AIMS

- To understand how the key differences in structure between metals, ceramics, glasses and polymers give rise to their thermal, mechanical and electrical properties
- To measure mechanical and thermal properties experimentally
- To understand the relationship between thermal, electrical and mechanical properties of materials

INTRODUCTION

The classification and properties of materials are based on their structure. Metals, for example, are classified as such due to their particular properties such as high electrical and thermal conductivity compared to non-metals.

The differences between metals and polymers, composites, foams and glasses in elastic limit, thermal conductivity and electrical resistivity can be understood by linking how the differences in structure impact each property. This lab aims to demonstrate how differences in key thermal, electrical and mechanical properties depend on the type of material classification, which is a function of their different structures.

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Young's Modulus (and other moduli) is related to the stiffness of bonds between atoms in a solid and in the packing of atoms. Bonding can take several forms, depending on how the electrons of the atoms interact. Metallic, covalent and ionic bonds are stiff, whilst hydrogen and Van der Waals bonds are not. Density is therefore related to Young's Modulus, for a particular type of compound, as it is the mass of atoms divided by the volume they occupy (*i.e.* packing).

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The material property that determines resistance is the electrical resistivity, ρ_e. It is directly proportional to electrical resistance, R, which is the ratio between potential V and current i (Ohm's Law). The reciprocal of resistivity is the electrical conductivity, κ_e and is therefore a measure of how well a material does not conduct electricity. Metals conduct electricity well, and therefore have a low electrical resistivity. Metals have strong bonds between atoms, and therefore have high melting points and high yield strength (elastic limit). Foams, on the other hand, do not conduct electricity and therefore have a high resistivity. They have a relatively low yield strength, in comparison to metals. Both these properties are related to their structure, which does not permit free movement of electrons.

In the first experiment you will use tensiometers to generate data for a stress-strain curve for metals (two samples) and polymers (three samples), until fracture. You will also be able to calculate the electrical resistivity for each of the samples and confirm the link between the electrical property and mechanical property, for metals and polymers, using an Ashby plot.

In the second experiment, you will measure a thermal property, specific heat capacity, of one of the metal samples. You will see how heat capacity is related to bulk density and thermal conductivity of the metal. Using this data, and the electrical property of the metal, you will be able to identify the metal on an Ashby plot.

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EXPERIMENTAL PROCEDURE

Note: It may be helpful to have the **Lab B Results** *link open and enter data into it as you do your lab, so that you can get immediate feedback on whether your data and calculations are correct. Please enter your data individually onto the Blackboard. Your report should be written in your allocated LAB group.*

Experiment 1: Measurement of Mechanical Properties (Stress, Strain) of Various Samples, and their relationship to Electrical (Resistivity, Conductivity) Properties

Two tensiometers will be used in this experiment: the first one (with data acquisition) on 2 metal samples, and the second one on 3 polymer samples. Measurement of the *yield strength* (MPa), also known as *elastic limit* (MPa), of the **two metal samples** is performed.

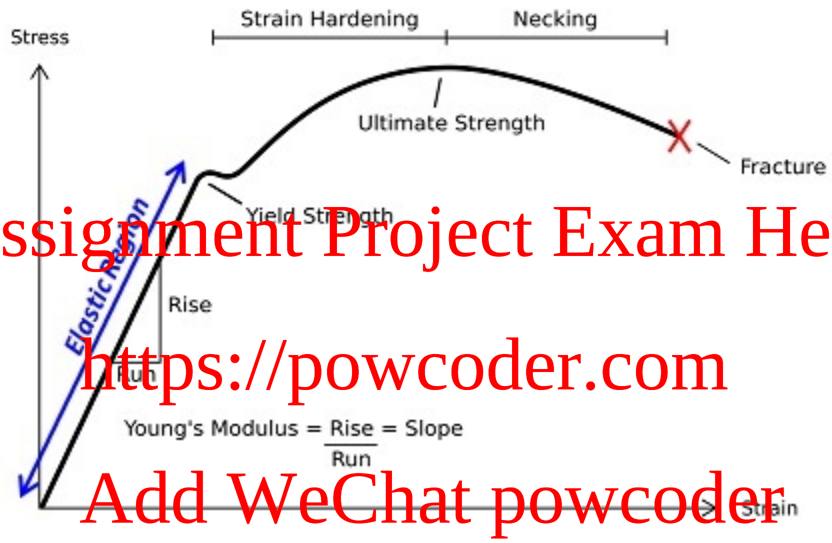

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Figure 1: Typical stress-strain curve for a ductile material

The TecQuipment SM1002 bench top tensile testing machine, fitted with an extensometer and data acquisition system (DAS) is shown in the schematic (Figure 2) below.

