GX804

OLLSCOIL NA hÉIREANN
The National University of Ireland

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Semester I Examinations, 2002

Third Year Mechanical Engineering Examination
Third Year Biomedical Engineering Examination

METALS AND METAL PROCESSING

Professor P. Mallon
Professor J.F. McNamara
Dr. P.E. McHugh

Attempt 3 Questions.
Time Allowed: 2 Hrs.

1 (a) For the unit cell of a cubic crystal structure with side dimension a, as shown in Figure 1, determine the Miller indices for the crystallographic plane (shown shaded) and the crystallographic direction (shown by the black arrow). Indicate clearly the steps taken. Can you see any geometrical relationship between the plane and the direction? (5)

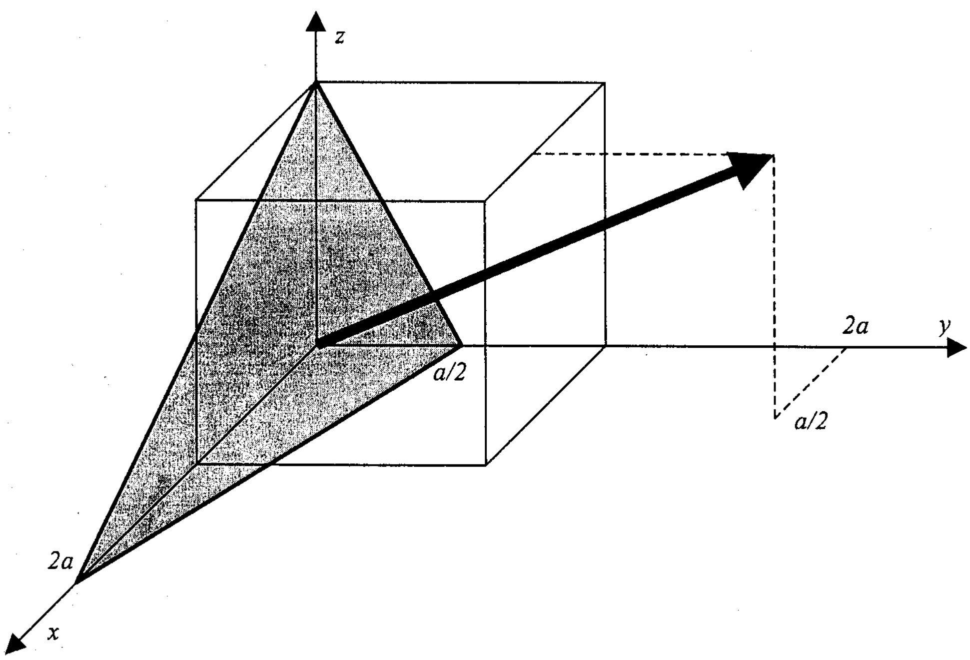

Figure 1

(b) Sketch FCC, BCC and HCP crystallographic unit cells, clearly indicating atomic positions. (4)

(c) For an FCC crystal structure, sketch and identify in terms of the Miller indices, one of the most closely packed planes in the unit cell, and a close packed direction on that plane. Calculate the total number of slip systems in such a crystal structure. Explain the relevance of the most closely packed planes and most closely packed directions. (4)

(d) Discuss the large difference between the theoretical strength based on the atomic bond strength and the experimentally measured critical resolved shear stress in a single crystal. (2)

(e) Discuss crystal imperfections with the aid of sketches under the following headings: (6)

- Point Defects
- Line Defects

(f) Calculate the Burgers vector **b** for (i) α-Fe
(ii) Al

where the atomic radius of α-Fe = 0.124nm and that of Al = 0.143nm. (4)

2 (a) Consider the engineering stress-engineering strain curve for a cylindrical steel specimen shown in Figure 2. The figure also shows a detail of the initial part of the curve. Use the figure to calculate the following for the steel specimen (in SI units):

- Young's modulus
- Yield strength (based on stress to cause a permanent strain of 0.002)
- Ultimate tensile strength
- The maximum load that can be carried by the specimen if it has an initial diameter of 8.5 mm.
- The change in length of the specimen when it is subjected to 65,250 N tensile load if the specimen has an initial length of 80 mm. (8)

(b) Sketch the shape of the specimen as it would be at points A, B, C and D on the curve. Define true stress and true strain. Sketch the curve in Figure 2 and show the following:

- The true stress-true strain curve.
- The engineering stress-engineering strain curve if the sample was unloaded to zero load at point A and reloaded. (5)

(c) Give brief definitions for the following terms.

