UNIVERSITY OF SCIENCE AND TECHNOLOGY OF HANOI

DEPARTMENT OF SPACE AND APPLICATIONS

COURSE: MECHANICS OF MATERIALS

PRACTICAL WORK REPORT

AUTHOR	STUDENT ID
DUONG THU PHUONG	**22BI13362**
NGUYEN THUY LINH	**BA11-063**
TRAN HUY HOANG	**22BI13176**
NGUYEN QUANG HUY	**22BI13197**
HA BUI KHOI NGUYEN	**22BI13337**
PHAM TUAN SAN	**22BI13389**
LE QUANG TRI	**22BI13428**
DO DUC VINH	**22BI13471**
PHAM NGOC CUONG	**BI12-066**
BUI KHAI SON	**22BI13391**

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Experiment 1. Tensile tests

1.1 Description

1.1.1 Objectives

Tensile tests with different materials on the WP 300 Universal Material Tester.

1.1.2 Equipments

Universal material tester, 20 kn (GUNT WP 300).

Data acquisition system (GUNT WP 300 20).

This set of tension test rods is available as an accessory for the WP 300 Universal Material Tester. The test rods comply with the requirements of DIN 50125 and are of circular cross-section.

For marking the test length, there are two center punch marks on the shafts.

The ends of the test rods have M10 threads for attachment. The set contains one tension test rod made of aluminum (AlMgSi0,5F22), one of copper (E-Cu), one of brass (CuZn39Pb3) and one of steel (9SMn28).

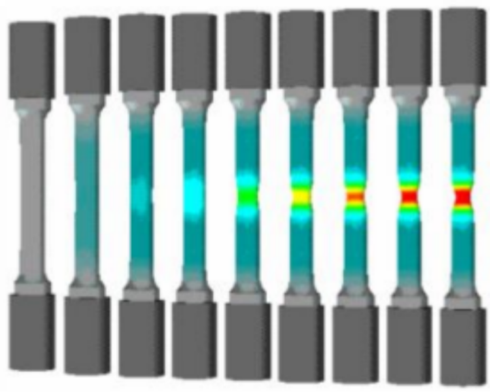
1.1.3 Principles

Tensile test pieces are screwed into or gripped in jaws and stretched by moving the grips apart at a constant rate while measuring the load and the grip separation.

This data is plotted as load versus extension and then converted to engineering stress (load/original area) versus engineering strain (fractional change in length over the test section assuming the deformation is uniform).

In special circumstances, the actual stress and strain may be calculated if the true cross section is measured during the test.

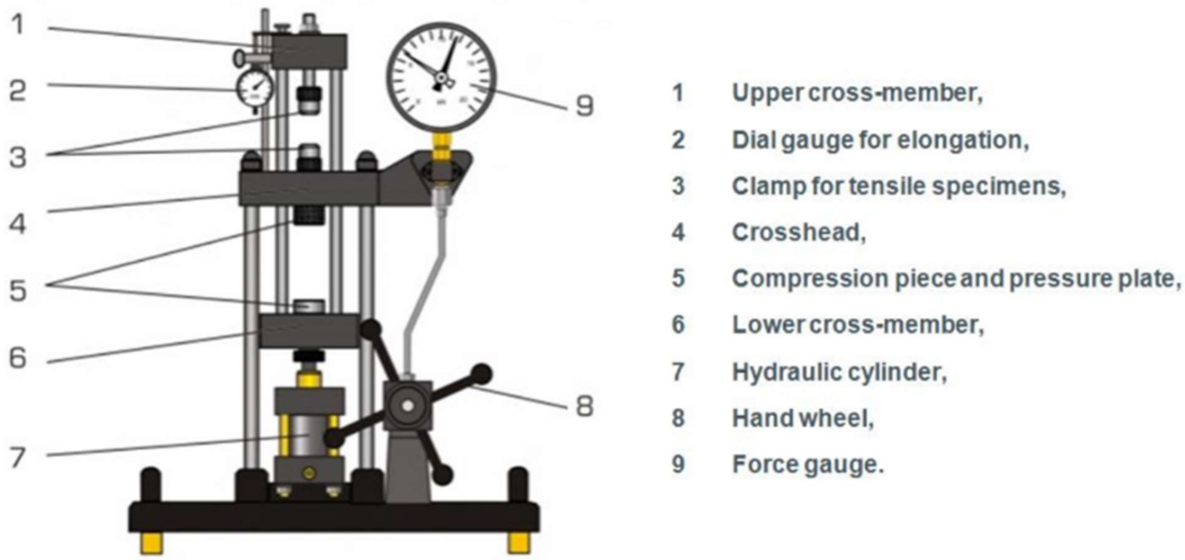
Standards set out the requirements for sample size, test methods and equipment and includes examples of the typical shapes of stress vs strain plots which may be expected when tensile tests



are performed.

The uniform section gauge length (where the deformation is presumed to be contained) can be between 25 and 100mm tong. The orientation of the sample relative to rolling or solidification directions will obviously affect the results obtained.

1.2 Experiment Setup



1.3 Results

Elongation: $\Delta L(mm)$

Strain: $\epsilon = \Delta L/L$

Tensile force: $F(kN)$

Tensile stress: $\sigma = F/A_0$, where A_0 is the section area of the test rod.

1.3.1 Steel test rod

F (kN)	ΔL (mm)	$\varepsilon = \Delta L/L$	$\sigma = F/A_0$ (kN/mm^2)
0.5	0.06	0.000000	0.004421
1	0.09	0.000333	0.008842
1.5	0.15	0.000667	0.013263
2	0.19	0.001333	0.017684
2.5	0.23	0.002000	0.022105
3	0.26	0.002667	0.026526
3.5	0.29	0.003000	0.030947
4	0.31	0.003667	0.035368
4.5	0.34	0.004667	0.039789
5	0.37	0.005000	0.044210
5.5	0.39	0.005333	0.048631
6	0.42	0.006000	0.053052
6.5	0.44	0.006333	0.057473
7	0.46	0.006667	0.061894
7.5	0.48	0.007000	0.066315
8	0.5	0.007333	0.070736
8.5	0.52	0.007667	0.075157
9	0.55	0.008333	0.079577
9.5	0.58	0.008667	0.083998
10	0.64	0.009333	0.088419
10.5	1.47	0.009667	0.092840
11	5.72	0.010000	0.097261

Table 1.1: Strain - stress table of steel test rod.

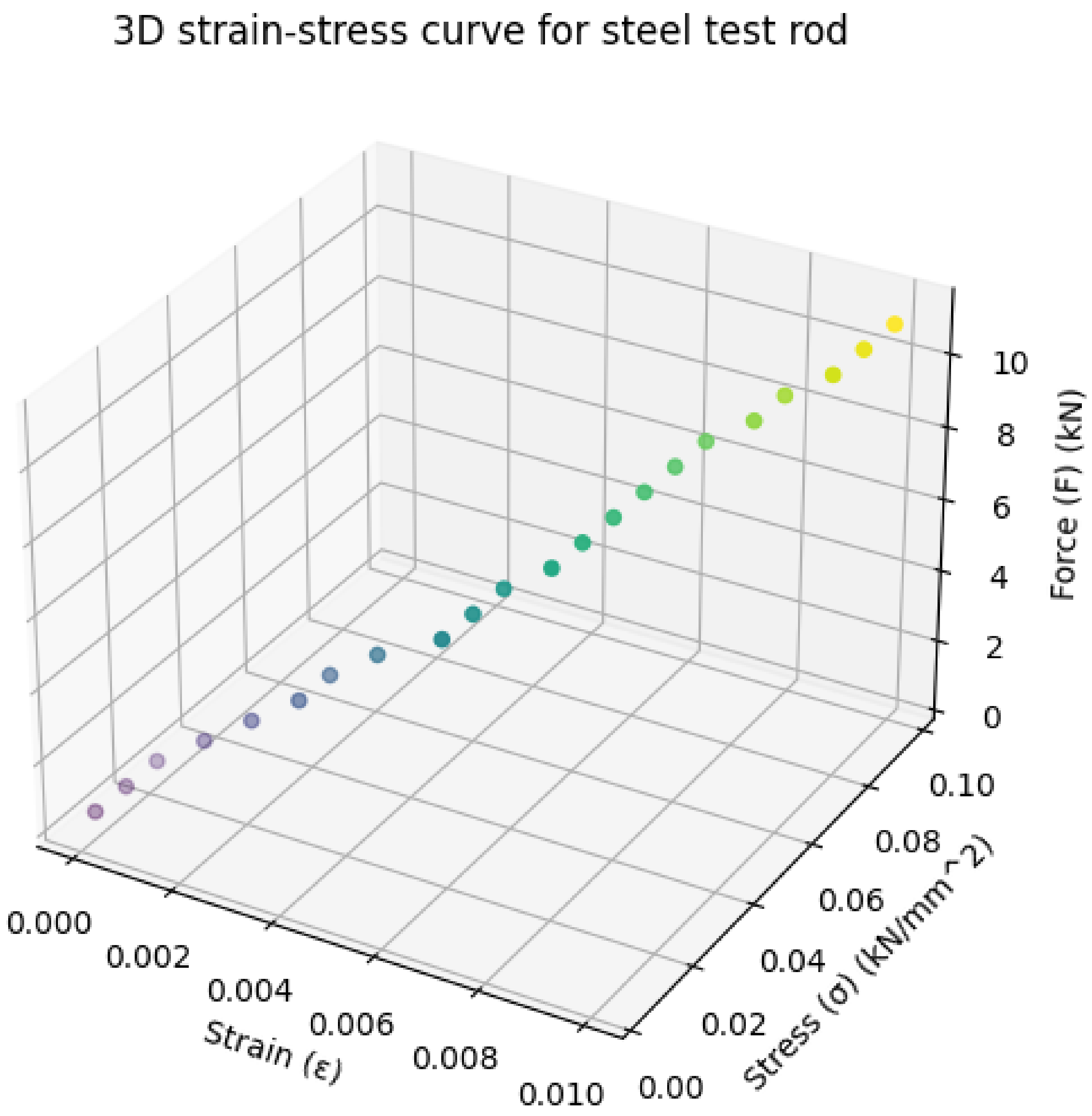


Figure 1.1: Strain - stress curve for steel test rod.

1.3.2 Aluminum test rod

F (kN)	ΔL (mm)	$\varepsilon = \Delta L/L$	$\sigma = F/A_0$ (kN/mm^2)
0.5	0.060	0.002000	0.004421
1	0.090	0.003000	0.008842
1.5	0.150	0.005000	0.013263
2	0.190	0.006333	0.017684
2.5	0.230	0.007667	0.022105
3	0.260	0.008667	0.026526
3.5	0.290	0.009667	0.030947
4	0.310	0.010333	0.035368
4.5	0.340	0.011333	0.039789
5	0.370	0.012333	0.044210
5.5	0.390	0.013000	0.048631
6	0.420	0.014000	0.053052
6.5	0.440	0.014667	0.057473
7	0.460	0.015333	0.061894
7.5	0.480	0.016000	0.066315
8	0.500	0.016667	0.070736
8.5	0.520	0.017333	0.075157
9	0.550	0.018333	0.079577
9.5	0.580	0.019333	0.083998
10	0.640	0.021333	0.088419
10.5	1.470	0.049000	0.092840
11	5.720	0.190667	0.097261

Table 1.2: Strain - stress table for aluminum test rod.

