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INSTITUTE OF APPLIED TECHNOLOGY

Engineering Materials

Module 4: Tensile Test

PREPARED BY

IAT Curriculum Unit

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Module 4: Tensile Test

Module Objectives

After the completion of this module, the student will be able to:

- Explain the terms stress and strain.
- Present graphically the relationship between stress and strain.
- Use the stress-strain diagram to identify:
  - a) The elastic range.
  - b) The yield point.
  - c) The plastic range.
  - d) The ultimate tensile strength.
  - e) The fracture stress.
  - f) The modulus of elasyicity.
- Explain what the tensile test is and why we are performing it.
- Describe the main parts of the universal test machine used to perform the tensile test.
- Setup and perform a tensile test for aluminum, brass, copper and steel using a certain procedure.
- Plot and analyse a stress-strain diagram given a set of data for a tensile test.
- Use the modulus of elasticity to calculate the stress, strain, and elongation.

Module Contents

Introduction

The tensile test is used to measure the amount of tensile (pulling) force that a part can take before it separates into two pieces. It is used to study how the material reacts as the load is applied. An example of a tensile force is shown in Fig. 4.1.

Cables are under tension

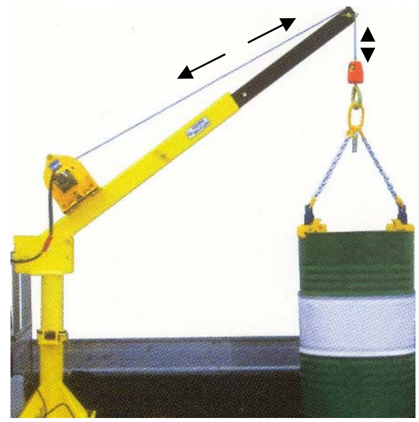


Fig. 4.1: Tensile forces

1. What is the Stress?

Stress is the pressure caused by a force that is acting over a given area of a material as shown in Fig. 4.2a.

The following formula is used to determine the stress.

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

Where:

σ **=** Stress in N/ m² (Pascal).

F = Applied Load in Newton (N).

A = Cross-sectional area in m².

Example:

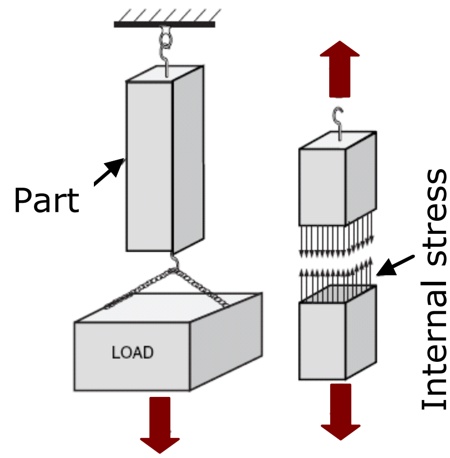
Fig. 4.2b shows a round steel bar of 0.05 m² area that is subjected to a tensile force of 500 N. What is the tensile stress?

Answer:

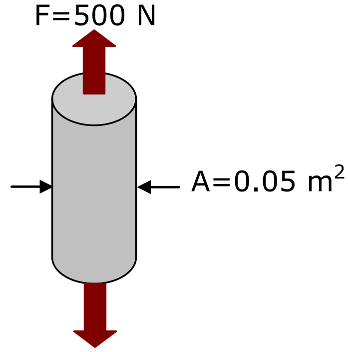
Tensile stress σ = F/A

Stress σ = 500/0.05

= 10,000 N/ m² (Pascal)



(a)



(b)

Fig. 4.2**:** (a) Load being applied to a part (b) Round steel bar under tensile load.

Calculating stress is an important design skill because it enables you to design parts to withstand the forces or loads that will be placed on them.

2. What is the Strain?

Strain is the ratio of the increase in length of the body to its original length that is caused by the action of stress on the body. Fig. 4.3 shows the elongation of a specimen after applying a force of 200 N. The strain can be calculated using the following formula:

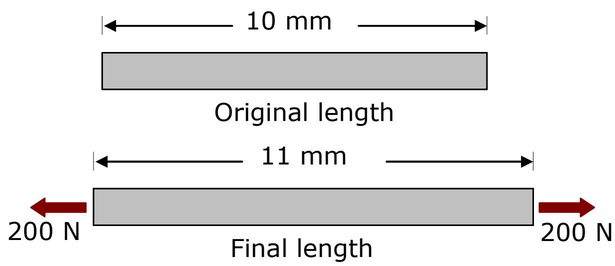


Fig. 4.3: Effect of tensile load on length (due to stress).

$$\textit{Strain } \varepsilon = \frac{\Delta L}{Lo} = \frac{L - Lo}{Lo}$$

Where:

ε= Strain.

