University of Wollongong Dubai
Materials in Design (ENGG 103) Laboratory

EXPERIMENT 2: TENSILE TESTING

1. Objectives:

The objectives of this experiment are to gain experience conducting tensile tests using a Universal Testing Machine (UTM) to obtain and analyze stress-strain curves for different materials.

2. Background

The tensile test is widely used to evaluate the mechanical properties of metals and polymers for engineering applications. Whilst the tensile test is commonly used for metals and polymers, the stress strain behavior of ceramics are normally measured under compression simply because ceramic materials are very brittle and weak under tension and more meaningful stress/strain data can be acquired by performing compression tests.

In the tensile test a dog-bone shaped sample (see Figure 3) is stretched under tension until failure. The elongation of the sample until fracture is recorded as a function of applied load and the data is converted into an engineering stress/strain curve, see Figure 1. A dog-bone shaped sample is used to prevent failure occurring at the clamped ends and to constrain the failure zone near the centre of the sample, where conditions are more controlled. The main properties that can be measured in a tensile test are; the **Young's Modulus**, the **yield or proof stress** (or strength), the **tensile strength (UTS)**, the **% elongation** and the **% reduction in area**. Figure 1 shows a typical engineering stress-strain curve for a metal. Apart from the % reduction in area all the properties mentioned above can be determined graphically from the stress-strain curve (see Figure 1).

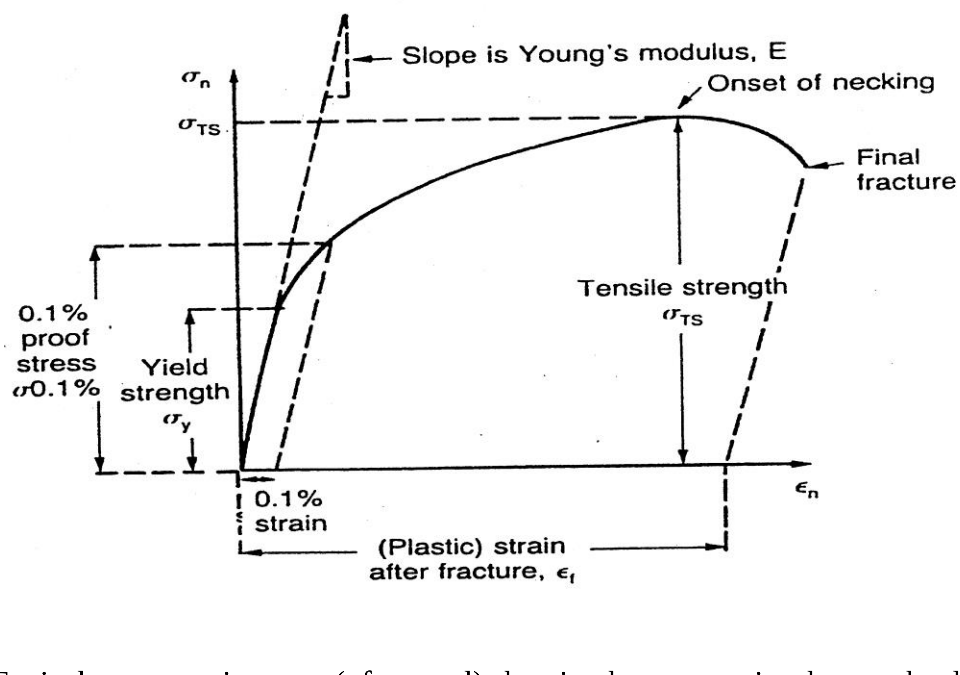


Figure 1: Typical stress-strain curve (of a metal) showing key properties that can be determined.

Engineering stress (σ) is the applied forced (F in Newton's) divided by the original cross sectional area (A_o) of the sample. If the applied force were divided by the instantaneous cross sectional area, the stress would be called true stress.

$$\sigma = \frac{F}{A_o}$$

Engineering strain (ε) is simply the ratio of the 'length extension' (Δl) divided by the original length (l_o), sometimes expressed as a percentage extension.

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

The **Young's Modulus (E)** is calculated from the initial slope of the engineering stress/strain curve;

$$E = \frac{\sigma}{\varepsilon}$$

It is a measure of the elasticity (or recoverable strain) within the material. Young's modulus can be directly related to the stretching of inter-atomic bonds, and is sometimes described as the stiffness of a material.

The **yield stress** is the '*elastic limit of the material'* that is – the stress at which the material begins to yield plastically. Any stress below the yield stress causes fully recoverable elastic deformation (through bond stretching), any stress above the yield stress will cause the inter-atomic bonds to be broken and reformed in a mechanism causing permanent deformation, not recoverable once the stress is removed.

Sometimes the yield stress can be difficult to identify on the stress/strain curve, in such instances a **proof stress** is used, proof stress is defined as the intersection of the stress/strain curve with a line drawn from a particular % of strain parallel to the slope of the linear part of the curve, see Figure 1 (0.1%-proof stress in this case = the stress required to effect 0.1% of deformation).