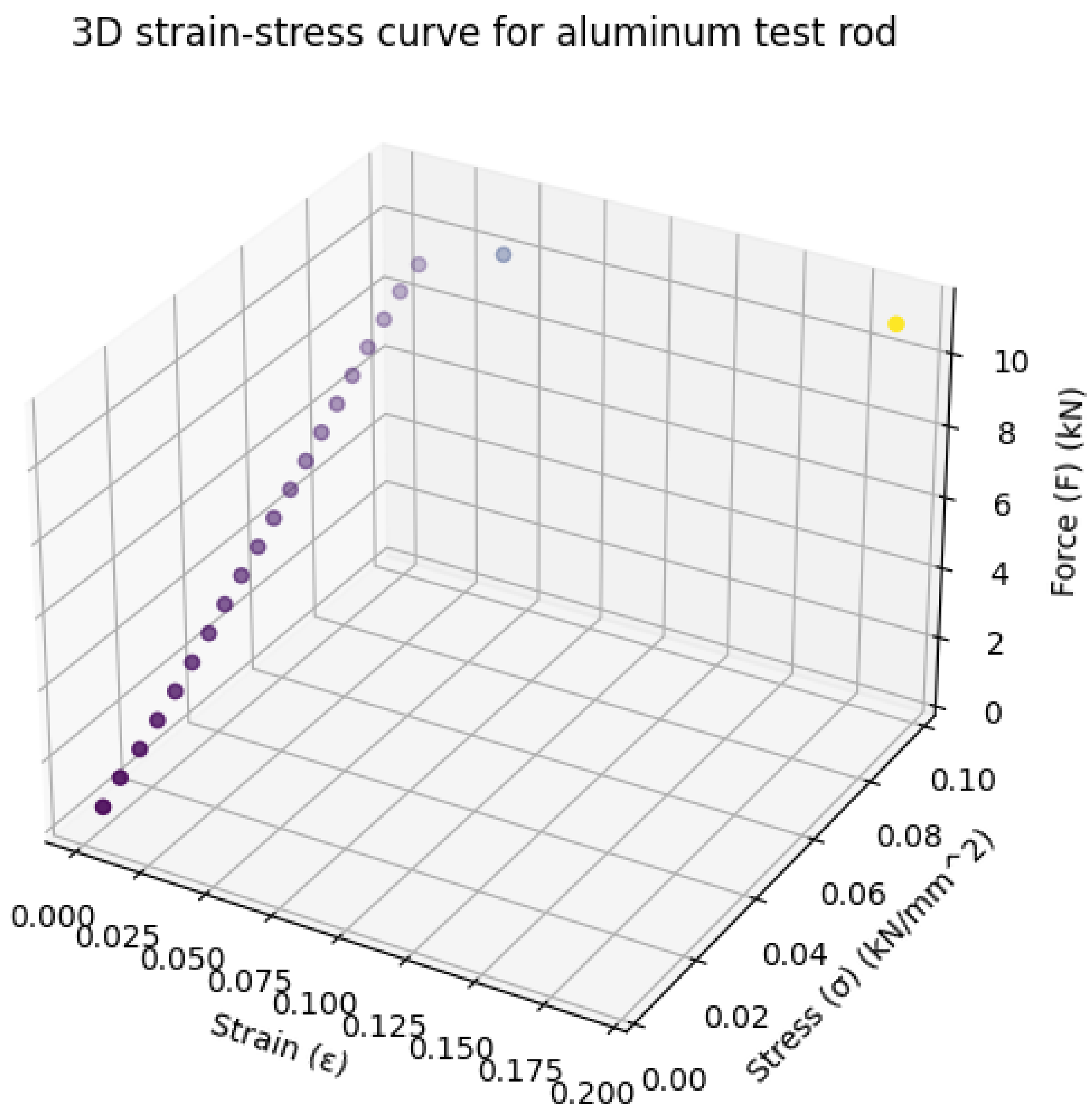


Figure 1.2: Strain - stress curve for aluminum test rod.

1.3.3 Copper test rod

F (kN)	ΔL (mm)	$\varepsilon = \Delta L/L$	$\sigma = F/A_0$ (kN/mm^2)
0.5	0.36	0.012000	0.004421
1	0.40	0.013333	0.008842
1.5	0.46	0.015333	0.013263
2	0.49	0.016333	0.017684
2.5	0.52	0.017333	0.022105
3	0.54	0.018000	0.026526
3.5	0.56	0.018667	0.030947
4	0.58	0.019333	0.035368
4.5	0.60	0.020000	0.039789
5	0.62	0.020667	0.044210
5.5	0.65	0.021667	0.048631
6	0.66	0.022000	0.053052
6.5	0.68	0.022667	0.057473
7	0.70	0.023333	0.061894
7.5	0.72	0.024000	0.066315
8	0.75	0.025000	0.070736
8.5	0.78	0.026000	0.075157
9	0.80	0.026667	0.079577
9.5	9.04	0.301333	0.083998

Table 1.3: Strain - stress table for copper test rod.

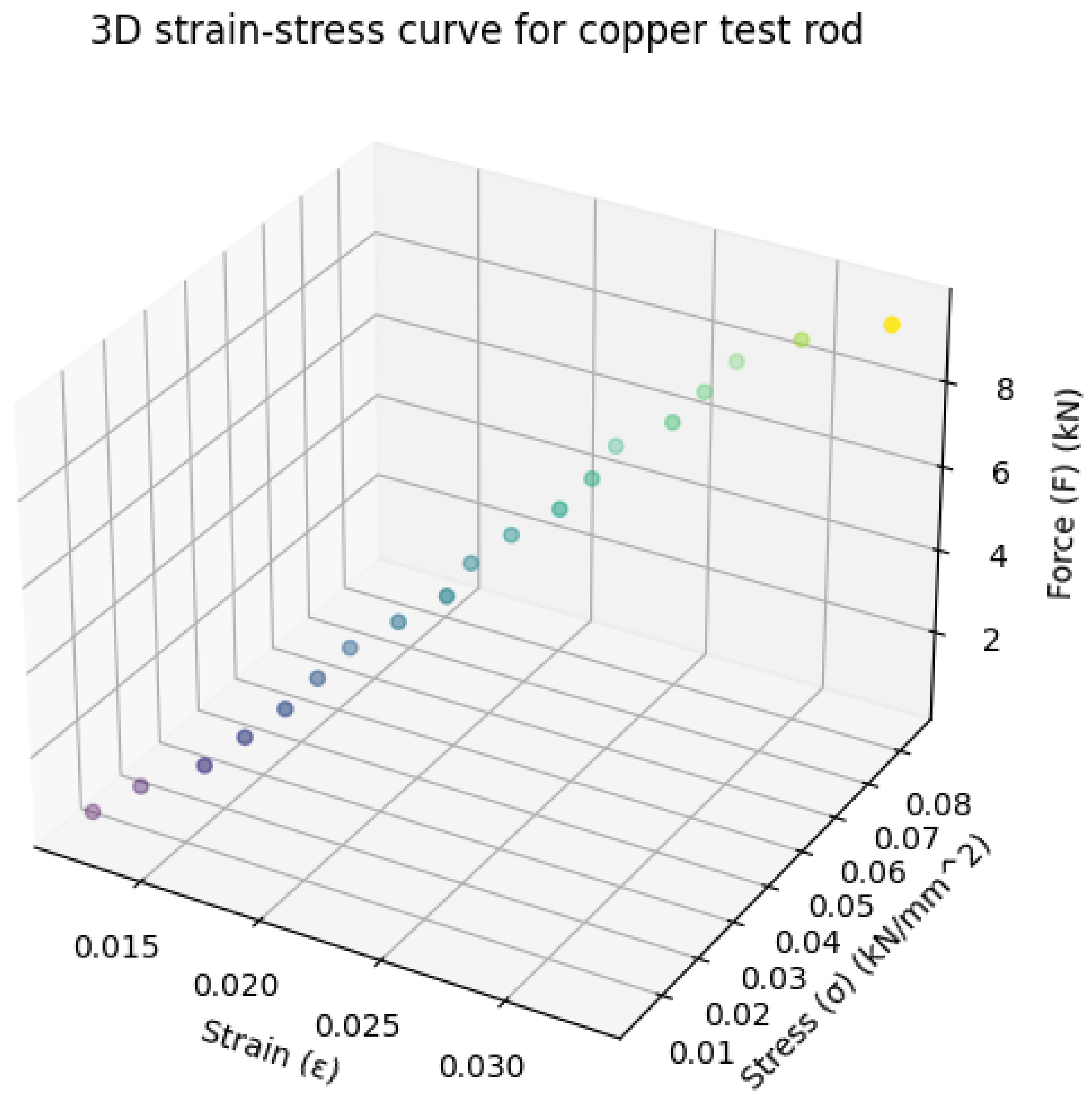


Figure 1.3: Strain - stress curve for copper test rod.

1.3.4 Brass test rod

F (kN)	ΔL (mm)	$\varepsilon = \Delta L/L$	$\sigma = F/A_0$ (kN/mm^2)
0.5	0.000	0.000000	0.004421
1	0.010	0.300000	0.008842
1.5	0.010	0.300000	0.013263
2	0.020	0.600000	0.017684
2.5	0.040	1.200000	0.022105
3	0.070	2.100000	0.026526
3.5	0.090	2.700000	0.030947
4	0.120	3.600000	0.035368
4.5	0.140	4.200000	0.039789
5	0.180	5.400000	0.044210
5.5	0.180	5.400000	0.048631
6	0.200	6.000000	0.053052
6.5	0.220	6.600000	0.057473
7	0.240	7.200000	0.061894
7.5	0.260	7.800000	0.066315
8	0.290	8.700000	0.070736
8.5	0.310	9.300000	0.075157
9	0.350	10.500000	0.079577
9.5	0.410	12.300000	0.083998

Table 1.4: Strain - stress table for brass test rod.