$\Delta L = L - L_o$ = the elongation of the material.

L= Final length.

L_o=original length.

Strain has no units of measure because in the formula the units of length are cancelled.

Example:

A 100 mm length aluminum bar is subjected to a tensile force and has been stretched to be 102 mm length as shown in Fig.4.4. Calculate the strain.

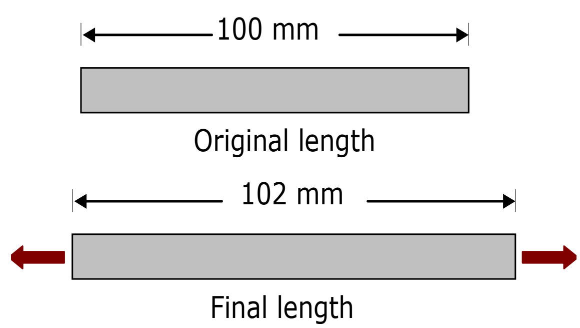


Fig. 4.4: Aluminum bar stretched due to stress.

Answer:

$$\varepsilon = \frac{L - Lo}{Lo} = \frac{102\ mm - 100\ mm}{100\ mm}$$

$$= 0.02.$$

It is important to note that the strain and the increase in length due to stress are not the same, but they are related to each other. In Fig. 4.4, the elongation is 2 mm. This was used to calculate the strain of 0.02.

The strain allows you to determine the characteristics of the material independent of the actual length of the part. For example if the part in Fig. 4.4, was 200 mm, it would have elongated 4 mm instead of 2mm. However the strain would still be the same 0.02.

3. Stress – Strain curve

As the tensile load on a part increases, its elongation and strain also increase. At some level of stress the part will finally break. Up to this point, a material goes through several changes in its characteristics. These characteristics are very important to the performance of the part in operation.

A stress-strain diagram is a graph derived from measuring load (stress) versus extension (strain) for a sample of a material.

The nature of the curve varies from material to material. The following diagram shown in Fig. 4.5 illustrates the stress-strain behavior of a typical material.

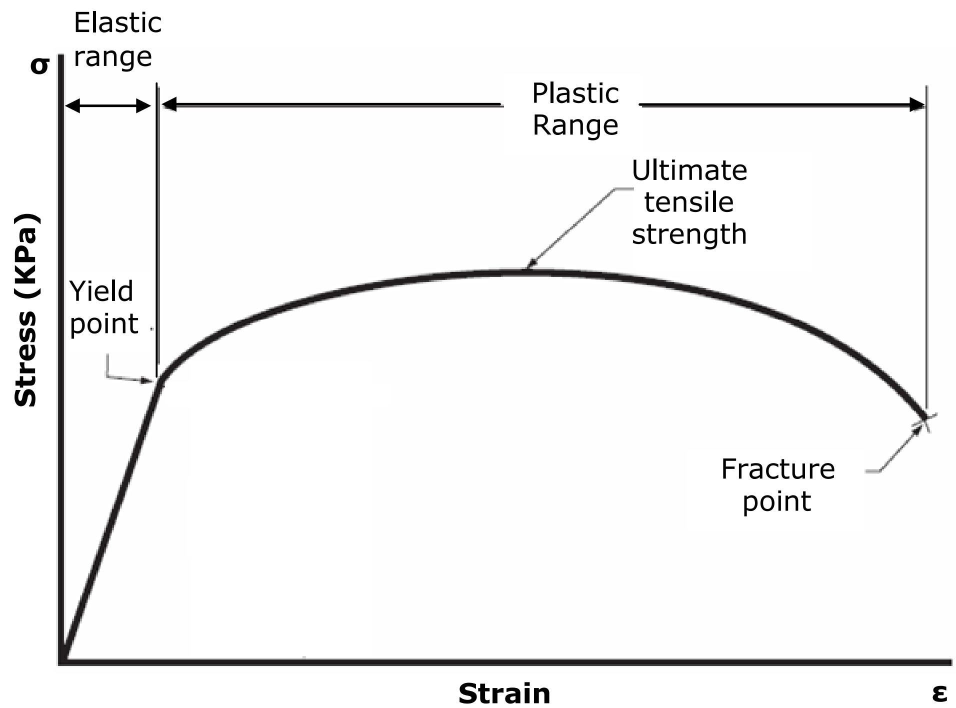


Fig. 4.5: Stress- strain curve.

3.1 Elastic Range

The elastic range of the diagram represents the amount of stress and strain a part can take without being permanently changed. For example, when a rubber hand is stretched and then released (i.e. the force is removed), the rubber hand returns to its original length. This means the material was placed under a stress that was within its elastic range.

