Workshop M1: Crystallography and Strengthening Mechanisms in Metals

LEARNING OUTCOMES

- Understand the basic bonding mechanisms in solid materials
- Identify some basic crystallographic principles
- Develop an understanding of the fundamental relationships between structure and mechanical properties of metallic materials.

ACTIVITY

A series of activities is presented below. Within your group work through these activities ensuring that you are all aware of principles involved, the information given, the determinations required

Random groups will be selected to present their summaries to the class.

Activity 1: Identifying Primary and Secondary Bonding in Materials (15 minutes)

Working as a group nominate what type(s) of bonding would be expected for each of the following materials:

Material	Primary Bonding	Secondary Bonding
Rubber	Covalent bonding	Van der waals bonding
Sodium chloride	Iconic bonding	N/A
Nylon	Covalent bonding	Van der waals bonding
Solid Argon	Van der waals bonding	N/A
Bronze	Metallic bonding	N/A
Steel	Metallic bonding	N/A
Aluminium phosphide	Covalent bonding	Van der waals bonding

Activity 2: Identifying Crystal Structures (20 minutes)

In the three diagrams below, determine the Miller Indices for the 'shaded' crystallographic planes shown, and demonstrate that determination.

Plane	Intercepts	Reciprocals	Reduction	Miller Index
Figure 1	(a， a,∞)	(1/a,1,a,0)	(1/a,1/a,0)	(1， 1， 0)
Figure 2	(a,a,a)	(1/a,1/a,1/a)	(1/a,1/a,1/a)	(1,1,1)
Figure 3 Plane A	(2/3， 1/2， 1/2)	(3， 2， 2)	(3， 2， 2)	(3， 2， 2)
Figure 3 Plane B	(1/2， ∞， 1/2)	(2， 0， 2)	2 (1， 0， 1)	(1， 0， 1)

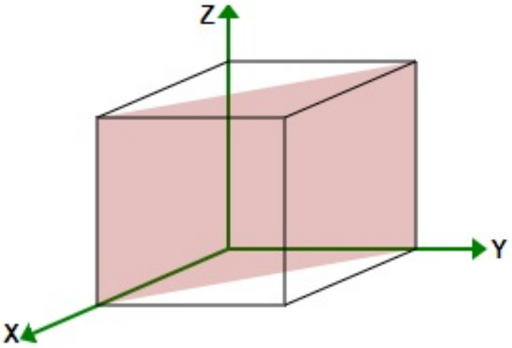


Figure 1

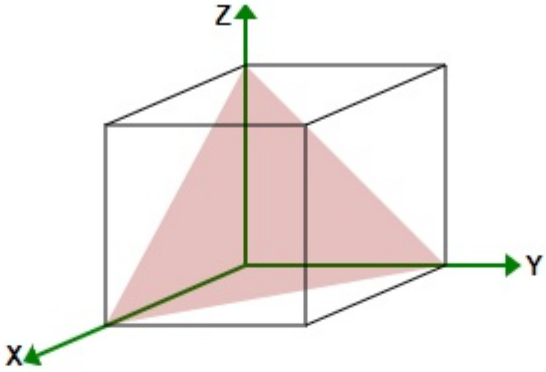
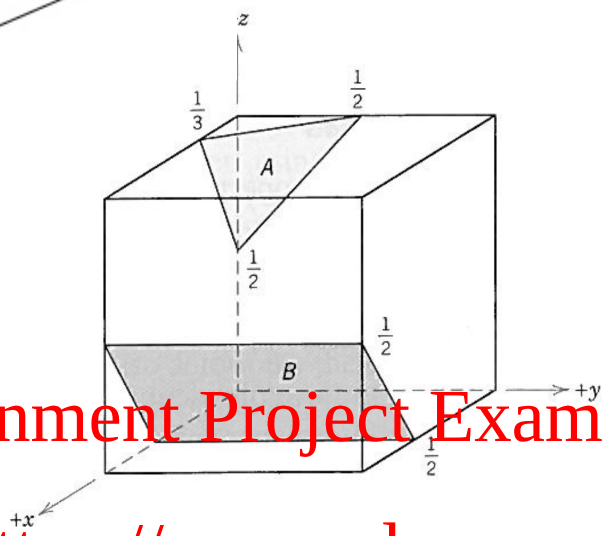


Figure 2

Figure 3



Activity 3: Elastic Deformation in Materials (15 minutes)

For a bronze alloy, loaded in tension, the stress at which *plastic* deformation begins is 285 MPa and the Young's Modulus (E) of elasticity is 111 GPa.

i. What is the maximum load (kN) that may be applied to a specimen of circular cross section, with a radius of 9 mm, *without causing plastic deformation*?

ii. If the original specimen length is 110 mm, what is the maximum length (mm) to

iii. which it may be stretched *without causing plastic deformation*?

