

University of Wales Trinity Saint David

Materials in Service— On the Purpose, Method and Data Outputs of Tensile Testing

BEng Material Science – ACMA5007

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Tensile Testing Literature Review (Task 1)

A tensile test is a destructive test method that determines a materials' mechanical properties including ultimate tensile stress, yield strength and ductility. A constant force is applied to permanently deform a test specimen until fracture to establish how the material responds to stress.

(Jawaid, et al., 2019)

History

During the industrial revolution there was an increased need for strong structural materials, however, during this time material testing methods were undeveloped and the properties of these materials were unreliable. "The art of construction is involved in mystery and obscurity" stated Van Nostrand's engineering magazine.

Without a method to test the strength of materials, the safest method was to experiment, however results often led to explosions or structural failings, this was until in 1880, engineer Tinius Olsen created 'the little giant', a revolutionary machine to measure tensile transverse and compression in one universal test; this provided the basis for which all modern tensile testing machines are designed.

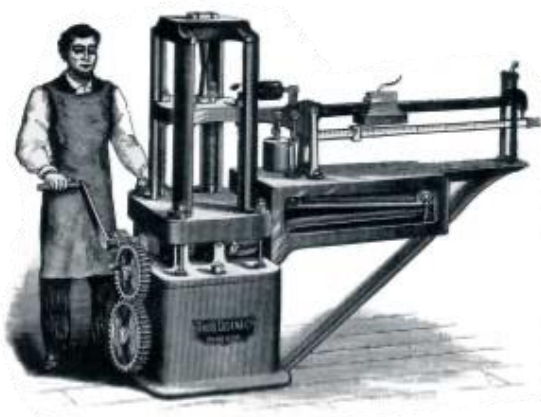


Figure 1 - The Little Giant

(Hayward, 2005)

The little giant was made from a system of gears where upper and lower crossheads gripped a test specimen, elongating it as an operator manually rotated a handle. A weighing table beneath transmitted the force through levers to a weighing beam where the load could be measured to produce graphical data.

(Tinius Olsen, 2021)

Purpose

Tensile testing is widely used across many industry sectors, both small and large scale due to its numerous benefits.

Yield strength, ultimate tensile strength, elongation, ductility and plastic strain ratio values are examples of mechanical properties that can be identified through tensile testing. Having the ability to know metallurgical characteristics prior to use allows optimum materials to be manufactured safely into products best suited to their function.

(TWI Ltd, 2021)

The importance of testing mechanical properties can be highlighted through engineering malfunctions, one instance of this is the Boston molasses tank failure; in 1919 a tank containing 2.2 million gallons of molasses exploded. The giant tank burst filling the streets with a wave of molasses strong enough to remove buildings from their foundations; the cost of damage totalled at \$100 million and the accident killed 21 people. After further investigation it was found that the root cause was that the steel used has been mixed with too little manganese, thus giving it a high transition temperature, resulting in brittleness during periods below 15°C. In this case, more thorough mechanical testing would eliminate the cause of failure.

(Betancourt , 2019)



Figure 2 - Boston Molasses Tank Disaster Newspaper Extract

(Taneja, 2016)



Figure 3 - Image of Boston Flooding 1919

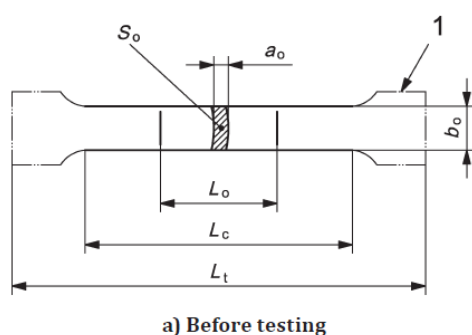
(Betancourt , 2019)

Method and Equipment

Standardised tensile test procedures are carried out in accordance with industry standards, an example of a tensile testing method for metallic materials is BS EN ISO 6892-1:2016. A consistent testing method must be followed so that the test data is comparable with other tests and effecting factors are controlled, such as speed of test and temperature.

Test Piece Dimensions

The shape and dimensions of a tested specimen is determined by the dictating testing standard, the properties may be constrained by the product from which the test piece is taken. Often, the correct test piece is obtained through machining, pressing or casting. In the metallurgical laboratory within TATA Steel, a 38mm strip of steel is machined into a reduced gauge cross section piece.



Key

- a_o original wall thickness of a tube
- b_o original average width of the longitudinal strip taken from a tube
- L_c parallel length
- L_o original gauge length
- L_t total length of test piece
- L_u final gauge length after fracture
- S_o original cross-sectional area of the parallel length
- S_u minimum cross-sectional area after fracture
- 1 gripped ends

Figure 4 - Diagram of Tensile Test Piece.

(BSI Standards Publication, 2016)

Figure 5 - Key to Figure 2

(BSI Standards Publication, 2016)



Figure 6 - Image of Tensile Test Piece from Tata Steel

(Morgan & Betambeau, 2016)

A machined tensile specimen must have a transition radius separating the parallel length and gripped ends, this radius must exceed 20 radians in order to meet the standard requirement.

BS EN ISO 6892-1:2016 states that parallel length (L_c) measures 80mm and recommends that the total length of test piece (L_t) exceeds 200mm.

Original average width (b_o) is to measure 20mm $\pm$ 1mm which is calculated using an average of three readings across the parallel length.

(BSI Standards Publication, 2016)

Tensile test specimens must have a gauge length smaller than the gripped edges; this is to concentrate stress at the centre (given that $\text{stress} = \text{force} / \text{cross sectional area}$), thus encouraging fracture at the centre of the testing. This is important to standardise test results, accurately measure properties and also to retain broken test pieces for microscopic analysis (the grips damage the larger parts of the specimen).

Testing Conditions

In order to comply with standardised testing regulations, testing conditions must be consistent and controlled so that testing is repeatable and reliable;

- The force measuring system needs to be set to zero before any strain is applied to the test piece, it must be noted that no clamping force is to affect the measurements.
- To avoid slippages that result in false readings, the test piece must be suitably gripped and to reduce any bending motions the force applied is to be as linear as possible.
- Force must be applied at a constant rate to mitigate variation during the test.
- This testing method is carried out at room temperature.

(BSI Standards Publication, 2016) (Zhang, et al., 2021)

Procedure

Every test specimen requires a gauge and width check using a measuring device prior to testing. For this method example, an Instron 250kN tensile testing machine with supporting compatible gauge and width measurement device will be used.



Figure 7 - Instron Tensile Testing Machine

(Instron Testing Systems, 2021)

1. Clean the measuring transducers on the device and calibrate at the start of each testing cycle to ensure accuracy of testing results (any debris left may lead to incorrect readings making further calculations invalid).
2. Place the specimen centrally within the measuring device and run the measure program, the device will take three cross sectional measurements and report an average gauge and width for the specimen.
3. On the tensile testing machine, ensure that grips are both open sufficiently in readiness to receive the specimen, also that crosshead (displacement zero) is at the correct level and force set to zero.
4. Ensure when loading the specimen in to the grips, that it is vertically central with the parallel length set fully against the backstops. The shoulder radii should not be making contact with the backstops.
5. Close the grips on the machine sufficiently so that no slipping can occur during the testing process (slipping could produce anomalies in the graph).
6. With the specimen positioned correctly, run the tensile testing program, force is applied, moving the crosshead upwards, elongating the test piece until fracture.
7. Extensometers make contact with the test piece to provide an accurate value for elongation. Fingers also make contact with the test piece, recording the reduction in width to calculate r values.
8. Throughout the test, the tensile machine will continuously send data to a compatible software (in this case Bluehill 3), the software will receive the raw data and produce a visual stress/strain graph.
9. Post-test, remove the broken specimen pieces from the grips and reset machine to initial condition in readiness for another test (repeat steps 1 to 8).