The mechanism of plastic deformation in metals is the movement of dislocations along slip planes within the crystal structure (a detailed description of dislocations and strengthening mechanisms in metals can be found in the chapter 10 of the textbook [1]). Any obstruction to the movement of dislocations will strengthen a metal, such as the presence of solute atoms, precipitates, or increased grain boundaries (and hence finer grains). An increase in dislocation density will also impede dislocation movement because of dislocation entanglements (this is achieved through *'strain hardening' or 'cold working'* the metal).

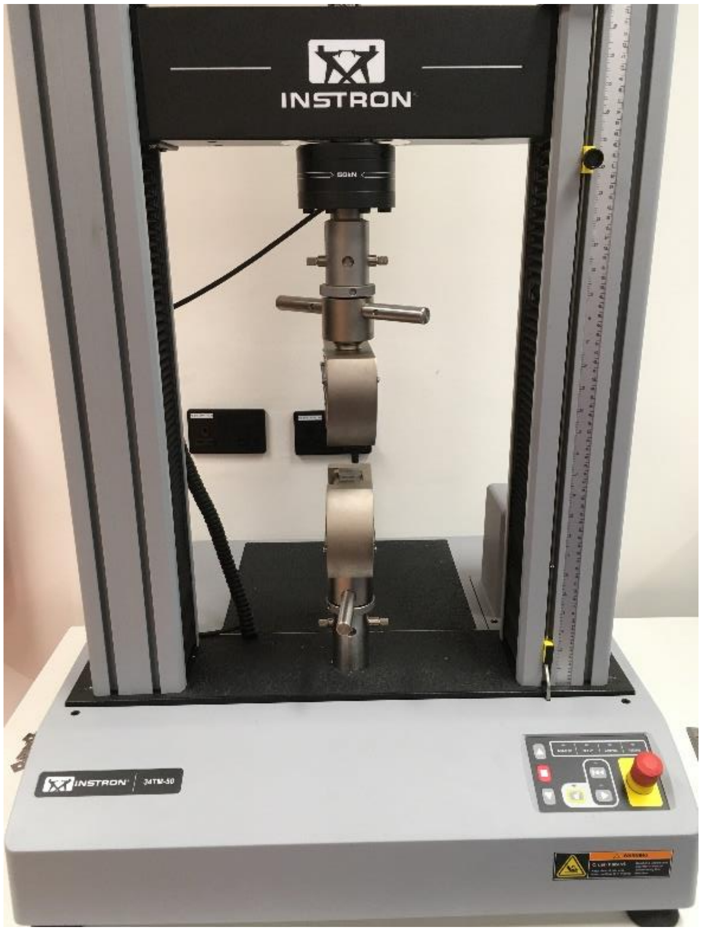
Consider the stress/strain behavior above the yield stress in Figure 1, it is apparent that the stress required to cause further extension above the yield stress is increasing. This is directly attributed to an increase in dislocation density which in turn increases the strength of the metal, in other words the metal is being *'work hardened'*. The maximum point in the stress/strain curve occurs at the **tensile strength** (Figure 1). At this point the metallic sample begins to *'neck'* and the stress required to cause further extension will drop as the necking region extends. This is due to the reduced cross sectional area of the sample, since engineering stress $\sigma = F/A_o$. It is important to note that the material does not become weaker, it in fact continues to strain harden. The lowering of the stress at strains beyond the tensile strength is due to the fact that we define the stress by dividing the load by the **original** cross sectional area. To determine the true stress, we need to divide the load by the instantaneous area and if we do, the stress beyond the tensile stress will indeed continue to increase with strain.

The related properties **ductility** and **toughness** can often be confused, the definition of ductility is the amount of plastic deformation of the material prior to fracture, and this can be simply measured as the % elongation to fracture (see Figure 1). Alternatively, ductility can be measured by the % reduction in area; however, this value cannot be determined directly from the stress/strain curve. Toughness is defined as the total amount of energy absorbed by a material prior to fracture. Since most of the energy absorbed is consumed in plastic deformation. It makes sense that the toughness and ductility are related. Some of the energy absorbed is consumed by the creation of fresh surfaces. The total amount of absorbed energy, i.e. the toughness can be measured from the stress strain curve by calculating the area under the stress-strain curve.

In this experiment, we will also explore a very important 3D printing parameter: Infill pattern. The infill pattern significantly alters the mechanical properties of the 3D printing part in addition to other parameters such as infill percentage which was discussed in the previous experiment. To study the effect of the infill pattern, three 3D printed samples from Polylactic Acid (PLA) are created with different printing patterns; 1- Vertical lines, 2- Horizontal lines and 3- Mixed Vertical, Horizontal and inclined lines. Similar to Fiber composite materials, the 3d printed part's properties are strong along the direction of the material deposition, however, are there side effects to this? In this experiment, we will explore the difference between the proposed patterns and find out why would we use printing patterns that have relatively lower strength than other stronger patterns.

