University of Salford

BEng(Hons) Mechanical Engineering

Solid Mechanics Lab Report

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0.1 Summary & Introduction

This laboratory session was carried out to explore the material properties of samples of mild steel in a two part test on two seperate specimens.
The first test was the destructive testing of a round tensile test specimen of mild steel with the intention of observing the mechanical changes in the specimen to certain properties:
These were

- The yield point stress
- The Ultimate Tensile Stress
- The percentage of elongation
- The percentage reduction of area

The second test was the non-destructive testing of a longer round tensile test specimen again of mild steel, with the intention of determining the Youngs Modulus (E) of the material.

Both tests were tensile tests in which the specimens were in uniaxial tension.

0.2 Method and Equipment used

0.2.1 Equipment used

- In both tensile tests a Denison tensile test machine rated at 6.7 ton-force or 67kN set to a 32.5kN scale was used to apply a uniaxial load to the specimens.

- A point tipped micrometer accurate to 3 decimal places on the mm scale used to determine the Diameter of the specimenafter fracture at the fracture point.

- A compass used to measure the gauge length of the specimen.

- An Engineers rule with mm increments used to measure the distance between the compass points.

- A Ewing Extensometer used to measure the extension of a material from it's starting length.

0.2.2 Method

Test 1 : Test to Destruction

The method of testing was as follows:

1. Record the Length of the specimen, measured with a rule to the nearest mm.

2. Record the Diameter of the Specimen, measured with the point-tipped micrometer to the nearest micrometer.

3. Fix the specimen in the jaws of the tensile test machine and begin applying a load, the machine will plot a force/extension graph.

4. Load untill failure.

5. record new gauge length and new diameter.

Test 2: Determination of youngs modulus

The method of testing was as follows:

1. Record the Length of the specimen, measured with a rule to the nearest mm.

2. Record the Diameter of the Specimen, measured with the point-tipped micrometer to the nearest micrometer.

3. attach the Ewing Extensometer to the Tensile test machine.

4. Apply gradual force and measure extension using the extensometer as regular intervals.

5. Plot Graph of Force/Extension.

These methods outline the way in which the Data was collected.

0.3 Theory, Calculations, and Results

Theory and Definitions

Elasticity: External loads tend to deform materials from their original shape and size. Elasticity is the ability of a material to return to its original shape and size after removing the load applied. Elastic deformation (change of shape or size) lasts only as long as a deforming force is applied to the object, and disappears once the force is removed. This is so because the atoms in the metal change their position due to external stress but can't take new positions because the change of position is too small (or in acceptable range)[1]

Plasticity: External loads tend to deform materials from their original shape and size. Plasticity is the ability of a material to retain the deformation even after external load is removed. In plastic deformation, the atoms in the material due to external force are displaced and take up new positions. They cannot come back to their natural positions once force is removed.[1]

Youngs Modulus (E): Young's modulus, also known as the tensile modulus or elastic modulus, is a measure of the stiffness of an elastic material and is a quantity used to characterize materials.
It is defined as the ratio of the uniaxial stress over the uniaxial strain in the range of stress in which Hooke's law holds.[2]

Tensile Testing: In a tensile test of mild steel specimen, usually a round or flat bar is gradually pulled in a testing machine until it breaks. Two points, called gauge points, are marked on the central portion. The distance between these points, before the application of the load, is called gauge length of the specimen. The extensions of the gauge length and the values of the corresponding loads are required at frequent intervals. The extensions are measured by an instrument called an extensometer.

The strains corresponding to the recorded extensions are calculated by dividing the latter by the gauge length, while the stresses are calculated by dividing the loads by the original area of cross-section of the specimen. Stresses so arrived at is called nominal stress to distinguish it from actual stress which is obtained by dividing the load at a particular instant by the area of the cross-section at that instant. Actual stress is greater than nominal stress in a tensile test because the load increases, and correspondingly the area of the specimen decreases.[4]

Yield Strength: The yield strength or yield point of a material is defined in engineering and materials science as the stress at which a material begins to deform plastically. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed. Once the yield point is passed, some fraction of the deformation will be permanent and non-reversible.

