Kingston University London

Department of Mechanical Engineering

Faculty of Engineering, Computing, and the Environment

Engineering Mechanics and Materials

PRACTICAL BOOKLET

Key Information

- Bring this booklet with you when you are due in the lab for the practical session. Your rota appears on your timetable.
- You must read this booklet prior to attending the practical session.
- Attendance will be taken; note that no show implies a zero mark.
- Bring your health and safety kit for the practical session and wear it properly at all times while in the labs.
- Conduct the experiment using the lab sheet instructions. You may ask questions to lecturers if needed.
- After conducting the experiments, students will be grouped by the lecturer to produce a lab report. Solo reports will not be accepted.
- The report must be submitted electronically, via CANVAS, by one student only, using the template provided, and within two weeks after the session.
- Make sure you reference properly any material used in the report. Plagiarism will be checked using Turnitin software and similarities larger than 10% will be penalised.
- The file name should contain the surname of student submitting the report and module name (e.g., Williamson_ Engineering Mechanics and Materials).
- Feedback will be given via CANVAS within twenty working days.
- Each member of the team must submit a team reflection using template provided.

Assessment criteria

	Assessment criteria	Maximum mark
Content	**Front cover and Abstract, Table of Content & Contribution Page** Abstract (200 words maximum) should be well written, clearly, and succinct, summarise the aims, methods, results, and conclusions of the practical. Front cover, table of content and contribution page should be included.	2
	Introduction Clearly written, well structured, with evidence of relevant extra reading and background information. You should identify the main aims and objectives of the practical and explain the rationale for performing the study.	2
	Methods and Experimental Procedures Clearly describe the experiment, the apparatus used, the experimental procedures, and the methods.	2
	Theory Detail and explain the appropriate theory for the experiment you have carried out.	2
	Results Present clearly all calculation details, graphs, and tables. All figures and tables should be captioned correctly, with complete and descriptive captions. Provide references if applicable.	37
	Discussion Discuss in detail the results from the practical, compare the expected results to those obtained, analyse the experiment errors, relate the results to the objectives, provide your scientific opinion. Answer all questions from booklet	37
	Conclusions/Recommendations Brief summary of conclusions from the experiment and your recommendations.	2
Presentation	**Overall appearance and structure of report, effort** Report well structured, well written, clear, concise writing and well presented. Appropriate level of effort demonstrated. Report maximum 20 pages and word processed, minimum font size 11.	2
	Grammar/Spelling/Language Report is free of grammatical and spelling errors.	2
	Referencing All references corrected listed in “Reference” section and properly cited in the report following Harvard style.	2

Team Reflection	Evidence of team skills, initiative, and personal responsibility shown as a team member by producing consistent quality work. Evidence of Individual and Team Effectiveness and Progress.	**10**
Total		**100**

Level 4 grade criteria

CLASS	%	LETTER GRADE	OVERALL DESCRIPTION	GUIDELINE GRADE DESCRIPTIONS
FIRST	85-100	A+	Outstanding	Your work meets all of the criteria described below for the A and A- grades. On top of that, it shows that you have got an exceptional grasp of the skills and knowledge covered in this module. Your work also shows that you are able to analyse key concepts in a way that is unusually advanced for this level of study and that goes beyond the theories and models that we studied. Your work shows that you have followed good academic practice in terms of citation and referencing, presentation format and clear, accurate English.
1ST	75-85 70-74	A A-	Excellent Very good	Your work shows a thorough grasp of the skills and knowledge required for this module. It is clear from your work that you have engaged in wide reading and study that goes well beyond the core areas needed to complete the assessment. Your work shows a good ability to analyse key concepts using the models and theories that we covered in the course of the module. You have shown that you are able to define problems and/or practical issues clearly and to apply appropriate methods and tools covered in the module to tackle them. Your work shows that you have followed good academic practice in terms of citation and referencing, presentation format and clear, accurate English.
2.1	67-69 64-66 60-63	B+ B B-	Good	Your work shows a good knowledge and understanding of the material covered in this module. Your work also shows that you are able to analyse ideas using the principles, theories and approaches that we covered in the module. Your work also shows that you are able to define problems and/or practical issues clearly and to apply appropriate methods and tools covered in the module. However, although your work does show that you recognise some of the complexities of this area of study, not all of your conclusions are based on sufficient evidence. Most of your work shows good academic practice in terms citation and referencing, presentation format and clear, accurate English
2.2	57-59 54-56	C+ C	Satisfactory	Your work shows some knowledge and understanding of the material covered in this module. Your work tends to be descriptive, with only limited analysis using the principles, theories and approaches that we covered in the module.