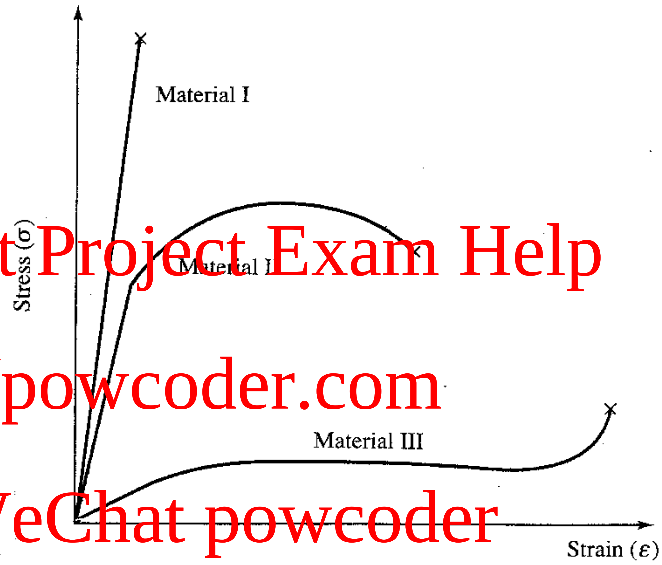
Maximum Load (kN)	Maximum Length (mm)
Max load $= F = 285\,MPa \times \pi r^2 =$ $285\,MPa \times \pi \times (9\,mm)^2 = 72.5\,kN$	Max extension $\delta l = \frac{FL}{(\pi r^2)\cdot E}$ $= \frac{72.5\,kN \times 110\,mm}{\pi \times (9\,mm)^2 \times 111\,GPa} = 0.282\,mm$ Max length $= l + \delta l = 110.282\,mm$

Activity 4: Stress-Strain curves for various materials (20 minutes)

Figure 4.1 shows the stress strain curves for three materials. For these materials, answer the following questions, giving reasons for your selection.

a) Which material has the lowest yield strength?
b) Which material has the highest ductility?
c) Which material has the highest toughness?
d) Which material has the highest elastic modulus?
e) Which material has the lowest ultimate tensile strength (UTS)?
f) State respectively which material behaves like a:
   i. Ceramic
   ii. Metal
   iii. Polyme

Figure 4
(NB. The points marked X relate to the fracture stress of each individual material)



Question	Material Selected	Reason
(a)	Material III	Because the yield point of material III is the lowest
(b)	Material III	because it has a high plastic deformation
(c)	Material II	Because the area under the curve of material II is the biggest
(d)	Material I	because material I has high elastic modulus because the slope of the graph of material I is the greatest
(e)	Material III	material III has a low ultimate tensile strength because its highest point in the graph is the lowest
(f)	Material Selected	Reason
ceramic	Material I	Ceramic is brittle,so it has a high elastic mudulus, material I has a high elastic modulus
metal	Material III	Metal is ductile, so it has a high ductility, material III has a high ductility

polymer	Material II	Polymer has very high toughness. Material II has high toughness

Activity 5: Strengthening Mechanisms – Grain Size Reduction (20 minutes)

The yield strength of a steel, with an average grain size of 0.040 mm, is 148 MPa. For the same steel with a grain size of 0.023 mm the yield strength is 178 MPa. In order to strengthen this steel, the grain size has been further reduced to 0.016 mm.

Plot the above values according to the Hall-Petch equation below. and graphically estimate the new yield strength of the steel. Confirm this value analytically.

Given: Yield Strength and representative grain sizes

Assumption(s): Hall-Petch equation is valid and all strengthening is due to grain size changes.

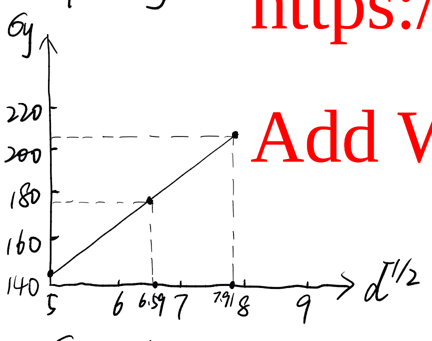
$d = 0.040mm \rightarrow d^{-1/2} = 5.00$, $\sigma_y = 148 MPa$

$$\sigma_y = \sigma_0 + K.d^{-1/2}$$

$d = 0.023mm \rightarrow d^{-1/2} = 6.59$, $\sigma_y = 178 MPa$

$d = 0.016mm \rightarrow d^{-1/2} = 7.91$, $\sigma_y = ?$

Graphicaully



$\sigma_y \approx 203$

Analyticauy:
$$\begin{cases} 148 = \sigma_0 + K \cdot 0.040^{-1/2} & ① \\ 178 = \sigma_0 + K \cdot 0.023^{-1/2} & ② \end{cases}$$ Solve ①② $\Rightarrow$

$$\begin{cases} \sigma_0 = 53.89 \ (\text{Units}: MPa) \\ K = 18.82 \ (\text{Units}: MPa \cdot (mm)^{1/2}) \end{cases}$$

$\therefore d = 0.016 \Rightarrow \sigma_y = 53.89 + 18.82 \times 0.016^{-1/2} = 202.68 \ (MPa)$

Graphically, yield strength σ_y ~ 203 (MPa)

Analytically, yield strength σ_y = 202.68 (MPa)

σ_0 = 53.89 (units?)

K = 18.82 (units?)