Ultimate tensile strength: Ultimate tensile strength (UTS), often shortened to tensile strength (TS) or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before necking, which is when the specimen's cross-section starts to significantly stretch.

Test 1

The first test made use of measurable dimension in order to determine the mechanical changes that had occured during the tensile testing in order to evaluate the materials properties, the measurements taken are as follows (the method has been specified).

Measurement	Gauge Length (mm)	Diameter (mm)	cross sectional area (mm^2)
Initial	40 (L_0)	7.98	50 (A_0)
Final	54 (L)	4.30	14.52 (A)

$$\text{Yield load} = 16\text{kN}$$

$$\text{Ultimate tensile Load} = 21\text{kN}$$

$$\text{Stress } \sigma = \frac{Force}{Area}$$

$$\text{Yield Stress} = \frac{16000}{50} = 320\ \frac{N}{mm^2}$$

$$\text{Ultimate tensile Stress} = \frac{21000}{50} = 420\ \frac{N}{mm^2}$$

$$\text{Percentage Elongation} = \frac{L - L_0}{L} \times 100$$

$$\%\ \text{Elongation} = \frac{54 - 40}{40} \times 100 = 35\%$$

$$\text{Percentage Reduction in Area} = \frac{A_0 - A}{A_0} \times 100$$

$$\%\ \text{Reduction in Area} = \frac{50 - 14.52}{50} \times 100 = 71\%$$

Test 2

$$\text{Youngs Modulus}(E) \equiv \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{\sigma}{\varepsilon} = \frac{F/A_0}{\Delta L/L_0} = \frac{FL_0}{A_0 \Delta L}$$

While Theoretical Youngs Modulus could be determined using this equation, the method dictates that a graph be plotted in order to determine the graident of the elastic region of extension, thus allowing the computation of the Modulus using the slightly altered equation:

$$\text{Youngs Modulus E} = \frac{P}{\delta} \times \frac{L}{A}$$

After Collecting data from the Ewing Extensometer A table was produced:

Mild Steel Test Bar:

- Diameter = 12.7mm
- Gauge Length 203.2mm

The extensometers measurements were converted to mm using a conversion factor of $\times 0.005$

Load(kN)	Extension	Extension (mm)
2.5	0	0
5	4	0.02
7.5	7	0.035
10	11	0.055
12.5	15	0.075
15	21	0.105
17.5	24	0.120
20	28	0.140

These Results were ploted using Maple and a line of best fit was used externally to compute an approximate linear gradient, theoretically as this specimen is still well with it's elastic limit the actual data should be linear, however human error has caused the mesurements to be innacurate.