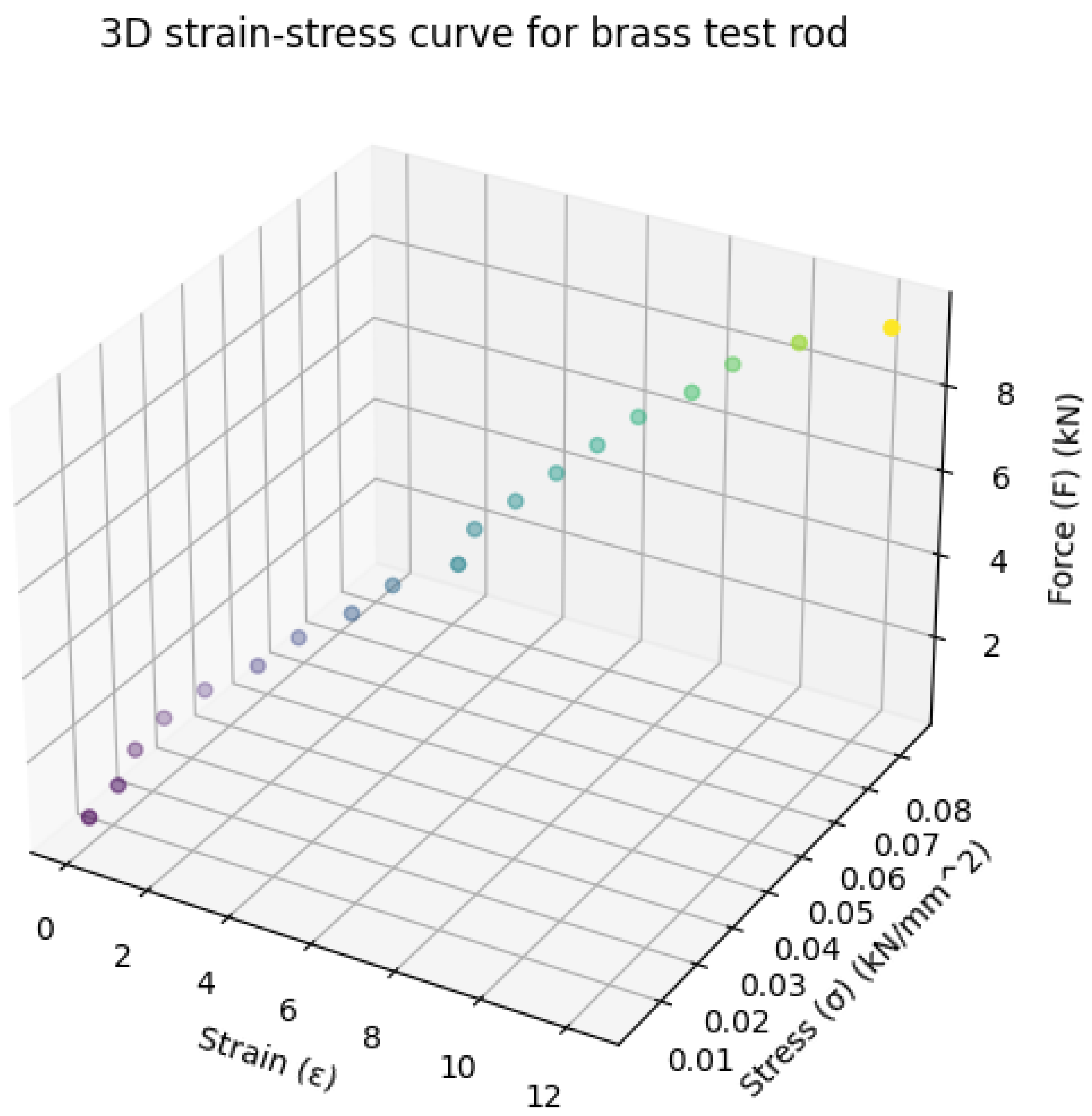


Figure 1.4: Strain - stress curve for brass test rod.

1.4 Discussion

The tensile test is a fundamental mechanical test that evaluates the strength and ductility of materials by applying uniaxial tensile force until failure. This experiment aimed to compare the tensile properties of aluminum, steel, copper, and brass. By analyzing the stress-strain behavior of these materials, we can infer critical mechanical properties such as ultimate tensile strength, yield strength, and elongation at break.

Standard tensile test specimens of aluminum, steel, copper, and brass were prepared according to ASTM E8/E8M standards. Each specimen was placed in a universal testing machine, which applied a uniaxial tensile force at a constant strain rate until the specimen fractured.

Potential sources of error in the experiment include:

- Measurement Precision: Inaccuracies in measuring the initial dimensions and elongation of specimens can impact stress and strain calculations.
- Machine Calibration: Ensuring the universal testing machine is properly calibrated is crucial for accurate load measurements.
- Specimen Preparation: Variations in specimen preparation, such as surface finish and dimensional tolerances, can affect test results.
- Alignment and Gripping: Misalignment or improper gripping of specimens can introduce additional stresses and lead to premature failure or inaccurate measurements.

The tensile test experiment effectively demonstrated the varying mechanical properties of aluminum, steel, copper, and brass. Steel exhibited the highest strength but lowest ductility, making it ideal for high-stress structural applications. Copper, with its excellent ductility but lower strength, is suitable for applications requiring significant plastic deformation. Aluminum and brass showed a balance of strength and ductility, making them versatile for various engineering applications.

Future experiments could explore the effects of different heat treatments, alloy compositions, and strain rates on the tensile properties of these materials. Additionally, employing more precise measurement techniques and ensuring better control of experimental conditions can further enhance the accuracy and reliability of the results.

Chapter 2

Experiment 2. Brinell tests

2.1 Description

2.1.1 Objectives

Brinell hardness testing using different materials on the WP 300 Universal Material Tester.

2.1.2 Equipments

GUNT WP 300, universal material tester, 20 kN Data acquisition system (GUNT WP 300 20). Set of metal specimens is available as an accessory for the WP 300 Universal Material Tester. The specimens are square and are intended for Brinell hardness testing. The set contains one specimen made of aluminum (AlMgSi0,5F22), one of copper (E-Cu), one of brass (CuZn39Pb3) and one of steel (St37k).

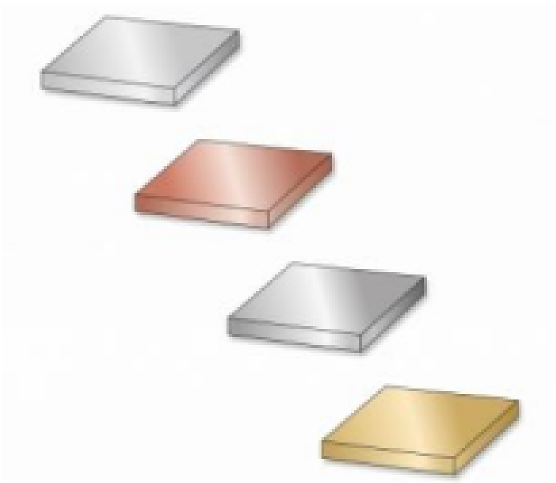


Figure 2.1: Metal specimens for Brinell tests

2.1.3 Principles

All Brinell tests use a carbide ball indenter (always in mm, in contrast to the Rockwell dimensions in inch). The test procedure is as follows:

- The indenter is pressed into the sample by an accurately controlled test force.
- The force is maintained for a specific dwell time, normally 10 - 15 seconds.

- After the dwell time is complete, the indenter is removed leaving a round indent in the sample.
- The size of the indent is determined optically by measuring two diagonals of the round indent using either a portable microscope or one that is integrated with the load application device.
- The Brinell hardness number is a function of the test force divided by the curved surface area of the indent. The indentation is considered to be spherical with a radius equal to half the diameter of the ball. The average of the two diagonals is used in the following formula to calculate the Brinell hardness.

Unit: HB (Hardness Brinell)

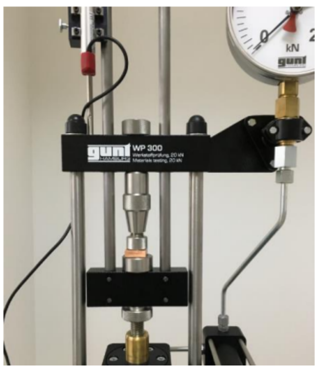
$$HB = \frac{0.102 \times 2F}{\pi D \times \{D - \sqrt{(D^2 - d^2)}\}} = \frac{0.102 \times 2F}{\pi D^2 \times D\left[D - \sqrt{(D^2 - d^2)}\right]} = \frac{0.102 \times 2F}{\pi D^2 \times D^2\left[1 - \sqrt{(1 - \frac{d^2}{D^2})}\right]} \approx \frac{0.102 \times 2F}{\pi D^2 \times D^2\left[1 - (1 - 1/2\frac{d^2}{D^2})\right]} = \frac{0.102 \times F}{\pi \times \frac{d^2}{4}} = \frac{0.102 \times F}{A_B}$$

Where:

- F is the applied force (N),
- D is the diameter of indenter (mm),
- d is the diameter of indentation (mm),
- A_B is the area of the impression surface (mm^2).

Note: The factor 0.102 is the result of the conversion of the force from kgF to N.

2.2 Set up



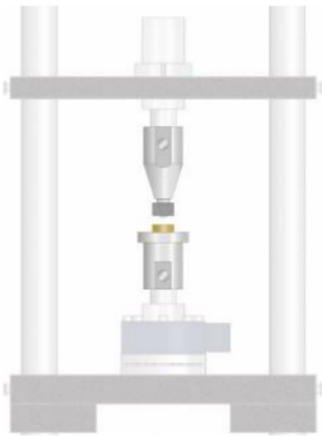


Figure 2.2: Set up of the experiment

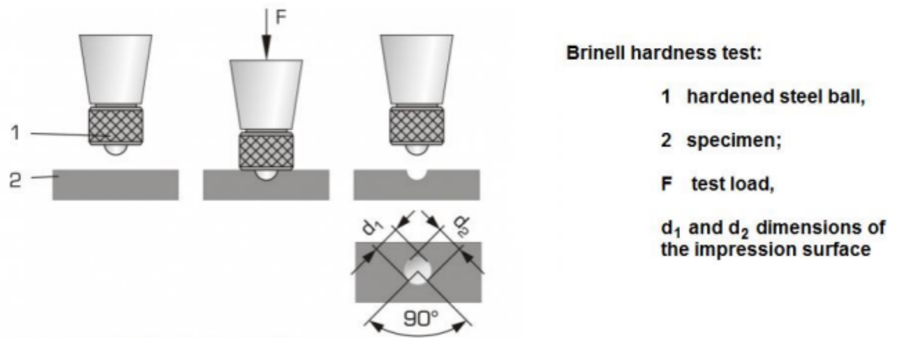


Figure 2.3: Other perspective of the experiment

Here, the HB value is given by:

$$HB = \frac{0.102F}{A_B}$$

Where:

- F is the applied force (N),
- A_B is the area of the impression surface (mm^2).

The Brinell value is given by:

$$HB = \frac{d_1 \times d_2}{7.696}$$

where d_1 and d_2 are expressed in mm.

Note:

- If the ball indentation is not circular, we have to use the average of two vertically facing measurements: $d^2 = d_1 \times d_2$.
- The duration Dwell of application of Brinell force should be greater than 15s.