Materials

There are an extensive range of material types that can undergo tensile testing; however, the main focus materials are metals, plastics, woods, polymers and textiles. The test is utilised across many industry sectors such as prosthetics in medicine to steel in manufacturing and automotive.

(Test Resources, 2021)

Polymers

Monotonic tensile testing is commonly used to assess the mechanical properties of high-density polymers such as polyethylene (HDPE); this method is similar to the one described in BS EN ISO 6892-1:2016 for metallic materials. The procedure differs where sample preparation is concerned, polymer test specimens are commonly produced through cut or injection moulding into a 'dog bone' shape before undergoing a universal tensile test.

(Zhang, et al., 2020)

However more fragile, thinner polymer samples have proved more challenging to tensile test, additional measures have been put in place to calculate their mechanical properties. Polymers like polystyrene films have low length to width ratios, having thicknesses as small as 45 nm. Recent breakthroughs in methodologies have meant that an effective test (although still difficult) can be carried out in accordance to ASTM D882. The method uses very small test specimens and can also be used for metallic materials such as gold foil.

(Zhang, et al., 2020)

Ceramics

One category of material that tensile testing is not applicable to is ceramics; the strength of ceramic material cannot be determined through a tensile test because of their brittle properties. Ceramic test specimens are likely to fracture during sample preparation and grip compressing. The tensile properties of ceramics are poor, breaking after 0.1% strain so are often used where compressive loads are applied and tested via a three/four-point bend test. (Johnstone & Ruiz, 1995)

Metallic Materials

Predominantly tensile testing is carried out on metallic materials to assess if their mechanical properties are sufficient for purpose. With the need for materials to be stronger, lighter and able to withstand more extreme conditions, the tensile testing of metals is more important than ever. Almost all pure and alloyed metals are tensile tested dependant on their use. High strength and formability are essential properties for automotive products, elongation key for any parts that need to be moulded in specialised shapes and toughness safety critical for products such as crash barriers; having prior knowledge of these physical properties allows for the production of items optimum for purpose, mitigating the risks of failure. (Xie, et al., 2021) (Zhu, et al., 2020)

Test Data

Advancements in testing technologies over recent years have allowed us to measure more mechanical properties using tensile testing more accurately than ever before. The vast amounts of test data obtained can be categorised to determine the following properties:

Ultimate tensile strength

Ultimate tensile strength is a measure of the maximum stress that a material can withstand. The strength of a material is often considered the most important mechanical property for structural purposes. (Sahu, et al., 2021)

Proof stress value

A materials proof stress determines the amount of stress that can be endured before plastic deformation occurs. The value is taken when 0.2% plastic deformation is exhibited. Prior knowledge of this property is crucial, identifying what stress must not be exceeded to surpass its elastic limit helps manufacturers avoid permanent deformation or fracturing of material. (Qin, et al., 2005)

Yield point elongation (YPE)

During the period of discontinuous yield (where an increase in strain occurs without increasing stress), the elongation difference is measured to produce a value for yield point elongation. A YPE is only calculated if discontinuous yielding occurs, which isn't always the case. When YPE is present it is an indication that the material will exhibit unpredictable creasing, stretching and fluting during further process, an undesirable trait for high quality materials used in industries such as automotive and aerospace.
(Li, et al., 2013)

Elongation at break

Elongation at break is the percentage value of the material length at fracture against original material length. The higher the tensile elongation value, the more ductile it is. Knowing this value before manufacturing a material into a product is very important. This is especially important when making products such as wiring and cables, without knowing this value there's a potential of fracture during production due to brittleness.
(Petrouty, 2017)

Plastic strain ratio (R value)

The plastic strain ratio of a material measures its 'drawability'; its ability to resist thinning/thickening when under stress/compression. It's a crucial property to understand for shaping materials. The optimum time to calculate plastic strain ratio is after YPE and before ultimate tensile strength, the calculation for R value is shown below;
(Lee & Oh, 1985)

$$r = \frac{\epsilon_w}{\epsilon_t}$$

Where

$$\epsilon_w = \ln\left(\frac{width_f}{width_o}\right)$$

$$\epsilon_t = \ln\left(\frac{thickness_f}{thickness_o}\right)$$

Figure 8 - Calculation for R value

(Instron, 2019)

N value

A materials N value is an indication of how much harder and stronger it becomes during plastic deformation. It measures how materials respond to cold working (below recrystallisation temperature), where it is common for strength and hardness increases and ductility decreases. N value is an important property to be aware of when rolling, forging and drawing wires.
(Instron, 2021)

Young's Modulus

Young's modulus (also known as modulus of elasticity) determines how 'stiff' a material is; measuring how much strain a material undergoes per unit of stress applied. The more rigid the material, the higher the young's modulus value. The value for young's modulus for a material will remain constant up to the elastic limit, obeying Hooke's Law where stress is proportional to strain. The ratio is calculated by dividing stress by strain or measuring the gradient of a stress/strain graph.

(Vaidya & Pathak, 2018)

$$E = \frac{\text{Stress}}{\text{Strain}}$$

where stress (σ) = $\frac{F}{A}$, and

$$\text{Strain } (\epsilon) = \frac{\Delta l}{l_0}$$

Figure 9 - Young's modulus equation

(Vaidya & Pathak, 2018)

The raw data obtained during a tensile test is force (N) and extension (m); if this graph was to be utilised, it must be considered that the size of the test piece will significantly affect the values. This makes the data almost impossible to compare with other tests carried out on different test pieces. In order to maximise the usage of the tensile test data, the values of force and extension are converted to stress (Nm^{-2}) and strain using the following calculations;

Stress = Force / Cross sectional area

Strain = Extension / Original length

Plotting a stress strain graph eliminates the effect of sample size on the data, standardising the calculation so that they are universally comparable.

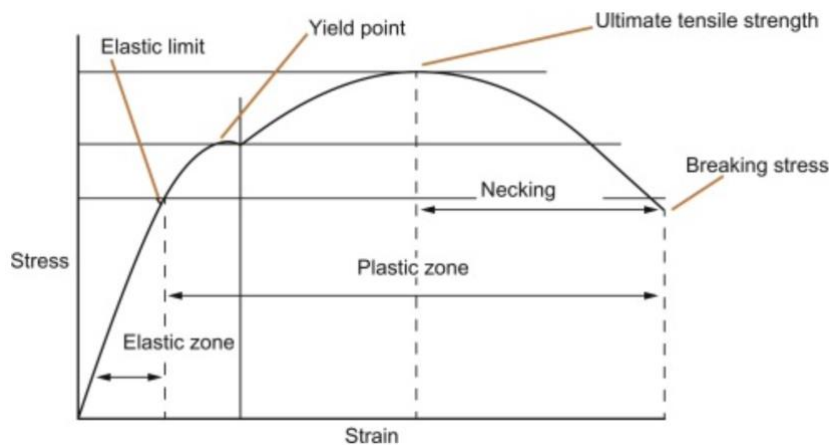


Figure 10 - Example of stress/strain graph

(Singh & Verma, 2016)

Tensile Data Calculations (Task 2)

The following figures were obtained in a standard tensile test on a specimen of low carbon steel:

diameter of specimen, 12.72mm;

gauge length 54mm;

minimum diameter after fracture, 7.45mm.

Using the above information and the table of results provided, produce;

- (1) A load/extension graph over the complete test range;
- (2) A load/extension graph to an enlarged scale over the elastic range of the specimen.