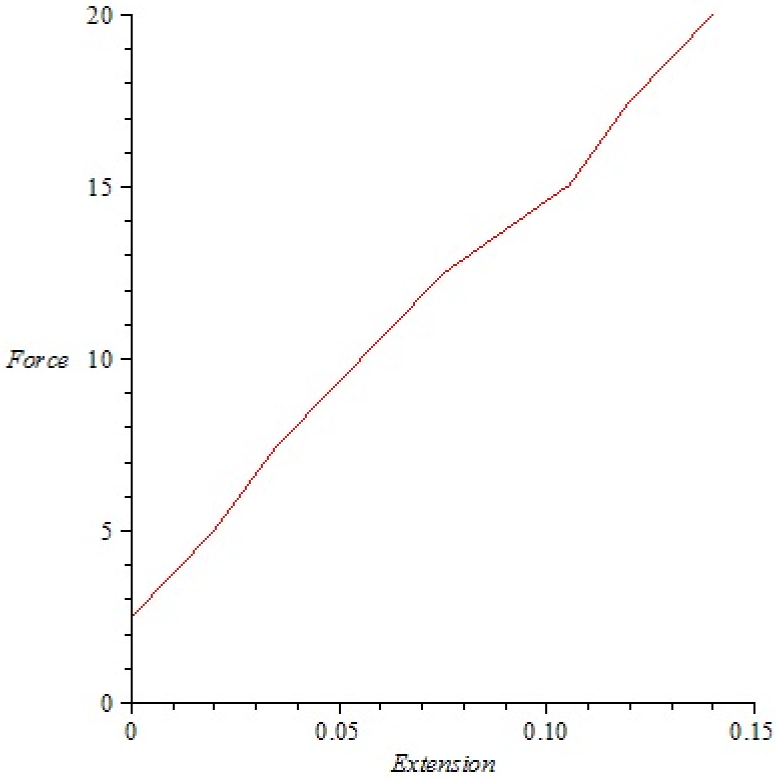


Figure 1: Graph of Force-Extension

$$\text{Area}= \frac{\pi D^2}{4} = \frac{\pi \times 12.7^2}{4} = 126.676\ mm^2$$

$$\text{Gradient} = \frac{\delta y}{\delta x} = \frac{20-5}{0.13} = 115.38\ \frac{N}{mm^2}$$

$$\frac{L}{A} = \frac{203.2}{126.676} = 1.604 \frac{1}{mm}$$

$$115.38 \times 1.604 = 185.1\ \text{GPa}$$

which is 85% accurate to the Data book value of 208GPa[3]

Theoretically the result using 20kN Force, 203.2mm length , 0.14mm extension and 126.676mm^2 area yields 229GPa which would indicate that the extension or force has been measured innacurately and the cause of error here is uncertain, with possibilities including the Stress Strain machine or the Ewing extensometer, and more likely human error in measurements.

Calculation:

$$\frac{20 \times 10^3}{126.676 \times 10^-4} \times \frac{203.2}{0.14} = 2.29 \times 10^9 GPa$$

0.4 Discussion of Results

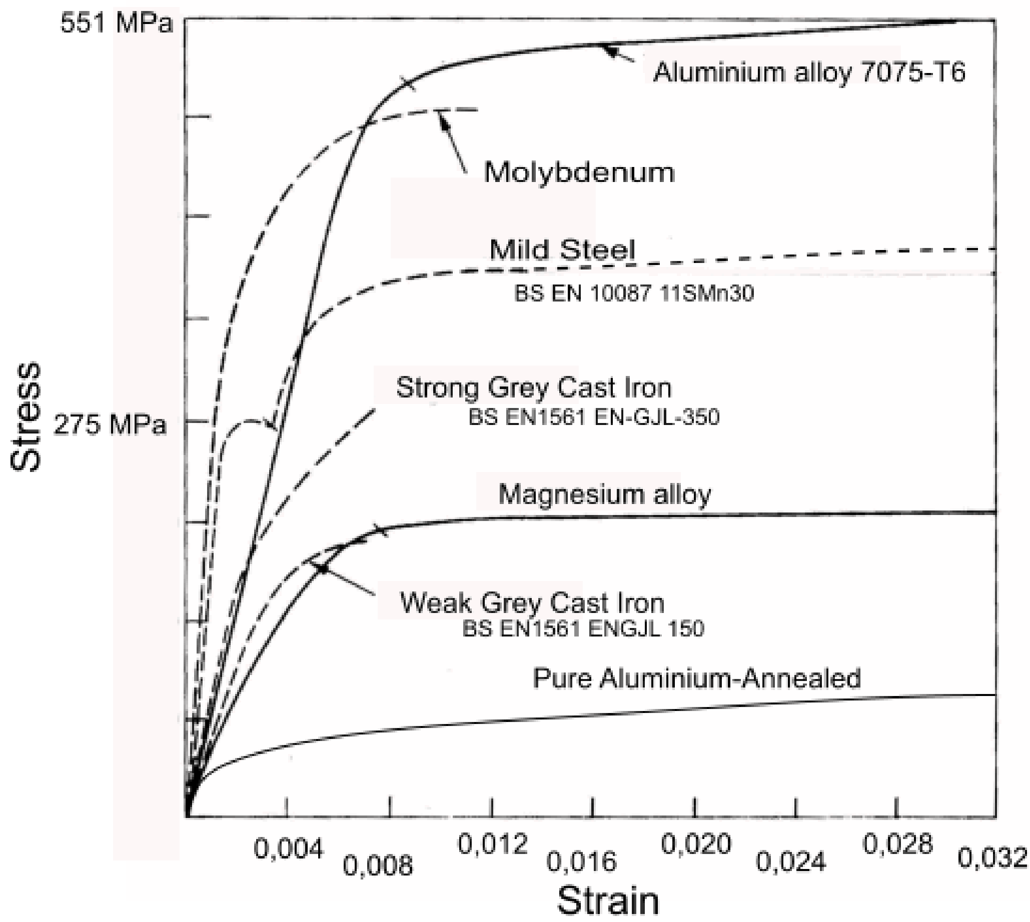
0.4.1 Characteristics of Load Extension Diagram