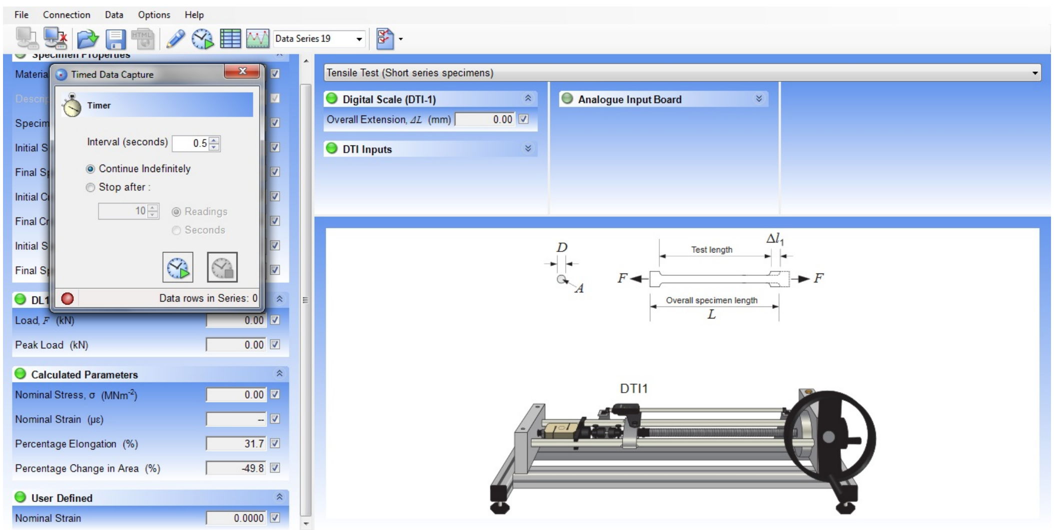

Figure 2: Schematic and data interface for TecQuipment SM1002 bench top tensile testing machine

Samples 1 and 2 were tensile-tested using this tensiometer, and the data obtained are shown in Figures 3 and 4 below. If you are doing this lab face-to-face, you will obtain your own graphs for samples 1 and 2.