- ductility
- hardness
- toughness (6)

(d) Sketch a resolved shear stress – shear strain curve for a single crystal of a metal and explain it in the context of dislocation motion. Compare this with a typical polycrystalline stress-strain curve (such as that shown in Figure 2) and explain why its shape differs from that of the single crystal. (6)

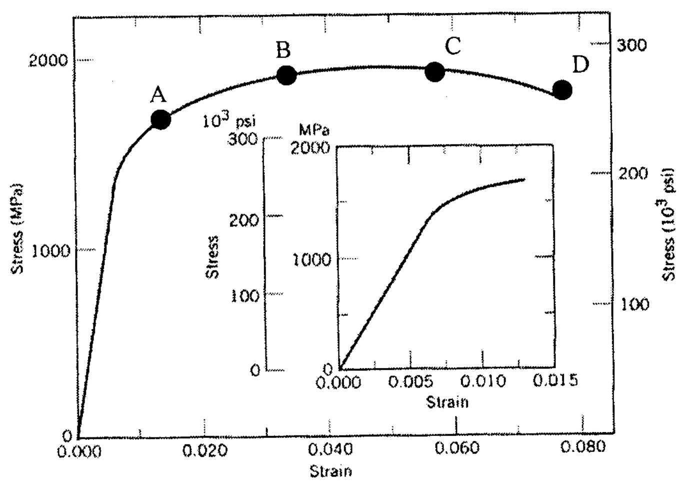

Figure 2

3 (a) Describe with the aid of sketches how grain boundaries and grain size influence dislocation flow and material strength in a polycrystalline metal. Discuss the stages and the effects of annealing a metal component following cold working. Describe how the relationship between grain growth and temperature is of critical importance here. (10)

(b) Write down the Hall Petch equation that relates material yield strength (σ_y) to average grain size (d) and briefly discuss its form. The yield point of iron that has an average grain diameter of 0.05 mm is 135 MPa; the yield point increases to 260 MPa when the grain size is 0.008 mm. Assuming that the Hall Petch equation applies to this material, evaluate the Hall Petch constants σ_0 and k_y. What grain size would be required to produce iron with a yield strength of 205 MPa?

(10)

(c) For some polycrystalline materials the average grain size (d) varies with time according the following equation:

$$d^2 = d_0^2 + Kt$$

where d_0 is the initial grain size, K is a temperature dependent parameter and t is time. The grain size for a brass material in an oven at 650°C was found to be 0.039 mm after 30 min and 0.066 mm after 90 min. Assuming the above equation applies, determine the constant K and the initial grain size. What grain size would you predict after 150 min? (5)

4 (a)

(i) In the nitriding process for steel, a nitrogen environment is used to set the surface nitrogen content at 2.0 wt %. If the initial nitrogen content is 0.01 wt % calculate how long it will take for at 900°C for the nitrogen content to reach 0.6 wt % at a diststance of 0.5 mm from the surface. Assume that the diffusivity of nitrogen in steel at 900°C is 1.2 x 10^{-10} m^2/s. For a semi-infinite slab the concentration at a distance x from the surface at a time t is given by: (10)

$$\frac{c(x,t)-c_0}{c_s-c_0}=1-\mathrm{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$$

c_0 = bulk concentration
c_s = surface concentration
D = diffusivity

(ii) Consider the diffusion of copper into aluminium. At 500°C the diffusivity is 4.8 x 10^{-14} m^2/s and at 600°C it is 5.3 x 10^{-13} m^2/s. Determine the approximate time at 500°C that will produce the same diffusion result (in terms of concentration of copper at some specific point in the aluminium) as a 10 hour heat treatment at 600°C. Comment on the result. (5)

(b) Figure 4 shows a phase diagram for solder, the Pb-Sn system. Calculate the amount in kg, and composition, of each phase present in 1kg of a 60 wt % Pb – 40 wt % Sn alloy at 300°C, 200°C and 100°C. (10)