The stress-strain diagram is generally accepted as the plotted results of a tensile test completed under carefully controlled conditions on a speciman of a metal. The stress-strain diagram important for design engineers in that it establishes the physical properties of the material under test including the yield strength, the ultimate strength, the elongation at fracture, the elastic limit etc. The test is carried out on a bar of uniform cross section, in a testing machine which indicates the tensile load being applied. The elongation of a calibrated length of the test piece (called the gauge length) is recorded by and extensometer or strain gauge.

The load is gradually increased until the specimen breaks.

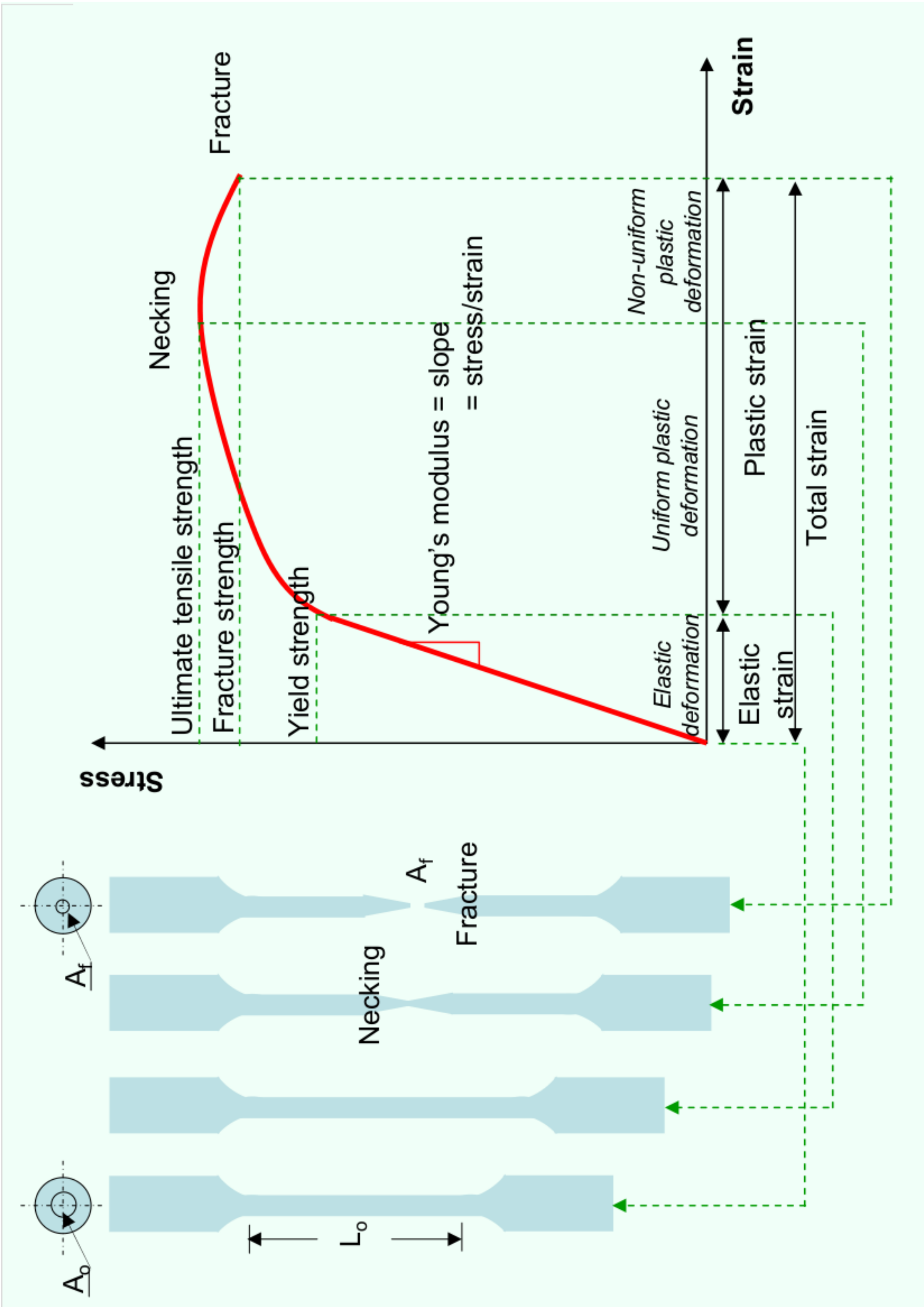
The measured load results and the extension results are then converted to stress values (Load/specimen area) and strain values (extension / gauge length) and the results are plotted on a graph.
The stress levels resulting from this test are nominal or practical engineering values.
The tensile test does not provide any information as to the strength of a material under highly cyclic loading, and does not identify the resistance of the material to shock loading.
Other test procedures are required to test these factors.