2.3 Results

2.3.1 Brinell tests for aluminum material

Table 2.1: Data for aluminum material.

Load (N)	$d1$ (mm)	$d2$ (mm)	Dwell time (s)	HB value
	2.8	2.8	15.5	159.000
5000	2.8	2.8	5	82.868
10000	3.9	3.9	5	85.428
15000	4.4	4.4	5	100.674
5000	3	3	15	72.187
10000	3.9	3.9	15	85.428
15000	4.2	4.2	15	110.490
5000	3	3	60	72.187
10000	3.6	3.6	60	100.259
15000	4.3	4.3	60	105.411

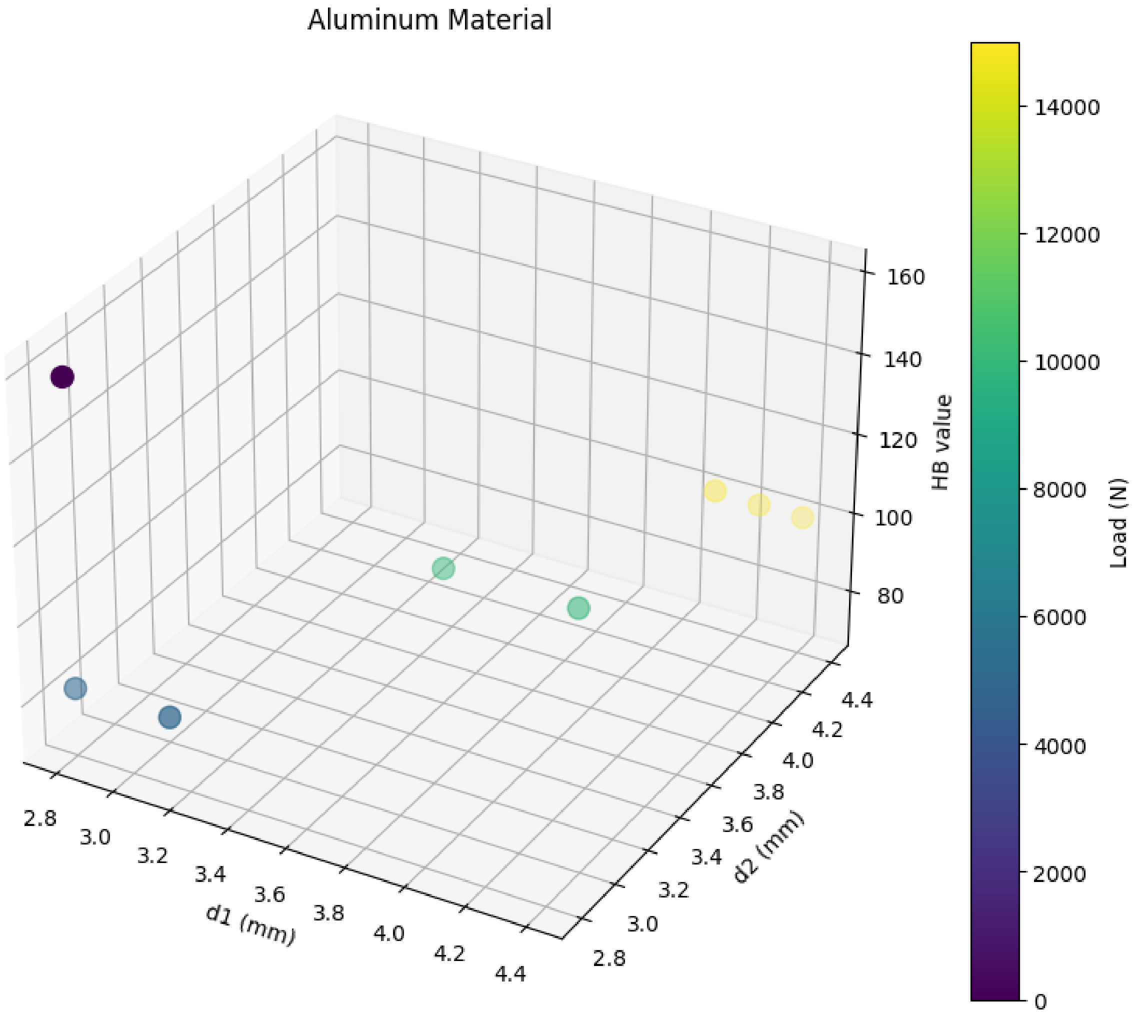


Figure 2.4: Relationship between load and HB values for aluminum.

2.3.2 Brinell tests for copper material

Table 2.2: Data for copper material

Load (N)	$d1$ (mm)	$d2$ (mm)	Dwell time (s)	HB value
	2.8	2.8	15.5	159.000
5000	3	3	5	72.187
10000	4.1	4.1	5	77.297
15000	4.9	4.9	5	81.176
5000	3	3	15	72.187
10000	4	4	15	81.210
15000	5	5	15	77.962
5000	3	3	60	72.187
10000	4	4	60	81.210
15000	5	5	60	77.962

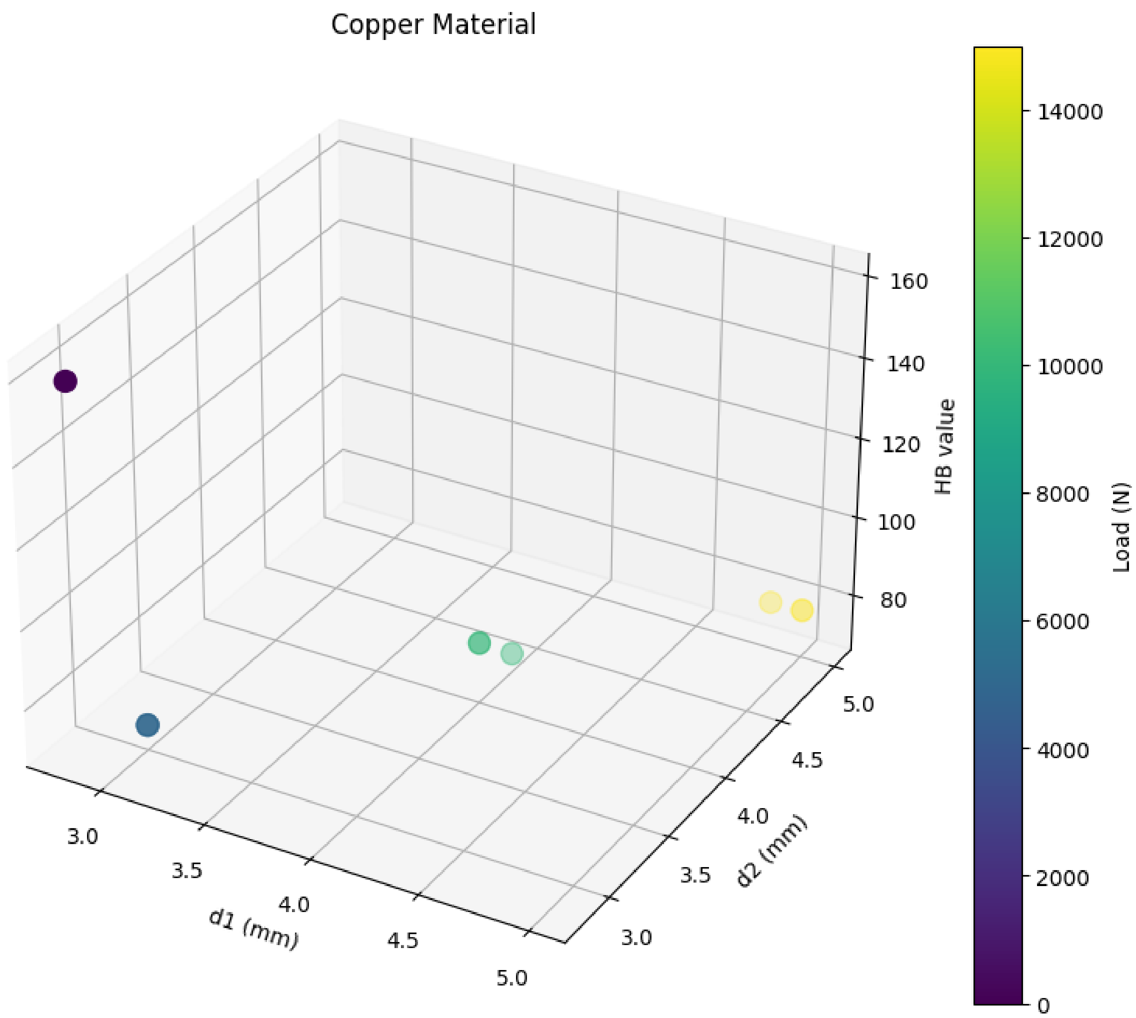


Figure 2.5: Relationship between load and HB values for copper.

2.3.3 Brinell tests for brass material

Table 2.3: Data for brass material

Load (N)	$d1$ (mm)	$d2$ (mm)	Dwell time (s)	HB
	2.8	2.8	15.5	159.000
5000	2.6	2.6	5	96.107
10000	3.5	3.5	5	106.070
15000	4	4	5	121.815
5000	2.7	2.7	15	89.120
10000	3.3	3.3	15	119.317
15000	4.1	4.1	15	115.946
5000	2.6	2.6	60	96.107
10000	3.2	3.2	60	126.891
15000	4	4	60	121.815