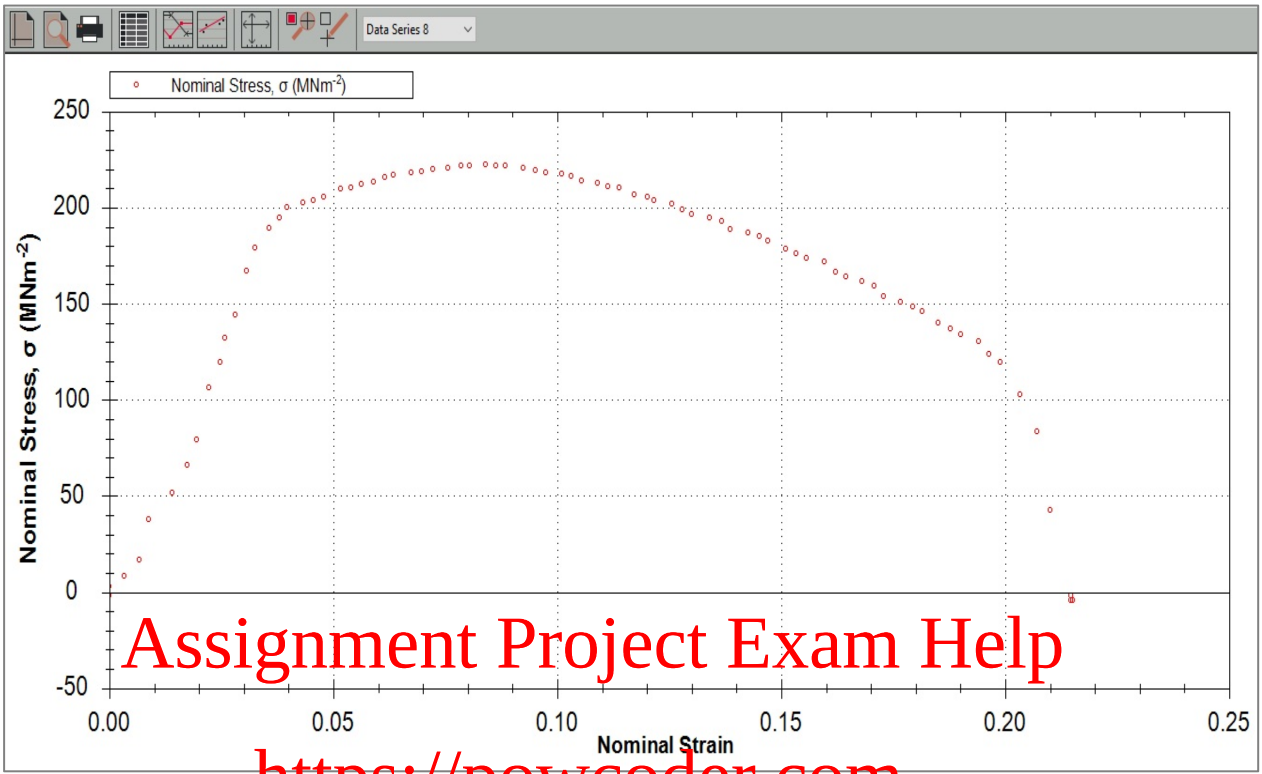

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Figure 3: Stress-strain curve from data acquisition for sample 1

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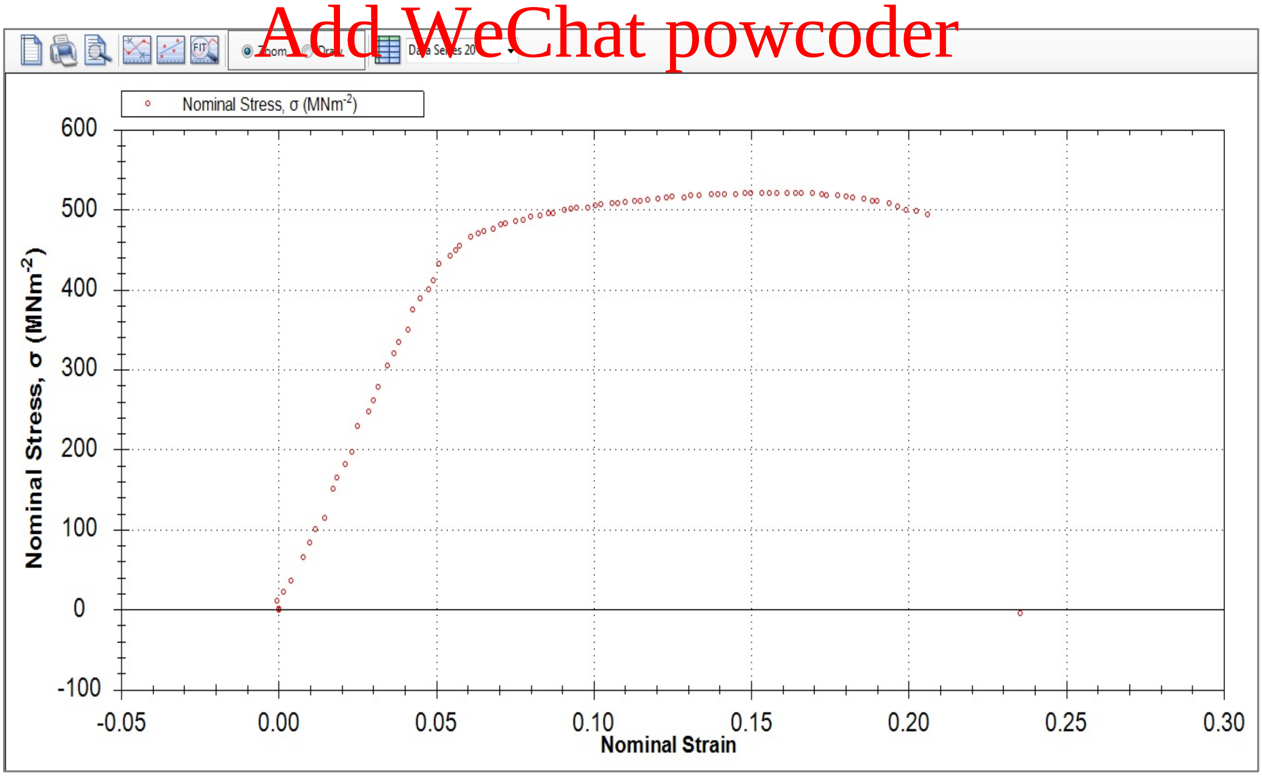