Different materials clearly result in different graphs.[5]



Stress Strain Graph showing the curves of some different engineering metals

Stress Strain comparison of metals This graph has been plotted to indicate the material properties of a range of metals in order to visually compare them, Samples with shorter strains such as Molybdenum are more brittle than those with longer ones, the length of plastic region indicates how much permenant deformation the sample can recieve without undergoing fracture, similarly the gradient of the linear region indicates the youngs modulus, and a steeper gradient indicates a greater youngs modulus and therefore a material that is stronger.



Stress
Strain
Fracture
Necking
Ultimate tensile strength
Fracture strength
Yield strength
Young's modulus = slope
= stress/strain
Elastic
deformation
Uniform plastic
deformation
Non-uniform
plastic
deformation
Elastic
strain
Plastic strain
Total strain
A
o
L
o
A
f
A
f
Necking
Fracture

Annotated plot with Specimen comparison The annotated plot describes the process of tensile testing whilst showing the effects of the force on the specimen at various points.

Initially as the specimen is stressed it deforms in a linear fashion and obeys hookes law that stress is directly proportional to strain, during this phase which is completely elastic the specimen undergoes micro-elongation and if the stress was removed the specimen would return to it's original length.

As the Stress increases the specimen's elongation approches a limit of proportionality where the gradient diverges from being linear to non linear, this point is known as the yield strength and is defined as the stress at which a material begins to deform plastically. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed. Once the yield point is passed, some fraction of the deformation will be permanent and non-reversible.[9]