(1) Load/Extension Graphs

Specimen A - Carbon Steel 0.1

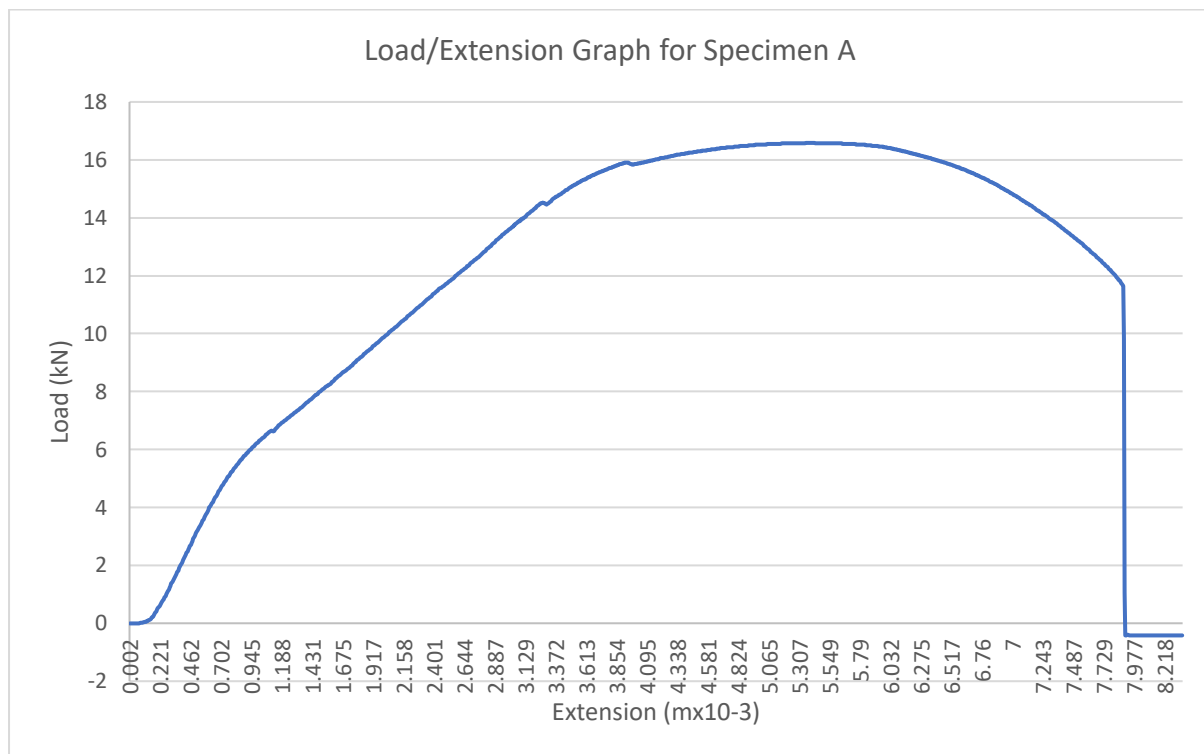


Figure 11 - Load/extension graph for specimen A

Specimen C - Carbon Steel 0.29

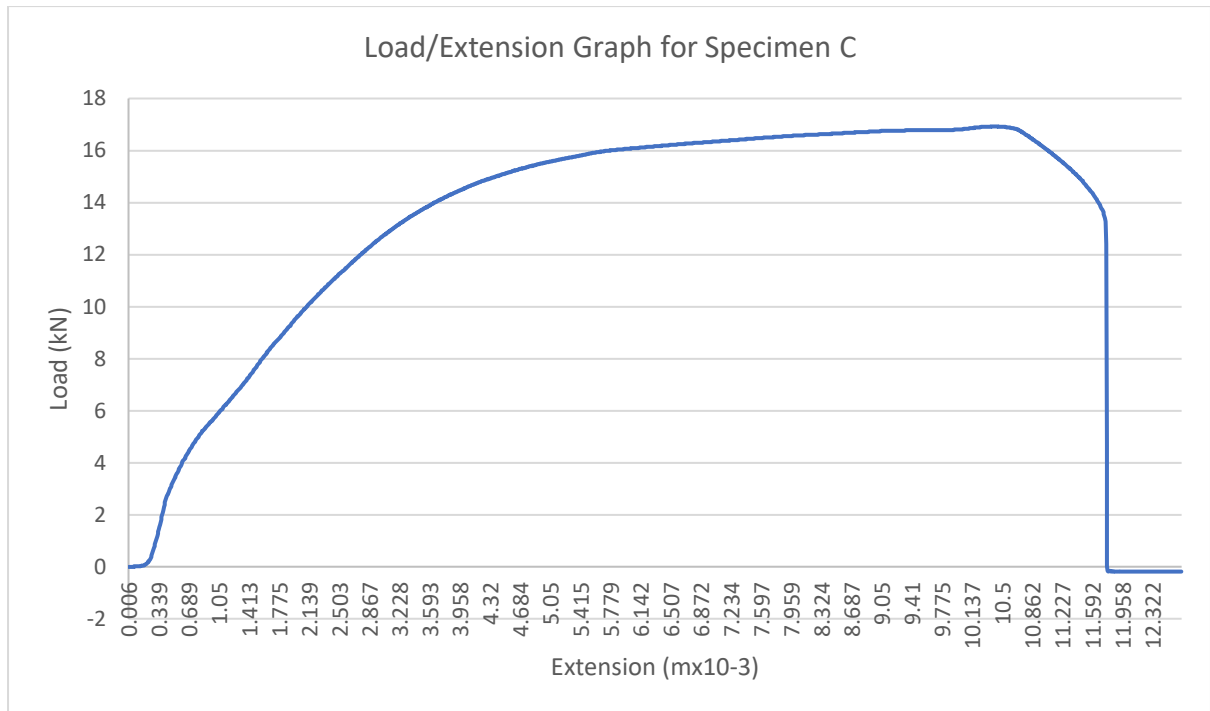


Figure 12 - Load/extension graph for specimen C

Specimen R - Aluminium

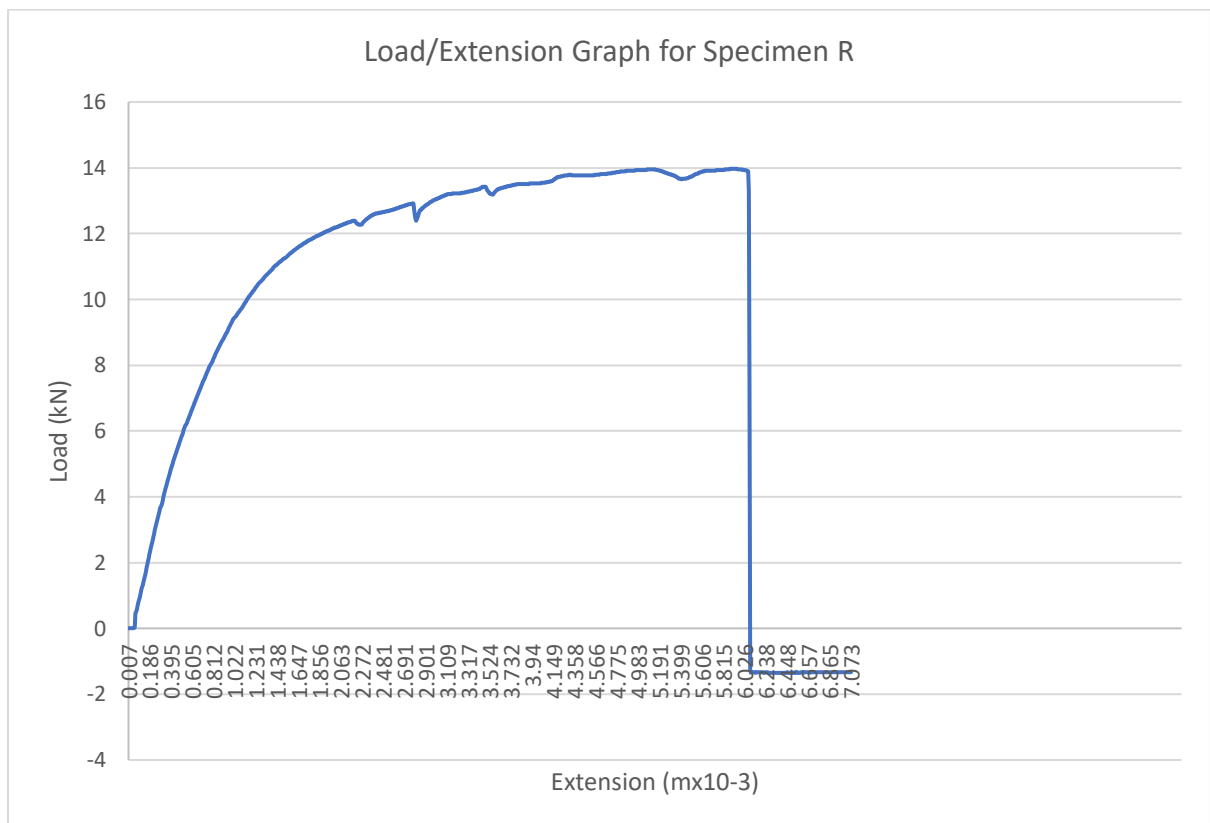


Figure 13 - Load/extension graph for specimen R

Specimen W – Copper

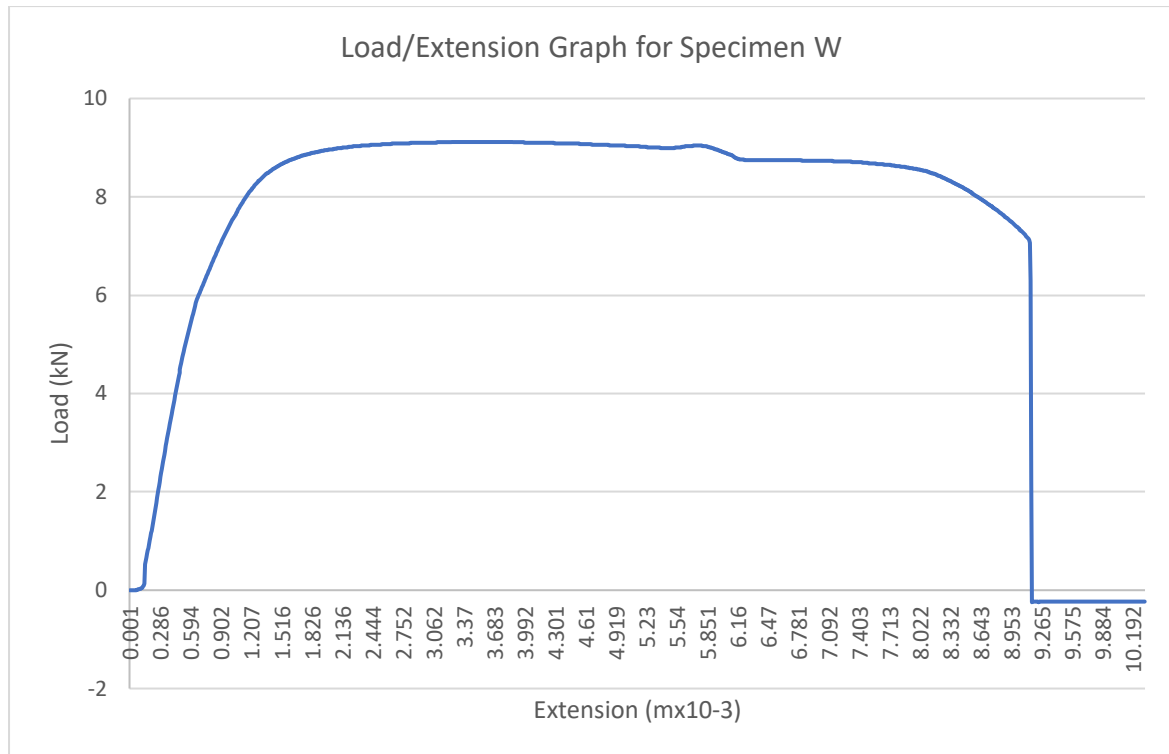


Figure 14 - Load/extension graph for specimen W

Specimen X – Brass

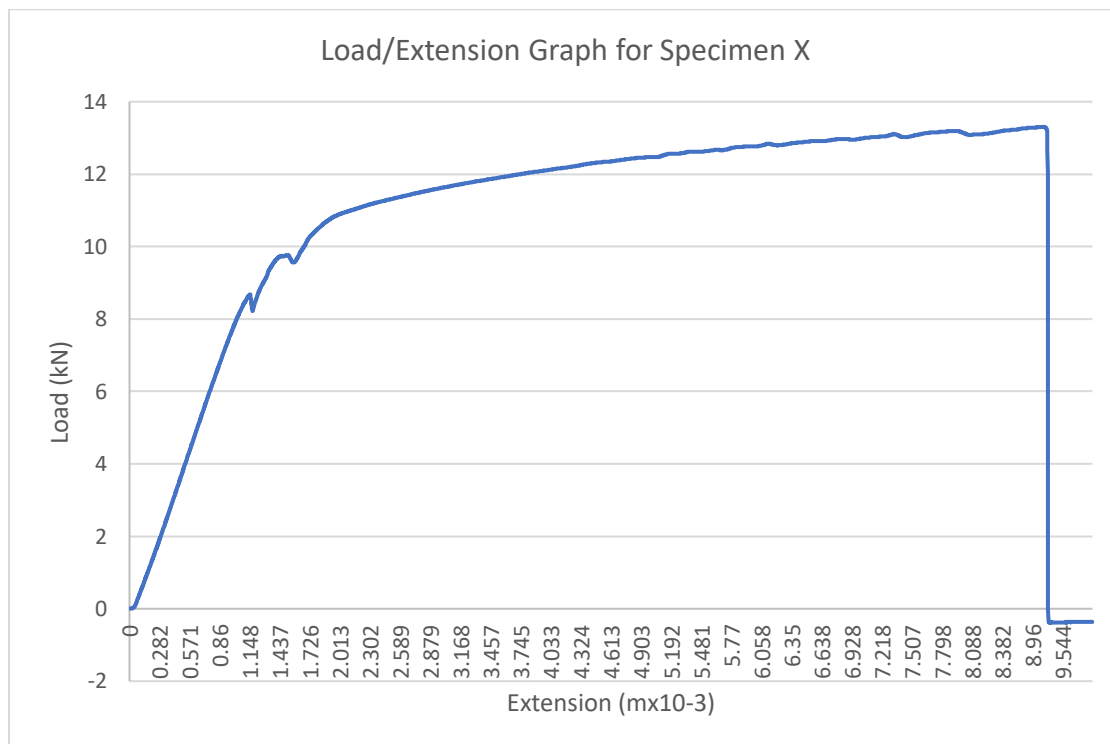


Figure 15 - Load/extension graph for specimen X

Comparative graph

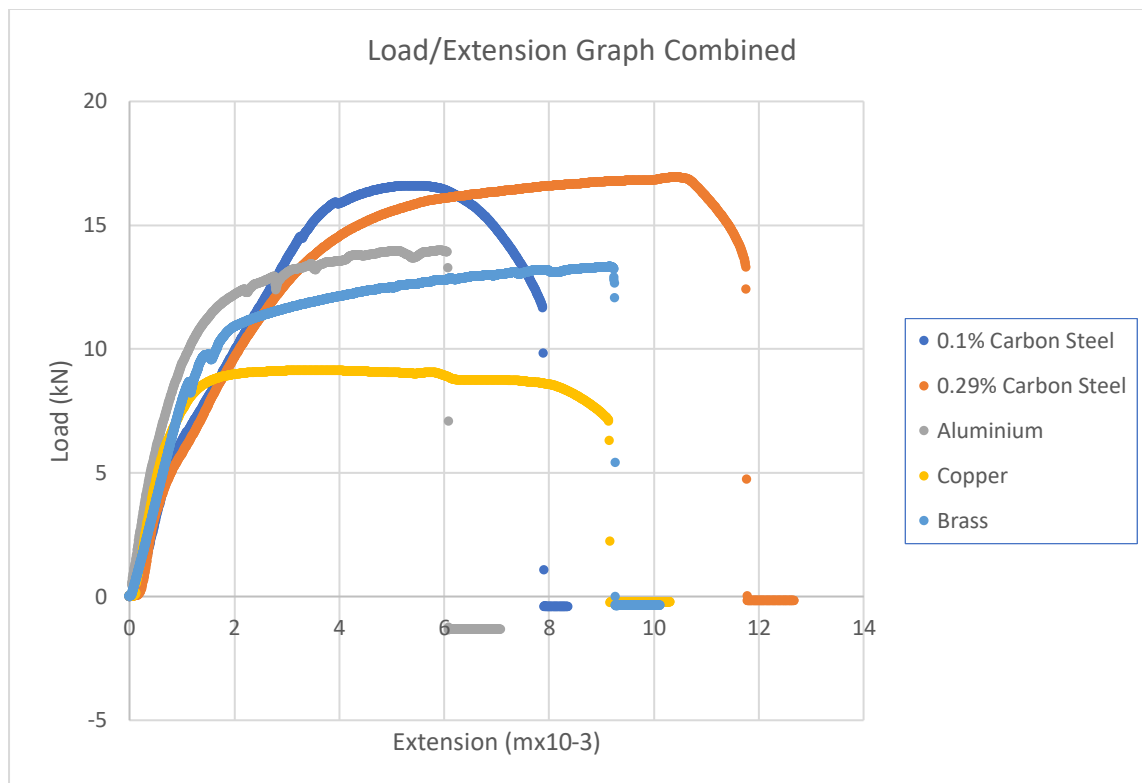


Figure 16 - Comparative load/extension graph for all figures

(2) Enlarged Load/Extension Graphs

Specimen A - Carbon Steel 0.1

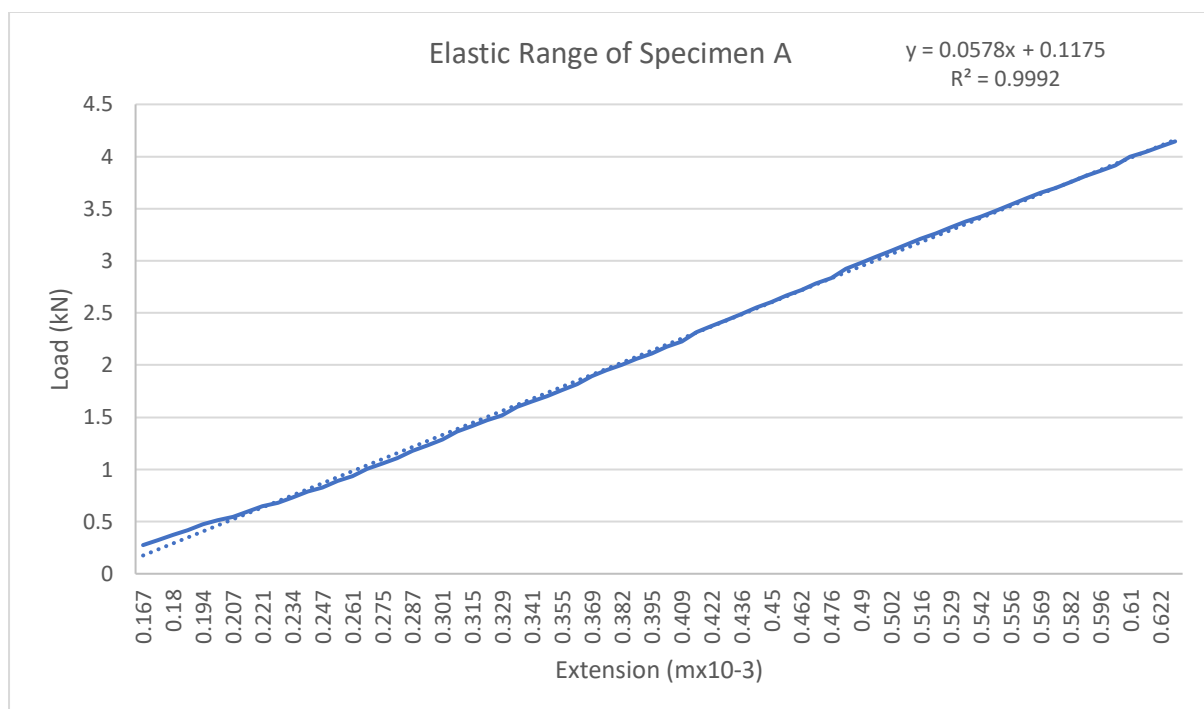


Figure 17 - Enlarged load/extension graph for specimen A

Specimen C - Carbon Steel 0.29

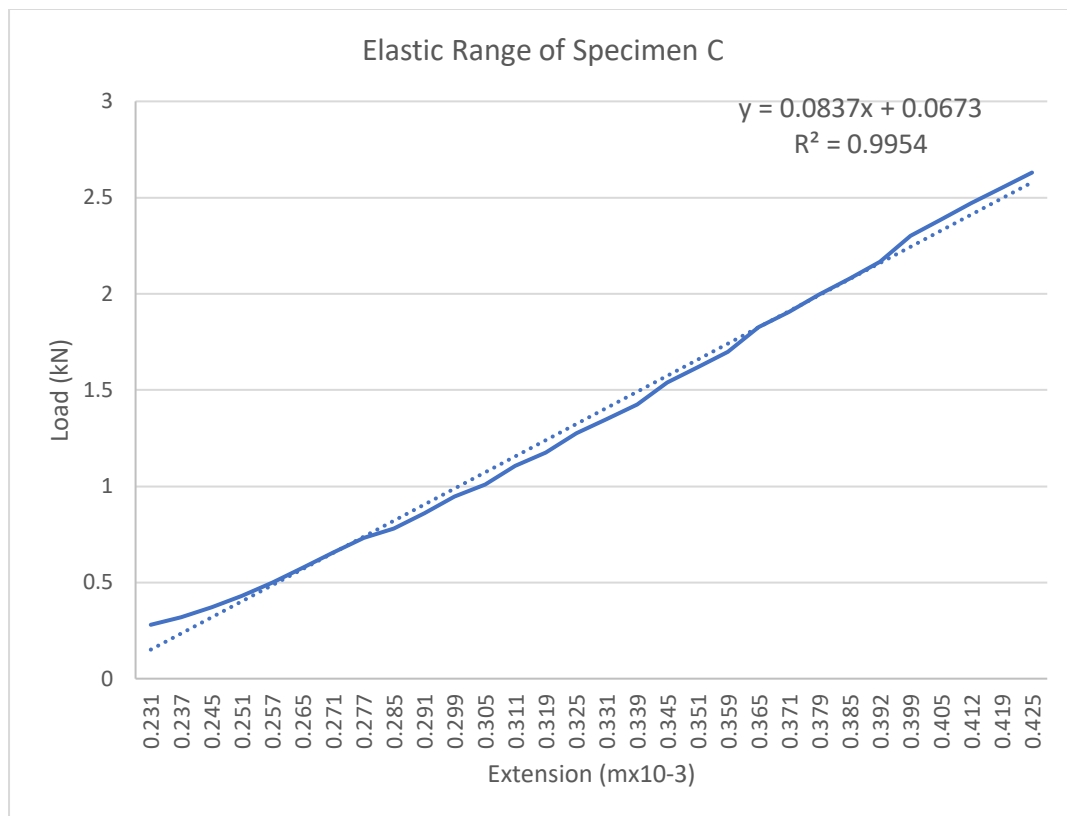


Figure 18 - Enlarged load/extension graph for specimen C

Specimen R - Aluminium

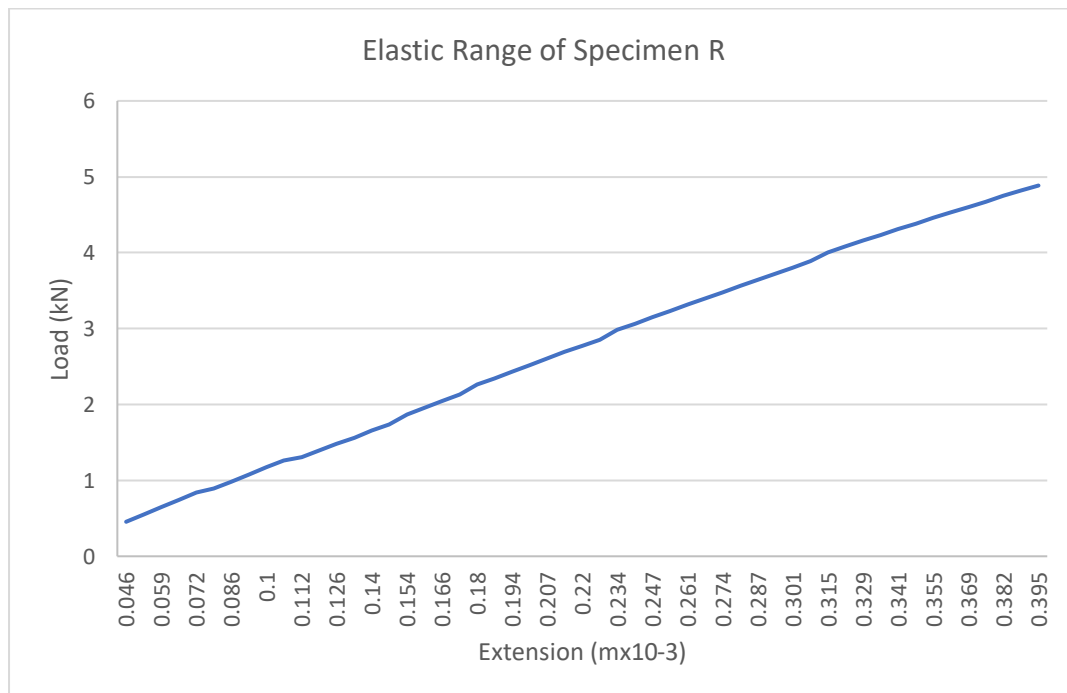


Figure 19 - Enlarged load/extension graph for specimen R

Specimen W – Copper

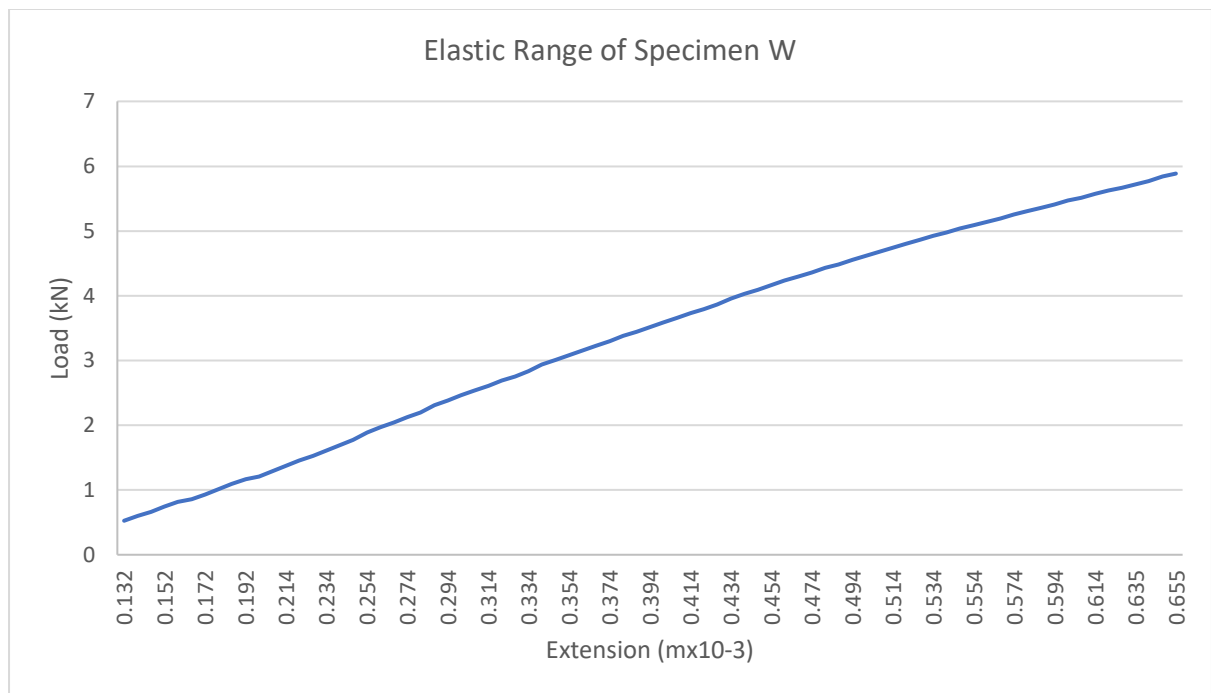


Figure 20 - Enlarged load/extension graph for specimen W

Specimen X – Brass