3. Experiment apparatus

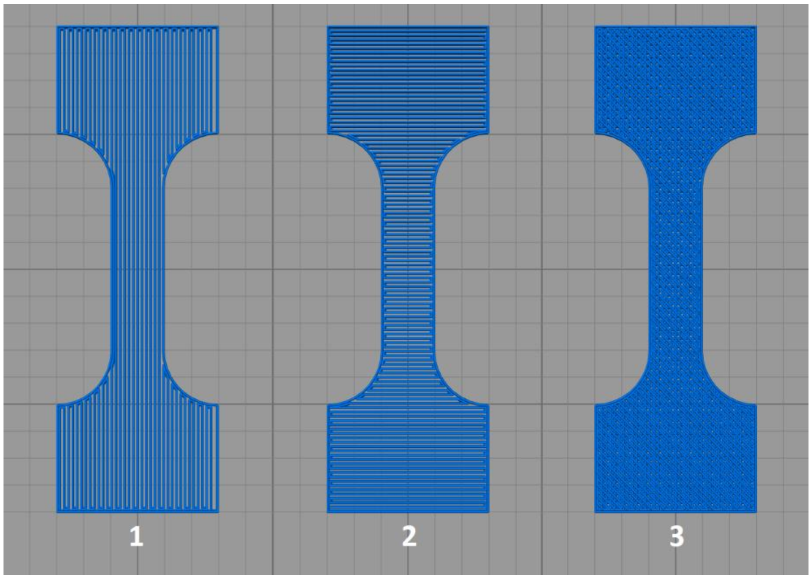
1- Instron UTM with 50 kN load frame.



2- Metallic test specimens

Sample number	1	2	3
Material	High carbon steel	Galvanized mild steel	Aluminum
Gauge length (L_o), mm	55	55	55
Thickness (t), mm	0.9	0.9	0.9
Width (b), mm	6	6	6

3- 3D printed PLA test specimens



Sample number	1	2	3
Material	PLA	PLA	PLA
3D printing direction	Vertical longitudinal lines	Horizontal latitudinal lines	Mixed orientations 0^o to 180^o in increments of 45^o.
Infill percentage	100%	100%	100%
Gauge length (L_o), mm	30	30	30
Thickness (t), mm	2	2	2
Width (b), mm	10	10	10

Report requirements

1- **Cover page:** Includes your name, ID, course title and code, name of teachers, etc

2- **Results (7 marks)**

a- Use the data of Force-Displacement taken from the UTM to generate Stress-Strain data for all the samples, then perform the following

- Plot all the **<u>Metallic samples'</u>** engineering stress-strain curves on a single graph. (one graph with 3 curves) (**don't forget the legends**) **<u>(1 marks)</u>**
- Plot all the **<u>3D printed samples'</u>** engineering stress-strain curves on a single graph. (one graph with 3 curves) (**don't forget the legends**) **<u>(1 marks)</u>**
- **<u>For the metallic samples only</u>**, consider the data points that correspond to the elastic region and plot them for all samples on one graph, and show the slopes of each of the curves. (Slope corresponds to elastic modulus). **<u>(1 marks)</u>**
- Plot the **<u>Mild steel</u>** engineering stress-strain curve on a new graph. On that graph, indicate the following properties (Use arrows and text boxes): **<u>(1 marks)</u>**
  - 0.2% proof yield strength.
  - Ultimate Tensile Strength.
  - Elastic strain
  - Plastic strain
- For **<u>High carbon steel</u>** sample only, calculate the True stress-strain values and plot them on a new graph along with the engineering stress-strain values. (You should end up with a graph with two curves). **<u>(1 mark)</u>**

<u>Take special care of: Axis titles, Axis units, Graph titles and legends.</u>

b- Create a table that summarizes the properties of:

- **<u>Metallic samples (1 mark)</u>**

	Young's Modulus (From experiment)	Young's Modulus (From literature)	0.2% Yield Strength	Ultimate Strength	Total Elongation	Ductility
	GPa	GPa	MPa	MPa	m	%
High Carbon Steel						
Mild steel						
Aluminum						

- **<u>3D printed samples (1 mark)</u>**

	Young's Modulus (From experiment)	Ultimate tensile Strength	Ductility
	GPa	GPa	%
PLA 1			
PLA 2			
PLA 3			

3- Discussion (3 marks)

a- Write a paragraph concluding the experiment objectives, procedure and outcomes.

b- Compare the properties of the three metallic materials using the table you created in the Results section.

c- High carbon steel is superior to mild steel in terms of strength due to the higher carbon content. Was this evident according the results you obtained from the experiment? Search the internet and provide a comprehensive and <u>scientific</u> explanation on how carbon content influence the strength of steel.

d- Compare the properties of the three 3D printed samples using the table you created in the Results section.

e- From your results, which 3D printed sample had the highest strength? Why would an engineer select the sample with the mixed orientations over the one with vertical lines, although the sample with vertical lines will statistically show higher strength?