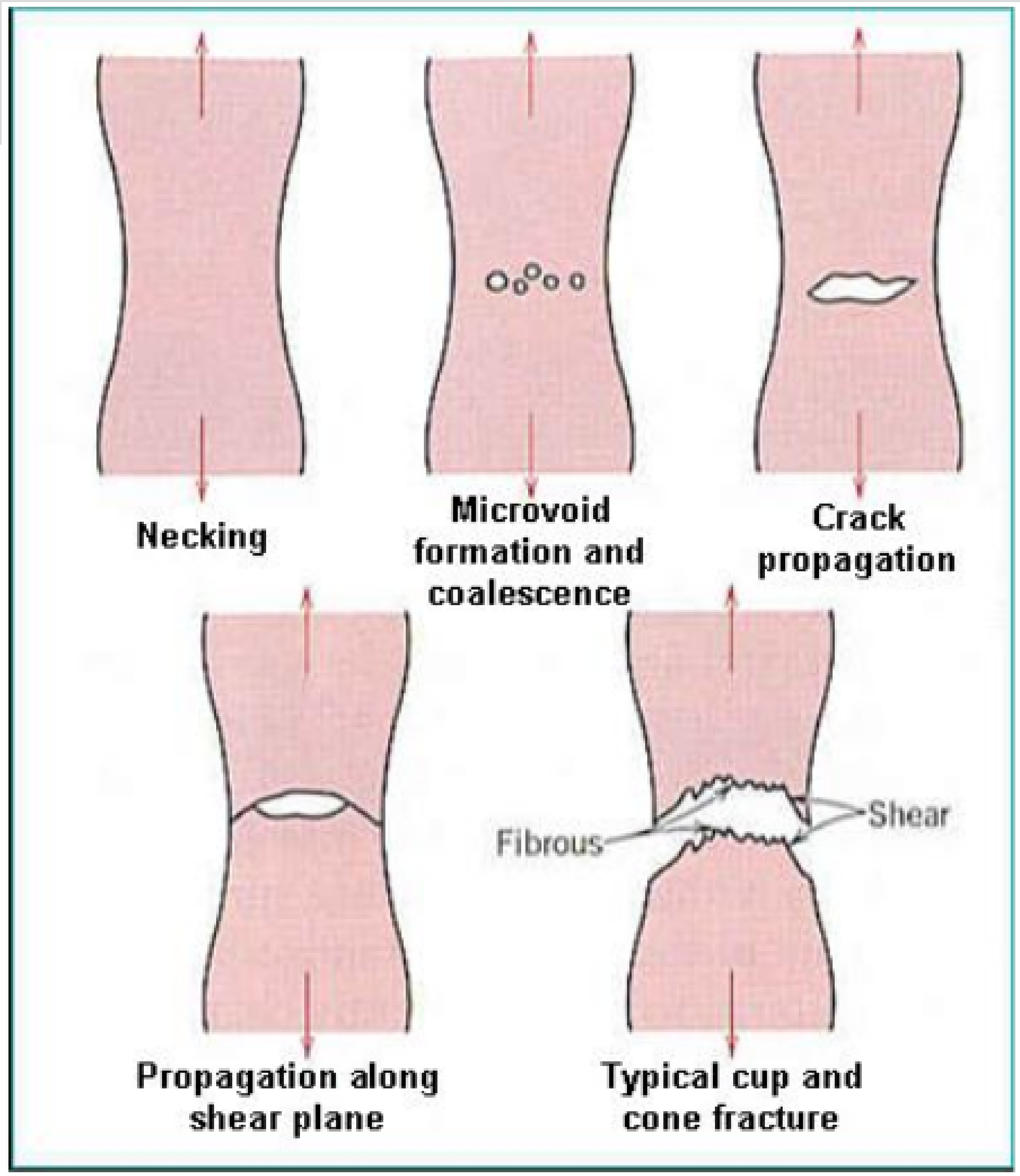
Between the Yield strength and the Ultimate tensile strength the specimen undergoes a period of uniform plastic deformation, where the gradient is constant as the specimen is stretched prior to necking and fracture as the force is increased the extension increases at a proportional rate during this phase and the specimen undergoes strain hardening and general extension.[7]

Under tensile stress plastic deformation is characterized by a strain hardening region and a necking region and finally, fracture (also called rupture). During strain hardening the material becomes stronger through the movement of atomic dislocations. The necking phase is indicated by a reduction in cross-sectional area of the specimen. Necking begins after the ultimate strength is reached. During necking, the material can no longer withstand the maximum stress and the strain in the specimen rapidly increases. Plastic deformation ends with the fracture of the material.[5]