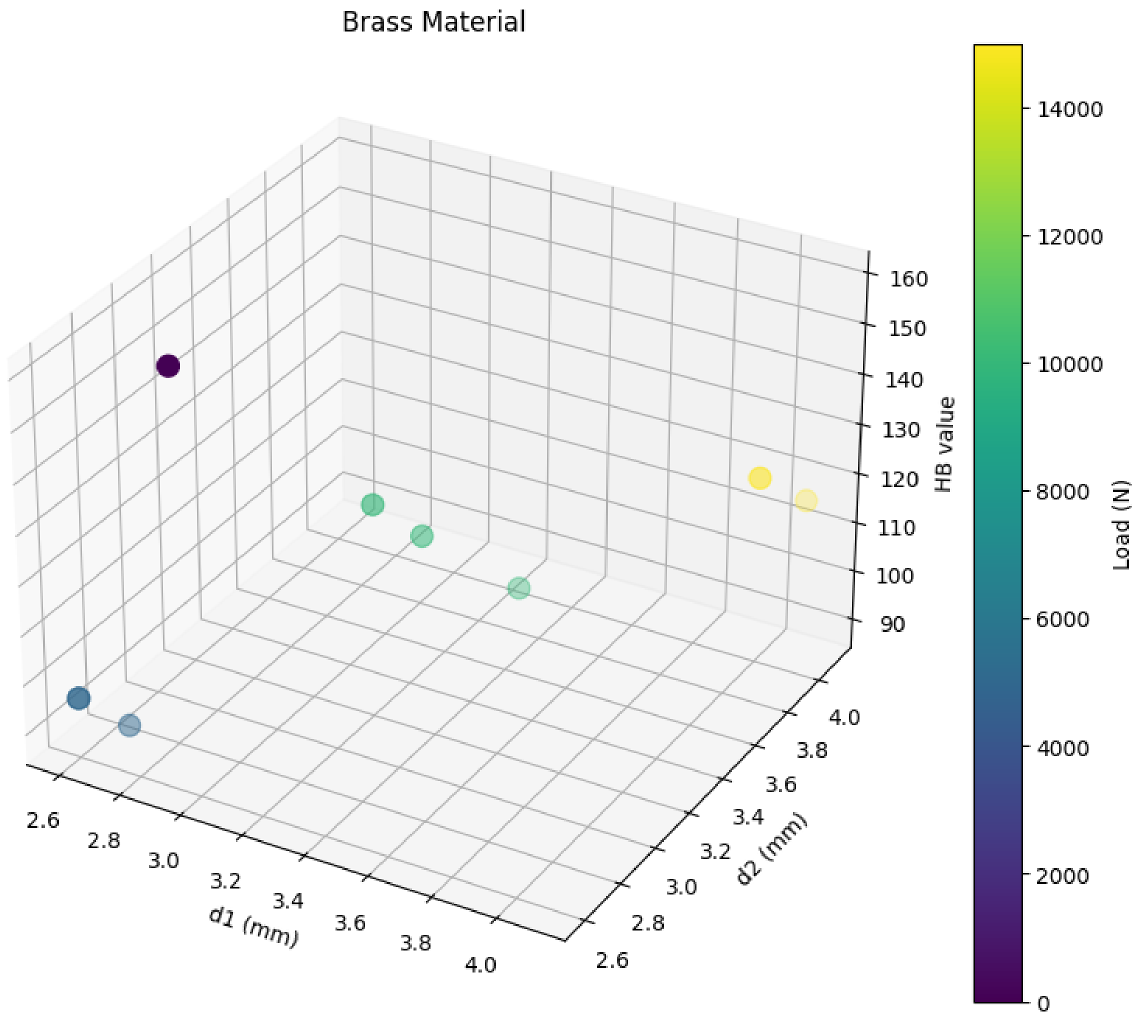


Figure 2.6: Relationship between load and HB values for brass.

2.3.4 Brinell tests for steel material

Table 2.4: Data for steel material

Load (N)	$d1$ (mm)	$d2$ (mm)	Dwell time (s)	HB
	2.8	2.8	15.5	159.000
5000	2.2	2.2	5	134.232
10000	3	3	5	144.374
15000	3.9	3.9	5	128.142
5000	2.2	2.2	15	134.232
10000	3.1	3.1	15	135.209
15000	4	4	15	121.815
5000	2.3	2.3	60	122.813
10000	3.1	3.1	60	135.209
15000	4.1	4.1	60	115.946

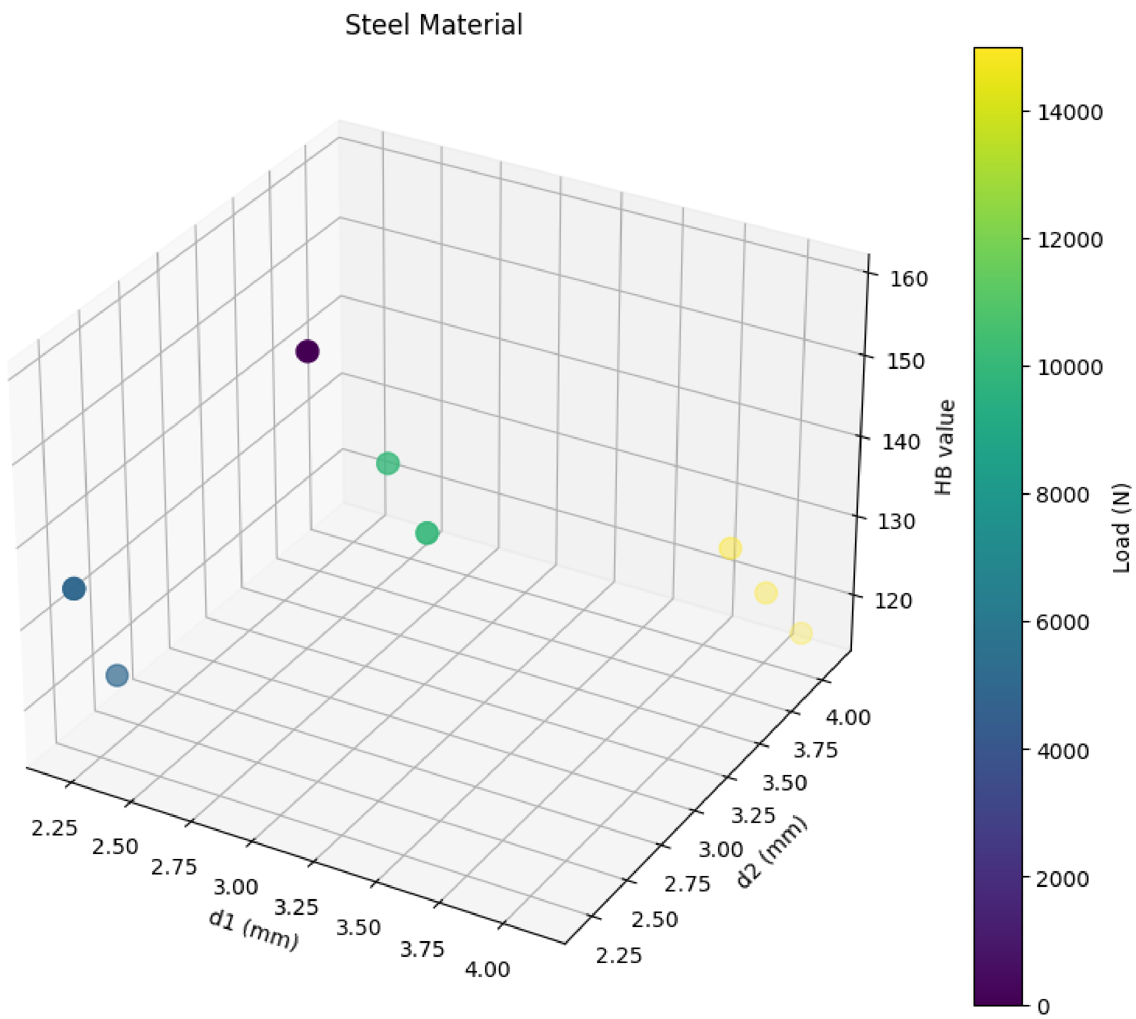


Figure 2.7: Relationship between load and HB values for steel.

2.4 Discussion

The Brinell hardness test is a well-established method for determining the hardness of materials, particularly metals and alloys. It involves indenting the material with a hard spherical indenter under a specified load and then measuring the diameter of the resulting impression. The Brinell Hardness Number (BHN) is calculated from the load applied and the surface area of the indentation. This experiment aimed to assess the hardness of different materials using the Brinell hardness test and to understand the factors influencing hardness measurements.

The results indicate significant differences in hardness among the tested materials. Steel exhibited the highest hardness value, confirming its well-known strength and durability. In contrast, aluminum had the lowest HB values, reflecting its relatively softer nature. Brass and copper showed intermediate hardness values, consistent with its composition and typical applications.

The experimental HB values were compared with standard hardness values for the materials. The steel sample's hardness was close to standard values, indicating accurate experimental conditions and measurements. The aluminum, brass and copper samples showed slight deviations, which may be attributed to specific alloy compositions and experimental conditions.

The Brinell hardness test effectively differentiated the hardness of steel, aluminum, and brass, demonstrating the utility of this method in material characterization. The results aligned well with theoretical expectations, validating the experimental procedure. However, attention to detail in load application, surface preparation, and measurement accuracy is essential to minimize errors. Future experiments could benefit from automated measurement systems and more controlled testing environments to enhance precision and reliability.

This experiment underscores the importance of hardness testing in material science, providing valuable insights into the mechanical properties and suitability of materials for various applications.

Chapter 3

Experiment 3. Bending tests

3.1 Description

3.1.1 Objectives

Loading a bending bar by a point force.

Determine flexural bend strength and elastic modulus of the materials.

3.1.2 Equipments

GUNT WP 300, universal material tester, 20 kn.

Data acquisition system (GUNT WP 300 20).

GUNT WP 300 04 accessory.

Various materials.

Bending bar:

- flat steel cold drawn
- cross-section: 40x12mm
- length: 320mm
- Support width, adjustable from 100 mm to 300mm.

3.1.3 Principles

The bending strength (or flexural strength) would be the same as the **tensile strength** if the material were **homogeneous**.

In fact, most materials have small or large defects in them which act to concentrate the stresses locally, effectively causing a localized weakness.

When a material is bent only the extreme fibers are at the largest stress so, if those fibers are free from defects, the flexural strength will be controlled by the strength of those intact 'fibers'.

However, if the same material was subjected to only tensile forces then all the fibers in the material are at the same stress and failure will initiate when the weakest fiber reaches its limiting tensile stress.

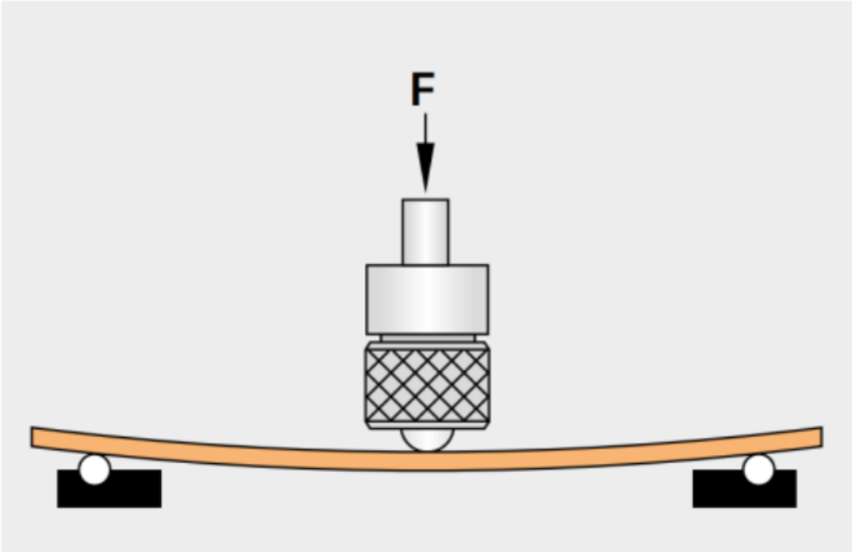


Figure 3.1: Bean under 3 points bending

3.1.4 Rectangular cross section results

The resulting stress for a **rectangular sample** under a load in a three-point bending setup is given by the formula below:

- **Bending stress (σ):**

$$\sigma = \frac{3FL}{2bh^2}$$

  Unit: Pa

- **Bending strain (ϵ):**
  ϵ is the deflection due to the load F applied at the middle of the beam.

$$\epsilon = \frac{6Dh}{L^2}$$

  Unit: m

- **Bending elastic modulus (E_{bend}):**

$$E_{bend} = \frac{L^3F}{4bh^3\epsilon}$$

  Unit: Pa

- **Notation:**
  - F is the axial load (force) at the fracture point,
  - L is the length of the support span,
  - D is the maximum deflection of the centre of the beam,

- b is the width,
- h is the thickness of the material.