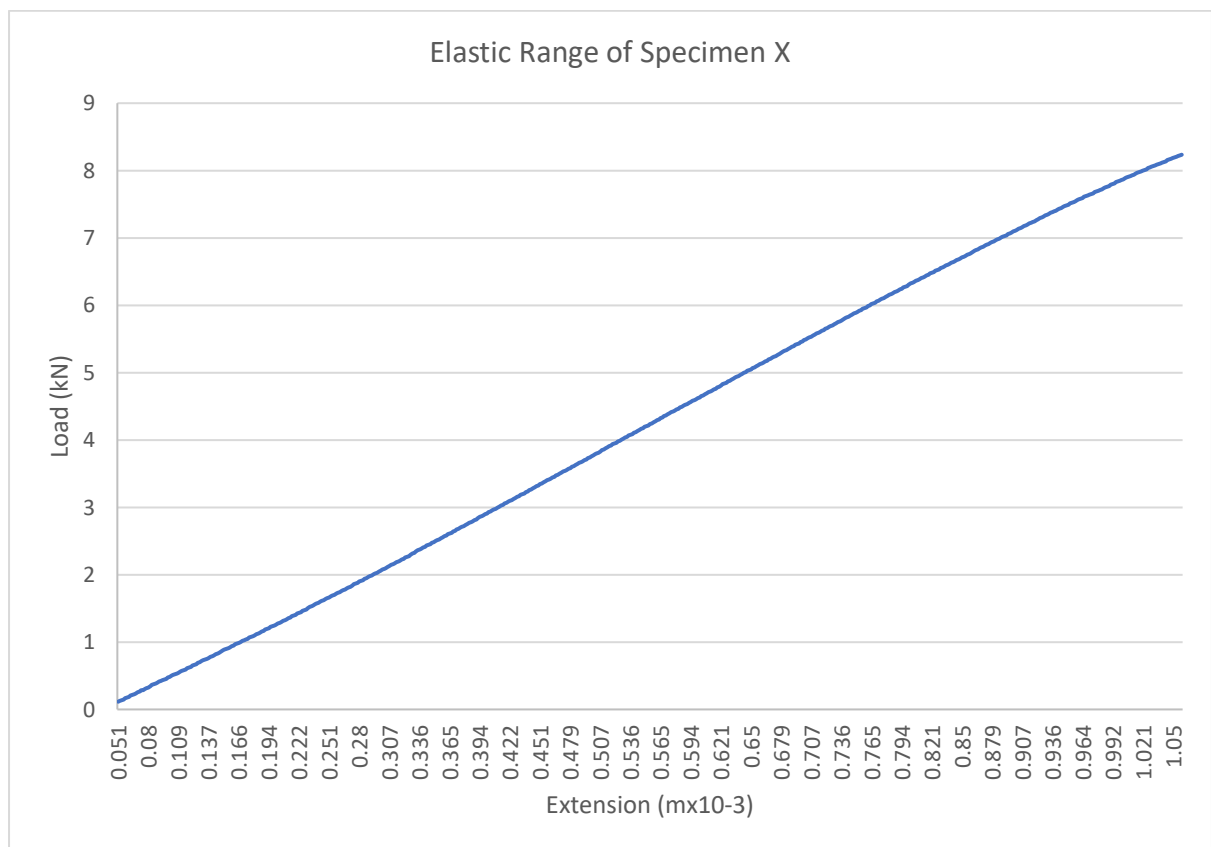


Figure 21 - Enlarged load/extension graph for specimen X

(3) Specimen A Calculations

Using the two graphs of samples A and C and other information supplied, determine the values for A and C of:

- a) Young's modulus of elasticity;

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

E = Young's modulus, pressure units

σ = uniaxial stress, or uniaxial force per unit surface, pressure units

ϵ = strain, or proportional deformation (change in length divided by original length), dimensionless

Figure 22 - Young's modulus equation

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{\text{Load} \times \text{Gauge Length}}{\text{Area} \times \text{Extension}} = \frac{\text{Load}}{\text{Extension}} \times \frac{\text{Gauge Length}}{\text{Area}}$$
$$\frac{\text{Load}}{\text{Extension}} = \text{Gradient of figure 17 graph}$$

Gradient of figure 17 graph = $5.78 \times 10^6 \text{Nm}$ (see equation of straight line on figure 17)

Gauge length = $54 \times 10^{-3} \text{m}$

Cross-sectional area = $\left(\frac{\text{diameter}}{2}\right)^2 \times \pi = \left(\frac{12.72 \times 10^{-3}}{2}\right)^2 \times \pi = 127.08 \times 10^{-6} \text{m}^2$

Therefore,

$$E = 5.78 \times 10^6 \times \frac{54 \times 10^{-3}}{127.08 \times 10^{-6}} = \boxed{2.46 \times 10^9 \text{Nm}^{-2}}$$