Metals have this same ability to stretch, although it is very limited.

This means that metals can be stretched slightly and still return to their original shape.

The ability of a part to retain its shape when stress is applied is very important to part design. If a part is permanently deformed, all dimensions and tolerances are lost even if the part does not, break, it has still failed. Therefore, most parts are designed so that the part's stress stays within the elastic range when a load is applied.

3.2 Yield Point

The yield point is reached at the exact moment that the stress on a material exceeds the material's elastic range. Notice in Fig. 4.5 that the yield point immediately follows the elastic range.

3.3 Plastic Range

The plastic range is the range that immediately follows the yield point of a material. In this range, a material is being permanently elongated. Notice, in Fig. 4.5, when a material is stressed into the plastic range, a small increase in the stress creates a much larger increase in strain.

In operation, a part must not exceed its elastic range, because, as you have learned, it will lose its dimensions and tolerances. However, in the production of parts, some processes take advantage of the plastic range to change the shape of the raw material into a new shape, for example using the press to make parts.

3.3 The Ultimate Tensile Strength:

The Ultimate Tensile Strength is the highest stress the material can withstand as shown in Fig. 4.5. It is calculated by dividing the maximum tensile load by the original specimen's cross sectional area.

$$\textit{Ultimate Tensile Strength} = \frac{\textit{Maximum Load (N)}}{\textit{Original Area (mm}^2\textit{)}}$$

3.4 The fracture point

The fracture point occurs when the material is stressed beyond the material's ability to elongate any further and the part breaks, as shown in Fig. 4.5.

At first, you may think that the fracture point would be the same as the ultimate tensile strength, because the material should break at the highest stress value. While this is true for some materials, it is not true for all. Depending on the material, this point will occur at different levels of stress. For example, in Fig. 4.6, the stress/strain diagrams of two materials are shown. One is a ductile material and the other is a brittle material.

Notice that the fracture point of the ductile material has a lower stress value than its ultimate tensile strength.

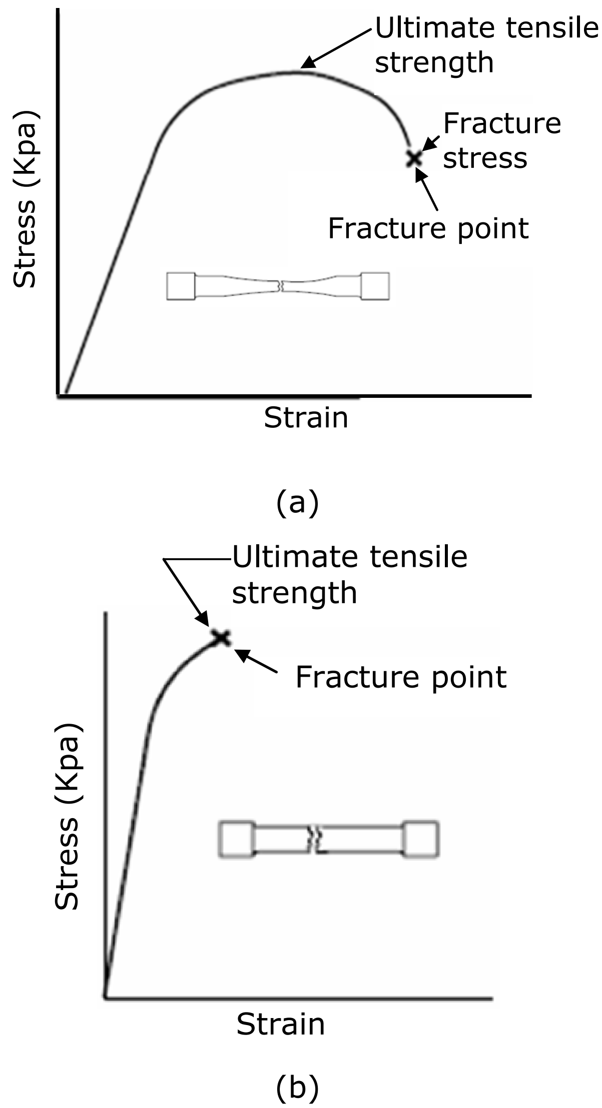


Fig. 4.6: (a) Ductile material. (b) Brittle material.

This is because a ductile material begins to form a "neck" where it reaches its ultimate tensile strength. Necking is the reduction in diameter of the material, as shown in Fig.4.7. Because the area of the material is getting smaller, less stress is required to break the material after the necking has occurred at a higher stress.

