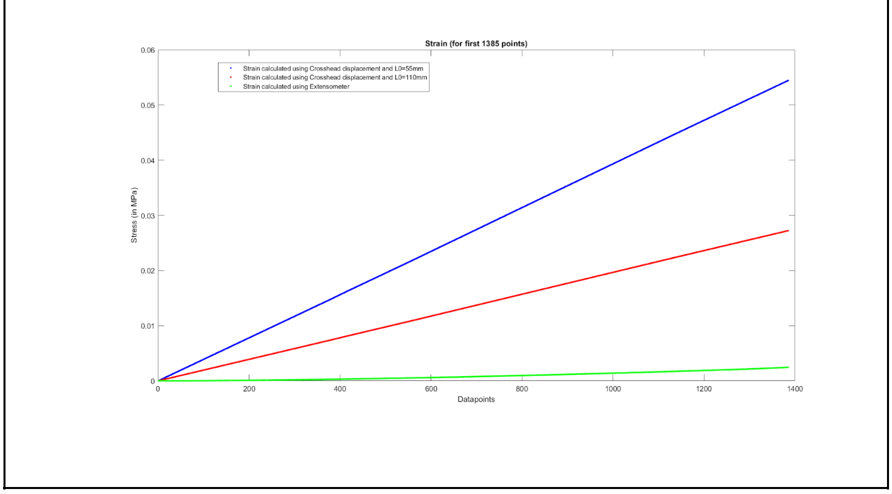
Mechanical Properties	Metric
Ultimate Tensile Strength	310 MPa
Tensile Yield Strength	276 MPa
Shear Strength	207 MPa
Fatigue Strength	96.5 MPa
Modulus of Elasticity	68.9 GPa

% Error formula = |Approximate value – Exact Value|/Exact value * 100.

% Error in Modulus of elasticity, (wrt E of Al6061 alloy) = $\frac{71.4-68.9}{68.9} * 100 \ = 3.63\%$

- **The extensometer data have to be used to calculate the Shear Modulus, E and not the data from the Crosshead displacement.**
  Because of the different CrossSection areas, the extension in the grip and the gauge part will be different. This variation can't be incorporated simply by considering L0 to be 110 mm or 55mm (as is evident from the plot below).



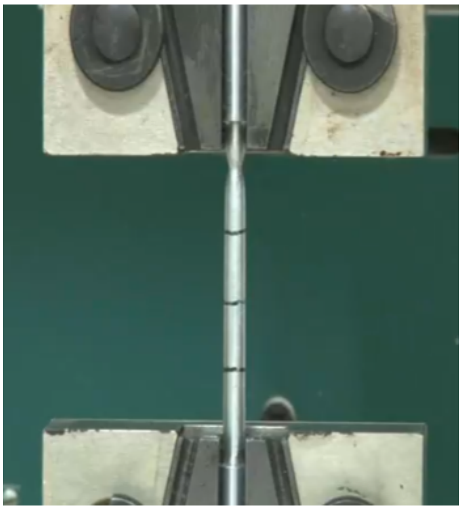
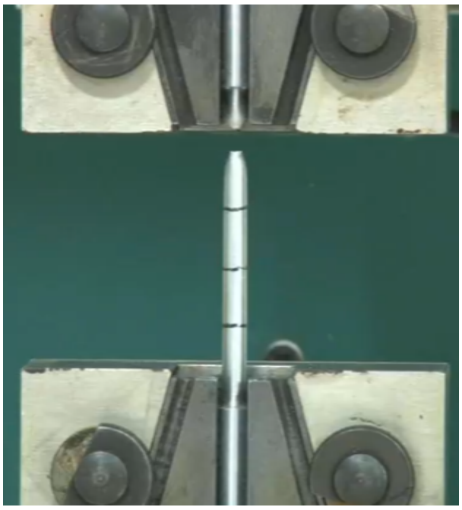


It can be shown that E green = 71.38 GPa , E blue = 3.22 GPa , E red = 6.46 GPa

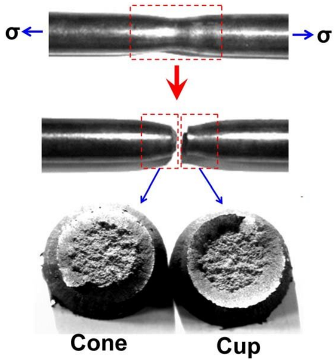
% Error in Modulus of elasticity E blue, (wrt E green) = $\frac{71.4-3.2}{71.4} * 100 \ = 95.5\%$