	50-53	C-		There is some evidence in your work that you have applied the methods and tools covered in the module appropriately. You have recognised some, but not all, of the complexities of this area of study. Your work follows good academic practice to some extent in terms of citation and referencing, presentation format and clear, accurate English.
3RD	47-49 44-46 40-43	D+ D D-	Adequate	Your work shows that you have gained a basic knowledge and understanding of the material covered in this module. Your work is descriptive, rather than analytical, and you have made a number of assertions without any evidence to back up your arguments. There is some evidence in your work that you have applied the methods and tools covered in the module appropriately. Your work shows some evidence of good academic practice in terms of citation and referencing, presentation format and clear, accurate English, but this is not always consistent throughout.
MARGINAL FAIL	35-39	F5	Unsatisfactory	Your work shows only a limited knowledge and understanding of the material covered in this module. Your work is descriptive and shows no attempt to analyse ideas or arguments. There are some inaccuracies in your work and it is not always logical or coherent. Your work has not followed good academic practice in terms of citation and referencing, presentation format and clear, accurate English.
FAIL	34 OR BELOW	F4	Poor	Your work shows little knowledge or understanding of the material covered in the module. Your work is descriptive and shows no attempt to analyse ideas or arguments. Some of your work is irrelevant and it is not always logical or coherent. Your work suggests that you have not understood the methods and tools covered in the module. You work does not meet most of the Learning Outcomes for this module. Your work has not followed good academic practice in terms of citation and referencing, presentation format and clear, accurate English.

Practical notes in this booklet

1. **Materials Lab (RVMB035)**

   Experiment: Tensile Test

2. **Statics Lab (RVMB 036B)**

   Experiment: Analysis of Truss

3. **Dynamics Lab (RVMB 036B)**

   Experiment: Centrifugal Force

Experiment 1

HEAT TREATMENT OF A PRECIPITATION HARDENING ALUMINIUM ALLOY AND THEIR TESNSILE PROPERTIES

1. Introduction

Precipitation hardening in alloys is a sequence heat treatment process to improve the mechanical property of material. In this process, the alloy is first soaked for a certain length of time at a temperature above the solid solution line at which solutes dissolve in the matrix to produce a single phase. It is then water quenched and aged at a lower temperature for precipitates to form and increase the hardness and strength of material.

2. The Aluminium Alloy

The material investigated is a Magnesium-Silicon Aluminium alloy to the HE30 BS1476 specification, with the following chemical composition:

Aluminium remainder
Copper 0.1 % maximum
Magnesium 0.4 - 1.5 %
Silicon 0.6 - 1.3 %
Iron 0.6 % maximum
Manganese 0.4 - 1.0 %
Zinc 0.1 % maximum
Chromium 0.5 % maximum
Titanium 0.2 % maximum

3. The Heat Treatment Procedure

Three tensile and three hardness specimens are provided. One tensile and one hardness sample are to be tested in as-received condition. The other 2 tensile and 2 hardness samples have been heat treated in a muffle furnace at 520 °C for 30 minutes, then water quenched immediately. One hardness coupon and one tensile specimen are tested after this condition. The two remaining, water-quenched samples have been placed in a circular air oven at 184 °C for 60 minutes.