- b) The ultimate tensile stress;

(Maximum load taken from figure 11)

$$\text{Ultimate tensile stress} = \frac{\text{Maximum load}}{\text{Cross sectional area}} = \frac{16.585 \times 10^3}{127.08 \times 10^{-6}}$$
$$= \boxed{130.51 \times 10^6 \text{Nm}^{-2}}$$

c) The stress at the upper and lower yield points;

(Values for upper and lower yield points take from figure 11 graph)

$$\begin{aligned}\text{Stress at upper yield point} &= \frac{\text{Load at upper yield point}}{\text{Cross sectional area}} = \frac{15.905 \times 10^3}{127.08 \times 10^{-6}} \\ &= 125.16 \times 10^6 \text{Nm}^{-2}\end{aligned}$$

$$\begin{aligned}\text{Stress at lower yield point} &= \frac{\text{Load at lower yield point}}{\text{Cross sectional area}} = \frac{14.460 \times 10^3}{127.08 \times 10^{-6}} \\ &= 113.79 \times 10^6 \text{Nm}^{-2}\end{aligned}$$

d) The percentage reduction of area;

$$\text{Percentage reduction of area} = \frac{\Delta \text{ Cross sectional area}}{\text{Original cross sectional area}} \times 100$$

Original cross-sectional area = $127.08 \times 10^{-6} \text{m}^2$

$$\text{Minimum cross-sectional area} = \left(\frac{\text{diameter}}{2}\right)^2 \times \pi = \left(\frac{7.45 \times 10^{-3}}{2}\right)^2 \times \pi = 43.59 \times 10^{-6} \text{m}^2$$