Figure 4: Stress-strain curve from data acquisition for sample 2

The gauge length and gauge length diameter measurements in Table 1 can be obtained by measurements for sample 1 and sample 2 (Online students: watch the video LabB_V1). Using the data obtained from the tensile tests, please complete Table 2 below (Online students: watch videos LabB_V2 and LabB_V3).

Table 1: Dimensions of metal samples

Sample	**1**	**2**
Gauge length diameter (mm)		
Gauge length, L_0 (mm)		
Minimum diameter of failed specimen (mm)		
Maximum extension for failed sample (mm)		
Gauge length, L_1 (mm)		
Maximum strain ϵ (mm/mm)		

Table 2: Data from Stress (σ) vs Strain (ϵ) curve for metal samples

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Sample	**1**	**2**
Yield strength (MPa)		
Ultimate tensile strength (MPa)		
Young's Modulus, E (MPa)		

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Mechanical testing using the other tensiometer (without data acquisition) on the **three polymer samples** should be performed on your polymer samples. (Online students: Please watch the video LabB_V4). Then fill in Table 3. Based on the stress-strain curves for the metal testing, use the information in Figure 5 below to match the plastics listed to the samples tested.

Table 3: Observations of polymer samples

Sample	***3***	***4***	***5***
Time taken to fracture (ranking: A longest and C shortest)			
Yield strength (ranking: A highest and C lowest)			
Gradient of stress-strain curve (Young's Modulus) until yield strength in Fig. 5 (ranking: A highest and C lowest)			
Ultimate tensile strength (ranking: A highest and C lowest)			

Name of plastic, based on stress-strain curve in Figure 5			

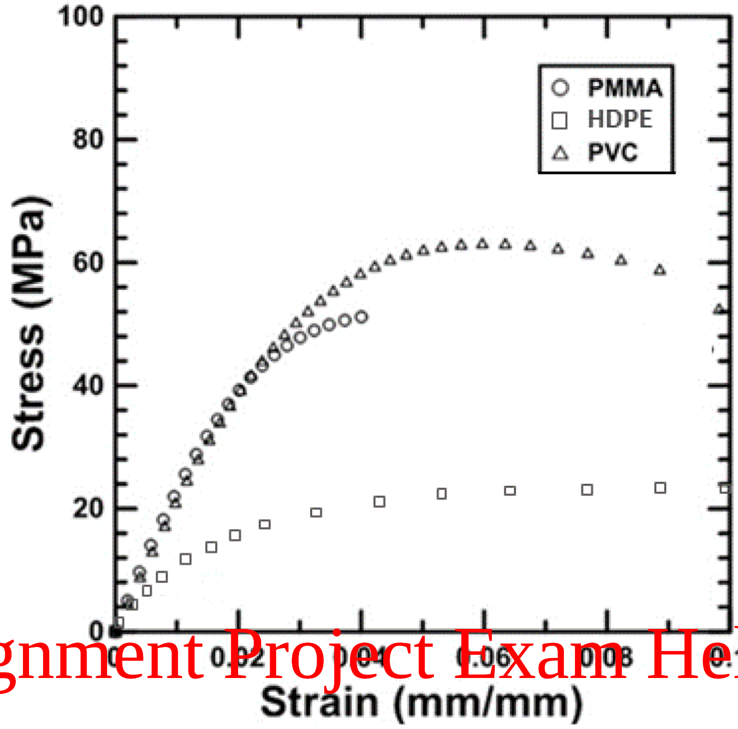

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Figure 5. Stress vs strain curves for various plastics modified from Park et al. (2017) and Patlazhan, Hizoum and Rémond (2008).