SAMPLE	CONDITION	TEST
T_1	As received	Tensile
T_2	520 °C, 30 min	Tensile
T_3	184 °C, 60 min	Tensile
H_1	As received	Hardness
H_2	520 °C, 30 min	Hardness
H_3	184 °C, 60 min	Hardness

4. Testing Procedure
4.1. Introduction

The mechanical properties of materials are determined by performing carefully designed laboratory experiments that replicate as nearly as possible the service conditions. In real life, there are many factors involved in the nature in which loads are applied on a material. The following are some common examples of modes in which loads might be applied: tensile, compressive, and shear. These properties are important in materials selections for mechanical design. Other factors that often complicate the design process include temperature and time factors.

The topic of this lab is confined to the tensile property of Aluminium and steel. Figure 1 shows a tensile testing machine similar to the one used in this lab. This test is a destructive method, in which a specimen of a standard shape and dimensions is subjected to an axial load. During a typical tensile experiment, a dog-bone shaped specimen is gripped at its two ends and is pulled to elongate at a determined rate to its breakpoint. The tensile tester used in this lab is manufactured by Zwick. It has a maximum load of 50 kN and a variable pulling rate.

Figure 1. A photograph of Tensile machine Zwick 50 kN

For analytical purposes, a plot of stress (σ) versus strain (ε) is constructed during a tensile test experiment, which can be done automatically using the software provided by the manufacturer. Stress, in the metric system, is usually measured in N/m^2 or Pa, such that 1 N/m^2 = 1 Pa. From the experiment, the value of stress is calculated by dividing the amount of force (*F*) applied by the machine in the axial direction by its cross-sectional area (*A*), which is measured prior to running the experiment. Mathematically, it is expressed in Eq. (1). The strain values, which have no units, can be calculated using Eq. (2), where *L* is the instantaneous length of the specimen and L_0 is the initial length.

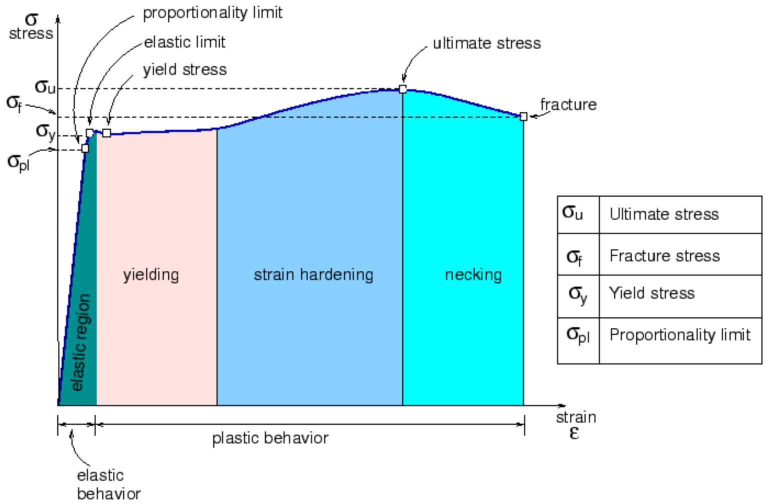
$$\sigma = \frac{F}{A} \tag{1}$$

$$\varepsilon = \frac{L - L_0}{L_0} \tag{2}$$

A typical stress-strain curve would look like Figure 2. The stress-strain curve shown in Figure 2 is a textbook example of a stress-strain curve. In reality, not all stress-strain curves perfectly resemble the one shown in Figure 2. This stress-strain curve is typical for ductile metallic materials. Another thing to take note is that Figure 2 shows an "*engineering stress-strain*" curve. When a material reaches its ***ultimate tensile strength*** (UTS) of the stress-strain curve, its cross-sectional area reduces dramatically, a term known as *necking*. When the computer software plots the stress-strain curve, it assumes that the cross-sectional area stays constant throughout the experiment, even during necking, therefore causing the curve to slope down. The "*true stress-strain*" curve could be constructed directly by measuring the change in the cross-sectional area of the specimen throughout the experiment.