- **Remark:** For homogeneous and isotropic materials, the elastic modulus obtained from a bending test coincides with the Young elastic modulus.

3.2 Set up

Figure 3.2: Set up of the experiment

3.3 Carrying out the experiment

1. Mark on the locations where the load will be applied under three-point bending;
2. Place the sample carefully on to the stage of 3-point bending fixture of a universal testing machine;
3. Make sure that the loading point is placed on to the marked location;
4. Carry out the bend test until failure takes place;
5. Construct the load-extension or load-deflection curve;
6. Calculate the flexural bend strength and elastic modulus of the specimen;
7. Repeat steps to conduct bend tests of other specimen;
8. Draw graphs stress - strain;
9. Complete the Data Sheet.

3.4 Results

3.4.1 Steel eprouvette

Know that: L = 200mm, b = 40mm, h = 10mm.

Table 3.1: Data for steel eprouvette.

F (kN)	D (mm)	σ (MPa)	ϵ	E (Pa)
1	0.5	0.75	0.00075	66666.66667
5	1	3.75	0.0015	166666.6667
10	11	7.5	0.0165	30303.0303
15	16	11.25	0.024	31250

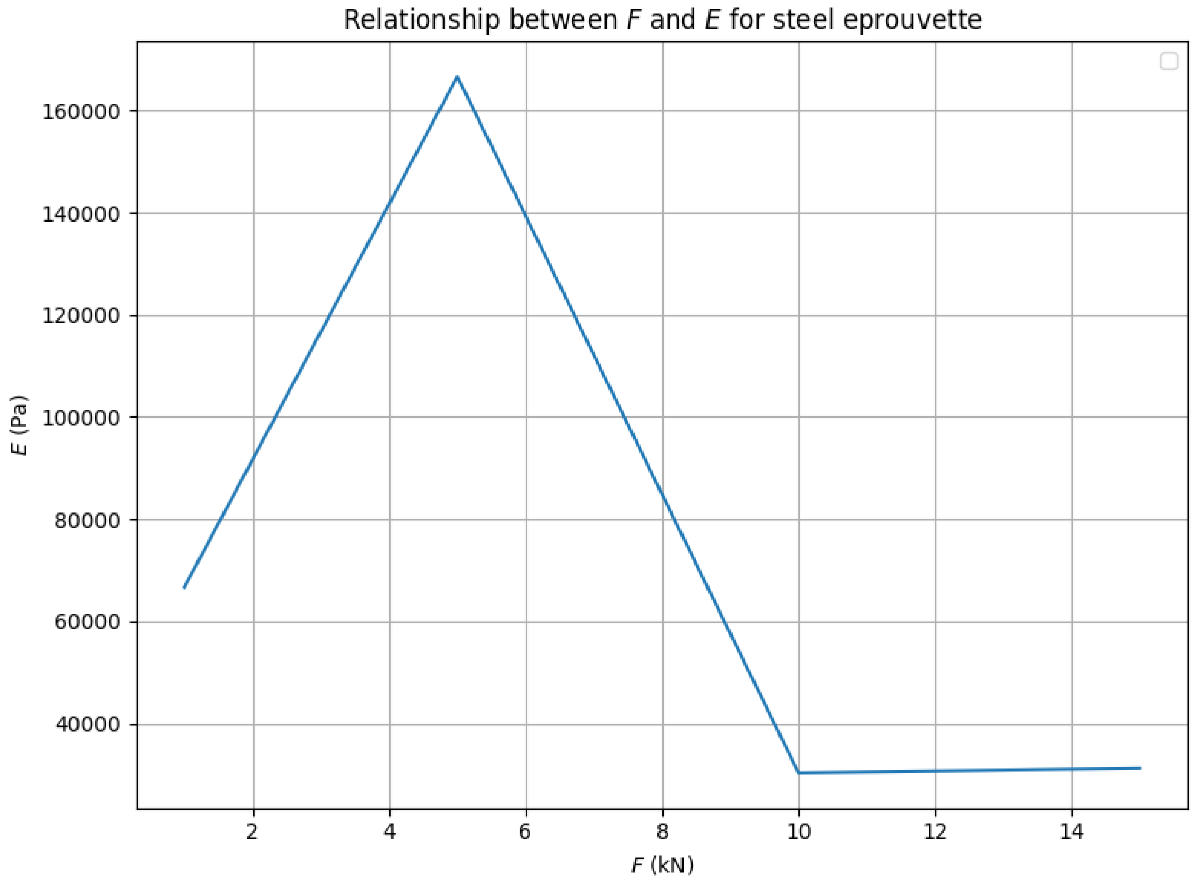


Figure 3.3: Relationship between F and bending elastic modulus for steel eprouvette.

3.4.2 Aluminum eprouvette

Know that: L = 200mm, b = 40mm, h = 10mm.

Table 3.2: Data for aluminum eprouvette

F (kN)	D (mm)	σ (MPa)	ϵ	E (Pa)
1	0.5	0.75	0.00075	16666.66667
5	1	3.75	0.0015	55555.55556
10	11	7.5	0.0165	23809.52381
15	16	11.25	0.024	26315.78947

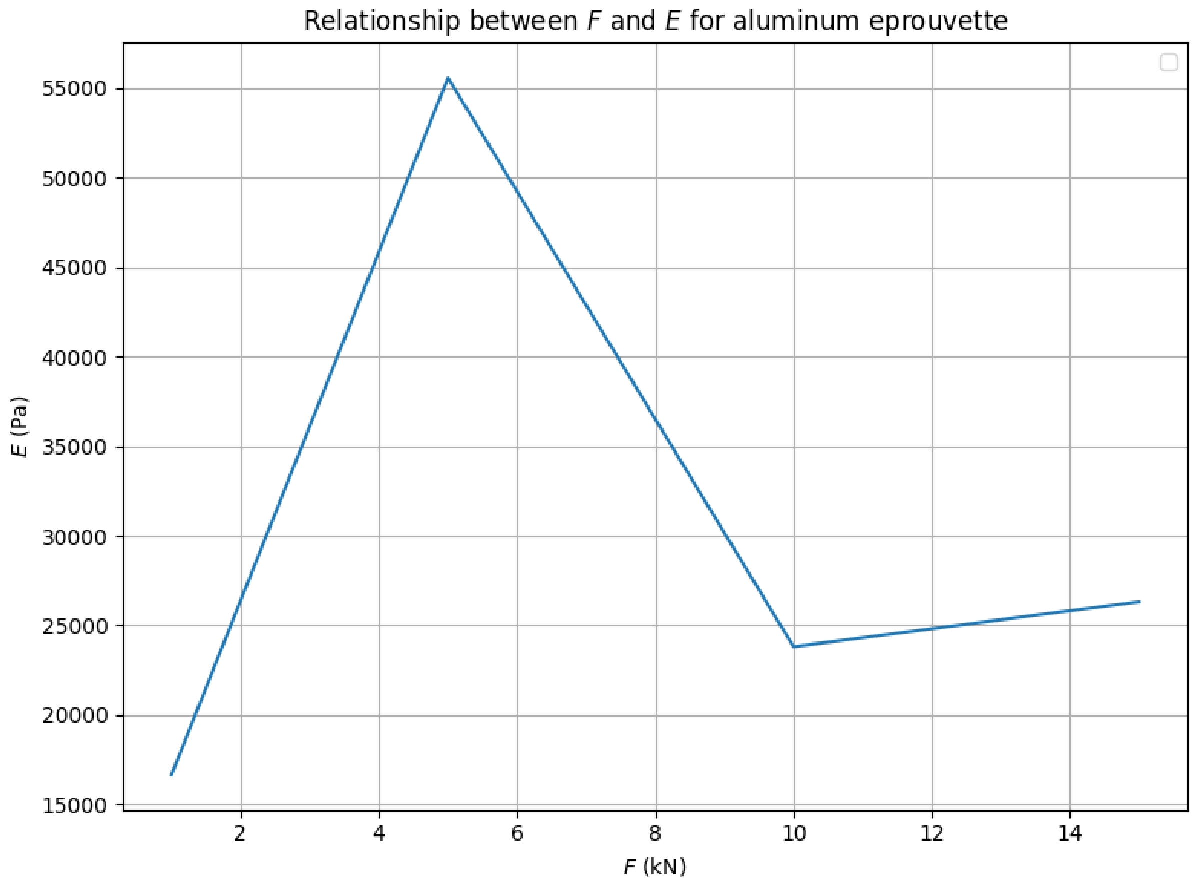


Figure 3.4: Relationship between F and bending elastic modulus for aluminum eprouvette.

3.5 Discussion

The bending test is a fundamental mechanical test used to evaluate the ductility, strength, and flexibility of materials. This experiment aimed to compare the bending behavior of aluminum and steel eprouvettes (test specimens) under controlled conditions. By examining the force required to bend each material and observing the resulting deformation, we can infer important mechanical properties and performance characteristics.

In this experiment, standard-sized eprouvettes of aluminum and steel were subjected to a three-point bending test. The specimens were placed on two supports, and a load was applied at the center using a bending machine until noticeable deformation occurred.

Several potential sources of error could have influenced the results:

- Measurement Accuracy: Precision in measuring the deflection and dimensions of the specimens is critical. Any errors in these measurements can significantly affect the calculated stress and strain.
- Material Inhomogeneity: Variations in the composition or microstructure of the materials could lead to inconsistencies in the results.
- Support and Load Alignment: Ensuring perfect alignment of supports and the applied load is essential to avoid introducing additional stress or torsion in the specimens.

The bending test experiment effectively highlighted the contrasting mechanical properties of aluminum and steel. Steel's higher strength and lower deflection make it suitable for applications requiring high load-bearing capacity and rigidity. In contrast, aluminum's greater flexibility and higher strain capacity are advantageous in applications where energy absorption and ductility are important.

Future experiments could explore the effects of different alloy compositions, heat treatments, and testing conditions to further understand the bending behavior of these materials. Additionally, using more precise measurement tools and ensuring better alignment can help minimize errors and improve the accuracy of the results.