$$\text{Percentage reduction of area} = \frac{127.08 \times 10^{-6} - 43.59 \times 10^{-6}}{127.08 \times 10^{-6}} \times 100 = 65.7\%$$

e) The percentage elongation;

$$\text{Percentage elongation} = \frac{\text{Final extended length} - \text{Original length}}{\text{Original length}} \times 100$$

Original length = $54 \times 10^{-3} \text{m}$

Final extended length = (elongation) + (original length)

Final extended length = $(8.292 \times 10^{-3} \text{m}) + (54 \times 10^{-3} \text{m}) = 62.29 \times 10^{-3} \text{m}$

(Elongation taken from tensile data provided)

$$\text{Percentage elongation} = \frac{62.29 \times 10^{-3} - 54 \times 10^{-3}}{54 \times 10^{-3}} \times 100 = 15.4\%$$

f) The nominal stress at fracture;

$$\begin{aligned}\text{Nominal stress} &= \frac{\text{Load at fracture}}{\text{Original cross sectional area}} = \frac{9.815 \times 10^3}{127.08 \times 10^{-6}} \\ &= 77.23 \times 10^6 \text{Nm}^{-2}\end{aligned}$$

g) The actual stress at fracture

$$\begin{aligned} \text{Actual stress} &= \frac{\text{Load at fracture}}{\text{Minimum cross sectional area}} = \frac{9.815 \times 10^3}{43.59 \times 10^{-6}} \\ &= \boxed{225.17 \times 10^6 \text{ Nm}^{-2}} \end{aligned}$$

(4) Specimen C Calculations

Using the two graphs of samples A and C and other information supplied, determine the values for A and C of:

a) Young's modulus of elasticity;

$$\begin{aligned} E &= \frac{\text{Stress}}{\text{Strain}} = \frac{\text{Load} \times \text{Gauge Length}}{\text{Area} \times \text{Extension}} = \frac{\text{Load}}{\text{Extension}} \times \frac{\text{Gauge Length}}{\text{Area}} \\ \frac{\text{Load}}{\text{Extension}} &= \text{Gradient of figure 18 graph} \end{aligned}$$

Gradient of figure 18 graph = $8.37 \times 10^6 \text{ Nm}$ (see equation of straight line on figure 18)

Gauge length = $54 \times 10^{-3} \text{ m}^2$

Cross sectional area = $\left(\frac{\text{diameter}}{2}\right)^2 \times \pi = \left(\frac{12.72 \times 10^{-3}}{2}\right)^2 \times \pi = 127.08 \times 10^{-6} \text{ m}^2$

Therefore,

$$E = 8.37 \times 10^6 \times \frac{54 \times 10^{-3}}{127.08 \times 10^{-6}} = \boxed{3.56 \times 10^9 \text{ Nm}^{-2}}$$

b) The ultimate tensile stress;

(Maximum load taken from figure 12)

$$\begin{aligned} \text{Ultimate tensile stress} &= \frac{\text{Maximum load}}{\text{Cross sectional area}} = \frac{16.925 \times 10^3}{127.08 \times 10^{-6}} \\ &= \boxed{133.18 \times 10^6 \text{ Nm}^{-2}} \end{aligned}$$

- c) The stress at the upper and lower yield points;

After thorough observation of figure 12 graph, it was determined that no yielding was exhibited, therefore no upper yield points can be identified.