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The electrical conductivity σ of the samples is given in the table below. Convert the given values into electrical resistivity ρ_e in μΩ.cm, given that $\rho_e = \frac{1}{\sigma}$. Check the required units and convert them as needed.

Table 4: Electrical properties of the samples

Sample	**1**	**2**	**3**	**4**	**5**
Electrical conductivity σ $(\Omega.m)^{-1}$	3.8×10^{7}	1.6×10^{7}	1×10^{-16}	1×10^{-15}	1×10^{-15}
Electrical resistivity ρ_e (μΩ.cm)					

On Figure 6 below, plot your results for yield strength (MPa) vs electrical resistivity (μΩ.cm) for your samples 1-5, noting that it is a *log-log scale* for all samples. You can estimate the yield strength of the polymer samples from Figure 5.

Compare your results with what you suspect your samples might be and think about what structural factors may influence yield strength and resistivity of your samples.

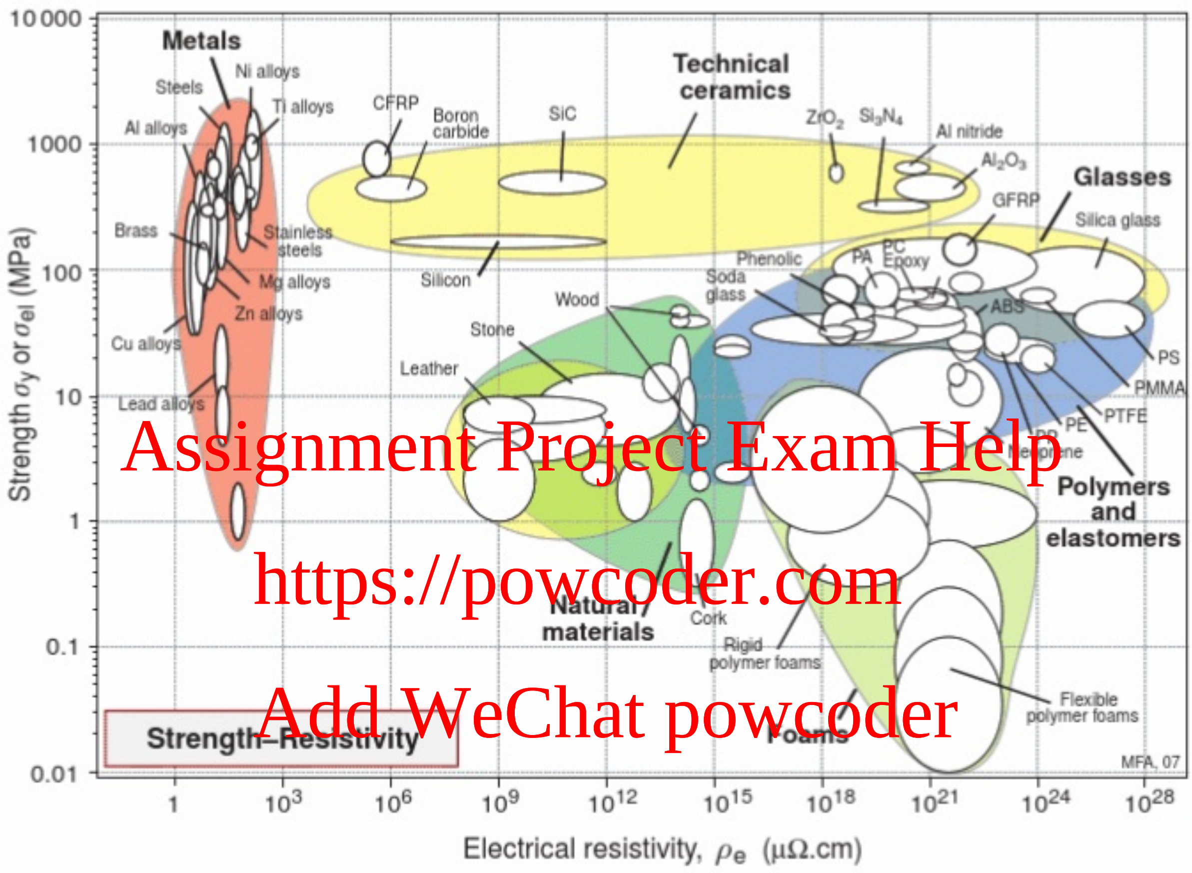

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Figure 6. Material property chart relating material strength (yield strength or elastic limit) with electrical resistivity. (Ashby, Shercliff, and Cebon 2007, 319).

Experiment 2: Measurement of a Thermal Property (Specific Heat Capacity) of a Metal, and its Relationship to Electrical Properties

The measurement of specific heat capacity of a metal is done by equating the heat lost by the metal, to the heat gained by a small volume of water (of measured mass). Water at room temperature has a specific heat capacity of 4.184 kJ/kg.K. The heat (Q) lost by the metal, and gained by the water (assuming no energy is lost in the heat transfer) is:

$$Q = m_{metal} C_{p,metal} \Delta T_{metal} = m_{water} C_{p,water} \Delta T_{water}$$

where m is mass, C_p is specific heat capacity and ΔT is the temperature change experienced.

Weigh the metal and then using tongs, place it carefully in a beaker filled approximately 100 ml of hot water. Heat this water to boiling on the hotplate, until the thermocouple touching the metal reaches a constant temperature for 2 minutes. (The temperature should be 99-100°C.) Record this temperature using your thermocouple, and also the hand-held thermometer at the same time.