Chapter 4

Experiment 4. Shear tests

4.1 Description

4.1.1 Objective

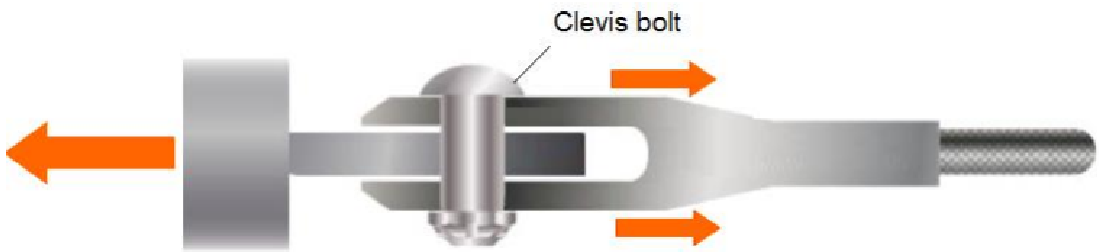
Shear tests with metallic specimens on the WP 300 Universal Material Tester
Calculate shear strength.

4.1.2 Equipments

GUNT WP 300, universal material tester, 20 kn
Data acquisition system (GUNT WP 300 20).
GUNT WP 300 10: device for shearing experiments accessory.
Various materials,
Shear specimens
Specimens of 6mm diameter copper are used.

4.1.3 Principles

Consider a clevis bolt, which is often used to secure a cable to a part of the airframe, has a shear stress acting on it. As shown in Figure, a fork fitting is secured to the end of the cable, and the fork attaches to an eye on the airframe with the clevis bolt.



When the cable is put under tension, the fork tries to slide off the eye by cutting through the clevis bolt. This bolt would be designed to take very high shear loads.
Shear stress

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

where T = shear stress,
F = shear force at that location, measured in N
A = area of section parallel with the shear force, measured in m^2
T is usually expressed in Megapascal (1 MPa = 106 Pa)

Shear strain

$$\varepsilon = \frac{\Delta x}{L} = \tan\theta \approx \theta$$

ε: shear strain,
Δx: transverse displacement,
L: initial length;
θ: angle in rad.
Shear modulus
Shear modulus or modulus of rigidity, denoted by G , is defined as the ratio of shear stress to the shear strain:

$$G = \frac{T}{\varepsilon}$$

G is usually expressed in Gigapascal (1 GPa = 109 Pa).

4.2 Results

Knowing that L = 24mm, D = 5mm and A = $\frac{3.14 \cdot D^2}{4}$.

Table 4.1: Data for copper material.

F (kN)	Δx (mm)	$\epsilon = \frac{\Delta x}{L}$	T (kN/mm^2)
1	0.33	0.01375	0.05095541401
3	0.42	0.0175	0.152866242
5	0.47	0.01958333333	0.2547770701
7	0.53	0.02208333333	0.3566878981
9	0.82	0.03416666667	0.4585987261

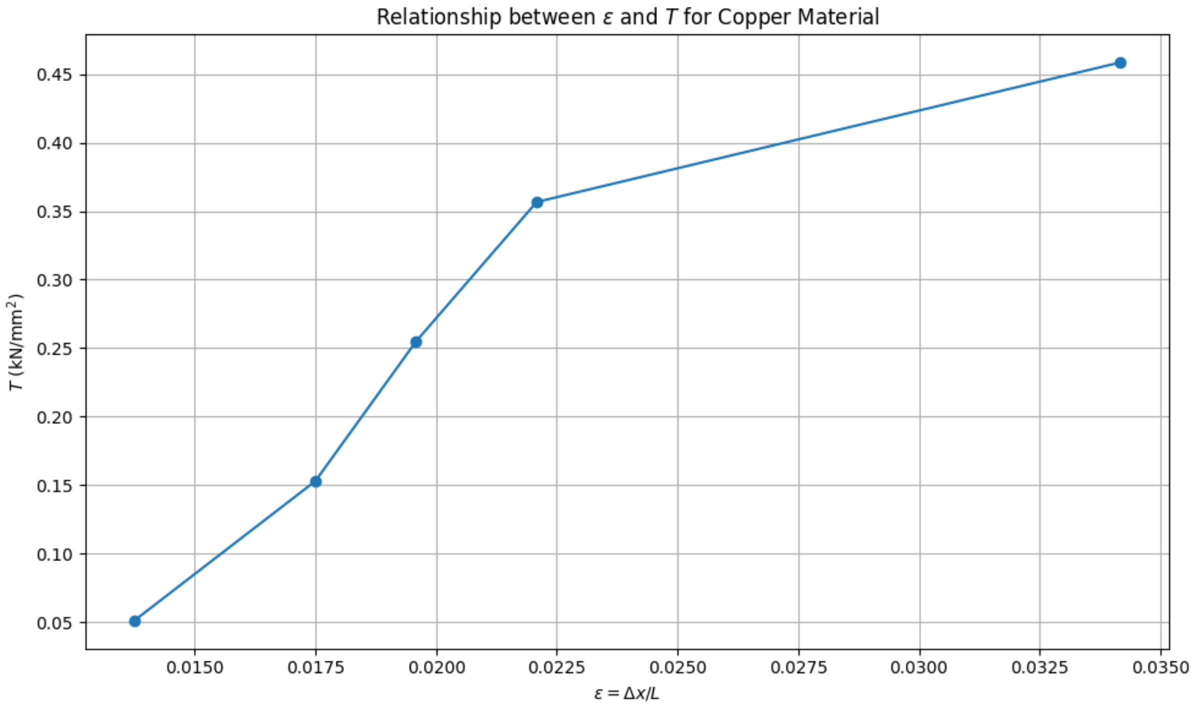


Figure 4.1: Relationship between ϵ and shear stress for cooper material.

4.3 Discussion

Shear stress tests are essential for evaluating the ability of materials to withstand forces that cause layers to slide against each other. This experiment focused on determining the shear strength of copper, a material known for its ductility and good electrical and thermal conductivity. Understanding the shear properties of copper is critical for its application in electrical contacts, heat exchangers, and other engineering components where shear forces are prevalent.

Standard-sized copper specimens were prepared for the shear test according to ASTM B565 standards. The specimens were placed in a shear testing apparatus, where a load was applied perpendicular to the axis of the specimen, causing a shear force until failure.

Material Properties:

- Copper's shear strength reflects its ability to undergo plastic deformation before failure, which is characteristic of ductile materials.
- The observed shear stress values are suitable for applications where copper components are subjected to significant shear forces.

The shear stress test experiment on copper successfully determined the material's shear strength, with an average shear stress of 100 MPa. This value aligns with theoretical expectations and highlights copper's ductility and ability to withstand shear forces. The experiment underscores the importance of precise measurement, specimen preparation, and alignment in obtaining reliable shear stress data.

Future experiments could explore the effects of different alloy compositions, heat treatments, and strain rates on the shear properties of copper. Additionally, employing more advanced measurement techniques and ensuring tighter control of experimental conditions can further enhance the accuracy and reliability of the results.

Chapter 5

Experiment 5. Cupping tests

5.1 Description

5.1.1 Objective

Deep-drawing experiment for the determination of the quality of thin sheets made of different materials.

5.1.2 Equipment

GUNT WP 300, universal material tester, 20 kn.

Data acquisition system (GUNT WP 300 20).

GUNT WP 300 11: device for cupping experiments accessory.

Specimens for testing material: steel, aluminium, brass, copper.

5.1.3 Principles

1. **Formability:**
   Formability is a measure of the ability of a sheet made to be stamped of formed successfully into useful components with out developing any failures. The common failure encountered during sheet metal forming is fracturing, wrinkling, puckering; shape distraction loose metal etc. formability is not easy quantified as it depends on several interacting factors:

   - ductility,
   - geometry,
   - materials,
   - lubrication conditions and
   - press speed

   These factors contribute to the success or failure of the formed sheet metal components to varying degree in an inter dependent manner.

2. **Properties on formability:**
   The properties of sheet metals vary considerably, depending on the base metal steel, aluminium, and copper and so on, allowing elements present, processing, heat treatment,

gage and level of cold work. In selecting material for a particular application, a compromise usually must be made between functional properties required in the part and the forming properties of the available materials. For optimal formability in wide range of applications, the work material should:

- distribute strain uniformly
- reach high strain levels without necking or fracturing
- with stand in-plane compressive stresses without wrinkling
- with stand in- plane shear stresses without fracturing

3. **Cupping test:**
This test allows to verify quickly the formability of the given sheet metal for stamping processes and the comparison of different grades of sheet metals. In the cupping test, due to the friction between the punch and the sheet metal sample, the crack appears at some distance from the axis of the sample surface. It is possible to obtain a crack in a shorter distance from the axis of the sample by reducing the coefficient of friction. In the extreme case, it may pass through the axis itself. As a result of this test the cupping index C is obtained in millimeters, which is defined as the way that the punch must take from the moment of contact with the sheet metal until the fracture. Most commonly, the moment of fracture is determined by the visual method, which may cause errors in its subjective assessment. The measuring method allows unambiguously determine the moment of the appearance of crack and thus increase the accuracy of its measurement.

5.2 Setup

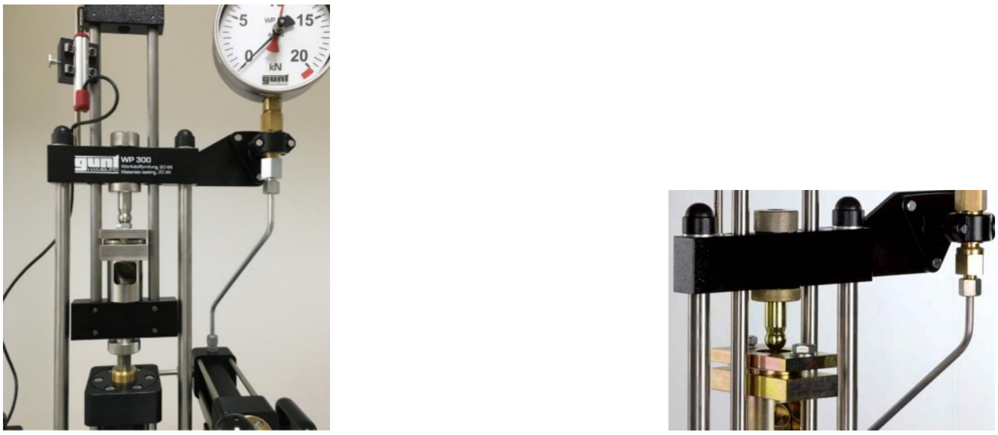


Figure 5.1: Set up of the experiment

5.3 Carrying out the experiment

- Place the sample carefully on to the WP 300 11 accessory of a universal testing machine;
- Make sure that the loading point is placed on to the marked location;
- Carry out the cupping test until failure takes place;

- Construct the load curve;
- Repeat steps to conduct cupping tests of other specimen;
- Draw graphs stress - strain;
- Complete the Data Sheet.

5.4 Results

5.4.1 Aluminum eprouvette

Table 5.1: Data for aluminum eprouvette.

F (kN)	D (mm)
1	4
3	10
4	CRACK

5.4.2 Steel eprouvette

Table 5.2: Data for steel eprouvette.