% Error in Modulus of elasticity E red, (wrt E green) = $\frac{71.4-6.5}{71.4} * 100 \ = 90.9\%$

- **About the Cup and Cone Failure Observed :**

	
“Necking” is Formed at Top half region	The material Fractures

A cup and cone fracture is a type of failure observed in ductile metals and plastics that are subjected to a uniaxial force. It is essentially the separation of a body into two separate pieces due to the application of excessive tensile stress



- **Ductility :**
  The large plastic zone indicates that the given sample is ductile, A characteristic typical of Aluminium alloys
- **Toughness:** Can be calculated by evaluating the area under the Stress vs strain curve

- **Conclusion :**

--Summary of the Mechanical Properties of the Given Sample--

Mechanical Properties	**Values**
Elasticity Modulus (E)	71.380 GPa
Proportionality Limit	169.700 MPa, Corresponding strain = 0.002
Yield Point	177.971 MPa, Corresponding strain = 0.057
Ultimate Tensile Strength	241.491 MPa, Correspoding Strain = 0.164
Fracture Point	116.89 MPa, Corresponding Strain = 0.218
%elongation up to fracture	21.8%

*(Reporting data up to 3 significant digits)

- **References :**

  - **https://www.thomasnet.com/articles/metals-metal-products/6061-aluminum/**
  - **https://www.youtube.com/watch?v=dKTePNwxmnM**
  - **https://en.wikipedia.org/wiki/Shear_strength**
  - **Source of Images: Lectures and google**

- **Appendix :**

The Matlab code used:

```
%% G1 excel sheet:
% Total DataPoints -- 5498
% Column A -- Time Stamp (in sec)
% Column B -- Force data (in N)
% Column C -- Displacement of crosshead (in mm)
% Column D -- Strain data Calculated by Extensometer (mm/mm)
% Column E -- Engineering Stress data; A0 = CrossSection Area of
Gauge section (in MPa)

%% Defining the Variables [using ColumnB and ColumnC Data]
% X1_E --> Engineering Stress || Y1_E --> Engineering Strain
% X2_T --> True Stress || Y2_T --> True Strain

X1_E = Positionmm./55;
Y1_E = ForceN./(pi*(0.006)^2/4);

X1_T = log(1+X1_E);
Y1_T = Y1_E.*(1+X1_E);

%% Obtaining relevant data
p= 1;
q = 5467;
X1_E = X1_E(p:q);
Y1_E = Y1_E(p:q);


X1_T = X1_T(p:q);
Y1_T = Y1_T(p:q);

X= X1_E;
%Y= (X-0.002).* 7.5*010800737 * 10^9;
Y= (X-0.002).* 8*10^9;

%% Plotting the data
plot(X1_E,Y1_E,'.b')%,X1_T,Y1_T,'.r');
hold;

%% Defining the Variables [using ColumnE and ColumnD Data]
% X2_E --> Engineering Stress || Y2_E --> Engineering Strain
% X2_T --> True Stress || Y2_T --> True Strain

X2_E = Strainmmmm;
Y2_E = StressMPa.*(10^6);

X2_T = log(1+X2_E);
Y2_T = Y2_E.*(1+X2_E);

%% Obtaining relevant data

X2_E = X2_E(p:q);
Y2_E = Y2_E(p:q);

X2_T = X2_T(p:q);
Y2_T = Y2_T(p:q);

% plot(0.00245,169700000,'.g');
plot(0.0284818,177971000,'og');
plot(0.0821727, 241491000,'og');
plot(0.109273,116890000,'og');
hold

%plot(X2_E,Y2_E,'.g')%,X2_T,Y2_T,'.k');
%hold;
```

```
Strain_CrossHead_110 = Positionmm./110;
Strain_CrossHead_55 = Positionmm./55;
Strain_Extenso = Strainmmmm;
Stress = StressMPa;

p = 1385;

Stress=Stress(1:p);
Strain_CrossHead_110 = Strain_CrossHead_110(1:p);
Strain_CrossHead_55 = Strain_CrossHead_55(1:p);
Strain_Extenso = Strain_Extenso(1:p);
X = (1:p);

plot(X,Strain_CrossHead_55,'.b',X,Strain_CrossHead_110,'.r',X,Strain_Extenso,'.g');
%plot(X,Strain_CrossHead_55,'.b',X,Strain_Extenso,'.g');
hold;
```

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