After the ultimate tensile stress point has been reached the specimen will begin necking as the extension reduces the cross sectional area at the mid point of the fracture the stress-strain curve at this point exhibits Non-Uniform plastic deformation as the specimen is structually weakened.[8]

As the material is stressed and deformed to it's limit the area around the point of fracture experiences extensive necking and the specimin overall experiences a great change in length, at the point of fracture the material seperates into two pieces one end exhibits a rounded protrusion known as a cone and the other piece exhibits a void where the material has sheared, this fracture pattern is due to the crack propagation of the material because of it's ductility, had the material been more brittle a cleaner cut between the metal would have been observed, as the crack propagates quickly and evenly.

In most design situations a material that demonstrates ductile fracture is usually preferred for several reasons. First and foremost, brittle fracture occurs very rapidly and catastrophically without any warning. Ductile materials plastically deform, thereby slowing the process of fracture and giving ample time for the problem to be corrected. Second, because of the plastic deformation, more strain energy is needed to cause ductile fracture. Next, ductile materials are considered to be "forgiving" materials, because of their toughness you can make a mistake in the use, design of a ductile material and still the material will probably not fail. Also, the properties of a ductile material can be enhanced through the use of one of the strengthening mechanisms. Strain hardening is a perfect example, as the ductile material is deformed more and more its strength and hardness increase because of the generation of more and more dislocations. Therefore, in engineering applications, especially those that have safety concerns involved, ductile materials are the obvious choice. Safety and dependability are the main concerns in material design, but in order to attain these goals there has to be a thorough understanding of fracture, both brittle and ductile. Understanding fracture and failure of materials will lead the materials engineer to develop safer and more dependable materials and products.[10]



Cup and Cone fracture typical of mild steel

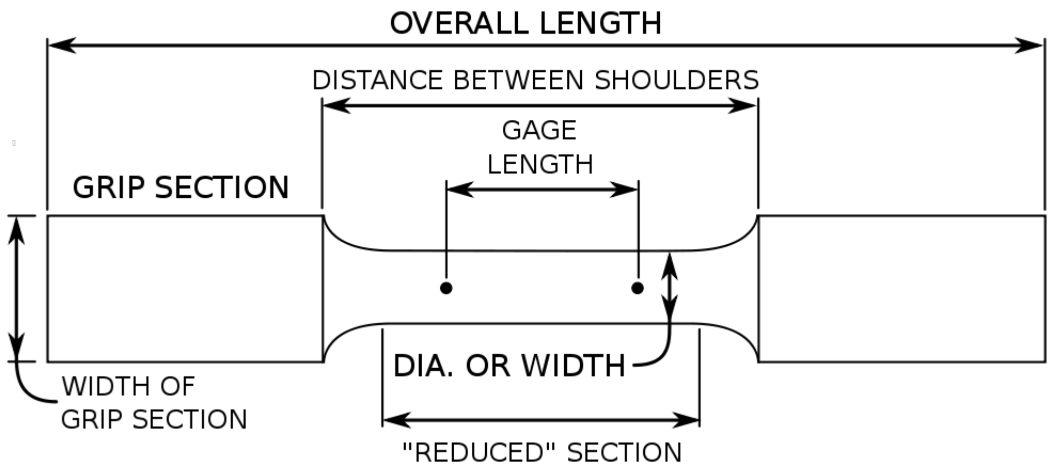
0.5 Conclusion

In Conclusion our measurements and calculations have allowed the material properties of the sample to be determined and recorded for reference, the material data has been within %15 accurate compared to the standardised results, which is an acceptable deviation considering the data values were taken from one sample which may have had defects, and also considering the potential error in the equipment and human involvement. Our findings have defined the yield point stress , the ultimate tensile stress, and the Youngs modulus of mild Steel.