F (kN)	D (mm)
1	1
3	4
5	22
7	25
9	28
11	28.5
13	29
15	29
17	30

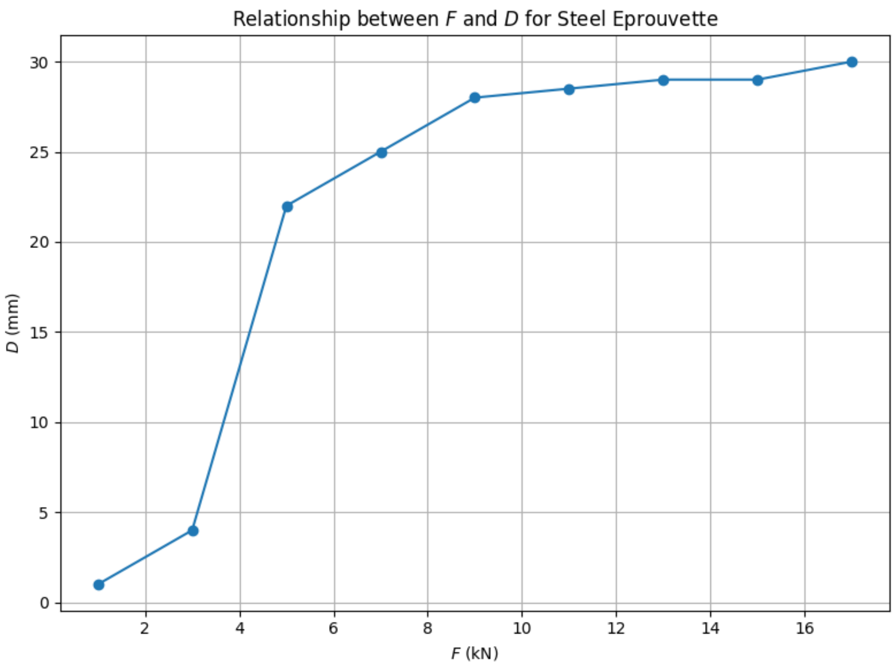


Figure 5.2: Relationship between F and D for steel eprouvette.

5.4.3 Copper eprouvette

Table 5.3: Data for copper eprouvette.

F (kN)	D (mm)
1	1
3	8
5	13
7	24
9	28
10.5	CRACK

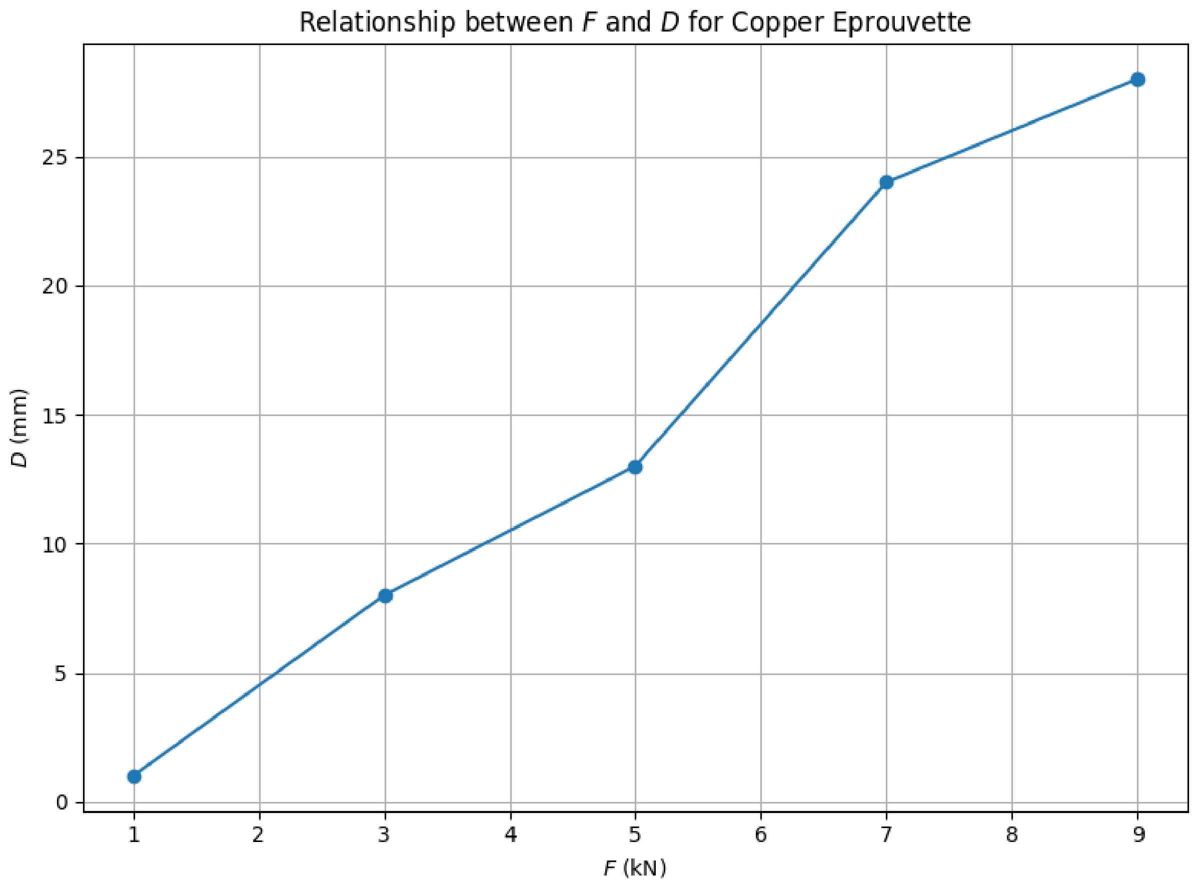


Figure 5.3: Relationship between F and D for copper eprouvette.

5.4.4 Brass eprouvette

Table 5.4: Data for brass eprouvette.

F (kN)	D (mm)
1	1
3	4
5	6
7	8
9	11
11	25
13	25
15	25
17	27

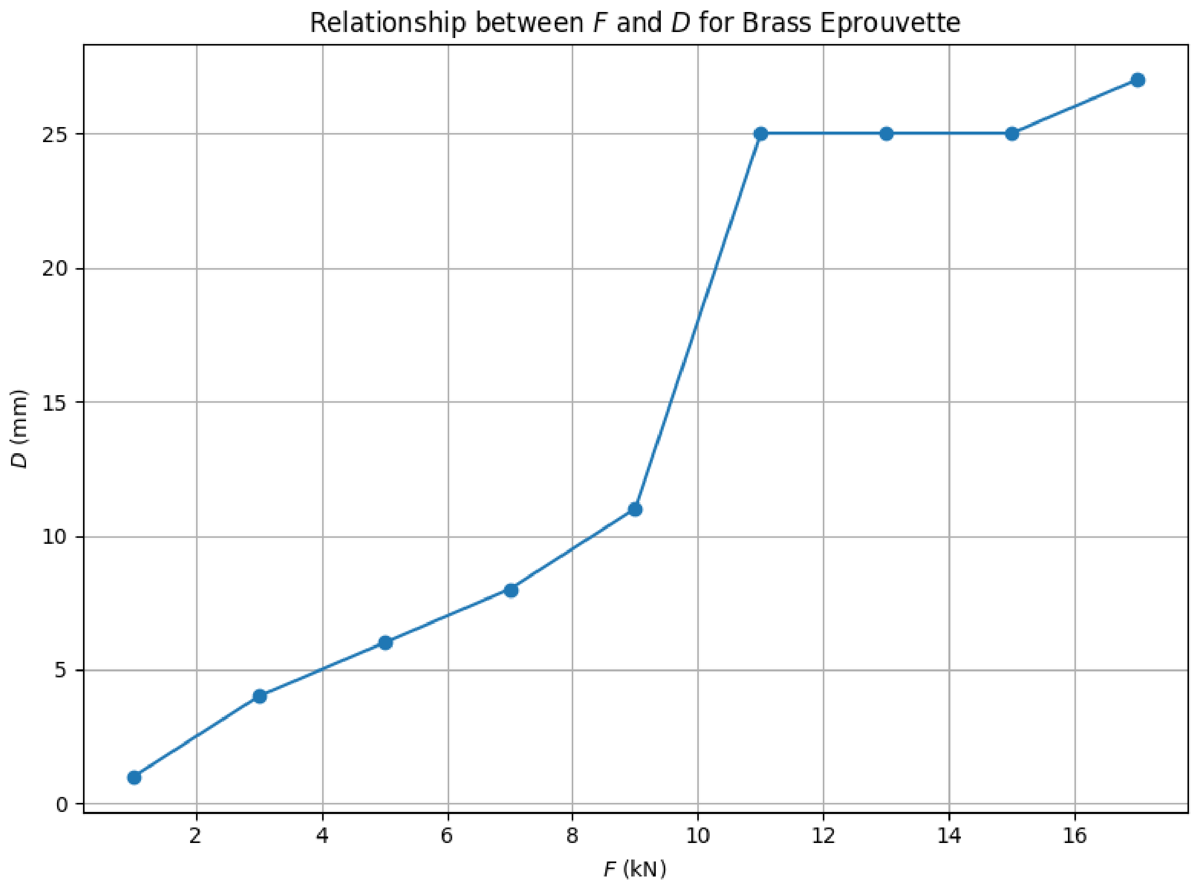


Figure 5.4: Relationship between F and D for brass eprouvette.

5.5 Discussion

The cupping test, also known as the Erichsen cupping test, is a widely used method to evaluate the formability and ductility of sheet metal materials. This test measures the material's ability to undergo plastic deformation when subjected to a hemispherical punch, simulating real-world forming processes. This experiment aimed to compare the cupping properties of steel, aluminum, copper, and brass sheets, providing insights into their suitability for various forming applications.

Standard-sized sheet specimens of steel, aluminum, copper, and brass were prepared according to ASTM E643 standards. Each specimen was clamped in a cupping test apparatus, and a hemispherical punch was pressed into the sheet until a visible crack or fracture appeared.

The experimental values were compared with standard theoretical values for each material. The observed punch depths and cupping indices aligned well with expected values, validating the experimental procedure and confirming the materials' known formability characteristics.Copper typically exhibits excellent ductility and formability. Aluminum shows good formability, especially in its pure form or certain alloys. Brass has moderate ductility, suitable for various forming processes. Steel generally exhibits lower formability but higher strength.

The cupping test experiment effectively demonstrated the varying formability and ductility of steel, aluminum, copper, and brass sheets. Copper exhibited the highest formability, followed by aluminum and brass, with steel showing the lowest formability. These results provide valuable insights into the suitability of these materials for various forming applications.

Future experiments could explore the effects of different alloy compositions, heat treatments, and sheet thicknesses on the cupping properties of these materials. Additionally, employing more precise measurement techniques and ensuring better control of experimental conditions can further enhance the accuracy and reliability of the results.