A brittle material, however, does not neck at all or very little. Since there is no reduction in the diameter of the material, the stress will always increase until the fracture point is reached. This means that the fracture point is the highest stress and therefore the ultimate tensile strength.

The percentage reduction in area and the extension are used as a measure of ductility. The percentage reduction in area can be calculated by using the following formula.

$$\%\ \text{Reduction in Area} = \frac{\textit{Original Area} - \textit{Final Area}}{\textit{Original Area}} \times 100$$

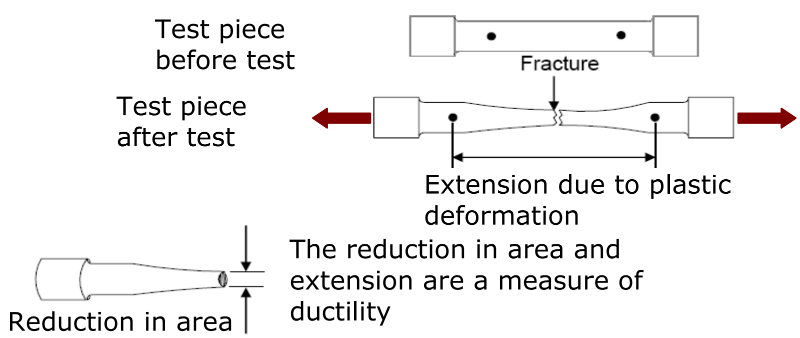


Fig. 4.7: Necking of a ductile material.

4. Universal testing machine

A tensile test measures the actual stress-strain characteristics of a material by applying a pulling load to a test part (specimen) until the specimen breaks as shown in Fig.4.8.

By using the universal testing machine, you will be able to obtain a load versus extension curve for four specimens made of different materials.

Fig. 4.8: Specimen breaks after the tensile test.

The main parts of the universal testing machine are shown in Fig. 4.9.

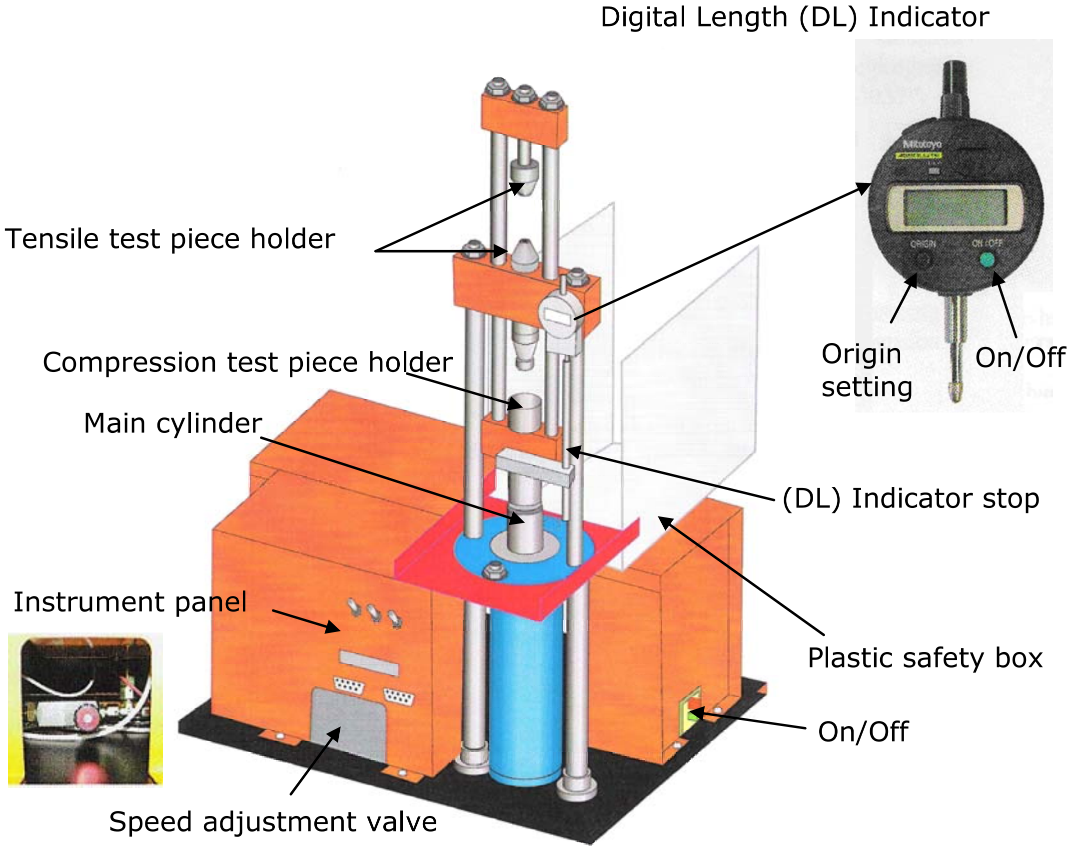


Fig. 4.9: The main parts of the universal testing machine.