The results have suggested that mild steel is a strong and relatively ductile material (%elongation of 35%) and the yield strength of 320 $\frac{N}{mm^2}$ would indicate mild steel is a suitable material to use when the requirement is supporting a load in tension.

The objective of the lab session was met and the material properties of mild steel have been determined.

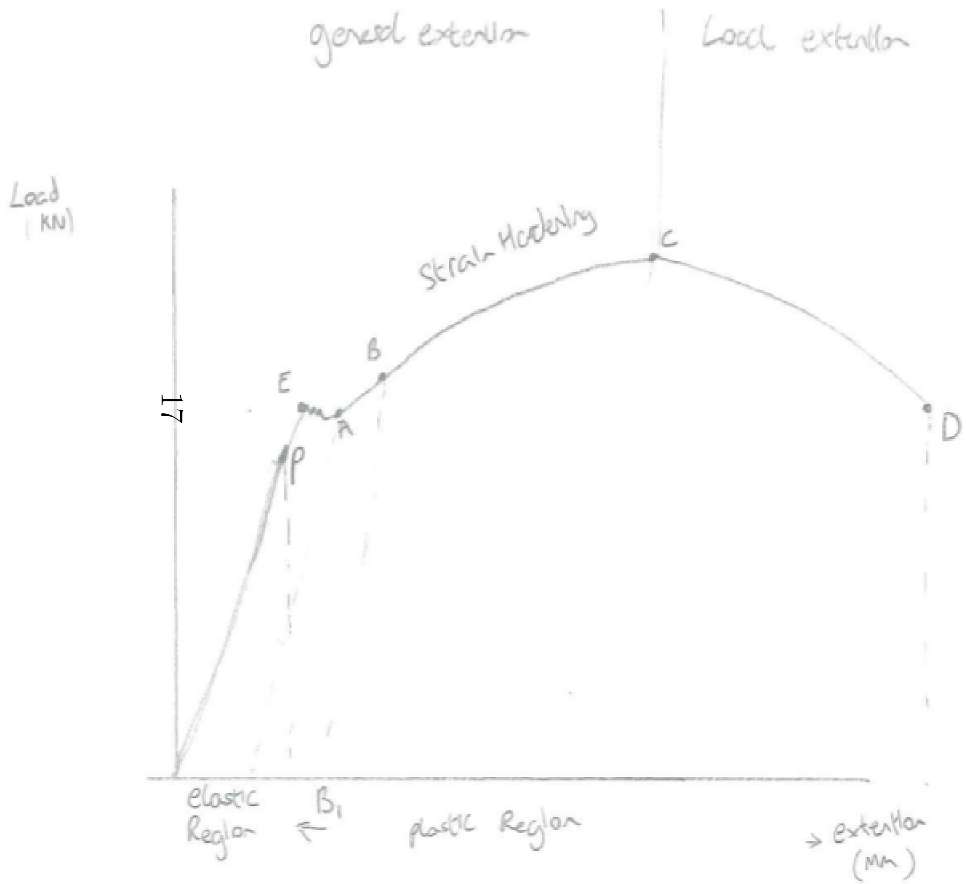
0.6 Related images



Specimen

micrometer

Denison tensile test machine



A = Yield point
B = higher elastic limit
C = Max Load
D = Fracture
P = Limit of proportionality
EL = Elastic Limit.

O - P = hooks Law
Stress ∝ Strain
$\left(\frac{\text{Force}}{\text{extension}} = \text{Constant.}\right)$

$\sigma = \frac{F}{A}\left[\frac{N}{MM^2}\right]$ $E = \frac{\sigma}{\epsilon} = \left(\frac{F}{A}\right) \cdot \left(\frac{L}{\Delta L}\right)$ $\left[\frac{N}{MM^2}\right] \cdot \left[\frac{L}{L}\right] = \frac{N}{MM^2}$

$\epsilon = \frac{\Delta L}{L}\left[\frac{MM}{MM}\right]$

Ratio

pascals $\left[\frac{N}{M^2}\right]$ Commonly GPA

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