Into a Styrofoam cup, use the digital balance to accurately weigh a mass of tap water (~30 ml) and take its temperature using the hand-held thermometer, after it has cooled down to almost room temperature.

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After the metal has been boiling for a few minutes (to ensure that it reaches the required temperature), using tongs, quickly but carefully transfer the metal to the Styrofoam cup containing the water. *Immediately* cover it with the lid, inserting the thermocouple through the perforated lid so that the tip touches the water, *but not the hot metal in the cup*. Record the maximum temperature obtained.

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(Online students: Watch LabB_V5 and LabB_V6 and take the relevant recordings and fill in the Table below.)

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Beaker	Mass of metal (g)	Initial temperature of H_2O (°C)	Final temperature of H_2O (°C)
Styrofoam Cup	Mass of H_2O (g)	Initial temperature of H_2O (°C)	Final temperature of H_2O (°C)

Table 5: Data for heat capacity measurement

Analyse your data as follows:

1. Calculate the heat Q (kJ) absorbed by the water, and hence the specific heat

capacity $C_{p,metal}$ of the metal in kJ/kg.K.

2. Compare your calculated C_p value with the value that your demonstrator will

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provide (C_p = 0.78 kJ/kg.K). What is the % error? Is it significant?

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3. Discuss the potential sources of uncertainty in the measurement of *Cp* by this

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method and identify the largest source of error.

4. Specific heat capacity (C_p) and density (ρ) are approximately inversely correlated for solids: $\rho C_p \approx constant.$ Plot the values in the table below and draw a graph of C_p vs ρ. Pay careful attention to your units, and any trendline you draw through the data points.

   Using the graph to estimate a value for the density of the metal (Sample 1) in g/cm^3 using C_p = 0.78 kJ/kg.K. How does your method of estimation impact the value of density?