5. Tensile test procedures

1. Use the Vernier caliper to measure the gage length and the diameter of the specimen as shown in fig. 4.10

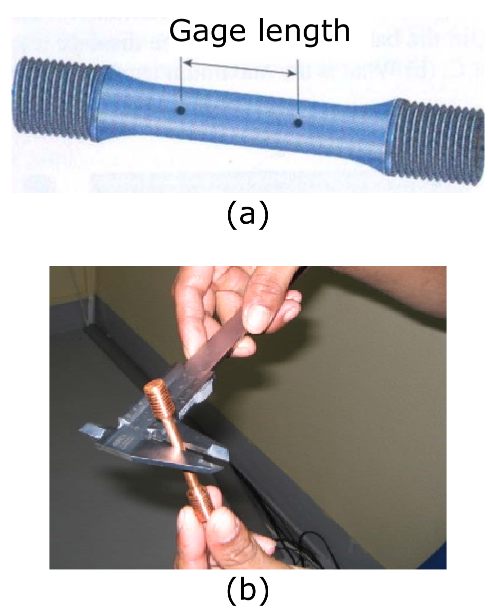


Fig. 4.10: (a) Measuring the gage length. (b) Measuring the diameter.

2. Switch on the machine as shown in Fig. 4.11.

Fig. 4.11: The machine ON/OFF switch

3. Place the specimen on the holder. Make sure that the specimen is centered on the machine as shown in fig. 4.12.

Fig. 4.12: The specimen is fixed on the holder.

4. Press the reset button to set the DL-indicator to zero as shown in Fig. 4.13.

Fig. 4.13: Reset the DL-indicator.

5. Close the plastic door as shown in Fig. 4.14.

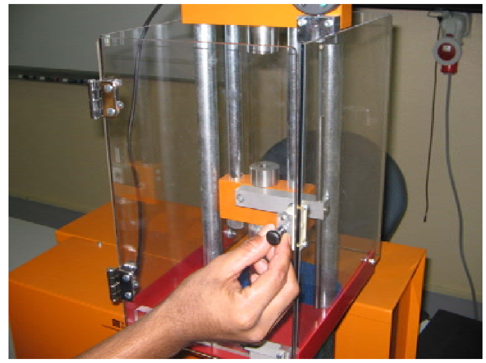


Fig. 4.14: Secure the plastic door

6. Adjust the speed by turning the speed adjustment valve 1/16 of a turn anticlockwise as shown in Fig. 4.15.

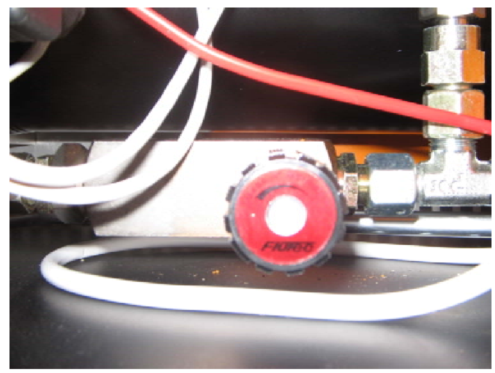


Fig. 4.15: Adjusting the speed valve.

7. Switch on the instrument panel and ensure that the middle button is set to PC as shown in Fig. 4.16.

Fig. 4.16: the instrument panel.

8. Click the measuring display button then click the start button to start the test as shown in Fig. 4.17.

Fig. 4.17: Measuring display box.

9. The machine starts and the cylinder moves slowly upwards. Meanwhile, the measuring values are stored in a table with four measurements per seconds as shown in Fig. 4.18.

10. Record the maximum load that the specimen resists.
11. Save the table and the graph as shown in Fig. 4.18.
12. Calculate the area of the specimen. Use this area and the maximum load to calculate the ultimate tensile strength.
13. Use the caliper to measure the final length, diameter and calculate the elongation, and reduction of area.