Theoretically, even without measuring the cross-sectional area of the specimen during the tensile test, the "*true stress-strain*" curve could still be constructed by assuming that the volume of the material stays the same. Using this concept, both the true stress (σ_t) and the true strain (ε_t) could be calculated using Equations 3 and 4, respectively. The derivation of these equations is beyond the scope of this lab report. In these equations, L_0 refers to the initial length of the specimen, L refers to the instantaneous length and σ refers to the instantaneous engineering stress.

Figure 2. *Various regions and points on the stress-strain curve.*



$$\sigma_t = \sigma \frac{L}{L_0} = \sigma(1+\varepsilon) \tag{3}$$

$$\varepsilon_t = ln\left(\frac{L}{L_0}\right) = ln(1+\varepsilon) \tag{4}$$

Figure 2 also shows that a stress-strain curve is divided into four regions: elastic, yielding, strain hardening (commonly occurs in metallic materials), and necking. The area under the curve represents the amount of energy needed to accomplish each of these "events." The total area under the curve (up to the point of fracture) is also known as the ***modulus of toughness***. This represents the amount of energy needed to break the sample, which could be compared to the impact energy of the sample, determined from *impact tests*. The area under the linear region of the curve is known as the ***modulus of resilience***. This represents the minimum amount of energy needed to deform the sample.

The linear region of the curve in Figure 2, which is called the elastic region (past this region, is called the plastic region), is the region where a material behaves elastically. The material will return to its original shape when a force is released while the material is in its elastic region. The slope of the curve, which can be calculated using

Eq. (5), is a constant and is an intrinsic property of a material known as **the elastic modulus**, E. In metric units, it is usually expressed in Pascal (Pa).

$$E = \frac{\sigma}{\varepsilon} \qquad (5)$$

4.2. Specimen

For the Aluminium specimen:

(1) Measure the thickness, width and gauge length of the specimens in mm.

(2) Also make note of any sample defects (e.g. edge defect, scratches on the surface, etc.).

4.3 Tensile Test

(1) Enter geometry of the sample before starting.

(2) Click on the Start button. Both the upper and bottom grips will start moving in opposite directions according to the specified pulling rate. Observe the experiment at a safe distance (about 1.5 meters away) at an angle and take note of the failure mode when the specimen fails.
(NOTE: Be sure to wear safety glasses. Do not come close to equipment when the tensile test is running).

(3) A plot of tensile stress (MPa) versus tensile strain (mm/mm) will be generated in real-time during the experiment.

4.4 Hardness Test

You will be using either the Vickers or the Rockwell hardness testing machines. Study and understand the principle of the hardness test as a quality control/material characterisation procedure and note the differences between the testing methods mentioned above.

Prepare the sample to be tested by cleaning the surface with 600 grade Silicon Carbide paper, prior to testing. Test each sample at least 3 times and take the average.

References

Callister, William D. “Materials Science & Engineering: An Introduction”, Sixth Edition, John Wiley & Sons Inc., (2003), ISBN 0-471-22471-5