Material	$\boldsymbol{C_p}$ **(kJ/kg.K)**	$\boldsymbol{\rho}$ **(g/cm^3)**

Carbon	0.71	3.51
Cast iron	0.46	7.2
Cellulose	1.6	1.5
Copper	0.39	8.79
Platinum	0.13	21.5
Stone	0.84	2.5
Tungsten	0.134	19.2
Rhodium	0.24	12.3

5. The metal used is the same one (sample 1) that you measured for yield strength and electrical resistivity in Experiment 1. If the thermal diffusivity (a) of the sample is 6.5 $\times 10^{-5}$ m^2/s, use Figure 7 to identify the metal. The thermal diffusivity of a material is related to its other properties by:

$$a = \frac{\lambda}{\rho C_p}$$

where λ is the thermal conductivity (W/m.K), C_p is in J/kg.K and density is in kg/m^3.

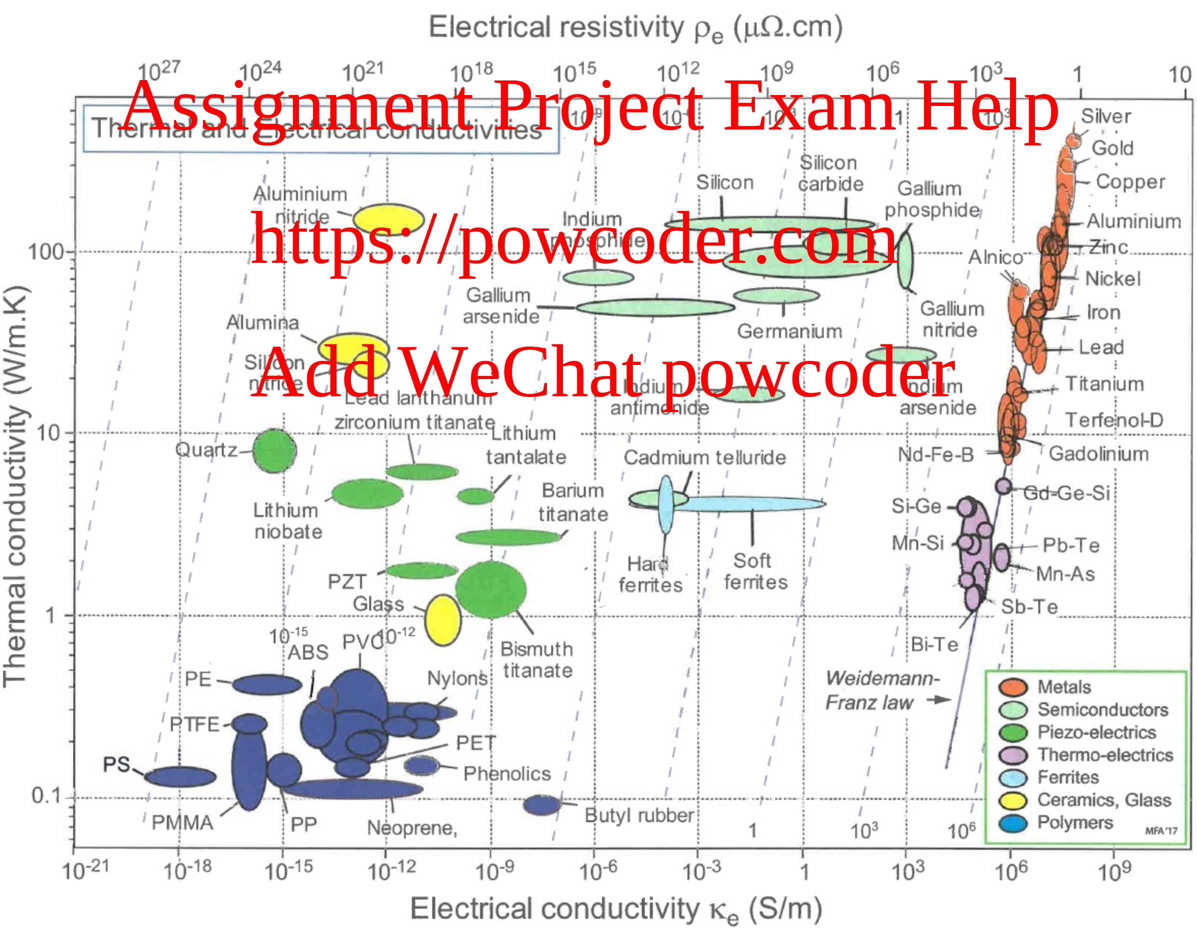

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Figure 7. Material property chart relating thermal conductivity with electrical resistivity and electrical conductivity (Ashby, Shercliff, and Cebon 2019, 421).