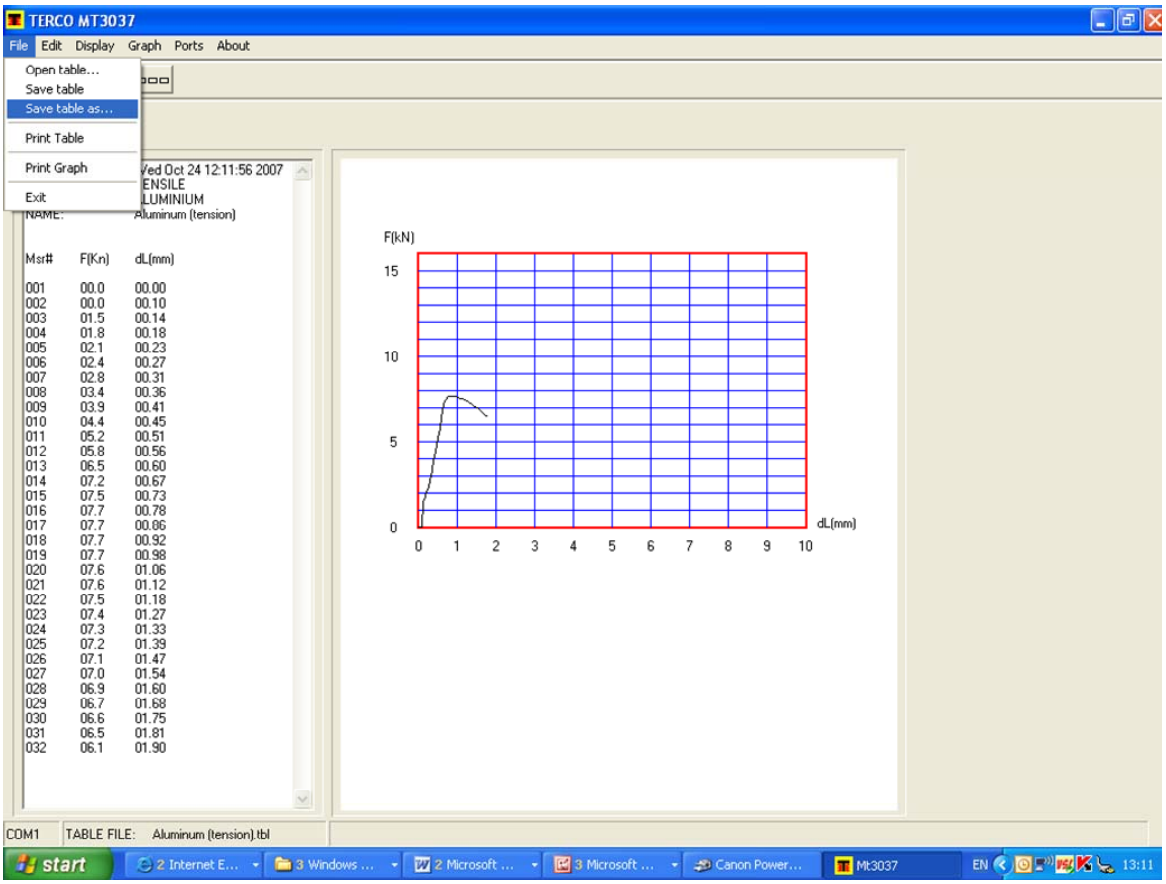


Fig. 4.18: Final test results

6. Tensile test results analysis

6.1 The tensile test results for an aluminum test piece.

Type of material	Aluminum
Original Gage Length, mm.	
Original Diameter, mm.	
Final Diameter	
Maximum Force (Load) in KN.	
Final Length, mm	
ΔL, mm (extension)	
Original Area, mm^2.	
Final Area, mm^2	
% Reduction in Area	
Ultimate Tensile Strength(σ_u), (N/mm2)	
Strain	
Fracture Stress	

Activity 1

Create the stress-strain diagram for the aluminium specimen using the sets of data result from the test. The data will be given in force and extension of the part. After plotting the curve, identify the following:

1- Elastic range.
2- Yield point.
3- Plastic range.
4- Ultimate tensile strength.
5- Fracture point.

Note: you can use the spread sheet or any other similar application to calculate the data and draw the stress-strain curve.

6.2 The tensile test results for a brass test piece.

Type of material	**Brass**
Original Gage Length, mm.	
Original Diameter, mm.	
Final Diameter	
Maximum Force (Load) in KN.	
Final Length, mm	
ΔL, mm (extension)	
Original Area, mm^2.	
Final Area, mm^2	

% Reduction in Area	
Ultimate Tensile Strength(σ_u), (N/mm2)	
Strain	
Fracture Stress	

Activity 2

Create the stress- strain diagram for the brass specimen using the sets of data result from the test. The data will be given in force and extension of the part. After plotting the curve, identify the following:

1- Elastic range.
2- Yield point.
3- Plastic range.
4- Ultimate tensile strength.
5- Fracture point.

6.3 The tensile test results for a copper test piece.

Type of material	Copper
Original Gage Length, mm.	
Original Diameter, mm.	
Final Diameter	
Maximum Force (Load) in KN.	