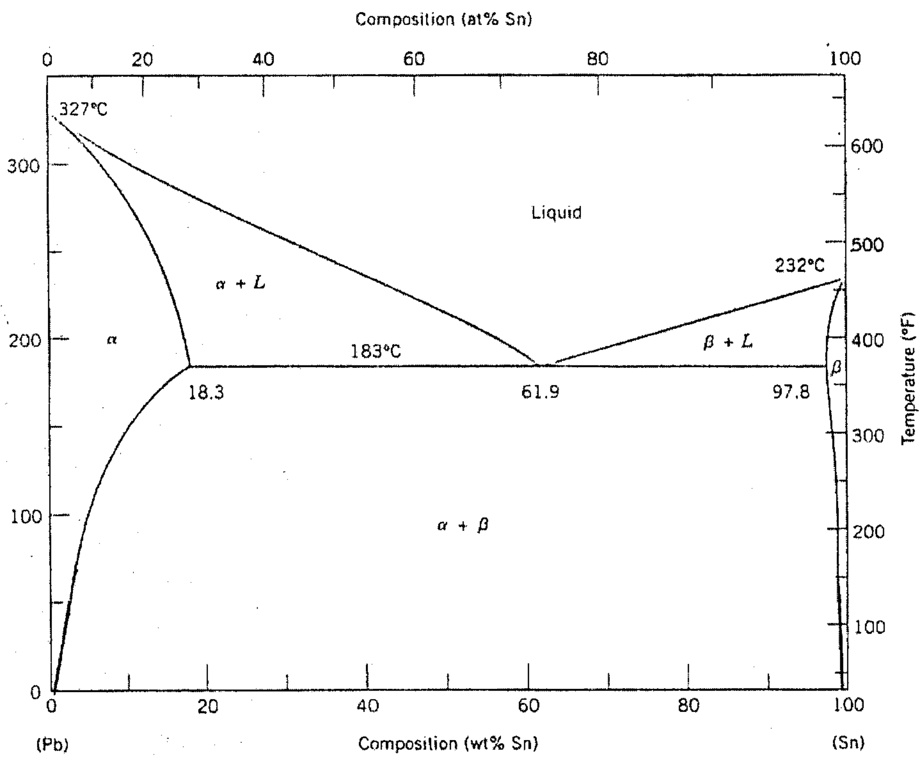

Figure 4

For assistance, the Error Function is shown below :

z	erf (z)	z	erf (z)
0.00	0.0000	0.70	0.6778
0.01	0.0113	0.75	0.7112
0.02	0.0226	0.80	0.7421
0.03	0.0338	0.85	0.7707
0.04	0.0451	0.90	0.7969
0.05	0.0564	0.95	0.8209
0.10	0.1125	1.00	0.8427
0.15	0.1680	1.10	0.8802
0.20	0.2227	1.20	0.9103
0.25	0.2763	1.30	0.9340
0.30	0.3286	1.40	0.9523
0.35	0.3794	1.50	0.9661
0.40	0.4284	1.60	0.9763
0.45	0.4755	1.70	0.9838
0.50	0.5205	1.80	0.9891
0.55	0.5633	1.90	0.9928
0.60	0.6039	2.00	0.9953
0.65	0.6420		

5 (a) Discuss the following heat treatments in terms of heating, cooling and their effect on the microstructure of plain carbon steels: (8)

- Process anneal
- Spherodizing anneal
- Normalising
- Full anneal

Sketch the temperature-composition regions of each on a phase equilibrium diagram.

(b) Draw and clearly label a Time Temperature Transformation (TTT) diagram for a 0.8wt% Carbon steel. Draw continuous cooling curves for the transformation of Austenite to: (8)

- Pearlite
- Martensite
- Bainite + Martensite

Comment on their microstructure and associated mechanical behaviour.

(c) Give a description of precipitation hardening, with the aid of sketches, under the following headings

- principle of precipitation hardening and comparison with other strengthening/hardening mechanisms
- examples of materials to which it is applied and the steps in the process
- focus on an Al-Cu alloy: microstructures that are generated and the influence of time and temperature on the resulting mechanical properties. (9)