Experiment 2

LOADS AND STRESSES IN A ROOF TRUSS

OBJECTIVES

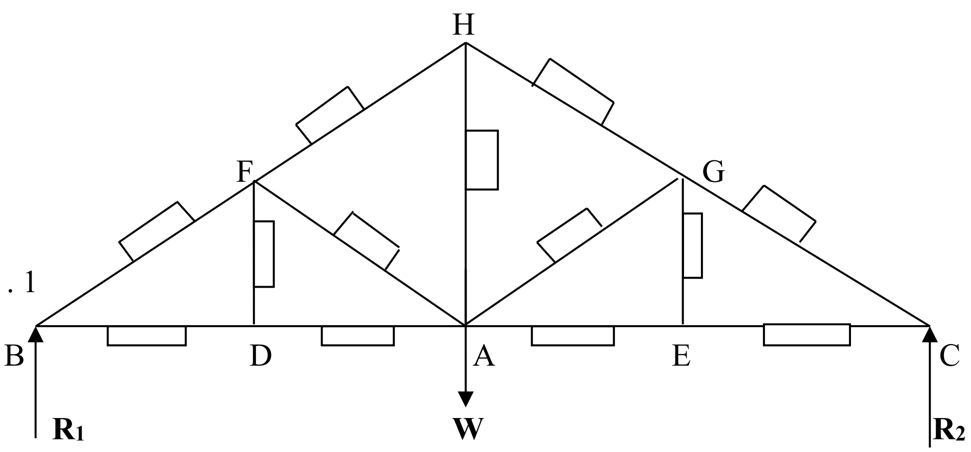
- To gain practical use of strain gauges and load cells
- To calculate stress in each member using the equation $\sigma = E\varepsilon$.
- To determine the loads in each member of the roof truss using the equation $F = \sigma A$.
- To compare the experimental values predicted with the theoretical values obtained using the method of joints.

Apparatus: Bench mounted loading frame with Roof truss.

Procedure:

1. Set up the equipment as illustrated in figure 1.
2. Check the digital force meter is zeroed with no applied load.
3. Increase the applied load in steps of 100 N to a maximum load of 500 N. *Do not exceed this load as damage may then occur to the Roof truss*. At each load increment, take measurement of the strain induced from gages 1 – 13.
4. Insert these results in the attached worksheet.
5. Decrease the load in steps of 100 N until a zero load is indicated. At each load reduction, take measurements of the strain induced from gauges 1 – 13.
6. Insert these results in the attached worksheet.

Fig . 1



Load (N)	Strain Gauge Readings ($\times 10^{-6}$)								
	Member 1			Member 2			Member 3		
	L	U	Ave	L	U	Ave	L	U	Ave
0									
100									
200									
300									
400									
500									

Load (N)	Strain Gauge Readings ($\times 10^{-6}$)								
	Member 4			Member 5			Member 6		
	L	U	Ave	L	U	Ave	L	U	Ave
0									
100									
200									
300									
400									
500									

Load (N)	Strain Gauge Readings ($\times 10^{-6}$)								
	Member 7			Member 8			Member 9		
	L	U	Ave	L	U	Ave	L	U	Ave
0									
100									
200									
300									
400									
500									

Load (N)	Strain Gauge Readings ($\times 10^{-6}$)								
	Member 10			Member 11			Member 12		
	L	U	Ave	L	U	Ave	L	U	Ave
0									
100									
200									
300									
400									
500									

Load (N)	Strain Gauge Readings ($\times 10^{-6}$)		
	Member 13		
	L	U	Ave
0			
100			
200			
300			
400			
500			

Where:

L	**Loading**
U	**Unloading**
Ave	**Average**

Calculation:

Relevant Theory: See lecture notes for details.

$$E = \sigma / \varepsilon$$

where σ = Stress, ε = Strain, E = Young's Modulus for the member

$$\sigma = F / A$$

where σ = Stress, F = Force in member, A = Area of cross section of member

For calculation, take E=210 GPa and diameter of member = 6 mm.

Experiment 3 (demonstration only)

CENTRIFUGAL FORCE

Introduction:
Centrifugal force exists in rotating machinery and its effect can be used as an advantage in some design applications, it also can cause drastic failures in rotating components. One example of advantageous use of centrifugal force is the design of automatic clutch in power transmission.

The centrifugal force is generated in high-speed rotating machinery such as turbines, compressors etc. due to a small out of balance component which can cause serious vibrations and subsequently lead to failure of vital components. The rotating parts therefore have to be well balanced and also be made strong enough to withstand the centrifugal effects. The magnitude of the centrifugal force in a system depends on three main parameters: mass of the body or out of balanced, angular speed and radius (distance from centre of rotation). In this experiment all the above three parameters may be varied in order to study their effects on the resulting centrifugal force.