Final Length, mm	
ΔL, mm (extension)	
Original Area, mm^2.	
Final Area, mm^2	
% Reduction in Area	
Ultimate Tensile Strength(σ_u), (N/mm2)	
Strain	
Fracture Stress	

Activity 3

Create the stress- strain diagram for the copper specimen using the sets of data result from the test. The data will be given in force and extension of the part. After plotting the curve, identify the following:

1- Elastic range.
2- Yield point.
3- Plastic range.
4- Ultimate tensile strength.
5- Fracture point.

6.4 The tensile test results for a steel test piece.

Type of material	Steel
Original Gage Length, mm.	
Original Diameter, mm.	
Final Diameter	
Maximum Force (Load) in KN.	
Final Length, mm	
ΔL, mm (extension)	
Original Area, mm^2.	
Final Area, mm^2	
% Reduction in Area	
Ultimate Tensile Strength(σ_u), (N/mm2)	
Strain	
Fracture Stress	

Activity 4

Create the stress- strain diagram for the steel specimen using the sets of data result from the test. The data will be given in force and extension of the part. After plotting the curve, identify the following:

1- Elastic range.
2- Yield point.
3- Plastic range.
4- Ultimate tensile strength.
5- Fracture point.

Activity 5

Analyze the stress -strain curves of the four different materials created earlier to find the following:

1. Which material has the highest tensile strength?

---

2. Which material has the highest yield strength?

---

3. Which material is the most ductile?

---

4. Which material is the most brittle?

---

5. Which material has the highest fracture stress?

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7. Modulus of elasticity

The modulus of elasticity is a term used to describe the relationship between stress and strain when a material is under load within its elastic range. As you can see in the stress/strain diagram shown in Fig. 4.19, the plotted line is a

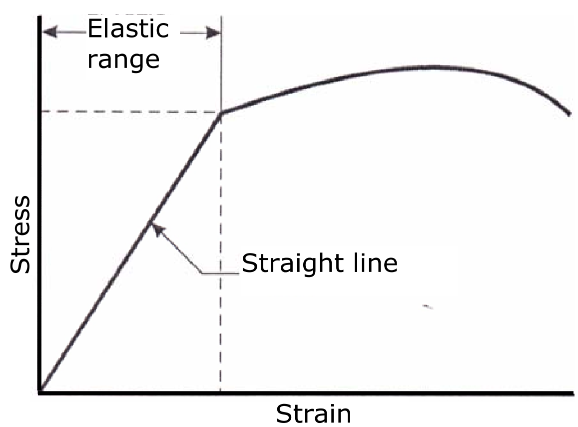

Fig. 4.19: Final test results

straight line through the elastic range. This is because stress and strain are proportional in this range. In other words, a certain percent increase in stress causes an equal percent increase in the strain.

This slope of this straight line is called the modulus of elasticity or Young's modulus. The formula used to calculate the modulus of elasticity is as follows:

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

Where E= modulus of elasticity in Kpa.

σ = Stress in Kpa.

ε= Strain.

The modulus of elasticity is important in determining how much the part will stretch given a certain amount of stress. The dimension or material type of the part can be changed in order to keep the elongation of the part within an acceptable range.

Example

The 0.2 % carbon cold rolled steel shaft shown in Fig.4.20 is subjected to load of 900 KN. Determine how much it will stretch?

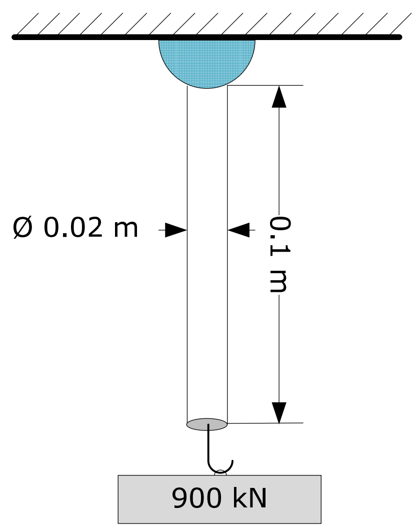

Fig. 4.20: 0.2 % carbon cold rolled steel shaft.

Answer

1.calculate the cross sectional area

$$A = \frac{\Pi\, d^2}{4}$$

A = 3.14 x $(0.01)^2$= $3.14\text{X}10^{-4}$ m^2

2. Calculate the stress

σ = F/A

$\sigma = 900\text{X}10^3 / 3.14\text{X}10^{-4} = 2.87\text{x}10^9$ N/m^2

Notice that 1 Giga= 10^9 or 1000,000,000.

Therefore σ= 2.87 GN/m^2 or 2.87 Gpa.