- d) The percentage reduction of area;

$$\text{Percentage reduction of area} = \frac{\Delta \text{ cross sectional area}}{\text{original cross - sectional area}} \times 100$$

$$\text{Original cross-sectional area} = 127.08 \times 10^{-6} \text{m}^2$$

$$\text{Minimum cross-sectional area} = \left(\frac{\text{diameter}}{2}\right)^2 \times \pi = \left(\frac{7.45 \times 10^{-3}}{2}\right)^2 \times \pi = 43.59 \times 10^{-6} \text{m}^2$$

$$\text{Percentage reduction of area} = \frac{127.08 \times 10^{-6} - 43.59 \times 10^{-6}}{127.08 \times 10^{-6}} \times 100 = \boxed{65.7\%}$$

- e) The percentage elongation;

$$\text{Percentage elongation} = \frac{\text{final extended length} - \text{original length}}{\text{original length}} \times 100$$

$$\text{Original length} = 54 \times 10^{-3} \text{m}$$

$$\text{Final extended length} = (\text{elongation}) + (\text{original length})$$

$$\text{Final extended length} = (12.642 \times 10^{-3} \text{m}) + (54 \times 10^{-3} \text{m}) = 66.64 \times 10^{-3} \text{m}$$

(Elongation taken from tensile data provided)

$$\text{Percentage elongation} = \frac{66.64 \times 10^{-3} - 54 \times 10^{-3}}{54 \times 10^{-3}} \times 100 = \boxed{23.4\%}$$

- f) The nominal stress at fracture;

$$\begin{aligned} \text{Nominal stress} &= \frac{\text{Load at fracture}}{\text{Original cross sectional area}} = \frac{12.4 \times 10^3}{127.08 \times 10^{-6}} \\ &= \boxed{97.58 \times 10^6 \text{Nm}^{-2}} \end{aligned}$$

- g) The actual stress at fracture

$$\begin{aligned} \text{Actual stress} &= \frac{\text{Load at fracture}}{\text{Minimum cross sectional area}} = \frac{12.4 \times 10^3}{43.59 \times 10^{-6}} \\ &= \boxed{284.47 \times 10^6 \text{Nm}^{-2}} \end{aligned}$$

Data Analysis (Task 3)

As mentioned previously, load/extension graphs are only relevant to specimens with identical values for gauge length and cross-sectional area, in this case this is true so load/extension values will be suitable for comparison (no visual change would be observed by dividing throughout by the same number, only the axis would be different). Note, if this were not the case, the values would be converted into stress strain values and a stress/strain graph would be used as they represent all geometries.

Strength

The strongest materials can be identified on the load/extension graph as the highest value on the Y axis (Load). Figure 16 determines that both low carbon steels are stronger than aluminium, copper and brass. This can be expected due to steels' high strength properties compared with that of a pure metal. Alloys are strong because they are made up of different sized atoms, distorting the regular arrangement of a pure metal, making it more difficult for the atoms to slide over each other ultimately withstanding a higher load before deformation.

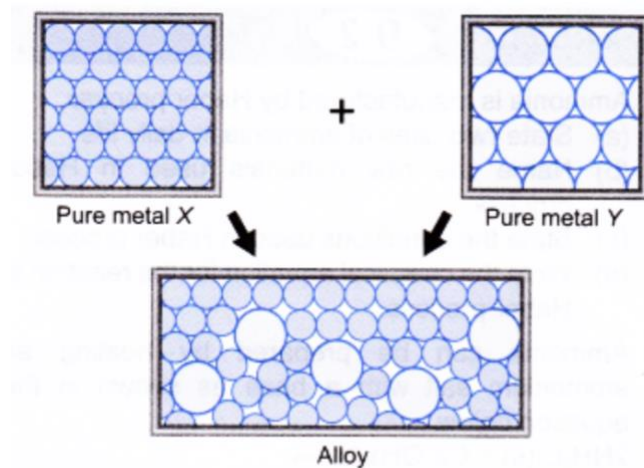


Figure 23 - Structure of metals and alloys

(Veerendra, 2020)

Brittleness

When materials exhibit a relatively small region of plastic deformation before failing, it is known as a brittle fracture. This can be identified on a load/extension graph by line ending immediately or soon after the yield point. This is often an undesirable trait for materials to have. Figure 16 shows that aluminium is the most brittle of all the sample materials. This is due to aluminium's low density in comparison to materials like low carbon steel; As the atoms are not packed as closely together, they can't slide and therefore break. (Note, Aluminium despite being the most brittle in this case, is actually relatively ductile in comparison to materials such as cast iron due to carbon impurities).

(Chen, et al., 2014)

Elasticity

The elasticity of a material can be measured using their value for Young's modulus, which is the gradient of a stress/strain graph, due to the proportionality of the test piece sizes the gradients on the load/extension graph will be used as an indication.

When comparing the two steel samples, figures 17 and 18 show that specimen C, despite having the same cubic structure has a steeper gradient than specimen A (during elastic deformation).

Specimen C has a higher carbon content than A which increases hardness and brittleness. When compared in figure 16 it suggests that specimen A is the harder of the two steel samples due to the steeper gradient, this would suggest that the samples have been incorrectly reported and that specimen A is the 0.29% carbon steel sample and sample C is the 0.1% carbon steel sample. (Note, only one sample of each material was tested, so this could be an anomalous result).
(Concepcion, et al., 2015)

Specimen R, aluminium, visibly has the highest gradient value in figure 16 which is expected due to aluminium's elastic properties. Aluminium has the largest elastic deformation period of all the tested materials. This is due to aluminium's tightly packed FCC structure allowing the atoms to slide when under stress.
(Chen, et al., 2014)

Ductility

A materials' cubic structure determines how much plastic deformation it can withstand before fracture, its ductility. Closely packed atoms can easily slide over each other, allowing more plastic deformation. The cubic structure of carbon steel changes dependant on temperature, the test was carried out at room temperature which determines that both specimens A and C are body centered cubic (BCC), (note, at 912°C the structure becomes face centred cubic (FCC)). BCC structures have an atomic packing (APF) factor of 0.68 whereas FCC is 0.74 meaning that BCC structures are less closely packed than FCC. Ultimately this establishes that specimens A and C have a reduced ductility.
(Libre Texts, 2020)

Figure 16 shows that specimen C is the most ductile, this is evidenced by the longest extension of the curve. This is however inconsistent with what is expected considering the higher amount of carbon when compared to specimen A. This supports the suggestion made in the elasticity section regarding potential incorrect identification of sample (again it. Must be noted, only one sample of each material was tested, so this could be an anomalous result).

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