Objective:
Study of various parameters affecting the centrifugal force in rotating machinery.

Apparatus:
The apparatus consists of two pivoted counter balanced\bell-cranks housed in slideable blocks, as shown in figures 1, 2 and 3. Various combinations of accurately machined masses fit to the ends of the bell-crank arms. Sufficient masses are pivoted to enable the mass on each arm to be increased by between 25 and 175 grams in increments of 25 grams. The slideable blocks are held in position by locating pins. Each block fits in five different radial positions corresponding to five equally spaced holes in each end of the horizontal rotating members. The rotating member is belt driven from a variable speed 12 V d.c. electric motor contained in the base unit. The motor control is via the speed controller. An optical tachometer sensor is also incorporated, and on the front of the module unit is an output socket for connecting to the Tachometer Unit.

When the unit rotates, the upper masses M_a tend to move outwards under the action of centrifugal force. With the upper masses at radius r and rotating at ω rad/s, the force

$$F = M_a.r.\omega^2$$

on each mass is:

Theoretical background:

A body moving in a circular path of radius r, with an angular velocity ω has an instantaneous forward velocity v as shown in the figure 4, at a fraction of time later δt the body moves by δθ and has a new forward velocity with the same magnitude as before but a different direction as shown in the figures 4 and 5. The change in the direction of velocity result in a centripetal acceleration which is directed towards the centre of rotation and has a magnitude of $r.\omega^2$, it generates a centripetal force m. $r.\omega^2$. There must be a force of equal magnitude acting in opposite direction to the centripetal force called centrifugal force.

Experimental Method:

Each parameter affecting the centrifugal force can be studied separately. In this experiment the effects of varying the angular velocity and the mass of the rotating body are determined for a constant radius. The procedure is as follows:

Procedure 1 for $F \propto \omega^2$ and $F \propto M_a$ (constant r)

1. Set both sliding blocks to outermost position r = 125mm
2. screw mass 25g onto each upper arm M_a of two bell-cranks (M_a = 40g)
3. screw masses of 175g on each lower arm of two bell-cranks (M_b = 190g)
4. replace dome and start motor using speed control until audible ‘click’ of bell-cranks pivoting. note speed
5. decrease speed until bell-cranks go back. Increase speed, then take another reading of the speed when the bell-crank pivots.
6. reduce the masses on lower arm by 25g at a time and obtain further results for each value down to 40g on lower arm
7. repeat these series of tests for values of 65g and 90g on upper arm

Procedure 2 for $F \propto r$

1. Your readings for M_a = 40g and r = 125mm should be the same as procedure 1
2. Set sliding blocks on both ends to r = 95mm

3. screw masses of 25g onto each upper arm
4. screw masses of 175g onto each lower arm
5. determine and record the rev/min for audible ‘click’ as for procedure 1
6. reduce masses on lower arm by 25g at a time and obtain results down to 40g
7. reset sliding blocks to r = 65mm and repeat the above