3. Calculate the strain based on the given stress by using the modulus of elasticity .The modulus of elasticity of most materials can be found in many handbooks in tables. An example of one of these tables is given in Fig.4.21. Looking down the second column, you will find the 0.2 % carbon cold rolled steel elastic modulus= 210 GN/m² this means 210x10^9 N/m².

MATERIAL SPECIFICATIONS
Average Mechanical Properties of Selected Engineering Materials (Values in SI Units Given in Parentheses)

MATERIAL	ELASTIC MODULI (E) 10^3 ksi (GN/m^2)	TENSILE STRENGTH 10^3 psi (MN/m^2)		COMPRESSION STRENGTH 10^3 psi (MN/m^2)	
		Yield	Ultimate	Yield	Ultimate
Aluminum					
2014-T6[a]	10.6 (73)	53 (365)	60 (410)	65 (450)	-
6061-T6[a]	10.0 (70)	35 (240)	38 (260)	35 (240)	-
6062-T6[a]	10.0 (70)	16 (110)	26 (180)	14 (96)	-
Cast iron					
Gray, class 20[b]	12 (83)	-	20 (140)	-	95 (660)
Malleable					
ASTM 32510[b]	26 (180)	32 (220)	50 (350)	-	208 (1430)
Steel					
0.2% C, hot-rolled	30 (210)	36 (250)	60 (410)	36 (250)	-
0.2% C, cold-rolled	30 (210)	60 (410)	80 (550)	60 (410)	-
Magnesium					
AZ 31B-H24[b]	6.5 (45)	32 (220)	42 (290)	-	-
AZ 92A-T6[b]	6.5 (45)	23 (160)	40 (280)	-	-
Titanium					
Pure Ti (Gr 1)[b]	16.5 (114)	30 (210)	40 (280)	-	-
Ti-6A1-4V (Gr 5)[b]	16.5 (114)	120 (830)	130 (900)	-	-
Concrete					
Low strength	3 (21)	-	-	1.2 (8)	3 (21)
High strength	5 (34)	-	-	2 (14)	5 (34)
Wood					
Douglas fir	1.9 (13)	8.1 (56)	-	6.4[c] (44)	7.4 (51)
Southern pine	1.6 (11)	5.1 (35)	-	4.0[c] (28)	5.8 (40)

[a]Aluminum Association designation.
[b]American Society of Testing Materials designation.
[c]Parallel to the grain of the wood.

Fig. 4.21: Table of material specifications

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

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

Strain (ε) =2.87x10^9 /210x10^9=0.0137.

4. The elongation in the shaft (ΔL) = Original length X strain.

= 0.1X0.0137

= 0.00137 m

5.The shaft final length = 0.1+0.00137 = 0.10137 m.

Activity 6

Determine the stress, strain, elongation, and the final length of the aluminum support bar shown in Fig. 4.22. Use the table in Fig.4.21 to find the modulus of elasticity of the material used.

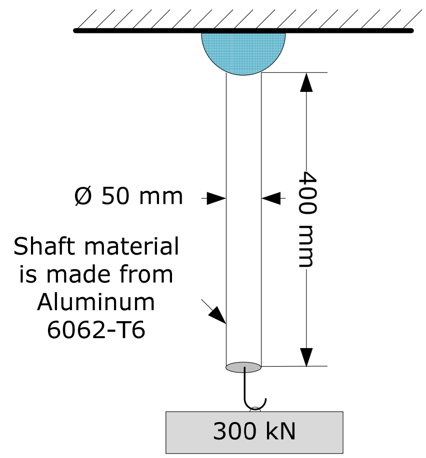

Fig. 4.22: Aluminum support bar.

Answer

1. Cross sectional area=________________________

2.Stress= ________________________

3.Modulus of elasticity (E)=________________________

4. Strain=________________________

5.Elongation=________________________

6. Final length

For further reading, you can use the following links:

1. http://test-equipment.globalspec.com/Industrial-Directory/tensile_test
2. http://www.instron.us/wa/applications/test_types/tension/default.aspx
3. http://online.engr.uiuc.edu/webcourses/burksdemo/demo.htm.

8. Supplementary recourses

1. Mechanical and Non-destructive testing video.
2. Tensile test video.

9. References

1. MT3037 Universal Testing machine manual.MT3037-312 July 2007.
2. Modern engineering materials edition 1.
3. Engineering materials 1. “An introduction to Properties, Applications, and Design”.
4. Modern Materials and Manufacturing Processes, R. G. Bruce, M. M. Tomovic, J. E. Neeley, and R. R. Kibbe, Prentice Hall, 2nd Ed., 1987, pp 55-60.
5. Different internet sites.

Student's notes