6. What did you learn about the relationship between mechanical, thermal and electrical properties of a metal from Figures 6 and 7? Why do you think this might be the case?

REPORT

You need to write a group report about **Experiment 2 only**.

Please use the Lab B Report Template available on Blackboard. The template contains some further guidance about what your report should contain. Please refer to the Workshop 1 materials for information about technical report writing, including presenting sample calculations.

REPORT MARKING (22%)

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Criteria	Big idea	Needs improving	Meets expectations	Exceeds expectations
Introduction (4 marks)	*What hypothesis are we testing?*	The introduction is essentially copied from the lab worksheet. It does not seem like the group has used much judgment about the contents. It is very long or very short. (0–2 marks)	The introduction is similar to what was covered in the lab worksheet, but there is evidence of some independent thought about the content. (2–3 marks)	The introduction covers the required content and shows clear evidence of independent research and thinking about the significance and theory. (4 marks)
Experimental Materials, Apparatus and Method (3 marks)	*What did you do?*	The information is essentially copied from the lab worksheet, but important information is missing or incorrect. (0–1 marks)	Information is paraphrased from the lab worksheet; almost all the important information is present, may be too long. (2 marks)	The information is clearly written; it is concise, yet retains all important details and does not make unneeded assumptions. (3 marks)
Results and Discussion (8 marks)	*What did you observe? What does it mean?*	The explanations are not clear or contain serious flaws; there is little justification. One of the sample calculations is missing or contains mistakes. (0–4 marks)	The explanations are mostly clear and correct with some justification provided. Both sample calculations are correct. Experimental uncertainty is considered briefly. (5-6 marks)	Insightful, correct explanations are given with credible justifications. Both sample calculations are clear and correct, and include uncertainty. Some extra, relevant points are made. (7-8 marks)
Conclusions and Recommendations (3 marks)	*What conclusions can we draw? What follow- up work is needed?*	Conclusions are missing or are actually a summary. Recommendations are missing or are unrelated to the experiment. (0–1 marks)	Some reasonable conclusions are given. One or two recommendations given but they may lack usefulness or practicality. (2 marks)	Concise conclusions show a thorough understanding of the work. Two or more relevant, valuable and practical recommendations are given. (3 marks)
Report writing (4 marks)		Spelling and grammatical mistakes are common. There is poor or inconsistent formatting. It is over the page limit. Overall, it seems that the group is not aware of report writing standards or	There are a handful of spelling and grammatical mistakes. The writing is mostly understandable and brief. Formatting is generally consistent and appropriate. The group seems to be aware of	The report is essentially free from spelling and grammatical mistakes. The writing is clear, concise and easy to read. Formatting is consistent and professional. Overall, the report appears to have

		has not applied them carefully. (0–1 marks)	report writing standards and has made a good effort to use them. (2-3 marks)	been compiled carefully; it is near industry quality. (4 marks)

Lab B Results (individual, 5%) and OHS (individual, 2%) make up the total marks for your Lab B.

REFERENCES

Ashby, Michael, Shercliff, Hugh, and Cebon, David. 2007. *Materials: Engineering, Science, Processing and Design.* Oxford: Butterworth-Heinemann.

Ashby, Michael, Shercliff, Hugh, and Cebon, David. 2019. *Materials: Engineering, Science, Processing and Design.* 4th ed. Oxford: Butterworth-Heinemann.

Park, Jong Sung, Lee, Sang Mok, Joo, Byung Soo, and Jang, Ho. 2017. "The effect of material properties on the stick–slip behavior of polymers: A case study with PMMA, PC, PTFE, and PVC" *Wear* 378–379: 11–16.

Patlazhan, S.A., Hizoum, K. and Rémond, Y. 2008. "Stress–Strain Behavior of High-Density Polyethylene below the Yield Point: Effect of Unloading Rate" *Polymer Science, Series a* 50(5): 507–513.

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