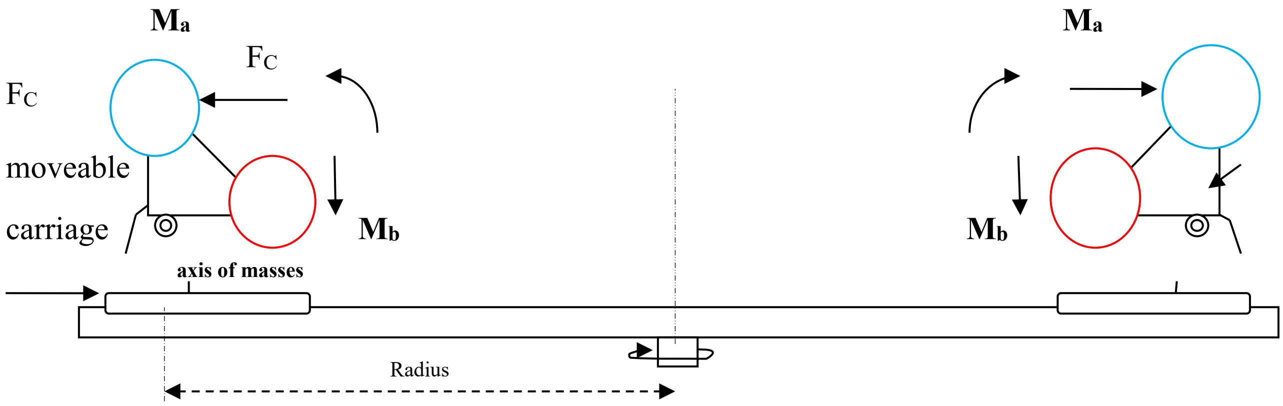


Figure 1. Drawing of centrifugal force testing apparatus.

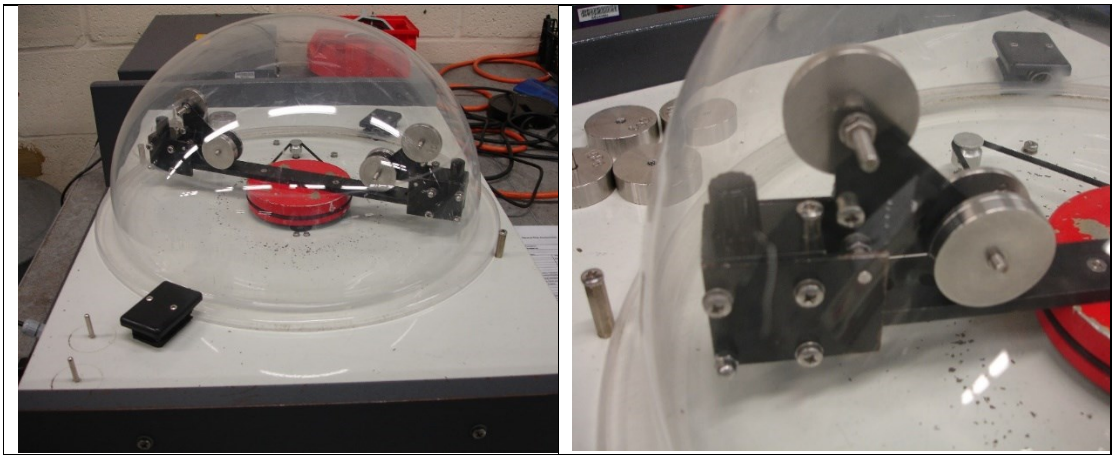


Figure 2. Actual experimental set-up

Report writing

When writing your report, the following needs to be addressed:

- Graph Aluminium results using raw data files and construct the true stress-strain curves (hint: use Eqs. (3) and (4) provided in the *Introduction* section).
- Calculate Young's Modulus (E) for each material and compare experimental values with literature values.
- Discuss any differences in mechanical behaviour between the Aluminium alloys (use pictures!)
- Analyse the fracture modes of each sample (ductile fracture, brittle fracture, or intermediate fracture mode).
- Explain any unexpected results.

Answer the following questions:

1. What is the hardness of the solution treated samples tested immediately? Explain the difference.
2. What is the difference between the yield stress and 0.1% proof stress?
3. In calculation of % elongation, why a certain gauge length is specified?
4. What property of material can be evaluated by % reduction of area?
5. What is the application of solution and precipitation hardening in the industry?
6. Describe the results you obtained in the context of materials selection in automotive industry (e.g., for chassis production, specifications, standards, tolerances, regulations, etc).
7. Explain how Youngs modulus is used to determine loading in a member of a truss structure and calculate it for a vertical member of the truss experiment.

NOTE: Should you encounter any issue with this tutorial, please do contact the setter.

End of booklet